Recommendations of the Mosquito Control for the Twenty-First Century Task Force

Appendix B: ERG Report Prepared for the Mosquito Control for the Twenty-First Century Task Force

This appendix includes a copy of the ERG Report prepared for the Mosquito Control for Twenty-First Century Task Force, as well as a report errata of corrections identified after report completion and Task Force member comments on the report upon release of the report to the Task Force. Please note that the report webpage contains information related to the report including public comments, and can be found at the following link: https://www.mass.gov/service-details/study-prepared-for-the-mosquito-control-for-the-twenty-first-century-task-force

Report Prepared for the Mosquito Control for the Twenty-First Century Task Force

Errata and Addenda for Mosquito Control Task Force Report

Summary of Mosquito Control for the 21st Century Task Force Comments

Report for the Mosquito Control for the Twenty-First Century Task Force

On July 20, 2020, an Act to Mitigate Arbovirus in the Commonwealth ("Act") was signed by the Governor. The Act created the Mosquito Control for the Twenty-First Century Task Force, which was charged with commissioning a study to complete a comprehensive evaluation of the Commonwealth's mosquito control process. This submission represents the commissioned study.

Eastern Research Group (ERG) developed 9 reports addressing all the topic areas requested by the Task Force. The following document is organized as follows:

Document revised on November 2, 2021, to clarify that this report was prepared for, not by, the Mosquito Control for the Twenty-First Century Task Force.

Report 1: Arbovirus History in Massachusetts

Prepared for:

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1. SCOPE OF WORK

This section examines the following topics requested by the Task Force:

- *Summarize the history of arboviruses in Massachusetts and the northeastern states, including but not limited to West Nile virus (WNV) and Eastern equine encephalitis (EEE).*
    - *Include data on per capita WNV and EEE risk in each mosquito control district (MCD) and in areas outside of MCDs, based on disease incidence.*
    - *Include number and types of mosquito traps, in addition to data on trap placement near habitat types and human populations.*
    - *Include data about types of habitat in relation to prevalence of virus-carrying mosquitoes contained in traps.*

This section is based on data provided by the Massachusetts Department of Public Health (DPH), reviews of state and MCD annual reports, and conversations with DPH staff. Two important data limitations should be noted. First, in accordance with DPH patient privacy and confidentiality protection policies, human case data for WNV and EEE were only provided at the county level and therefore could not be aggregated by MCD. Second, mosquito trap locations were only provided at the municipal level to minimize the risk of human tampering, thereby limiting the exploration of relationships among trap data, disease incidence data, and habitat location.

2. EXECUTIVE SUMMARY

In Massachusetts, the two most concerning mosquito-borne diseases are WNV and EEE (or "Triple E"). Surveillance in Massachusetts focuses on WNV and EEE because of the prevalence of these viruses in the environment and their potential to cause serious illness in humans, including meningitis, encephalitis, paralysis and death. This report discusses the mosquito species that are critical in the transmission of each virus and the history and geographic distribution of each virus in Massachusetts.

Symptomatic human cases of EEE and WNV are both rare in Massachusetts. Between 2000 and 2020, only three years had more than 20 cases of either disease. However, in the past two decades (2000 to 2020), there have been sporadic outbreaks of both diseases within the Commonwealth. EEE cases have appeared to follow "outbreak cycles," with several years of no or very low activity followed by two to three years with multiple reported cases. The peak number of EEE cases reported in a single year was 12 cases in 2019. Human cases of WNV vary from year to year, though the number of cases has been increasing, with a peak of 48 cases in 2018.

The years with peak numbers of positive tests for EEE in mosquitoes (2006, 2012, and 2019) align with peak years for human cases. Hardly any mosquito test results were positive for EEE from 2015 to 2018, aligning with the lack of human EEE cases over this period. Decades of testing indicate that there are only a few mosquito species that are key in the EEE transmission cycle, specifically *Culiseta melanura* and *Coquillettidia perturbans* with *Cs. melanura* in some years comprising almost all EEE-positive test results. In outbreak years, there are a few other mosquito species that have also been found to carry EEE. Since 2004, the greatest number of positive EEE tests and the greatest positivity rates of tests performed have consistently occurred in either the Plymouth County MCD or Bristol County MCD region. Positivity rate is defined as the number of mosquito tests that are positive for EEE/WNV, divided by the total number of tests. Plymouth County and Bristol County also have the greatest amount of EEE mosquito habitat in Massachusetts. The specific municipalities within MCDs that have more acres of mosquito habitat often correspond to the municipalities that have had the greatest number of positive EEE mosquito tests.

Peak years for human cases (2012, 2016, and 2018) were years that had above-average numbers of positive WNV mosquito tests, and this association was not due to increased testing. These data confirm that only a few mosquito species are key in the WNV transmission cycle in Massachusetts, specifically *Culex* mosquitoes, which comprise most positive test results across all years. In peak outbreak years, other mosquito species also tested positive for WNV. Positive WNV mosquito tests are consistently seen in the eastern and southeastern MCDs (Northeast, Central Massachusetts, Suffolk County, East Middlesex, Norfolk County, Plymouth County, and Bristol County). The WNV positivity rate ranged widely from year to year and across MCDs, with Suffolk County MCD having the highest average positivity rate. The elevated risk of WNV observed in the most populous counties is consistent with the prevalence of WNV-vector mosquitoes *Culex pipiens* and *Culex restuans.* These species breed in stagnant water in urban areas, which are considered the primary habitat driving WNV infections in Massachusetts.

EEE and WNV positivity rates have generally increased over time in MCDs, though in some cases marginally. In areas which do not participate in an MCD, there were no positive EEE mosquito tests from 2004 to 2011. From 2012 to 2020, the positivity rate outside MCDs increased to 1.2 percent. Most of these positive tests were reported during the outbreak in 2019. For WNV, the positivity rate outside of MCDs increased from 1.0 percent in 2004 to 2011 to 2.3 percent in 2012 to 2020.

3. THE HISTORY OF WNV, EEE, AND OTHER MOSQUITO-BORNE DISEASES IN MASSACHUSETTS AND OTHER NORTHEASTERN STATES

Mosquito-borne diseases are diseases caused by viruses that are transmitted among animals through the bite of an infected mosquito. In Massachusetts, the two most concerning mosquito-borne diseases are WNV and EEE (or "Triple E"). Surveillance in Massachusetts focuses on WNV and EEE because of the prevalence of these viruses in the environment and their potential to cause serious illness in humans. Symptoms of WNV can range from a fever to encephalitis or meningitis, though most infections are mild—with approximately 80 percent of cases being asymptomatic and less than 1 percent resulting in serious symptoms. EEE more often presents with serious disease, with approximately a 30 percent to 50 percent mortality rate and lifelong neurological disability among many survivors (Bharel & Cranston, 2020a).

Human cases of clinically apparent EEE and WNV infection are rare in Massachusetts (Figure 3-1). Between 2000 and 2020, only three years had more than 20 reported cases of either disease. However, in the past two decades (2000 to 2020), there have been sporadic outbreaks of both diseases within the commonwealth. EEE cases have appeared to follow "outbreak cycles," with several years of no or very low activity followed by two to four years with multiple reported cases. The peak number of EEE cases reported in a single year was 12 cases in 2019. Human cases of WNV vary from year to year, though the number of cases has been increasing, with a peak of 48 cases in 2018. Over the past 20 years, the incidence of WNV in Massachusetts has been about five times that of EEE. The difference in incidence between the two diseases is likely much larger because the high frequency of asymptomatic WNV infections results in the underreporting of cases. Regardless, public health officials express greater concern for EEE because of the disease's severity and high rate of morbidity and mortality (Massachusetts Department of Public Health, 2021).

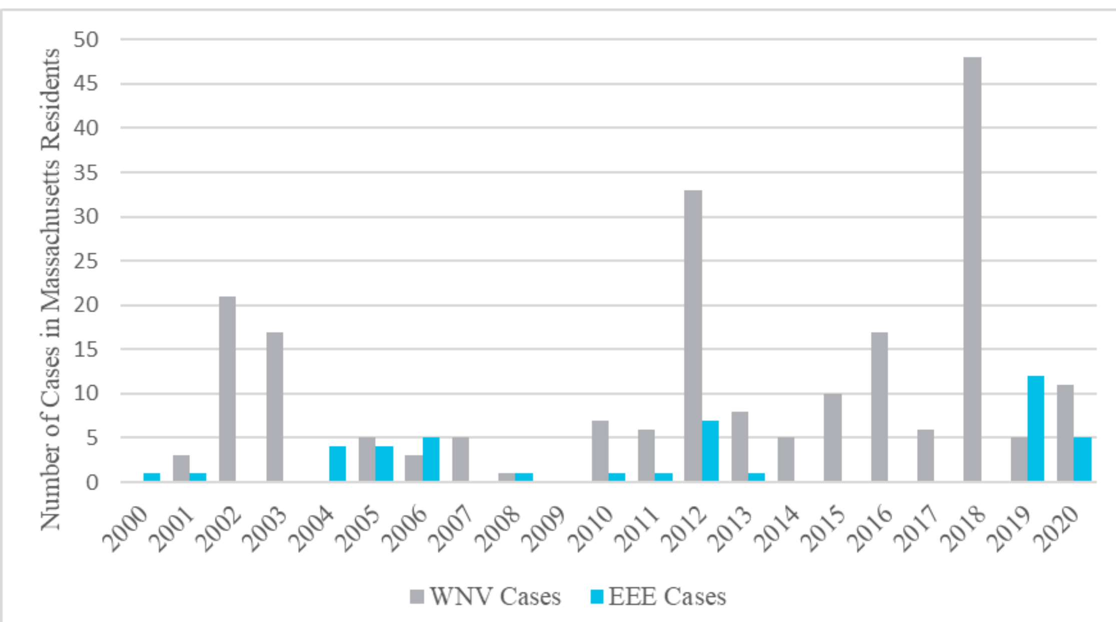

Figure 3-1. Cases of WNV and EEE in Massachusetts in past two decades.

For both EEE and WNV, the amount of circulating virus among specific mosquitoes is a determining factor for disease in humans. Both viruses spread primarily among birds and bird-biting mosquitoes in what is termed a virus "amplification cycle." The viruses can then be transmitted to humans via "bridge" mosquito vectors that feed on both birds and mammals (Bharel & Cranston, 2020a). However, the specific mosquito species and birds that are primary vectors for each virus are different, which leads to differences in patterns of disease throughout the state. This report discusses the mosquito species that are critical in the transmission of each virus and the history and geographic distribution of each virus in Massachusetts. The analyses presented here are based primarily on surveillance data collected by DPH and provided to ERG. These data include the number of positive test results in mosquitoes and the number of human cases of disease. In accordance with patient privacy and confidentiality protection policies, DPH could only release human case data to ERG at the county level. The mosquito trap location data were limited to the municipality level (Bharel & Cranston, 2020a).

3.1 Mosquito Surveillance for EEE and WNV (Statistics on the Number, Types, and Locations of Mosquito Traps)

Massachusetts has developed a robust mosquito surveillance system that monitors the relative abundance of populations of mosquito species and tests vector mosquitoes for EEE virus (EEEV) and WNV. Mosquito surveillance in Massachusetts informs DPH's projections of human risk of disease each year, which in turn guide mosquito control activities in the commonwealth. As such, mosquito surveillance serves a key function of monitoring and mitigating EEE and WNV (Bharel & Cranston, 2020a).

In 1957, Massachusetts' surveillance program began monitoring for EEEV in mosquitoes in Bristol County and Plymouth County. Since 2000, DPH began testing for both WNV and EEEV in mosquito samples and expanded trapping and testing throughout the state. Only vector species are tested for the presence of WNV and EEEV. Multiple mosquitoes of a certain species in a trap are tested together (a "pool"), and in instances when multiple traps are set at the same location, mosquitoes from multiple traps may also be pooled and tested in a single lab analysis. DPH may set traps throughout the Commonwealth or in collaboration with MCDs. MCDs may also set their own traps. DPH sets both long-term traps, primarily located in southeastern and eastern Massachusetts, and supplemental traps in other locations determined by mosquito activity and reports of EEE and WNV. While some traps are set outside MCDs, historically, limited data have been available from municipalities that are not part of MCDs. The changing participation of municipalities in MCDs over time complicates the analysis of surveillance and testing data provided by some MCDs. As such, the number of traps, placement of traps, number of tests for EEEV/WNV, and composition of MCDs all vary over the period for which DPH provided data for this report, 2004 to 2020.

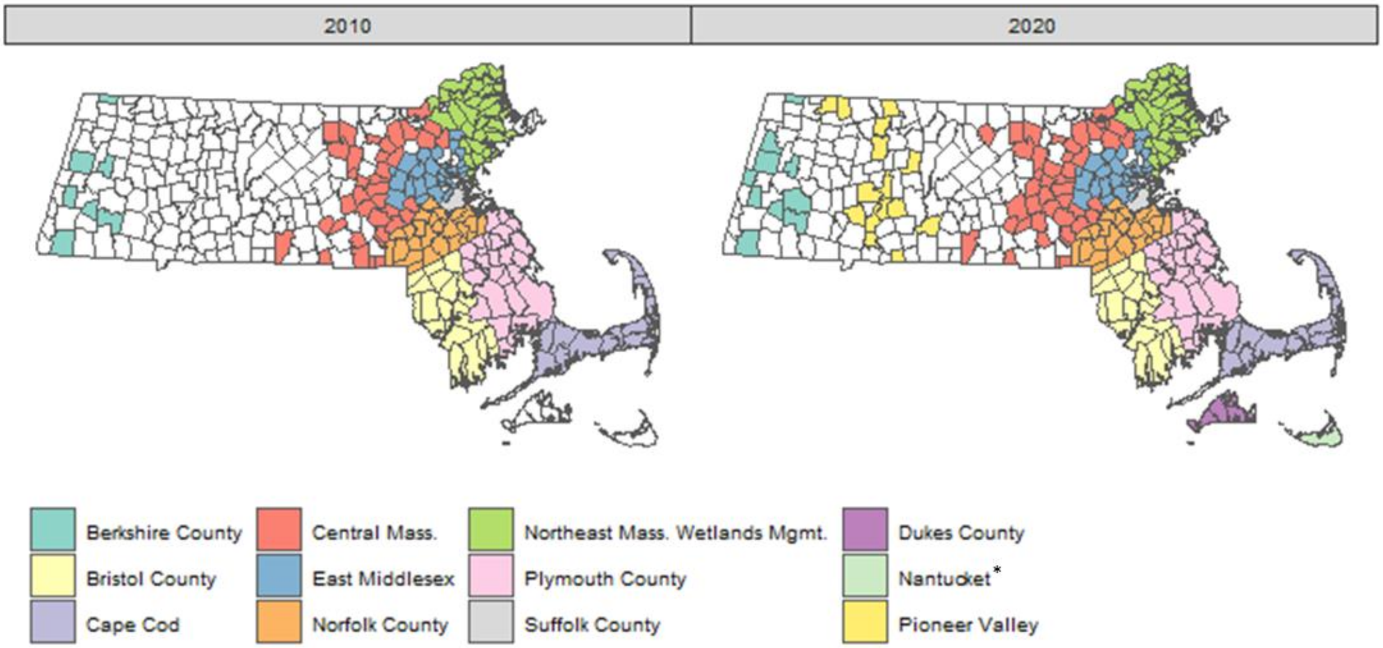

Figure 3-2. MCDs in 2010 and 2020.

*Between 2010 and 2020, the Nantucket MCD was formed and then dissolved. Nantucket still practices its own mosquito management, which includes some testing for WNV.

Figure 3-2 shows the changes in participation in MCDs between 2010 and 2020. Notable changes include the formation of the Pioneer Valley MCD in 2017 and the renewal of the Dukes County MCD. In addition, the Berkshire County and Central Massachusetts MCDs expanded as new municipalities joined them. Because participation in an MCD leads to financial investment in mosquito control, the number of mosquito traps and tests conducted within a municipality is higher for cities and towns in MCDs.

Figure 3-3 shows the number of tests for WNV/EEE conducted on mosquito pools each year, grouped by the 2020 MCD boundaries. Specifically, each trap location is classified as either in a 2020 MCD based on the trap location or as “not in 2020 MCD.” Figure 3-3 shows an increase in testing in municipalities following the formation of new MCDs over this period. For example, municipalities in the Pioneer Valley MCD showed an increase in testing in 2016, one year before the MCD was formed, and testing increased in the Dukes County MCD in 2013. Figure 3-3 also shows that the temporal pattern of mosquito tests generally follows EEE outbreak cycles, with peak testing conducted during peak human cases of EEE in 2006, 2012, and 2019. Human WNV peaks also coincide with these years, in addition to peaking in 2016 and 2018, indicating that human cases of both diseases in part drive the frequency of testing. MCDs and DPH will generally increase surveillance efforts, including increased testing, during outbreak years. Alternatively, as a cost saving measure, some MCDs may stop submitting tests when there are either few positive test results in a season, or consistently positive results for a given trap location.

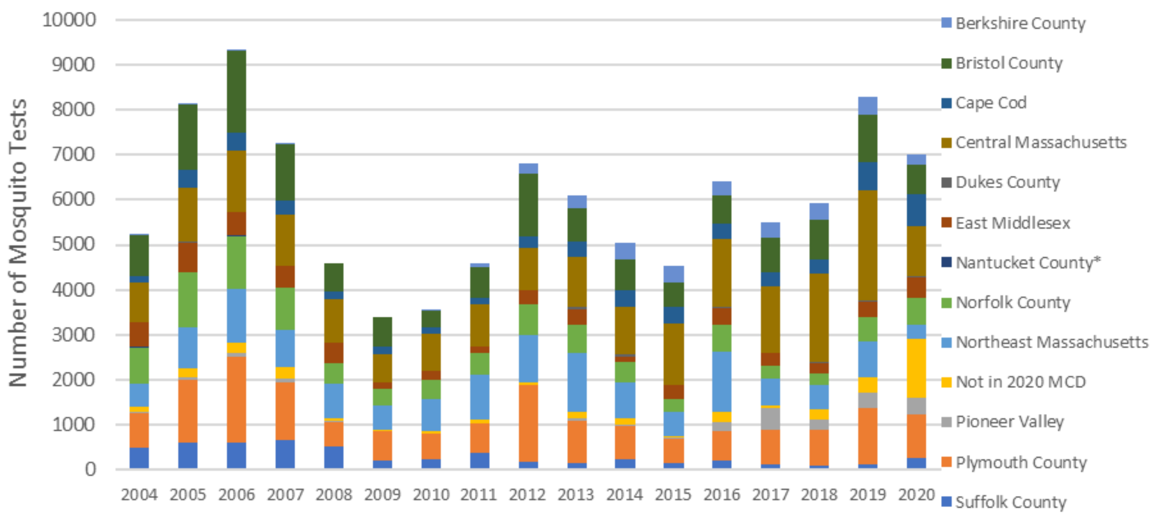

Figure 3-3. Number of mosquito tests by MCD (2004 to 2020).

*Between 2010 and 2020, the Nantucket MCD was formed and then dissolved. Nantucket still practices its own mosquito management, which includes some testing for WNV

Between 2004 and 2020, a relatively small number of mosquito tests were performed in municipalities that were not in the 2020 MCDs. In recent years, trapping and testing expanded across central and western Massachusetts. From 2004 to 2011, there were 46,061 EEEV/WNV mosquito tests, or on average 6,580 per year, conducted across 264 municipalities. From 2012 to 2020, there were 55,713 tests, or on average 6,964 per year, conducted across 334 municipalities. While the average testing rates in recent years were comparable to previous years, there was a great increase in the number of traps set and tests conducted in municipalities in western and central Massachusetts. Figure 3-4 shows that in 2020 specifically, DPH expanded mosquito traps and mosquito testing to include more than 1,300 mosquito tests in municipalities that were not part of a current MCD, mostly in central and western Massachusetts. The expansion of testing in municipalities not in MCDs was a deliberate goal DPH stated in its 2020 Massachusetts Arbovirus Surveillance and Response Plan, following the 2019 outbreak of EEE (Bharel & Cranston, 2020a).

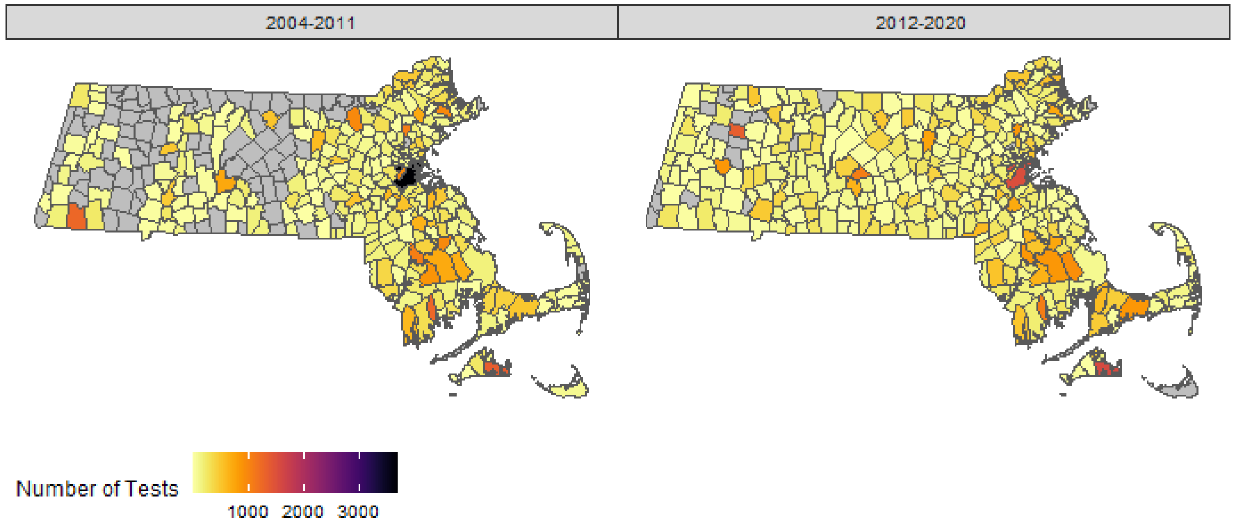

Figure 3-4. Number of mosquito tests by municipality.

Note: DPH testing data are broken into two time periods here to show the spread of testing results across the Commonwealth in recent years.

3.1.1 EEEV in Mosquitoes in Massachusetts

EEEV is frequently found in Massachusetts in some bird species in and around freshwater swamp habitats. These habitats also support the primary bird-biting mosquito vector, *Cs. melanura.* EEE is usually first detected in mosquitoes in late June or early July, coinciding with the hatching of susceptible bird populations, and it increases in prevalence through continuous transmission between mosquitoes and bird reservoir hosts (the virus amplification cycle). The virus circulates among birds, spread primarily by the bird-biting mosquitoes *Cs. melanura* and sometimes also by *Culiseta morsitans*; these species rarely bite humans. In Massachusetts, EEEV is enzootic to *Cs. melanura,* (i.e., EEE is generally prevalent in this species). It is presumed that EEE transfers to incidental hosts (e.g., humans, horses) by "bridge" mosquito vectors that feed on both birds and mammals. In Massachusetts, *Coquillettidia perturbans* is suspected to be the primary bridge vector species for EEE, though this species may play a role in viral amplification as well. Other bridge vector mosquito species include *Culex salinarius* and *Ochlerotatus canadensis* (Bharel & Cranston, 2020a).

Figure 3-5 shows the number of positive EEE mosquito tests by mosquito species conducted in Massachusetts from 2004 to 2010. Years with peak numbers of positive tests for EEE (2006, 2012, and 2019) align with peak years of human cases. These data confirm that only a few mosquito species are key in the EEE transmission cycle, specifically *Cs. melanura,* which in some years comprises almost all positive test results. In outbreak years, other mosquito species are better represented, in particular the key bridge vector mosquito *Cq. perturbans*. Positive EEE test results were also seen in the species *Cx. pipiens* and *Cx. restuans,* which are primarily bird-biters and the primary mosquito vectors for WNV.

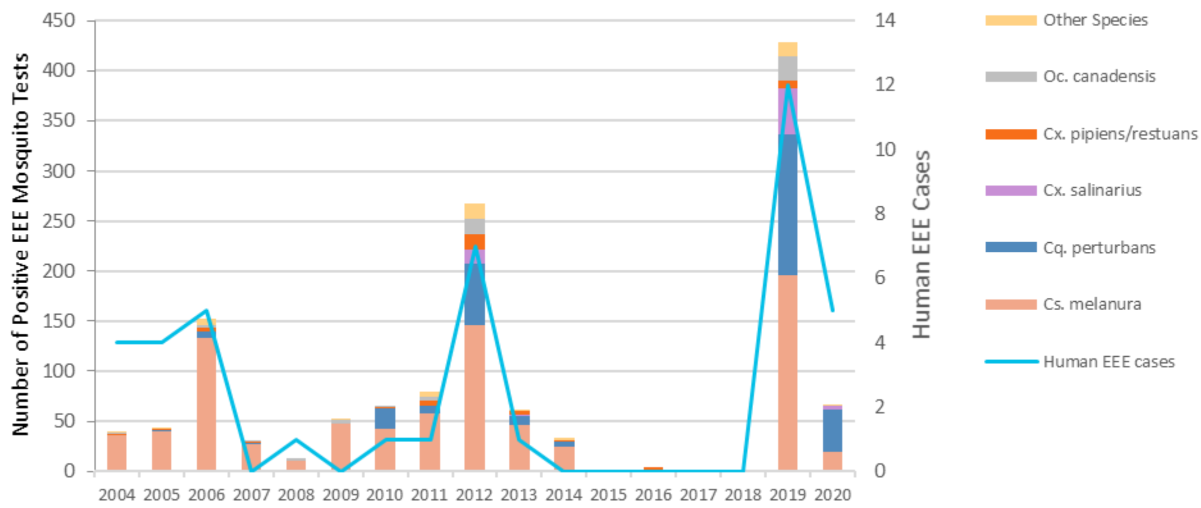

Figure 3-5. Positive EEE mosquito tests by species from 2004 to 2020.

Figure 3-6 and Figure 3-7 show the number of positive EEE mosquito tests from 2004 to 2020, by 2020 MCD. Since 2004, either the Plymouth County MCD or the Bristol County MCD had the greatest number of positive tests each year (except 2015, where only a single EEE-positive mosquito pool was found, in Central Massachusetts MCD). Although the Plymouth County and Bristol County MCDs also have consistently high amounts of testing in general, other MCDs, such as the Central Massachusetts MCD and Northeast Massachusetts MCD, have comparable levels of testing throughout the years but not as many positive test results. A substantial number of tests were performed from 2015 to 2018 (Figure 3-3), but hardly any test results were positive. The limited viral presence in mosquitoes over this period aligns with the lack of human EEE cases. The low number of positive of EEEV tests in collected mosquitoes over this period is likely due to the low rate of survival of *Cs. melanura* caused by drought conditions.

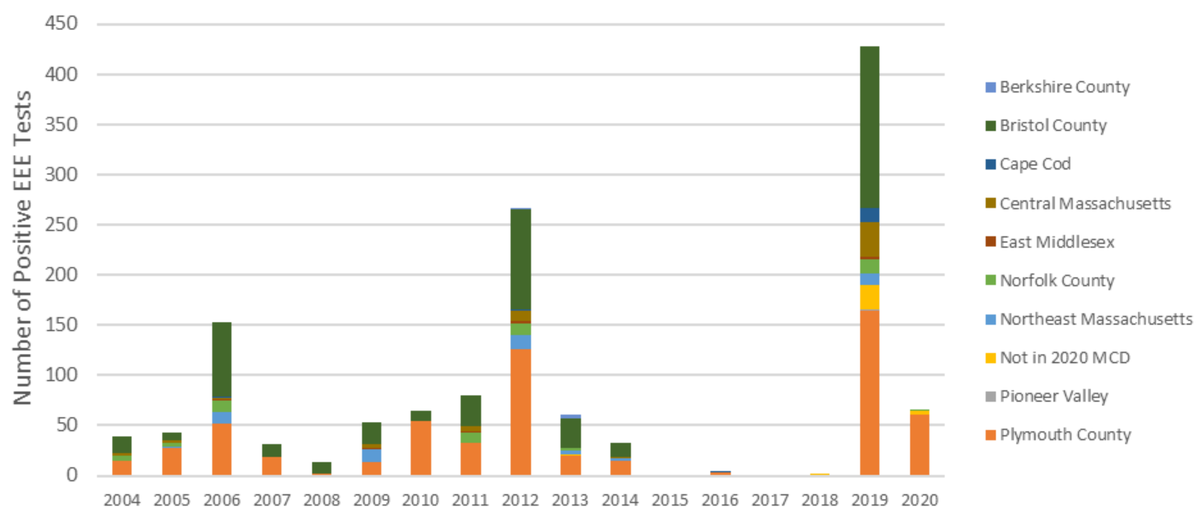

Figure 3-6. Positive EEE mosquito tests by MCD from 2004 to 2020.

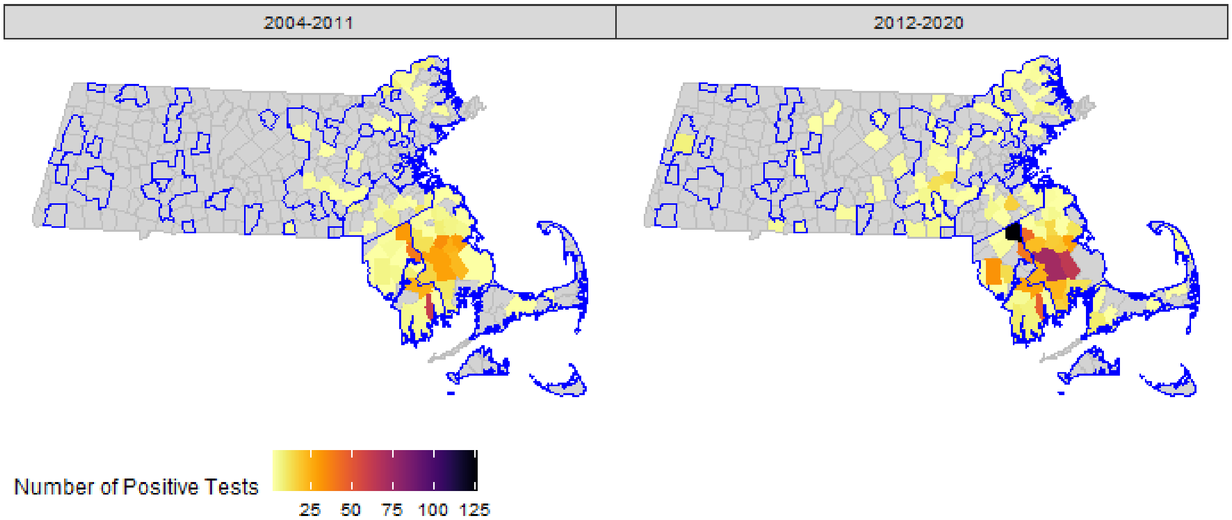

Figure 3-7. Positive EEE mosquito tests by municipality from 2004 to 2020.

Note: Municipalities within MCDs are highlighted in blue. DPH testing data are broken into two time periods here to show the spread of testing results across the Commonwealth in recent years.

To control for differences in testing when comparing the number of positive samples across current MCD boundaries, a EEE positivity rate was calculated (see Table 3-1). The positivity rate is defined as the number of mosquito tests positive for EEE divided by the total number of mosquito tests. The MCDs with the highest positivity rates are Bristol County and Plymouth County, known hot spots for EEE cases. EEE positivity rates have increased over time across all MCDs, though in some cases marginally. In areas which do not participate in an MCD, there were no positive EEE mosquito tests from 2004 to 2011. From 2012 to 2020, the positivity rate outside MCDs increased to 1.2 percent. Most of these positive tests were reported during the outbreak in 2019.

Table 3-1. Mosquito EEE Positivity Rates Across MCDs

	2004–2011		2012–2020	
MCD	**Total Number of Tests**	**Positivity Rate**	**Total Number of Tests**	**Positivity Rate**
Berkshire County	192	0%	2,897	0.2%
Bristol County	7,736	2.4%	7,331	4.2%
Cape Cod	1,884	0.1%	3,670	0.5%
Central Massachusetts	7,933	0.2%	13,057	0.4%
Dukes County	37	0%	223	0%
East Middlesex	3,087	0.1%	2,748	0.2%
Nantucket County	77	0%	0	-
Norfolk County	5,873	0.5%	4,319	0.7%
Northeast Massachusetts	6,473	0.4%	7,262	0.4%
Pioneer Valley	293	0%	1,722	0.1%
Plymouth County	7,853	2.7%	8,378	4.7%
Suffolk County	3,692	0%	1,565	0%
All MCDs	**45,130**	**1.1%**	**53,172**	**1.6%**
Not in 2020 MCDs	**931**	**0%**	**2,541**	**1.2%**

Table 3-2 and Figure 3-8 show acres of EEE mosquito habitat by MCD and by municipality, respectively. The total area was calculated as the sum of acres of freshwater swamps and marshes preferred by the EEE vector-mosquitoes Aedes vexans, Cq. perturbans, Cs. melanura, Oc. canadensis, and Ochlerotatus sollicitans. Specifically, the habitats indicated by DPH experts include wooded swamp (deciduous, coniferous, and mixed trees); shrub swamp; salt marsh; and shallow marsh, meadow, or fen (MassGIS, 2017). Plymouth County and Bristol County have the greatest amount of these types of habitat in Massachusetts. The specific municipalities within MCDs that have more acres of mosquito habitat often correspond to the municipalities that have had the greatest number of positive EEE mosquito tests. For example, in the Plymouth County MCD, the municipality of Middleborough has the greatest acreage of EEE mosquito habitat (Figure 3-8) and the greatest number of positive EEE mosquito tests (Figure 3-7).

Table 3-2. Acres of EEE Mosquito habitat by MCD

MCD	Acres
Plymouth County	76,767
Bristol County	61,687
Northeast Massachusetts	52,938
Central Massachusetts	52,680
Norfolk County	31,279
Cape Cod	23,313
East Middlesex	20,888
Berkshire County	19,576
Pioneer Valley	13,754
Nantucket County	2,621
Dukes County	2,281
Suffolk County	753

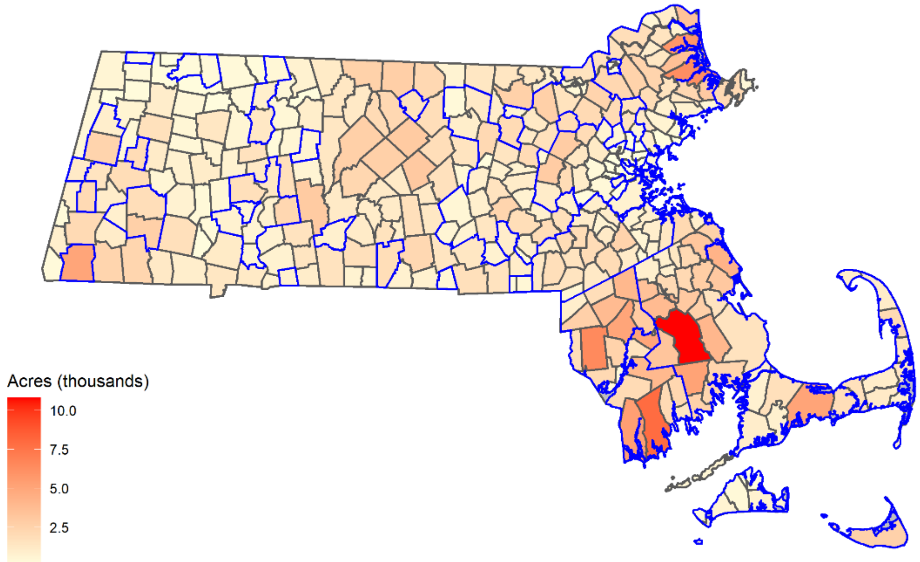

Figure 3-8. Acres of EEE mosquito habitat by municipality.
Note: Municipalities within MCDs are highlighted in blue.

3.1.2 WNV in Mosquitoes in Massachusetts

WNV was first identified in birds and mosquitoes in Massachusetts in 2000. WNV is amplified by a cycle of continuous transmission between *Culex* mosquito vectors and bird reservoir hosts. *Culex* mosquitoes breed abundantly in artificial containers in urban areas, such as catch basins, discarded tires, birdbaths, and other standing water (Tuiten et al., 2009). *Cx. pipiens* and *C. restuans* are the primary vectors in Massachusetts. These species mainly feed on birds but occasionally feed on mammals. Other species, including *Cx. salinarius* and *Ochlerotatus japonicus,* bite humans and birds and may also be involved in the transmission of WNV to humans (Bharel & Cranston, 2020a).

Figure 3-9 shows the number of positive WNV mosquito tests conducted from 2004 to 2010 by mosquito species. Peak years for human cases (2012, 2016, and 2018) occurred in years with above-average numbers of positive WNV mosquito tests, although some years with above-average positive test counts did not correspond to human case peaks. These data confirm that only a few mosquito species are key in the WNV transmission cycle in Massachusetts, specifically *Culex* mosquitoes, which comprise most positive test results across all years. Individual *Culex* species are grouped in Figure 3-9 because tests do not always distinguish between *Cx. pipiens* and *Cx. restuans,* although *Cx. pipiens* was the most dominant species. In peak outbreak years, other mosquito species also tested positive for WNV, specifically the bird-biting mosquitoes *Cs. morsitans* and *Cs. melanura* and the bridge vector species *Cx. salinarius.*

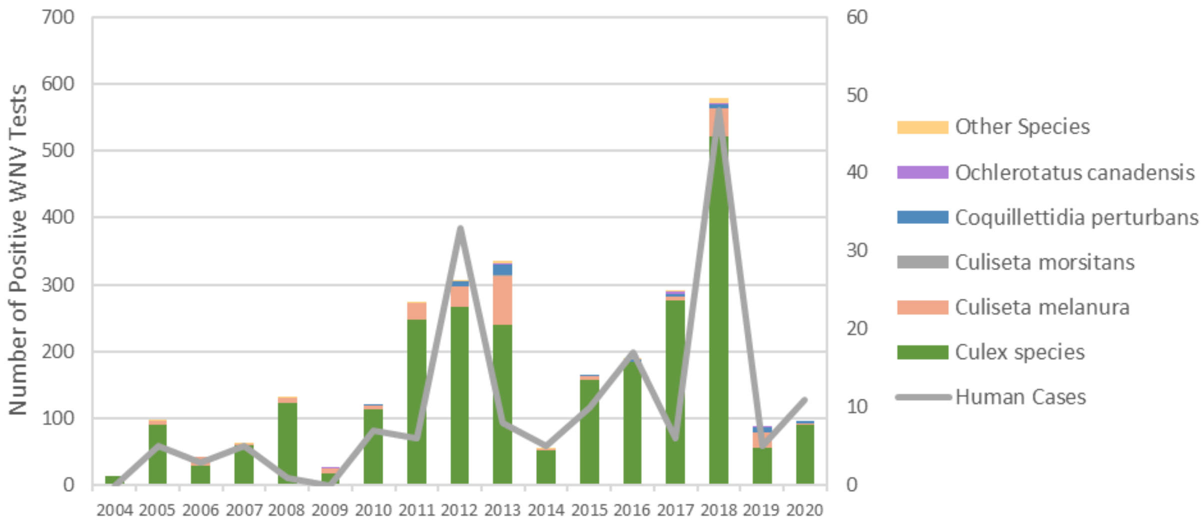

Figure 3-9. Positive WNV mosquito tests by species from 2004 to 2020.

Note: Culex species are grouped here because many tests did not specify the *Culex* species. However, a large majority of the identified *Culex* species are *pipiens* or *restuans*.

Figure 3-10 and Figure 3-11 show the number of positive WNV mosquito tests from 2004 to 2020 by 2020 MCD delineations. Positive WNV tests are consistently seen in the eastern and southeastern MCDs of Northeast Massachusetts, Central Massachusetts, Suffolk County, East Middlesex, Norfolk County, Plymouth County, and Bristol County. The number of positive WNV mosquito tests in the Pioneer Valley and Berkshire County MCDs has increased, though this may be due to increased testing. No positive tests for WNV have been reported by the Nantucket MCD to DPH since 2008. Dukes County has had few positive test results. Neither Dukes County nor Nantucket have reported any human cases of WNV during this period.

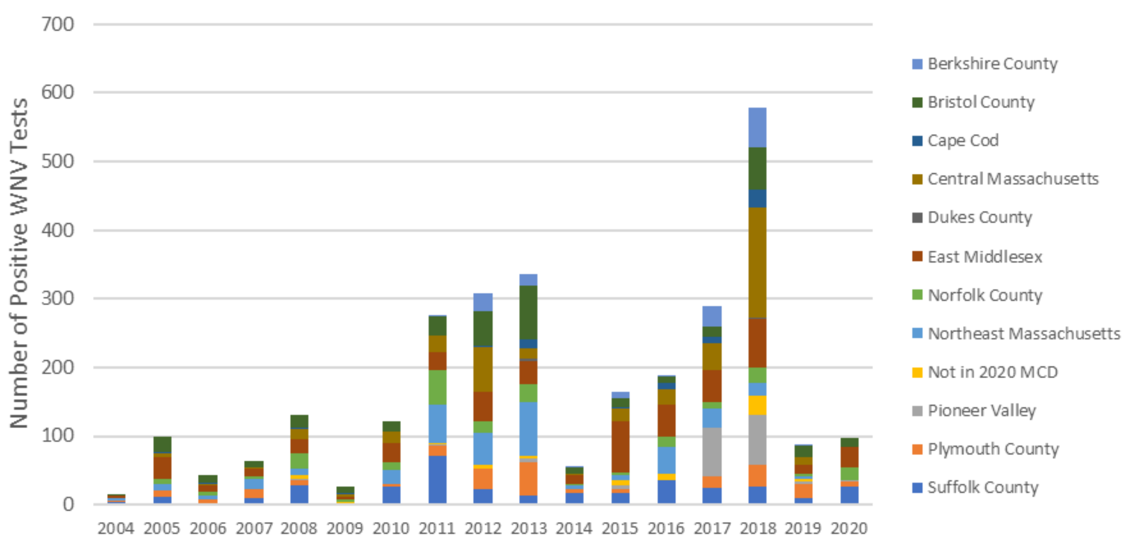

Figure 3-10. Positive WNV mosquito tests by MCD from 2004 to 2020.

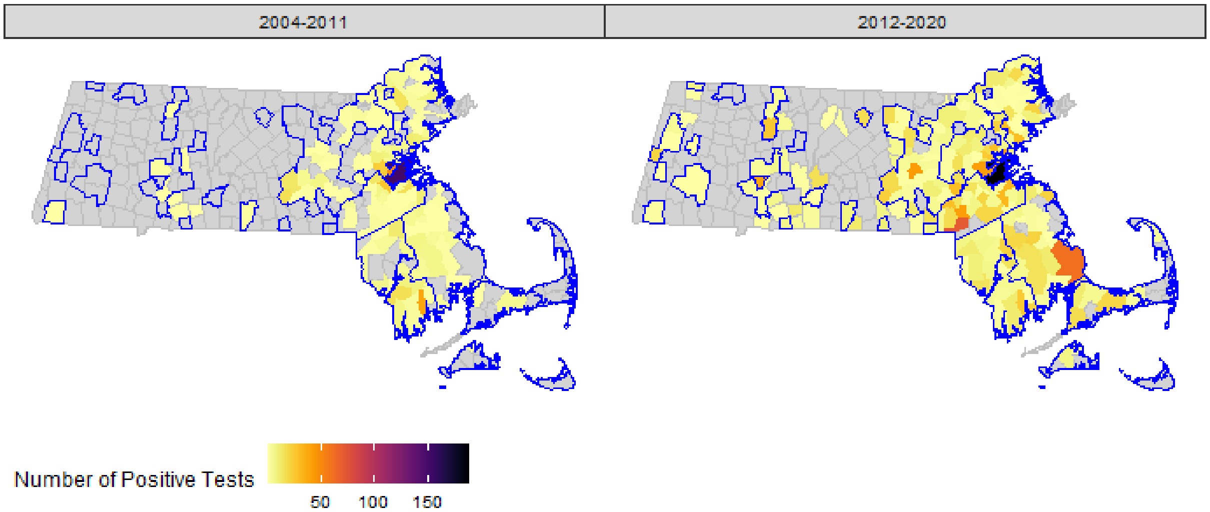

Figure 3-11. Positive WNV mosquito tests by municipality from 2004 to 2020.

Note: Municipalities within MCDs are highlighted in blue. DPH testing data are broken into two time periods here to show the spread of testing results across the Commonwealth in recent years.

To control for differences in testing when comparing the number of positive samples, a WNV positivity rate was calculated (tests positive for WNV divided by the total number of tests). The WNV positivity rate ranged widely from year to year and across MCDs (Table 3-3). For example, the MCDs of East Middlesex and Pioneer Valley have ranged from less than 1 percent positivity to 33 percent positivity in 2018. The Suffolk County MCD has the highest average positivity rate at 13.8 percent, and the maximum positivity was observed in 2018 at 25 percent. WNV positivity rates have generally increased over time across the Commonwealth. The positivity rate within MCDs increased from 1.7% in 2004 to 2011 to 3.7% in 2012 to 2020, and the positivity rate outside of MCDs increased from 1.0% to 2.3%. The high positivity rates observed in MCD and non-MCD municipalities demonstrates the widespread prevalence of WNV in mosquitoes in Massachusetts.

Table 3-3. Mosquito WNV Positivity Rates Across MCDs

	2004–2011		2012–2020	
MCD	Total Number of Tests	WNV Positivity Rate	Total Number of Tests	WNV Positivity Rate
Berkshire County	192	0.5%	2,897	5.0%
Bristol County	7,736	1.4%	7,331	3.6%
Cape Cod	1,884	0.3%	3,670	1.8%
Central Massachusetts	7,933	0.9%	13,057	2.6%
Dukes County	37	2.7%	223	2.2%
East Middlesex	3,087	4.2%	2,748	13.6%
Nantucket Mosquito Control Project	77	0.0%	0	-
Norfolk County	5,873	1.8%	4,319	3.5%
Northeast Massachusetts	6,473	1.9%	7,262	3.5%
Pioneer Valley	293	1.4%	1,722	9.2%
Plymouth County	7,853	0.7%	8,378	2.0%
Suffolk County	3,692	4.2%	1,565	13.8%
All MCDs	**45,130**	**1.7%**	**53,172**	**3.7%**
Not in 2020 MCDs	**931**	**1.0%**	**2,541**	**2.3%**

3.2 History and Risk of EEE for Residents of Massachusetts

Table 3-4 shows a history of EEE cases among Massachusetts residents. The first recorded outbreak of EEE in Massachusetts occurred in 1938. Subsequent outbreaks of EEE appear to follow cycles, with several years of no or very low activity followed by two to three years with multiple reported cases. These outbreak cycles historically occurred every 10 to 20 years and lasted two to three years. The more recent outbreak cycles of EEE in Massachusetts appear to have become more frequent, with gaps of two to six years between reported cases. The most recent outbreak began in 2019 with 12 cases and six fatalities and continued through 2020 with five cases and one fatality.

Table 3-4. Number of Reported Cases and Deaths for EEE Among Massachusetts Residents

Year(s)	Human EEE Cases	Human EEE Deaths
1938–1939	35	25
1955–1956	16	9
1973–1974	6	4
1982–1984	10	3
1990–1992	4	1
2000–2001	2	0
2004–2006	13	8
2008	1	1
2010–2013	10	5
2019	12	6
2020	5	1
Total	**114**	**63**

Sources: adapted from Bharel and Cranston (2020a) and Massachusetts Department of Public Health (2021).

From 2000 to 2020, 43 cases of EEE were reported among residents of Massachusetts (Table 3-4). More than half of these cases occurred among residents of Plymouth County (15 cases) and Bristol County (seven cases) in southeastern Massachusetts. All other counties reported fewer than five cases over the 21-year period. No cases of EEE were reported among residents of Suffolk, Barnstable, Hampshire, Berkshire, or Nantucket counties.

To compare the risk of EEE across counties while controlling for differences in population size, Table 3-4 shows the annual case rates of EEE in Massachusetts. On average, the annual risk of EEE across Massachusetts from 2000 to 2020 is 0.3 cases per million residents, and the range of risk across individual counties is 0 to 2.7 cases per million residents. The data in Table 3-5 indicate that Plymouth County and Bristol County, both in southeastern Massachusetts, have the highest EEE case counts in the commonwealth and rank among the highest for cases per million. The case rates for Dukes County and Franklin County are difficult to interpret because these counties have relatively low populations, and both have recorded just one case since tracking began. All other counties in Massachusetts either had lower case rates—or have never had a recorded case.

Table 3-5. Incidence of Human Cases of EEE by County from 2000 to 2020

County	Population[a]	Human EEE Cases	Annual Cases of EEE per Million Residents[b]
Dukes County	16,535	1	2.7
Plymouth County	494,919	15	1.4
Franklin County	71,372	1	0.7
Bristol County	548,285	7	0.6
Hampden County	463,490	3	0.3
Norfolk County	670,850	4	0.3
Essex County	743,159	4	0.2
Worcester County	798,552	4	0.2
Middlesex County	1,503,085	4	0.1
Suffolk County	722,023	0	-
Barnstable County	215,888	0	-
Hampshire County	158,080	0	-
Berkshire	131,219	0	-
Nantucket	10,172	0	-
Total		**43**	**0.3**

[a] Source: United States Census Bureau (2020).

[b] Annual risk is calculated as the number of cases divided by the population divided by 21 years and expressed as cases per million residents.

Human EEE case data have several known limitations. First, cases are indexed by the individual's county of residence and may not represent the location where the person became infected. It is possible that individuals were infected in other parts of the state, or even out of state, but were recorded as cases in their home counties. Further, the low total case counts and low populations of several Massachusetts counties can create artifacts in the data that may or may not provide an accurate picture of risk. For example, the case rate in Dukes County is higher than rates for the other counties, but Dukes County has very few residents (17,000 people) and only a single case reported over this period. It is therefore possible that the risk in Dukes County represents a one-off event rather than a real, sustained high risk level. Case rates were calculated as zero for Nantucket, Berkshire, Hampshire, and Barnstable counties. However, these counties have relatively small populations (fewer than 200,000 people), and the lack of cases in these counties does not necessarily imply zero risk.

Figure 3-12 shows the distribution of EEE cases over the three most recent outbreak cycles. At least one case of EEE was recorded among residents of Plymouth, Bristol, Middlesex, and Norfolk counties during each of the last three outbreak cycles. In terms of both the number of cases and risk level, the consistent presence of cases in Plymouth County and Bristol County across outbreak cycles indicates the persistence of EEE in these counties in particular. Middlesex County and Norfolk County have never recorded more than two cases in any one of the last 20 years.

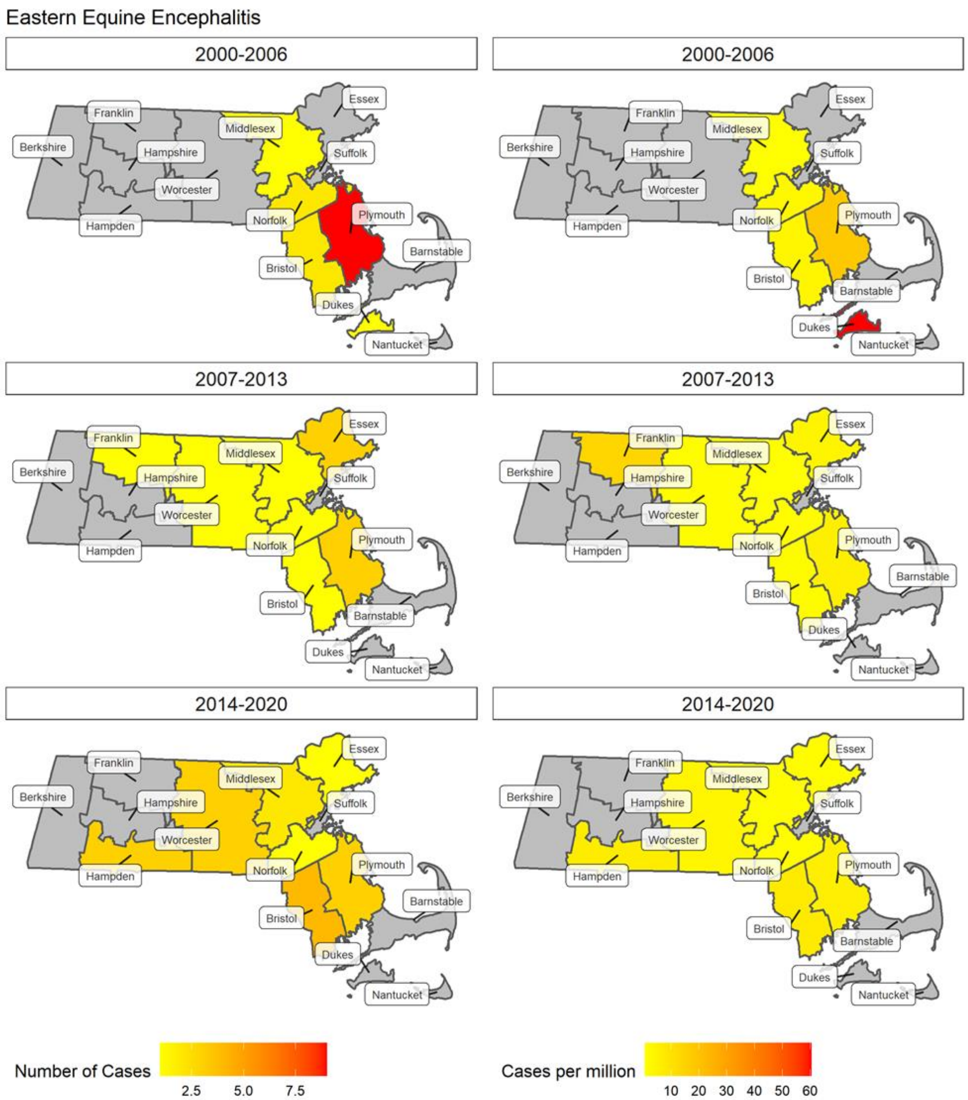

Figure 3-12. Human EEE cases and cases per million by county.

3.2.1 Risk of EEE in Massachusetts Compared to Other States

Table 3-6 shows the number of EEE cases reported from 2010 to 2019 by state collected by CDC's ArboNET data source. Of the 50 U.S. states and Puerto Rico, 23 states reported at least one EEE case from 2010 to 2019, with a total of 107 cases reported among U.S. residents. In the last decade, more cases of EEE have occurred in residents of Massachusetts (22 cases) than any other state, followed by Michigan (17 cases) and Florida (13 cases) (ArboNET, 2020a). Other northeastern states reported multiple cases each, and more than a third of all U.S. EEE cases were reported in New England residents. The data in Table 3-5 are based on where EEE patients lived, which may differ from where the individuals were infected.

Cases of EEE in other neighboring states do not correlate with cases in Massachusetts. Massachusetts experienced EEE outbreaks from 2010 to 2013 (with cases concentrated in 2012) and is experiencing an ongoing outbreak that started in 2019. Data from CDC's ArboNET are not yet available for 2020 for states other than Massachusetts, but cases in some neighboring states were elevated in 2019. Connecticut and Rhode Island reported a total of seven cases in

2019, out of nine total cases reported by the two states from 2010 to 2019. However, no cases were reported in 2019 in New York, New Hampshire, or Vermont. New Hampshire's three EEE cases were all reported in 2013, when only one case was reported in Massachusetts. Five of New York's seven cases were reported in years when there were no cases in Massachusetts. Vermont's two cases were both reported in 2012, the peak of the 2010 to 2013 outbreak, but no cases were reported in Vermont residents during the 2019 outbreak.

Table 3-6 also shows the case rates (i.e., the annual number of cases observed per million residents) for 2010 to 2019. The highest case rates were in four New England states: Rhode Island (0.38), Massachusetts (0.34), Vermont (0.32), and New Hampshire (0.23).

Table 3-6. Cases of EEE in Residents of Selected States, 2010 to 2019

State	Reported EEE Cases[a]	Annual Cases per Million Residents[b]
Massachusetts	22	0.34
Michigan	17	0.17
Florida	13	0.07
New York	7	0.04
Georgia	7	0.07
North Carolina	7	0.07
Connecticut	5	0.14
New Jersey	5	0.06
Rhode Island	4	0.38
New Hampshire	3	0.23
Maine	2	0.15
Vermont	2	0.32

[a] Source: ArboNET (2020a).

[b] Annual case rates are based on 2010 population data from the United States Census Bureau (2020). They include all U.S. states with more than two reported cases of EEE from 2010 to 2019 plus remaining New England states (i.e., Maine and Vermont).

3.3 History and Risk of WNV in Residents of Massachusetts

WNV was first identified in the United States in New York City in 1999, and the first human case was observed in Massachusetts in 2001 (Bharel & Cranston, 2020a). Since then, there have been 211 reported cases of WNV and 12 reported deaths (Table 3-7). Human cases of WNV are reported almost every year in Massachusetts, averaging approximately 10.6 confirmed cases per year since 2001. The number of cases per year has increased since 2001, but with considerable year-to-year variability, and cases have been reported every year since 2010 (Figure 3-1). Three years (2002, 2012, and 2018) account for 48 percent of the total cases observed in the commonwealth since 2001. Because many WNV infections are asymptomatic, the total number of infections likely is greater than the number of reported cases.

Table 3-7 shows the number of WNV cases and calculated WNV case rates from 2001 to 2020, broken down by county. Middlesex County, the most populous county in the state, had the highest number of cases (90) and the highest case rate. To compare the risk of WNV across counties while controlling for differences in population size, Table 3-7 also shows the annual risk of WNV in Massachusetts. The average annual risk of WNV across Massachusetts from 2001 to 2020 is 1.6 cases per million residents, and the range of risk across individual counties is 0 to 3.0 cases per million residents. By this metric, the most populous counties have the highest risks. Case rates were calculated as zero for Dukes County and Nantucket County. However, these counties have relatively small populations (fewer than 20,000 people), and the lack of cases in these counties does not necessarily imply zero risk.

Table 3-7. Incidence of Human Cases of WNV by County from 2001 to 2020

County	Population[a]	Human WNV Cases	Annual Cases of WNV per Million Residents[b]
Middlesex County	1,503,085	90	3.0
Suffolk County	722,023	36	2.5
Worcester County	798,552	20	1.3
Essex County	743,159	14	0.9
Norfolk County	670,850	13	1.0
Bristol County	548,285	11	1.0
Hampden County	463,490	8	0.9
Plymouth County	494,919	7	0.7
Barnstable County	215,888	6	1.4
Hampshire County	158,080	3	0.9
Franklin County	71,372	2	1.4
Berkshire County	131,219	1	0.4
Dukes County	16,535	0	-
Nantucket County	10,172	0	-
Total	**6,547,629**	**211**	**1.6**

[a] Source: United States Census Bureau (2020).

[b] Annual risk is calculated as the number of cases divided by the population divided by 20 years and expressed as cases per million residents.

Figure 3-13 shows the distribution of WNV cases over three time periods that capture the three WNV outbreaks between 2001 and 2019. At least one case of WNV was recorded among residents of Essex, Middlesex, Suffolk, Norfolk, Worcester, Bristol, and Hampden counties in each time period. Cases in other counties were variable, and no human cases were reported in Dukes County or Nantucket County.

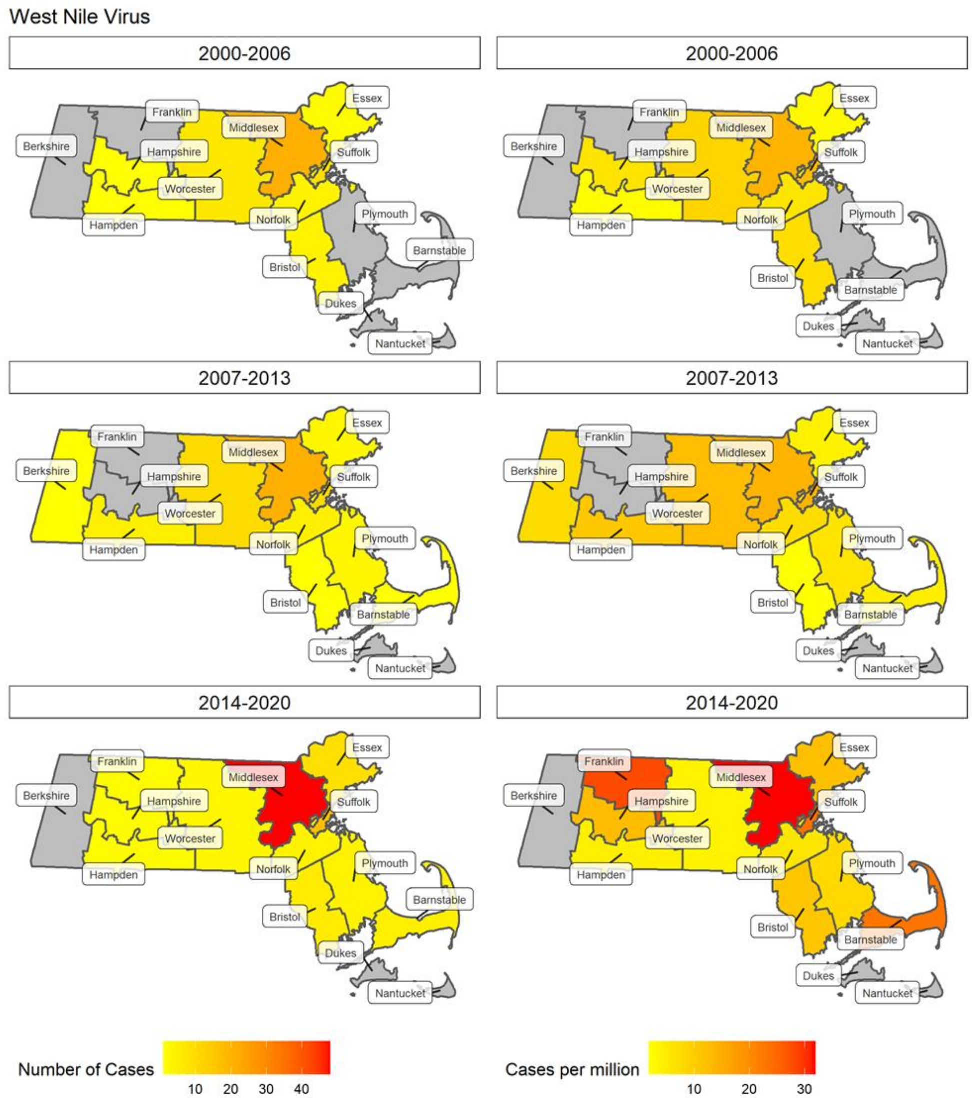

Figure 3-13. Human WNV cases and cases per million by county.

The consistently elevated risk of WNV observed in the most populous counties is consistent with the prevalence of WNV vector mosquitoes *C. pipiens* and *C. restuans*, which breed in small standing-water sources present in urban and suburban areas such as buckets, clogged gutters, and catch basins (Tuiten et al., 2009). Although other mosquitoes breeding in other environments can also transmit WNV, stagnant water in urban areas is considered the primary habitat driving WNV infections in Massachusetts (Bharel & Cranston, 2020a). Section 3.1 further discusses the role of mosquitoes in WNV incidence.

3.3.1 Risk of WNV in Massachusetts Compared to Other States

From 1999 through 2019, 51,801 cases of WNV disease were reported in the United States, with cases reported in all 50 states, D.C., and Puerto Rico. Table 3-8 shows the breakdown of cases among northeastern states between 1999 and 2019; 206 cases were reported among residents of Massachusetts in this time frame. Because WNV infections often cause no or only minor symptoms, it is sometimes more accurate to limit analysis to only neuroinvasive cases, which are more severe and therefore more consistently reported. Table 3-8 shows total reported cases and reported neuroinvasive cases in northeastern states. Nationally, 25,290 neuroinvasive WNV cases were reported from 1999 to 2019.

Table 3-8. Cases of WNV in Residents of Selected Northeastern States, 1999 to 2019

		All Cases (1999–2019)		Neuroinvasive Cases (1999–2019)	
State	Population	Reported WNV Disease Cases [a]	Annual Cases of WNV per Million Residents[b]	Reported Neuroinvasive Cases [a]	Annual Neuroinvasive Cases per Million Residents[b]
New York	19,378,102	973	2.4	731	1.8
New Jersey	8,791,894	321	1.7	215	1.2
Massachusetts	6,547,629	206	1.5	158	1.1
Connecticut	3,574,097	158	2.1	107	1.4
Rhode Island	1,052,567	22	1.0	15	0.7
Vermont	625,741	16	1.2	8	0.6
New Hampshire	1,316,470	7	0.3	5	0.2
Maine	1,328,361	4	0.1	3	0.1

[a] Source: ArboNET (2020a).
[b] Annual case rates are based on 2010 population data from the United States Census Bureau (2020).

Among northeastern states, total cases and neuroinvasive cases are highest among residents of the more populous states of New York and New Jersey, followed third by Massachusetts. Mosquitoes transmitting WNV are common in urban habitats and more common in densely populated areas; state population is used here as a surrogate for urbanization. Very few cases of WNV were reported in Maine and New Hampshire. When controlling for population, case rates are highest in New York and Connecticut.

3.4 History of Other Mosquito-Borne Diseases in Massachusetts

Mosquitoes can spread other diseases beyond WNV and EEE. In Massachusetts, the only other disease known to be transmitted by local mosquitoes to humans is Jamestown Canyon virus disease. Jamestown Canyon infection in the United States is most commonly reported in Wisconsin and Minnesota, but some cases have been reported in Massachusetts residents (Kinsella et al., 2020). Jamestown Canyon infection was first reported in a Massachusetts resident in 2013, and between one and four cases have been reported among residents every year since. Between 2013 and 2019, 12 total cases have been reported. Jamestown Canyon virus has been identified in vector candidate mosquitoes throughout the United States (Kinsella et al., 2020).

A few cases of other mosquito-borne diseases, including dengue virus disease and chikungunya virus disease, have been reported in Massachusetts residents, but no local transmission of these diseases has been identified. Cases of these diseases in Massachusetts residents are travel-related (i.e., the person was infected with the disease in a region where it is endemic). The same types of mosquito that spread chikungunya, dengue, and Zika, *Aedes aegypti* and *Aedes albopictus (or 'Asian tiger mosquito')*, have the potential to survive and spread in Massachusetts. *The Asian tiger mosquito* has already been found in localized areas within the Commonwealth (Hinkle, 2017). No locally transmitted cases of these diseases have been reported in Massachusetts (ArboNET, 2020b).

Report 9: Climate Change Impacts on Mosquito Populations and Mosquito-Borne Diseases discusses the potential climate-induced spread of other mosquito-borne diseases in Massachusetts in more detail.

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Report 2: Existing Mosquito Control Policy Structure and Its Effectiveness, Challenges Experienced

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1. EXECUTIVE SUMMARY

Mosquito control in Massachusetts is supported by a policy and decision-making structure that shares mosquito control management and related public and environmental health responsibilities—especially for aerial spraying—among Commonwealth agencies. As mandated by enabling legislation, Chapter 252 of the Massachusetts General Laws (M.G.L.), and Chapter 120 of the Acts of 2020, the three key entities with authority to conduct or support mosquito control in the Commonwealth are:

- **The State Reclamation and Mosquito Control Board (SRMCB or SRB),** a three-member body composed of representatives from the Massachusetts Department of Agricultural Resources (MDAR; currently serving as the SRB chair), the Department of Environmental Protection (DEP), and the Department of Conservation and Recreation (DCR). The SRB oversees mosquito control activities in the Commonwealth, can perform mosquito control operations including spraying, certifies budgets for mosquito control at the regional level, and establishes administrative and technical policy to ensure safety and efficacy of mosquito control programs. Additionally, in the event of a determination of a public health hazard, the SRB conducts aerial spraying operations. The SRB sits within MDAR, which provides additional support at the SRB's direction and assists with carrying out many of the day-to-day operations of the SRB through shared staff and resources.

- **Eleven regional mosquito control districts (MCDs)**, which serve as the primary organizations responsible for mosquito control activities (such as monitoring and surveillance, public education, and pesticide use if necessary) on lands within their participating municipalities.

- **The Department of Public Health (DPH),** which conducts surveillance and testing of mosquitoes in partnership with MCDs and monitors trends in Eastern equine encephalitis (EEE) and West Nile virus (WNV), in addition to working with MDAR and the SRB to achieve consensus on whether aerial application is warranted to address disease risk. While M.G.L. c. 252 does not reference DPH specifically, M.G.L. c. 111 grants DPH with broad authority to conduct disease investigations. Specifically, Sections 5, 6, and 7 outline DPH's ability to define and investigate diseases that are a danger to public health, thus providing authority for surveillance programs to identify, communicate, and control the spread of arboviral disease ("Mass. Gen. Laws ch. 111,").

To understand the effectiveness of this policy structure, ERG reviewed 51 documents related to existing policy, lessons learned, challenges, and best practices, and conducted 18 interviews (*note that this included three interviews that contained multiple individuals)* with 21 respondents, including Massachusetts agency staff, MCD superintendents and commissioners, local board of health representatives, Mosquito Control for the Twenty-First Century Task Force (MCTF) members, environmental nonprofit representatives, and mosquito control experts from other states. The evaluation focused on a series of questions about the existing policy structure and its decision-making and management effectiveness, best practices and lessons learned from within the Commonwealth and other northeastern states, strategies for improving the policy structure, challenges on public and private lands, and recommendations to overcome those challenges.

2. REPORT OVERVIEW

This report responds to the following research areas in the scope of work: 1) summarize the existing mosquito control policy structure in Massachusetts, including current practices and policies and a history of control measures, in addition to other relevant components, and 2) analyze challenges to controlling mosquitoes on state, federal, and/or privately owned land in the cities or towns and identify potential solutions to those challenges.

To address these research areas, ERG reviewed and evaluated the existing mosquito control structure in the Commonwealth and characterized mosquito control challenges on state, federal, and private lands. ERG reviewed 51 documents related to existing policy, lessons learned, challenges, and best practices. These documents included legislation, press releases, academic articles, white papers, agency reports, position papers, plans, and public letters. Additionally, ERG conducted 18 interviews with 21 respondents, including Massachusetts state agency staff, MCD[1] superintendents, MCD commissioners, local board of health representatives, MCTF members, environmental nonprofit representatives, and mosquito control experts from other states. (See Section 4 below for more details on the evaluation methods used.)

3. MASSACHUSETTS' MOSQUITO CONTROL POLICY STRUCTURE

Massachusetts laws and regulations place authority for different aspects of mosquito control with selected Commonwealth agencies, MCDs, and cities and towns. The remainder of this section summarizes the mosquito control policy structure in Massachusetts (Section 3.1), the enabling legislation for mosquito control (3.2), how mosquito control occurs on state, federal, and private lands (3.3), and mosquito control policy structures in selected other northeastern states (0).

3.1 Massachusetts' Mosquito Control Policy Structure

Mosquito control and surveillance in Massachusetts is a collaborative effort between public health and environmental agencies at the Commonwealth level and MCDs at the municipal and regional level. Overall, Massachusetts' mosquito control governance structure provides the SRB with full control over mosquito control operations throughout the Commonwealth, including aerial spraying in the event of a public health hazard. The SRB certifies the budgets and activities of the MCDs, while the MCDs maintain a high degree of autonomy in their day-to-day operations. MCDs are responsible for mosquito control at a regional level. Massachusetts' 11 MCDs work with their member communities to provide mosquito control services. Each MCD is led by a superintendent and overseen by boards of commissioners, with the exception of Dukes County which has no staff or board and only provides surveillance and testing through county assistance. Additionally, the recently formed MCTF serves in a purely advisory role by studying the Commonwealth's mosquito control program and making recommendations for improvements. The MCTF does not play a role in current mosquito control operations or inform decision-making for the SRB or MCDs. Further details follow on roles of the various parties with mosquito control responsibilities.

[1] Some mosquito control districts (MCDs) refer to themselves as mosquito control projects (MCPs) (e.g., the Cape Cod Mosquito Control Project). For consistency throughout this report, ERG refers to both MCDs and MCPs as MCDs.

3.1.1 Cabinet-Level Structure

At the cabinet level, mosquito control and surveillance in Massachusetts is managed through the Executive Office of Energy and Environmental Affairs (EEA) and the Executive Office of Health and Human Services (EOHHS). EEA seeks to protect, preserve, and enhance the Commonwealth's environmental resources (Commonwealth of Massachusetts, 2021e). The EOHHS agencies focus on the health, resilience, and independence of residents. Within EOHHS, DPH is the key agency with responsibility for providing assistance related mosquito control through surveillance and testing. *For a summary of the main responsibilities and programmatic outputs of the agencies, department, MCDs, and other groups involved, see Figure 3-1. For a visual overview of the organizational structure of mosquito control, see Figure 3-2.*

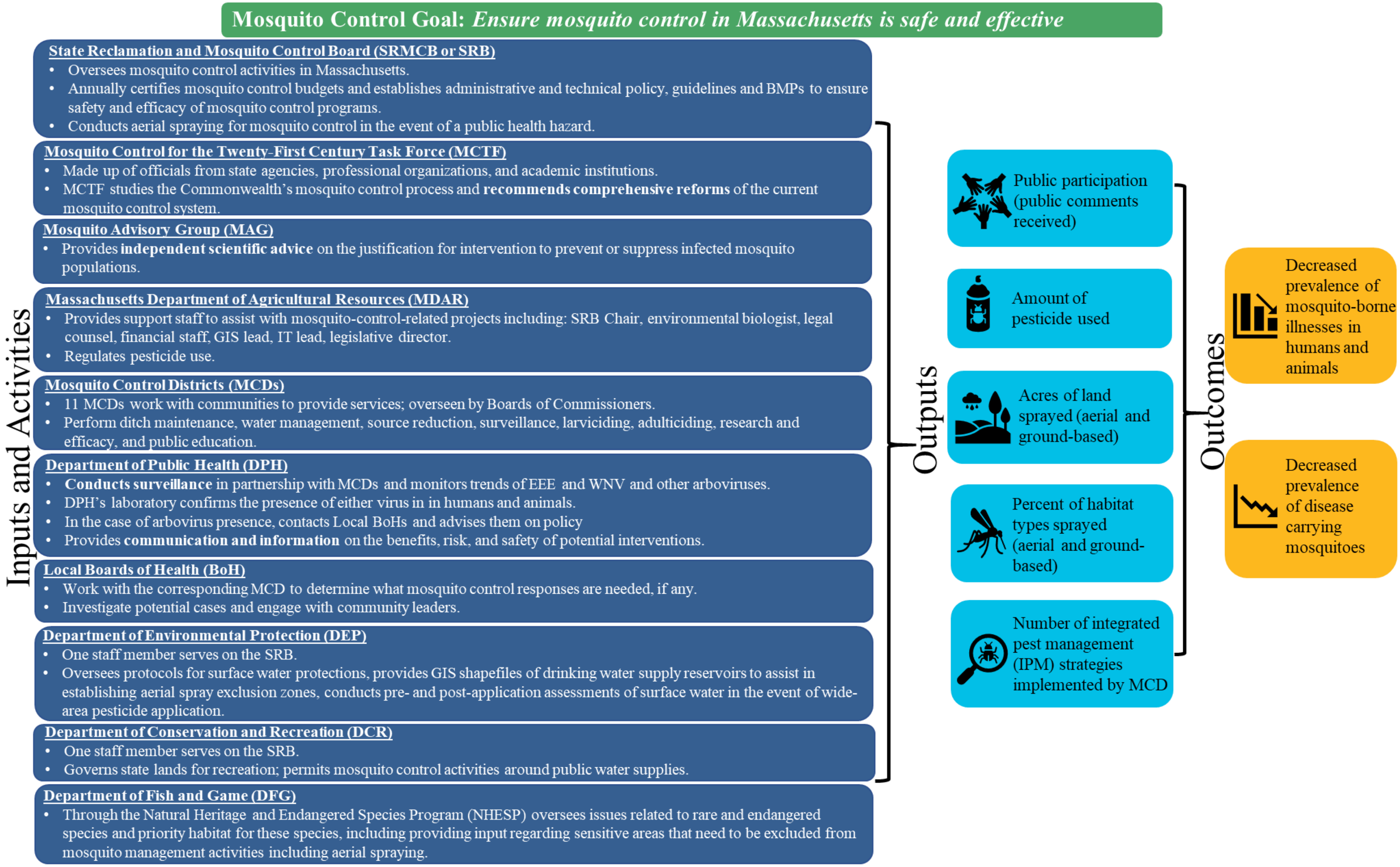


Figure 3-1. Logic model of the current inputs, activities, outputs, and outcomes of Massachusetts' mosquito control processes.

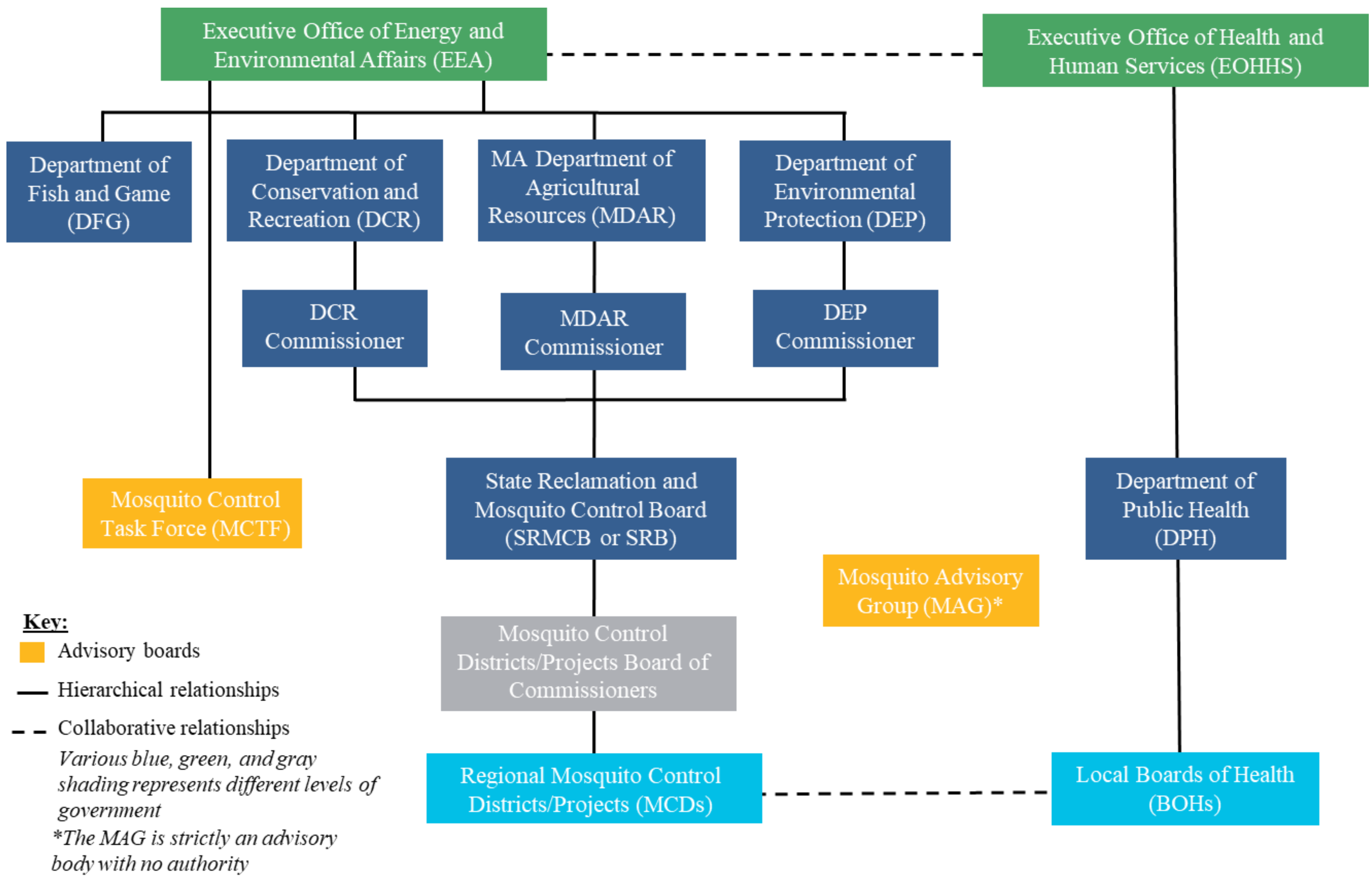


Figure 3-2. Mosquito control organization structure.

3.1.2 SRB

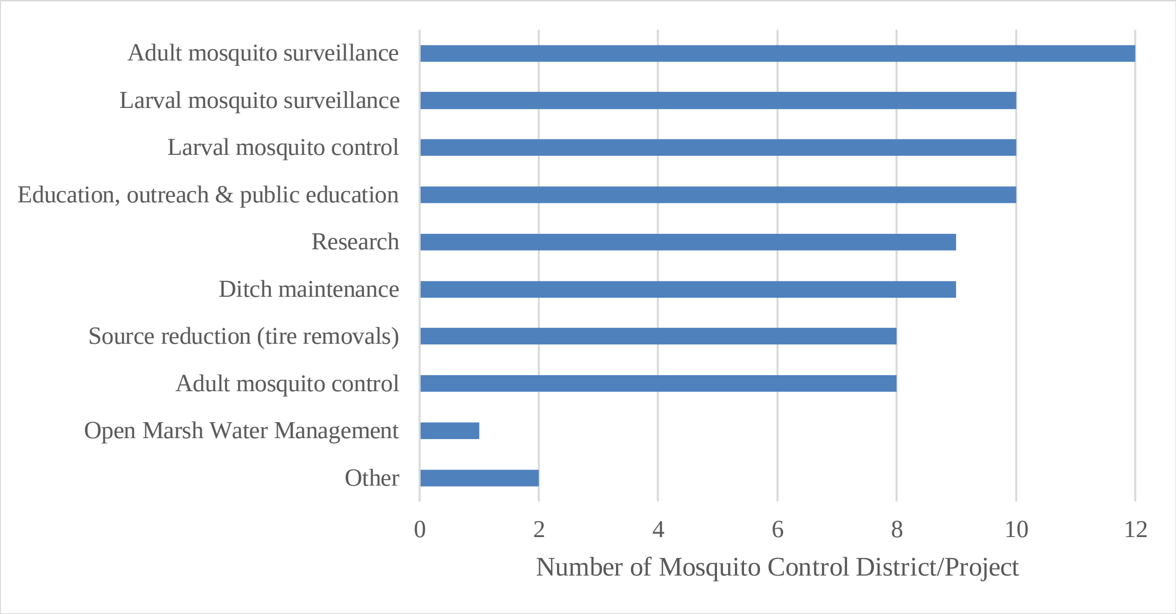
The SRB is a three-member board composed of Commissioners from MDAR, DEP, and DCR. The MDAR Commissioner currently chairs the SRB. The SRB sits within MDAR, which also provides shared resources and staff members (through both SRB and MDAR funding) in the following roles to support mosquito control activities in the Commonwealth: environmental biologist, legal counsel, financial staff, GIS lead, IT lead, and legislative director. The SRB works with DPH through all steps of mosquito control response, as further outlined below. DCR staff plan mosquito control activities and/or coordinate control activities with MCDs within DCR-managed parks and reservations (Massachusetts Department of Conservation and Recreation, 2006, 2012a, 2012b). DCR also oversees watershed management for Massachusetts Water Resources Authority reservoirs (Quabbin Reservoir, Ware River, Wachusett Reservoir, and Sudbury Reservoir watersheds) (Commonwealth of Massachusetts, 2021b). DEP oversees implementation of the federal Safe Drinking Water Act and state source water regulations to protect surface and groundwater water supplies (reservoirs, tributaries to reservoirs, and recharge areas of public wells as defined in regulation). To assist in identifying aerial spray exclusion zones, DEP provides GIS data related to drinking water reservoirs. DEP also supports surface water testing pre- and post-pesticide application during arbovirus emergencies (State Reclamation and Mosquito Control Board, 2019). *(See the Report 7: Massachusetts Drinking Water Regulations Related to Pesticide Application for further detail.)*

Massachusetts General Law, Ch. 252 (see Section 3.2), gives the SRB the authority to:

- Establish processes for municipalities to join or form MCDs.
- Approve funding methods for mosquito control.
- Certify budgets for the Massachusetts Department of Revenue to approve annual budget allocations for each MCD.
- Appoint and remove commissioners of MCDs. SRB appoints commissioners to represent the interests of their member communities, their residents, and the SRB.
- Establish policies, guidelines, and best management practices (BMPs) to ensure that MCDs operate in alignment with federal, Commonwealth, and local laws.
- Establish conditions under which mosquito control activities may be performed (Commonwealth of Massachusetts Mosquito Control for the 21st Century Task Force, 2020).

3.1.3 SRB Collaboration Across Agencies/Groups

The SRB works with MDAR, DPH, MCDs, local boards of health, and other agencies to implement and support mosquito control based on integrated pest management (IPM) principles (see Figure 3-3 for the types of IPM services offered by MCDs). The IPM Institute of North America defines IPM as “a sustainable, science-based decision-making process that combines biological, cultural, physical, and chemical tools to identify, manage and reduce risk from pests and pest management tools and strategies in a way that minimizes overall economic, health and environmental risks” (IPM Institute of North America, 2021). DPH and local boards of health contribute to IPM processes through their surveillance and testing responsibilities. DPH also supports the implementation of IPM through the distribution of educational materials to the general public and members of groups that may be involved in arbovirus surveillance such as veterinarians, animal control officers, and local boards of health (State Reclamation and Mosquito Control Board, 2019). IPM is a guiding principle for federal agencies (7 U.S.C. § 136r–1), so many state programs adopt these principles. *(See Report 5: Integrated Pest Management and Non-chemical mosquito Controls for further discussion of IPM.)*



Source: 2020 MCD reports. (Note: Services in the "other" category include inspectional services and pesticide resistance testing. The number of MCDs includes the Nantucket MCD, which is no longer in existence.)

Figure 3-3. Types of IPM services offered in 2020 by MCDs.

The SRB created an informal advisory group known as the Mosquito Advisory Group (MAG) in 2006 to provide independent scientific advice on options for mosquito control in the Commonwealth (Bharel & Cranston, 2020a). The MAG is composed of four expert members (Box 1) serving on an as-needed volunteer basis. The SRB chooses the MAG members, with input and approval from DPH (State Reclamation and Mosquito Control Board, 2019). Members of the MAG provide independent assessments and advice to the SRB, attend SRB meetings, and may participate in workgroups established by DPH or the SRB. Prior to 2019, MDAR, DPH, DCR, and DEP collaborated with the MAG to approve the list of pesticides that can be used during aerial spraying (State Reclamation and Mosquito Control Board, 2019), though MAG was not part of the selection process for 2019, 2020, or 2021.

Box 1. Current MAG Members

- Dr. Asim Ahmed, pediatric infectious disease specialist
- Dr. Anthony Kiszewski, epidemiologist
- Dr. Richard Pollack, MAG Chairman, public health entomologist
- Dr. Sam Telford, epidemiologist (focusing on public health burden of vector-borne infections)

3.1.4 DPH

DPH conducts mosquito surveillance and arbovirus testing, develops risk assessments, and disseminates information to the public about mosquito-borne diseases and changes in risk levels over the course of the mosquito season. DPH's authority stems from M.G.L. c. 111, which vests DPH with broad power to conduct disease investigations. Specifically, Sections 5, 6, and 7 outline DPH's ability to define and investigate diseases that are a danger to public health, thus providing authority for surveillance programs to identify, communicate, and control the spread of arboviral disease. The primary responsibility of DPH is to characterize the severity of risk as it relates to EEE and WNV, based on the most current DPH State Surveillance and Response Plan (State Reclamation and Mosquito Control Board, 2019). DPH staff analyze surveillance data and provide weekly summary reports during the standard mosquito season (spring through early fall) that include current risk level maps for both EEE and WNV.

The DPH Surveillance and Response Plan indicates that, when human risk is at a "high level of concern," DPH will work with MDAR, the MCDs, the SRB, and the MAG to achieve consensus on whether aerial application is warranted.[2] If the Departments agree on application, the DPH Commissioner may issue a "Certification That Pesticide Application Is Necessary to Protect Public Health" (Bharel & Cranston, 2020a) and the SRB can move forward with aerial application. DPH is also responsible for addressing public health concerns related to mosquito control pesticide applications. When MDAR and/or the SRB perform aerial spraying, DPH and the involved MCDs conduct pre- and post-spray trapping to determine spray efficacy (Bharel & Cranston, 2020a). DPH also surveys for possible pesticide-related illnesses as reported by emergency departments in the area, the Poison Control Center, or local health officials and individual residents contacting DPH directly. DPH provides recommendations on which pesticides to use in emergency response situations and develops messaging around pesticide-related health concerns (State Reclamation and Mosquito Control Board, 2019). Additionally, DEP monitors water supplies in the spray area for possible contamination, and MDAR's Apiary Program conducts beehive monitoring during and after aerial pesticide application. *(See Report 8: Impact of Mosquitoes, Mosquitoes as Disease Vectors and Mosquito Control measures for quantification of the impacts and effectiveness of spraying.)*

3.1.5 Summary

Overall, this decision-making structure ensures that key mosquito control management and related public and environmental health responsibilities are shared among Commonwealth agencies, especially regarding aerial spraying. For example:

- **Mosquito disease surveillance**. DPH, MCDs, local Boards of Health, and others collaborate to conduct surveillance.

- **Setting thresholds for action.** DPH works with MDAR, the MCDs, the SRB, and the MAG to achieve consensus on whether aerial application is warranted to address disease risk.

While the SRB has some statutory authority over the MCDs (e.g., the ability to certify MCD budgets, appoint and remove commissioners), under this governance structure each MCD can make relatively independent management decisions about its mosquito control activities, but

[2] Before July 1 of each year, MDAR consults with DPH, DEP, DFG, and the MAG to confirm options for pesticide to be used in an aerial application. A recommendation is made to the SRB, which votes to choose a product for use during the season if conditions require it (Bharel & Cranston, 2020).

all decisions must comply with SRB policies and applicable local, Commonwealth, and federal laws applicable to its operations.

3.2 Enabling Legislation

3.2.1 Massachusetts General Law Chapter 252

Massachusetts General Law (M.G.L), Chapter 252, is the major enabling legislation for mosquito control in the Commonwealth. Originally enacted in the first half of the 20th century through the "Mosquito Amendment" of Chapter 288 to the reclamation law (Norfolk County Mosquito Control District, 2015) and amended over the years, the initial mosquito control legislation was intended to dictate actions that could be taken to control mosquito populations, establish a governing body—the SRB—to oversee mosquito control, and develop procedures for establishing MCDs. M.G.L. c. 252 establishes a legal framework wherein some mosquito control activities are the responsibility of the MCDs, while others fall to the SRB, with the SRB providing high-level oversight of the MCDs. A few notable provisions under the original M.G.L. c. 252 include:

- **Section 5,** which allows for cities or towns to petition the SRB to form an MCD and have commissioners appointed by the SRB. This section also gives the SRB the authority to remove MCD commissioners.

- **Sections 5A and 5B,** which grants power to the SRB to undertake mosquito control activities without forming an MCD and designate areas of public nuisance due to mosquito infestation. Section 5A also allows for the formation of MCDs under 252, as opposed to by special enabling legislation. In regard to nuisance mosquitoes, Section 5B specifies that MCD commissioners may make a written determination of an area of public nuisance due to mosquito populations and notify the landowner of any necessary abatement actions and a specific timeframe in which the landowners must abate the nuisance. If a landowner does not undertake these treatment actions within the given timeframe, MCD commissioners or local boards of health have the authority to enter the property and control the nuisance.

- **Section 13,** which authorizes MCD commissioners to take actions, such as building temporary dams, to better control surface waters in the interest of mosquito control.

- **Section 14D,** which grants MCDs authority to be responsible for their own personnel decisions. This includes salaries, though salaries require approval of the SRB; this issue has caused some conflict between some MCDs and the SRB in the past. (See Box 2 in Section 4.1.2.1 for more details.)

In addition to M.G.L. c. 252, nine of the 11 MCDs were established through their own enabling legislation. The enabling legislation identifies key operational components, including the funding structure for the MCDs, establishes rules for how municipalities will join or leave the MCDs, identifies how the SRB will appoint Commissioners and in some cases who those Commissioners will be, and includes language establishing them as if they were created under M.G.L. c. 252. The power granted to the MCDs through their enabling legislation works in tandem with the specifications of M.G.L. c. 252. Notably, any changes enacted to M.G.L. c. 252 would not impact the MCDs' enabling legislation. Changes to the authority granted to the MCDs under their enabling legislation would require repealing all nine pieces of enabling legislation and all subsequent amendments made to each.

Beyond the requirements within M.G.L. 252 and the MCDs' enabling legislation, M.G.L. c. 131 Section 40, the Wetlands Protection Act, protects wetlands and requires any work done in wetlands to be permitted by the MA DEP or the local conservation commission. The Act references M.G.L. c. 252 and specifically notes that such organized mosquito control activities are exempt from the Act,; however, mosquito control activities in wetlands must still adhere to the Federal Clean Water Act (State Reclamation and Mosquito Control Board, 1998b).

Additionally, the Acts of 2020, Ch. 120, amended Ch. 252 to add Section 2A. Section 2A allows the SRB to engage in preventive management and eradication methods as it deems necessary in any area of the Commonwealth if the DPH Commissioner issues a written determination of elevated arborvirus risk. When this occurs, Section 2A authorizes the SRB to coordinate spray operations if it specifies the location, spray product, health risks, and dates and times of aerial spraying at least 48 hours before spraying occurs. Importantly, Section 2A(b)(2) requires EEA to establish a process for municipalities to opt out of all SRB spraying. For 2021, the process included development of an alternate management plan (meeting certain criteria) to be approved by EEA, which considers factors including the municipality's historical arbovirus risk and the regional impact of excluding the municipality. For 2021, applications to opt out were due by May 28 and approved opt-outs will be valid through December 31. Property owners may opt out their property from SRB spraying under 2A, although this landowner opt-out may be waived if the DPH commissioner certifies that the application is necessary to protect public health.[3] *(For more details on the opt-out process, see the Report 3: Opt-Outs and Exclusions.)* Finally, Section 2A also called for the establishment of the MCTF and outlines the procedures for task force formation, meeting, and recommendation development. Section 2A, including the provisions establishing these SRB authorities, municipal opt-out, and MCTF, will be automatically repealed at the end of 2022.

[3] Additionally, beyond the exclusion provisions of 252, there is also an exclusion option for property owners in Code of Massachusetts Regulations Title 333, Section 13.03, which allows for private landowners to request exclusion from MCD spraying efforts.

3.2.2 Formation of MCDs

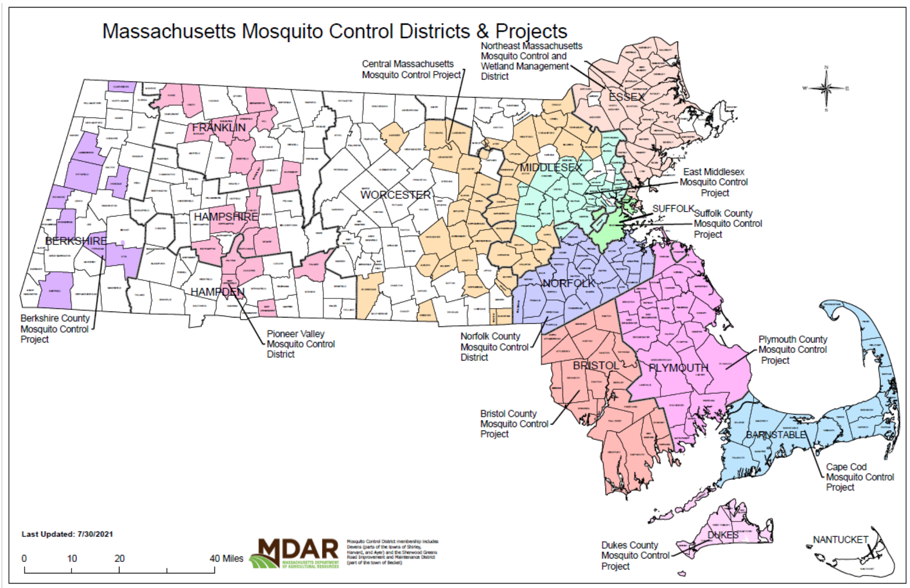


Figure 3-4. Map of MCDs and their geographic coverage (Massachusetts Department of Agricultural Resources, 2020).

In addition to M.G.L. c. 252, special enabling legislation resulted in the initial formation of nine of the MCDs currently in existence: Berkshire County, Bristol County, Cape Cod, Central Massachusetts, Dukes County, Norfolk County, Northeast Massachusetts, Plymouth County, and Suffolk County. The enabling legislation for each, as amended, included language that brought them under the authority of M.G.L. c. 252 and the SRB. The other two—East Middlesex and Pioneer Valley—were formed by the SRB through M.G.L. c. 252 with Pioneer Valley most recently in 2017. A key difference in the first nine MCDs formed under their own enabling legislation and the two newer MCDs is their funding mechanisms. Districts formed through their own enabling legislation determine their budgets through an annual appropriations process (colloquially known as the "Cherry Sheet" due to the color of the hard copy version of the form to be completed) overseen by the Commissioner of Revenue that assesses amounts local governments will pay for Commonwealth program services they receive. In municipalities that are part of or want to join a MCDs, under M.G.L. c. 252 assessments are determined by the geographic boundaries of the district, population, and taxable valuations of the member municipalities. These parameters also determine the annual payments that member municipalities must make (which are paid into the Commonwealth treasury) to be part of MCDs and receive their services (Ch. 252, Section 24). This differs for both Pioneer Valley MCD and East Middlesex MCD. Pioneer Valley, for instance, does not pay a flat rate but instead has a menu-based systems that allows communities to pay for the services they choose (Robertson, 2017). East Middlesex funding consists entirely of voluntary appropriations that originate from the municipal budgets of the participating communities (Town of Sudbury, 2021). All MCDs operate through trust accounts, with funds deposited rolling over each fiscal year and which can only be spent by that MCD for activities allowed under either its enabling legislation, M.G.L. c. 252, or both. All MCDs operate as Commonwealth entities and must comply with all applicable finance and procurement laws. Each MCD is headed by a director or superintendent (with the exception of Dukes County MCD, which is managed by the Dukes County Manager) and overseen by a team of commissioners (usually three to five depending on the MCD). Commissioners, who are residents and representatives of the MCD member towns, are appointed by the SRB to serve five-year terms. Commissioners review and approve MCD payrolls, invoices, and work performed by MCDs.

3.3 Mosquito Control on Federal, State, and Private Lands Within Massachusetts

M.G.L c. 252 and Chapter 120 of the Acts of 2020, in addition to other legislation, give the SRB, DPH, and MCDs the authority to conduct mosquito control in the Commonwealth. The 11 MCDs in Massachusetts are the primary organizations responsible for implementing mosquito control activities (such as monitoring and surveillance, public education, and pesticide use if necessary) on lands within their participating municipalities. M.G.L. c. 252 also gives the SRB oversight over all mosquito control in the Commonwealth and all MCDs, in addition to the authority to conduct mosquito control within any area of the Commonwealth, including those that are not part of an established MCD (State Reclamation and Mosquito Control Board, 2019).

3.3.1 Federal Lands

While M.G.L. c. 252 gives MCDs the authority to perform mosquito control activities in their districts, exceptions may apply for certain federal and state lands as well as privately-owned lands (which may be excluded by regulation). For example, Commonwealth authority allowing MCDs to perform mosquito control does not apply on federally owned property within the Commonwealth; therefore, districts must obtain permission to perform control activities on those lands, except in the event of a public health hazard. The federal government owns over 89,500 acres of land in Massachusetts (about 1.7% of the Commonwealth's land area). Federally owned property in Massachusetts includes Air Force bases; National Parks; and other federal lands owned by the Department of the Interior such as Fish and Wildlife–managed land, national monuments, and others.

3.3.2 State Lands

State lands cover 659,900 acres in Massachusetts (about 13% of the Commonwealth's land area) and consist primarily of state parks, state forests, and state reserves. Responsibility for mosquito control on state lands in the Commonwealth falls to MCD in which the state lands are located. Each MCD works with the relevant state agency responsible for the state land (such as DCR for state parks) within the MCD to provide mosquito control services as needed (Association of State and Territorial Health Officials, 2018).[4]

3.3.3 Private Lands

While Ch. 252 does not require private property owners to perform mosquito control or prevention on their property, if a local public health board orders property owners to control mosquito infestations or abate breeding sites and the property owner fails to do so, the local board or MCD has the authority to enter the property and address the nuisance or suppress disease risk (M.G.L. c. 252, Section 5B) (Association of State and Territorial Health Officials, 2018). When MDAR/SRB, DPH, the appropriate MCDs, in consultation with the MAG, agree

[4] Documents and interviews offered only limited information about responsible parties for mosquito control on state-owned lands in Massachusetts.

that spraying of aerial insecticides is warranted due to elevated risk of arbovirus transmission, SRB has the authority to apply adulticide in the affected areas.

3.4 Structure of Mosquito Control Programs in Selected Northeastern and Mid-Atlantic States

ERG was also charged with describing the mosquito control policy structures of selected other states in New England and the mid-Atlantic. ERG conducted initial research on multiple states in the northeast and more focused review of mosquito control policy structures for three states (New York, Connecticut, New Jersey) with established programs. ERG interviewed one representative from each of these states to understand their policy structures.

The remainder of this section summarizes the policy structures for mosquito control in New York, Connecticut, and New Jersey. The three states take similar approaches: multiple state agencies have oversight responsibility and other roles for mosquito control in the states, while local governments (either county or municipality) implement the majority of the mosquito control practices. None of these states have unique regional organizations (like the MCDs in Massachusetts) for mosquito control.

The information in this section is presented to respond to the scope of work request to summarize the policy structure of mosquito control program in selected states. However, readers should recognize that Massachusetts has unique mosquito control challenges and public health threats, and some program features in other states would not necessarily be effective in Massachusetts.

3.4.1 New York

The New York State Public Health Law and the New York State sanitary code give the New York State Department of Health (NYSDOH) and local health departments (LHDs) the primary responsibilities for conducting mosquito control in the state (New York State, 2012). It is important to note that LHDs in NYS operate at the county-level. Mosquito control in the state is structured around counties, which operate in a slightly similar way to Massachusetts' MCDs with regard to their regional responsibilities. Like Massachusetts, New York is a "home rule state," so decisions on control measures fall to the local authorities (e.g., LHDs) (New York State, 2012). The reliance on county governments for mosquito control in New York is a notable difference from Massachusetts. NYSDOH supports LHDs by performing lab testing on mosquito and clinical specimens; monitoring statewide human, animal, and mosquito surveillance trends; and providing data and subject matter expertise (New York State, 2012). NYSDOH also provides technical support and assistance on mosquito control measures to LHDs. The New York State Department of Environmental Conservation provides guidance on acceptable pesticides for use in the state and provides permits for aerial spraying, authorizes areas for targeted aerial spraying, and conducts onsite inspections of aerial spray applicators prior to flight (New York State, 2012). LHDs establish mosquito surveillance programs, conduct human surveillance, request declaration of public health threats by the state, decide what control measures to implement, and carry out those measures (e.g., source reduction, larval and adult control). NYSDOH approves declarations of public health threats and provides technical assistance to LHDs on control measures. The state's control program follows a standard IPM strategy, which emphasizes personal protective measures and public education, source reduction, larval control (through environmental management, biological control, and chemical control), and adult control as a final step when necessary (New York State, 2012).

3.4.2 Connecticut

Connecticut established its mosquito control program in 1997 through a legislative act (PA 97-289) to “monitor and control the spread of EEE, a potentially deadly disease” (U.S. Fish and Wildlife Service, 2017). The Department of Energy and Environmental Protection (DEEP), the Department of Public Health, the Department of Agriculture, the Connecticut Agricultural Experiment Station (CAES), and the University of Connecticut Department of Pathobiology and Veterinary Science form Connecticut’s interagency Mosquito Management Program (State of Connecticut, 2013). Local health departments/districts are responsible for conducting educational outreach and disseminating surveillance and risk information to communities, assisting the Department of Public Health in investigating cases of EEE, and performing mosquito control activities in their communities (State of Connecticut, 2020). DEEP’s Wetland Habitat and Mosquito Management (WHAMM) program conducts mosquito surveillance or “inspections,” pesticide applications, and open marsh water management (OMWM) on state-owned properties, and also provides technical assistance, guidance, and education to municipalities and homeowners concerning mosquitoes and control methods (State of Connecticut, 2013). The CAES conducts statewide trapping (in all eight counties) in areas known or suspected to support mosquito populations that have been infected with EEE in the past, could potentially support such populations, or “are proximate to locations where EEE-related human or equine cases have occurred” (State of Connecticut, 2020). In Connecticut, trapping only occurs in areas of known mosquito habitat or activity, whereas in Massachusetts trapping and surveillance takes place in all identified potential areas of mosquito habitat. Connecticut follows a tiered four-phase response model to combat EEE transmission risk. This model is based on passive human and veterinary surveillance and active mosquito surveillance[5] data collected through statewide trapping efforts. The phased model is outlined at a high level in Table 4-4 in Section 4.2.2.

3.4.3 New Jersey

Title 26, Chapters 3 and 9, of the New Jersey Health Statutes mandate mosquito control in New Jersey (U.S. Environmental Protection Agency, 1997). Under Title 26, counties are the primary entities responsible for mosquito control in New Jersey. The Director of the New Jersey Agricultural Experiment Station (NJAES) at Rutgers University serves as an advisor to all mosquito control agencies in the state. The State Mosquito Control Commission (SMCC) is a six-member advisory board made up of representatives from the Department of Environmental Protection, the Department of Health and Senior Services, the Department of Agriculture, and the NJAES. Title 26 mandates the SMCC to continuously study mosquito control operations in the state, recommend necessary budgets for mosquito control, and allocate state aid to counties for mosquito control. The SMCC serves as an advisory board to the Governor. The SMCC is funded through the Office of Mosquito Control Coordination (OMCC), housed in the Department of Environmental Protection. These commissions have the power to declare a mosquito nuisance warranting abatement measures whenever they deem it necessary and have

[5] Passive mosquito surveillance relies on human and animal disease reports to gather information in mosquito-related infections, while active mosquito surveillance relies on trapping mosquitoes and testing them for presence of disease (Marin/Sonoma Mosquito and Vector Control District, 2021).

the power to enter public and private property to perform mosquito control (U.S. Environmental Protection Agency, 1997).

New Jersey follows a standard model of IPM with a particular emphasis on surveillance, source reduction, and water management. For surveillance, the state primarily uses the New Jersey Light Trap, developed in New Jersey in 1932 (Reinert, 1989). The New Jersey Light Trap and other types of light trap are widely used for mosquito surveillance across the country and the world. For source reduction and water management, New Jersey practices OMWM. OMWM restores salt marsh through the creation of ponds, pond radials, and tidal ditches to increase water movement in a marsh, resulting in increased habitat for native species and decreased mosquito habitat (State of New Jersey).

Unique to New Jersey is the State Equipment-Use Program, administered by OMCC. This program allows counties to lease state-owned equipment to supplement their mosquito control activities. This equipment primarily consists of low-ground pressure equipment for water management projects (State of New Jersey). Another state-funded control method is the New Jersey State Airspray Program, funded by SMCC and administered by OMCC. This program provides contracted aircraft for the aerial spraying as needed and as requested by the counties (State of New Jersey, 2021).

4. Evaluating the Effectiveness of the Mosquito Control Policy Structure in Massachusetts

This section presents ERG's assessment of the effectiveness of the mosquito control policy structure in Massachusetts. ERG performed a mixed-methods evaluation that combined the following:

- **Development of evaluation questions and evaluation plan.** First, ERG defined evaluation questions to guide review of the Commonwealth's mosquito control activities. Evaluation questions (Table 4-1) centered on understanding key criteria related to mosquito control programs, including structure, decision-making effectiveness, and management effectiveness. Evaluation questions also focused on understanding best practices for and lessons learned from mosquito control within and outside the Commonwealth, identifying challenges to mosquito control on public and private lands, and determining solutions to overcome these challenges. ERG reviewed and vetted evaluation questions with EEA to ensure that the evaluation would meet the Commonwealth and MCTF's needs.

- **Document review and web-based research.** ERG reviewed documents recommended by EEA, in addition to conducting web-based research to identify resources related to best practices for mosquito control. The evaluation team reviewed 51 documents related to existing policy, lessons learned, challenges, and best practices. Documents reviewed include legislation, press releases, academic articles and white papers, agency reports, position papers, plans, and public letters.

- **Semi-structured interviews.** ERG conducted 18 interviews with 21 respondents, including Massachusetts state agency staff, MCD superintendents, local board of health representatives, MCTF members, environmental nonprofit representatives, and mosquito control experts from other states. Interviews covered the evaluation questions and were modified as needed to best fit the expertise of the respondents.

Following data collection, ERG applied a grounded theory approach using inductive and deductive coding (Fereday & Muir-Cochrane, 2006) to analyze qualitative interview responses, review data from publications, and identify key themes and trends from respondents' narratives. ERG's evaluation plan identified several overarching criteria for assessing the mosquito control policy structure in Massachusetts. Those criteria are shown in the first column of Table 4-1 (i.e., structure, decision-making effectiveness, and management effectiveness). The sections below summarize evaluation results.

Table 4-1. Plan for Evaluating the Effectiveness of Massachusetts' Mosquito Control Policy Structure

Evaluation Question	Data Sources			Potential Data Gaps and Limitations
	Review of Policies and Regulations	Review of Summary Documents	Interviews	
Structure: Does the current structure of mosquito control in Massachusetts reflect a balanced representation of the interests and issues that need to be addressed?	Primary	Primary	Supporting	Potential bias in informant perspectives.
Decision-making effectiveness: Is the decision-making process efficiently executed and effectively communicated? Are there inconsistencies that need to be addressed?	Primary	Supporting	Primary	Potential bias in informant perspectives; limited informant knowledge.
Management effectiveness: How effective is mosquito control management in relation to oversight of activities, finances, public participation, ensuring local options and choices in services received, and in control of nuisance mosquito populations? What past and present barriers have prevented Massachusetts cities and towns from joining regional MCDs or pursuing other local or regional approaches?	Supporting	Supporting	Primary	Potential bias in informant perspectives; limited objective analyses of program effectiveness.
Best practices: What lessons and best practices (e.g., tiered mosquito control) can Massachusetts learn and adopt from other programs in states with robust mosquito control programs (e.g., other northeastern states like Connecticut's tiered program)? How feasible is implementing these types of practices in Massachusetts?	NA	Primary	Primary	Regulatory ability to apply best practices from other states in MA; unique prevalence of EEE and practices to deal with it in MA as compared to other states.
Strategies for improvement: Is the structure of the SRB appropriate for fulfilling program goals? What potential changes could be made for these entities to better fulfill mosquito control goals?	Supporting	Supporting	Primary	Bias in informant perspectives; limited willingness to consider change; limited data on program effectiveness.
Public and private land challenges: What are the unique and prevalent barriers to effective mosquito control on private and public (federal, state, local) property?	NA	Supporting	Primary	Limited data on program challenges on different types of land.
Strategies for overcoming challenges on public and private lands: What strategies can the states, MCDs, and other entities use to address challenges to mosquito control on private and public lands? Are there any success stories or best practices to draw on?	NA	Supporting	Primary	Limited data on program challenges on different types of land; regulatory ability to apply new practices in MA.

4.1 Mosquito Control Policy Structure, Decision-Making, and Management Effectiveness

The sections below summarize ERG's assessment of the existing mosquito control policy structure and decision-making and management effectiveness, drawing on data from interviews, document review, and analysis of MCD annual reports.

4.1.1 Existing Mosquito Control Policy Structure

To gather feedback on the **perceived effectiveness of the Massachusetts' policy structure for mosquito control,** the evaluation reviewed summary documents[6] and respondent perceptions to answer three questions. Note that not all respondents answered all questions, therefore n-values may vary throughout the discussion.

- Is the Commonwealth's mosquito control policy structure designed to achieve the goals of safe and effective mosquito control?
- Does the structure reflect a balanced set of interests?
- Does the structure represent a balanced set of issues?

4.1.1.1 Policy Structure Alignment with Goals and Perceived Areas for Improvement

While more than half of respondents praised certain elements of the current policy structure, **over three quarters (10 out of 13) suggested ways the structure could be improved to meet Massachusetts's mosquito control goals more effectively.** Respondents' primary suggestion was to increase membership in MCDs across the Commonwealth and improve cohesiveness of control efforts. Respondents suggested a more coordinated approach to control measures MCDs undertake. For instance, multiple respondents mentioned the "hole" in central and western Massachusetts where there are no established MCDs. MCDs are largely concentrated in the eastern part of the state *(see Figure 3-4 above)*, except for the Berkshire County Mosquito Control Project and the newly established Pioneer Valley MCD; those two MCDs provide spotty coverage, with large areas of their parts of the Commonwealth unaccounted for, whereas the eastern MCDs provide mosquito control for almost the entire eastern third of the Commonwealth. While some respondents noted that certain areas of the Commonwealth might not need an established mosquito control program due to lack of disease-carrying mosquitoes, others were frustrated with the lack of statewide monitoring data available due to the MCD coverage gaps. Many respondents noted that mosquitoes do not adhere to political boundaries, so municipalities and local governments should not make decisions regarding mosquito control completely autonomously—they would be better served to take a coordinated approach with surrounding municipalities.

Beyond the overall structure of mosquito control in the Commonwealth, respondents also commented on specific structural aspects such as funding and administration. For instance, some

[6] Most documents the evaluation team reviewed did not offer analyses of the mosquito control policy structure: they provided background on the structure, rather than assessing its effectiveness. Therefore, the results reported in this section are mainly drawn from interview data, with any document data cited when relevant.

respondents (three out of 13) suggested that **a more uniform funding structure for MCDs across the Commonwealth would improve the overall effectiveness and cohesion of mosquito control.** While there are many reasons why a town may not join an MCD, respondents noted that the high cost of MCD membership was likely the primary reason for the "holes" in mosquito control programs and/or surveillance data across the Commonwealth. As previously discussed, different environments and geographies across the Commonwealth warrant different responses and different levels of mosquito control. However, these respondents felt that funding mechanisms for MCDs should be unified across the Commonwealth to allow, at the very least, for a Commonwealth-wide surveillance program that would therefore inform different levels of control as indicated by the surveillance data.

Close to one third of respondents (four out of 14) identified areas of improvement with the administrative organizational structure of MCDs, which were considered a weakness of the Commonwealth's mosquito control efforts. Concerns about the organizational structure of MCDs related to the lack of checks and balances and the way that MCDs are not uniformly structured. As discussed in Section 3.2.2, some MCDs were formed through their own enabling legislation while some were created directly under Ch. 252, resulting in inconsistencies in MCD structure and their funding mechanisms. Respondents also cited the lack of communication from the SRB to MCDs as a point of weakness. They suggested the SRB engage in more widespread communication to MCDs, and that an expert with a background in mosquito control be appointed to serve on the SRB. Furthermore, some respondents suggested removing the MCD commissioner position. These respondents' primary frustrations with the MCD commissioner structure related to the lack of transparency for their decision-making, commissioners' limited mosquito-related experience or expertise, and an imbalance of power between MCD commissioners and superintendents.

In contrast to respondent comments regarding areas for improvement of the policy structure, about half of respondents (seven out of 13) commented that the Commonwealth's **current policy structure is designed in a manner to achieve the goals of safe and effective mosquito control**. Respondents commented on aspects of the policy structure that they felt contributed to its effectiveness, such as the regional approach and the power of MCDs for determining the most relevant mosquito control approaches for their constituents. Respondents also noted that the complementary roles of the entities (e.g., the MCDs, the SRB, DPH) involved in mosquito control facilitate communication over important issues when needed. Respondents shared, for instance, that the MAG, MCDs, and DPH communicate often to share surveillance and monitoring results.

While not every town or region of Massachusetts is a member of an MCD, respondents shared that **MCDs' ability to perform mosquito control at a local level and scale is important** and increases the effectiveness of the control throughout the Commonwealth. Additionally, some respondents mentioned that home rule, which is "intended to enhance self-governance provisions for cities, towns and counties" (Commonwealth of Massachusetts, n.d.), supports the MCD structure and self-governance and decision-making related to mosquito control at the local level. However, other respondents expressed concerns that home rule has reduced the overall efficacy of a theoretically Commonwealth-wide mosquito program: a municipality might not be part of any MCD, or its board of health might not be equipped to inform mosquito control operations. These respondents mentioned that a purely Commonwealth-run program would be inefficient for dealing with regional differences in environment and politics but thought the district approach, if it encompasses all regions within the Commonwealth, could be efficient. While the legal framework exists for all communities in the Commonwealth to participate in MCDs and undertake their own mosquito control activities, as outlined in the discussion of M.G.L. c. 252 above, respondents shared that simply because the framework exists, not all towns or municipalities will join or create MCDs. See below for further discussion on challenges to joining an MCD, as perceived by interview respondents.

4.1.1.2 Representation of Issues and Interests

One third of respondents (five out of 15) shared that the current program does not reflect a balanced set of interests. Respondents mentioned that while MCD-based mosquito control allows for the tailoring of control measures when necessary, gaps remain in MCD representation, which contributes to uneven surveillance and monitoring information from areas of the Commonwealth that are not part of an MCD. Furthermore, respondents emphasized that there can be differing priorities among MCDs and within MCDs regarding mosquito control (e.g., preferences regarding chemical control vs. non-chemical options).

Close to half of the respondents (seven out of 15) shared that the program does reflect a balanced set of interests. Respondents mentioned that the program reflects the interests and needs of multiple geographies and can therefore respond to a variety of control needs such as different mosquito species in different areas. Specifically, respondents shared that the regional structure (e.g., MCD-based mosquito control) is a strength: control measures can be tailored to the needs of an area or region, rather than following a "one size fits all" model. Respondents also commented that special interests, such as environmental groups and beekeepers, are well reflected in the current structure. Respondents emphasized how MCDs work closely with conservation commissions and local boards of health to ensure environmental and conservation priorities are reflected in mosquito control activities.

Over half of respondents (eight out of 13) agreed that the current program represents a balanced set of issues (e.g., public health needs and concern for ecological impacts). Again, respondents cited the benefits of the regional approach (MCD-based) and how that approach allows districts to perform mosquito control at local levels as needed. One respondent also reiterated that all districts follow the IPM approach to management and that incorporating concern for public health and ecological impacts is inherent to an IPM approach.

However, close to half of respondents (six out of 13[7]), mentioned that the program does not represent a balanced set of issues (e.g., public health needs and concern for ecological impacts). Some respondents shared that DPH is not as involved in decision-making as the MCDs would like. These respondents mentioned that better communication from DPH to residents and MCDs might improve the balance of public health needs with ecological impacts, but that the current program structure does not facilitate this. Respondents also mentioned that the program is too focused on public health concerns, and therefore does not balance public health priorities with environmental and conservation priorities and goals. One respondent suggested that thresholds (e.g., arbovirus risk levels that trigger aerial spraying or other control measures) and tolerance levels for the number of arbovirus cases should better correlated to the

[7] Note that one respondent answered both yes and no when asked if the program represents a balanced set of issues.

response that is triggered. Respondents also mentioned that these thresholds are unclear and not uniform across the Commonwealth.

4.1.2 Decision-Making and Management Effectiveness

To gather feedback on the **management effectiveness and decision-making process for mosquito control activities in the Commonwealth**, the evaluation reviewed summary documents, annual MCD reports, and respondent perceptions to answer the following questions:

- How effective is mosquito control program management in relation to oversight of activities, finances, public participation, ensuring local options and choices in services received, and in control of nuisance mosquito populations?

- What past and present barriers have prevented Massachusetts cities and towns from joining MCDs or pursuing other local or regional approaches?

4.1.2.1 Decision-Making Effectiveness

To elicit feedback on the **decision-making processes for various activities related to mosquito control,** the interviewers asked respondents to rate the effectiveness of six criteria related to decision-making. Table 4-2 summarizes respondents' ratings on a scale of 1 to 5, which are then discussed below.

Table 4-2. Perceived Effectiveness of Decision-Making Process for Activities Related to Mosquito Control in Massachusetts

Activity	Activities by MCDs (n = 11)	When to Conduct Aerial Spraying at the State Level (n = 12)	When to Survey Mosquito Populations (n = 11)	Funding MCDs (n = 11)	Establishing MCDs (n = 10)
Rating	Moderate	Moderate	Moderate	Poor	Poor
Average Score	3.7	3.3	3.2	2.4	2.2
Range	1–5	2–5	1–5	1–4	1–4

Source: Interviews.
Scores are on a scale of 1 to 5: 1–3 = poorly effective, 3.1–4 = moderately effective, 4.1–5 = highly effective. N-values vary because not all respondents answered each question.

Respondents rated the **decision-making process for activities conducted by MCDs** as moderately effective (3.7 out of 5). Some respondents also mentioned that MCDs have evolved their control measures to respond to environmental concerns and emergent advances in mosquito control and surveillance techniques. Others cited the fact that districts follow IPM principles in their control activities and emphasized the benefit of having surveillance data from all MCD member towns *(see Report 5: Integrated Pest Management and Non-chemical Mosquito Controls for a more detailed discussion of IPM in the Commonwealth)*. Two respondents mentioned that increased funding to support research would allow for more informed decisions about the types of larvicides used and how the larvicide should be applied.

Respondents who gave moderate ratings (3.3 out of 5) for the **decision-making process for conducting aerial spray operations at the Commonwealth level** explained that the decision to spray is based on surveillance data collected from DPH—and as outlined in the 2020

Arbovirus Surveillance Plan (Bharel & Cranston, 2020a)—indicating the need for aerial spraying. Respondents mentioned that the decision-making process has evolved over the years and has been informed by previous EEE outbreaks, resulting in a better process and more experts in advisory positions helping the Commonwealth to decide when to conduct aerial spraying. However, some respondents shared the opinion that the decision-making process for aerial spraying is poor (rating of 2 or 3), citing lack of spray efficacy data and lack of transparency on the threshold for deciding to conduct aerial spraying. Respondents also mentioned that they would like to see more mosquito-control experts appointed to the SRB to provide additional advice and oversight for spraying activities in MCDs.

Respondents also gave moderate ratings (3.2) to the **decision-making process for surveying mosquito populations.** Most respondents shared that the surveillance program is generally effective and productive but did not rank it as highly effective due to the gaps in spatial coverage throughout the Commonwealth, as discussed in relation to the program structure above. Other respondents identified shortcomings in the surveillance data. They said larger, established MCDs tend to provide robust surveillance data, but less well established MCDs with lower budgets may not have the capacity to conduct trapping and surveillance on the same scale and therefore less data are available for these areas. Overall, ratings for this activity were largely dependent on an informant’s MCD or organizational affiliation. For example, those affiliated with MCDs gave primarily high ratings (4 or 5 out of 5), while respondents from areas that are not part of an MCD and respondents representing conservation organizations gave poor ratings (1 or 2 out of 5).

The **decision-making processes for funding and establishing MCDs** both received low effectiveness ratings from respondents. Most respondents shared the opinion that the lack of uniformity in funding for MCDs makes it difficult to mount a unified response to mosquito control. For instance, some noted that a robust, Commonwealth-wide control strategy depends on robust funding to support efforts throughout Massachusetts. Currently, funding varies greatly among MCDs, since contributions are generally determined based on cherry sheet calculations, as described above in Section 3.2.2 and exemplified by examining the annual MCD budgets for the last five years. (*See Report 5 for more information on annual MCD budgets.*) Some respondents advocated for a Commonwealth-wide funding mechanism or structure that would allow for communities that are not part of an MCD to receive mosquito control funds and would also fill the surveillance data gap that exists due to the “holes” in MCD coverage. *(For more examples of issues between MCDs and the SRB as it pertains to funding, see Box 2.)* Respondents generally rated the decision-making process for establishing MCDs as poor (1 or 2 out of 5), with only one or two respondents ranking it as highly effective (4 or 5 out of 5). Respondents giving low rankings to this decision-making process mentioned that each MCD was established through different enabling legislation—which adds to the differences caused by regional needs and perspectives, resulting in large variations to the approaches to mosquito control across the MCDs. Respondents also mentioned prohibitive startup costs, lack of capacity, and confusion around the process to form an MCD as barriers to establishing MCDs.

Box 2. Section 14 and *Commissioners of Bristol County MCD v. SRB*

This 2013 (Bristol County Superior Court) case concerned salary increases for the MCD staff (on the basis that MCDs can set their own salaries under Section 14). Therefore, it questioned how Section 14 should be interpreted. The judge concluded that record was insufficient to determine whether the summary judgment record (as recommended by a superior court) was appropriate in this case.

That said, the court's discussion of the question states that Section 14D should be interpreted in the context of the SRB's authority over MCD annual budgets (budget increases should not exceed budgets). The court states, "we interpret §14D to grant [MCDs]…the exclusive authority to set the compensation rates for their employees, but that authority nonetheless is subject to the board's responsibility for approving their annual project budgets" ("Commissioners of Bristol County Mosquito Control District v. State Reclamation & Mosquito Control Board," 2013).

Respondents provided mixed feedback on the **efficiency of communication of decisions to constituents**. Over half (seven out of 11) stated that decisions were communicated to constituents somewhat effectively, noting that outreach and education to community members could be improved. Respondents suggested using local media outlets more often to alert communities to upcoming spray events, as well as working to combat disinformation around mosquito control and pesticide use. However, respondents cited a lack of capacity for conducting additional education and outreach, due to lack of funding and staff, as a barrier to improvement in this area. Other respondents shared that communications between the MCDs and their member towns are strong, but communications between the SRB and MCDs could improve. Respondents elaborated on this point in saying that for example, when an MCD representative poses a question to the SRB that could be relevant across MCDs, the SRB communicates only with the MCD that asks the question rather than posting or sending answers to all MCDs. Respondents suggested that adding a member or staff person to the SRB whose primary responsibility is communicating with MCDs might help alleviate this problem, as well as promote uniformity of actions (when appropriate) across MCDs. However, respondents acknowledged that lack of funding for such a position could be prohibitive.

4.1.2.2 Management Effectiveness

To elicit feedback on the **perceived effectiveness of certain components of mosquito control management**, ERG asked respondents to rate the effectiveness of six criteria regarding management effectiveness on a scale of 1 to 5 (Table 4-3).

Table 4-3. Perceived Effectiveness of Mosquito Control Program Management

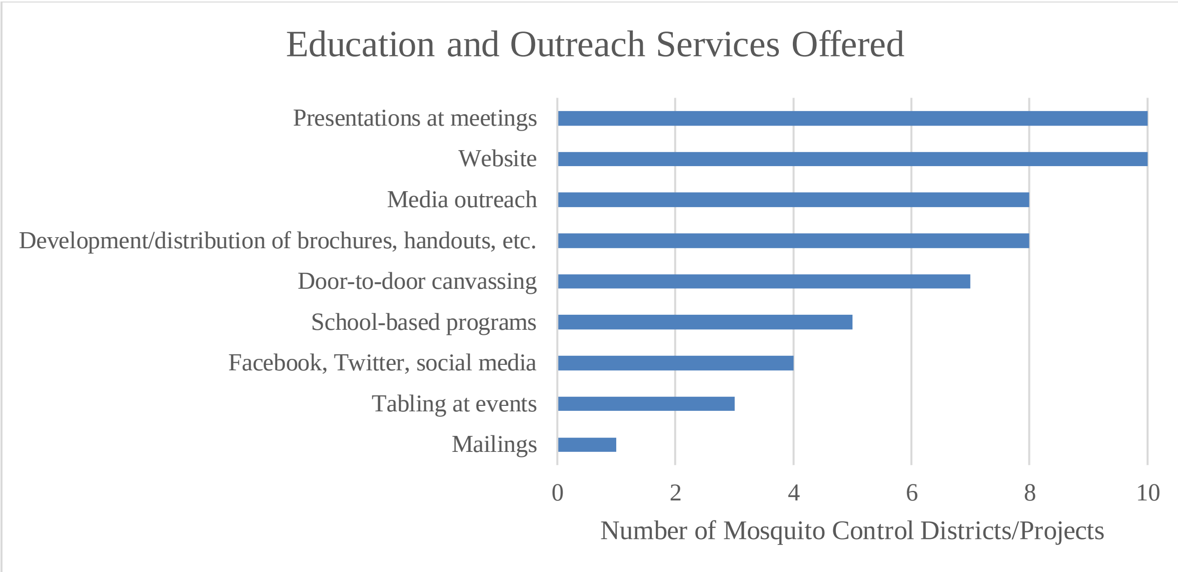
Component of Program Management	Oversight of Activities (n = 11)	Finances (n = 8)	Public Participation (n = 9)	Control of Disease Carrying Mosquito Populations (n = 8)	Ensuring Local Options and Choices in Services Received (n = 8)
Rating	Moderate	Moderate	Moderate	Moderate	Poor
Average Score	3.9	3.7	3.3	3.1	2.6
Range	1–5	1–5	0–5	1–5	0–5

Source: interviews.
Scores are on a scale of 1 to 5: 1–3 = poorly effective, 3.1–4 = moderately effective, 4.1–5 = highly effective. N-values vary because not all respondents answered each question.

The effectiveness of **oversight of MCD and SRB activities** received the highest ratings from respondents (3.9 out of 5). Respondents shared that oversight of mosquito control activities is generally highly effective, noting that decisions to perform aerial spraying are informed by surveillance data indicating that aerial spraying is necessary, and any adulticides used in spraying (both or aerial and truck-based spraying) must be approved by the SRB. However, some respondents were more reserved with their rankings and suggested that MCDs would benefit from increased communication and support from with DPH, in addition to DPH support with community outreach and education on mosquito control topics. Multiple respondents indicated there is a lack of oversight of MCDs by the SRB but explained that, according to M.G.L. 252 (discussed in previous sections), MCDs are independent entities and the SRB does not necessarily have the authority to provide hands-on oversight of MCD activities.

Respondents rated management of **mosquito control finances** moderately (3.7 out of 5). Respondents who were representatives from MCDs generally shared that their funding was sufficient, and the districts were able to perform various control activities with their existing budgets, even if the budgets were tight at times. However, some other respondents did not have strong opinions on the topic, and others expressed frustration at lack of transparency about the SRB's budget and funding. Two respondents expressed dislike of the current appropriations and assessment system and suggested a more centralized, Commonwealth-funded finance system.

Roughly half of respondents gave high ratings (4 or 5 out of 5) for **public participation** in the management and decision-making process, while the other half rated public participation as not at all effective (1 or 2 out of 5). Respondents who gave high ratings explained that MCDs conduct considerable public outreach and communicate often with their constituents. Several respondents who provided high ratings also noted that if public participation is poor, it is not necessarily the fault of the MCDs or the SRB: the public has multiple opportunities to attend meetings and listening sessions, but they often choose not to attend. Respondents who indicated low ratings for public participation shared that communities are generally not very responsive in public comment times for policy, that the program lacked concrete and productive ways to provide input, and that the public is generally disengaged from mosquito control activities until there are urgent issues or community members are displeased with the services they are receiving. Analysis of MCD annual reports (Figure 4-1) illustrated that MCDs are conducting many outreach and education activities; however, as indicated by the respondents, the efficacy, level of participation in, and reach of these activities is uncertain.



Source: Annual MCD reports.

Figure 4-1. MCD education and outreach activities.

Respondents gave moderate ratings (3.1 out of 5) to the effectiveness of **control of disease-carrying mosquito populations** in the Commonwealth. Most respondents indicated that it was difficult to rank the effectiveness of control of disease carrying mosquitoes, citing difficulties with proving the effectiveness of aerial spraying and other control measures and how these activities impact case rates of EEE and WNV. *(See the Report 8: Impact of Mosquitoes, Mosquitoes as Disease Vectors and Mosquito Control Measures for a detailed comparison and modeling of the effectiveness of various mosquito control scenarios.)* Furthermore, respondents noted that environmental variability across the Commonwealth and within MCDs creates challenges with reaching total control of mosquito populations, and even more challenges with demonstrating efficacy. A few respondents who were not representatives of MCDs mentioned the lack of Commonwealth-wide surveillance also contributes to challenges in proving efficacy of control measures and performing control in general.

4.2 Mosquito Control Best Practices

To gather feedback on **lessons and best practices** from within and beyond the Commonwealth, the evaluation reviewed summary documents and respondent perceptions to answer the following question:

- What lessons and best practices (e.g., tiered mosquito control) can Massachusetts learn and adopt from other programs in states with robust mosquito control programs (e.g., other northeastern states)? How feasible is implementing these types of practices in Massachusetts?

The section below summarizes findings related to this question. It discusses best practices from other states, as well as best practices within the Commonwealth.

4.2.1 *Overarching Best Practice Recommendations*[8]

Summary documents, academic articles, state best practice reports (13 out of 33 documents, articles reports), and close to half of respondents (four out 10) recommended **education and outreach as the primary best practice for mosquito management.** In particular, the Centers for Disease Control and Prevention and the American Mosquito Control Association made detailed recommendations regarding the principles of education and outreach in relation to mosquito control efforts. Their recommendations noted that:

- Community outreach is a core principle for IPM.
- Establish and maintain public trust by providing accurate, timely, and actionable information to the public to inform communities of potential disease risk and prevention strategies.
- Include adequate information to dispel rumors and misinformation (American Mosquito Control Association, 2017).

In addition, some respondents shared their experiences regarding the need for education and outreach. Key themes included:

- Misinformation around MCD activities and pesticide use is challenging for understaffed, under-resourced health departments or control districts to mitigate.
- Constituents often raise concerns about pesticide use in their communities, and some think an MCD's sole activity is pesticide spraying. Respondents expressed frustration about this perception and suggested that MCDs could share fact sheets or develop frequently asked question guides (FAQs) for community members to help dispel this misinformation.
- Massachusetts agencies could play a stronger role in public education and give MCDs more tools to educate their communities on their mosquito control activities.
- Emphasizing personal protection measures in public education campaigns. Personal protection measures include, but are not limited to, staying indoors during hours when mosquitoes are especially active, wearing protective clothing outside during active mosquito hours, and using mosquito repellents when outdoors.

Surveillance, data collection, and analysis was the second-most-recommended best practice in summary documents and by respondents. Surveillance and monitoring is one of the key principles of IPM—which, as previously discussed, is mandated by federal agencies and is a recommended best practice for state mosquito control programs across the country. Surveillance and monitoring must be at the core of any mosquito management program: it informs the risk

[8] For more on best practices, see Report 5: Integrated Pest Management and Non-chemical Mosquito Controls for additional discussion of best practice recommendations for non-chemical mosquito control. Also, see Report 6: Best Practices to Maximize Impact of Pesticide Use on Mosquito Populations and Minimize Non-target Impacts of Mosquito Pesticides.

level for potential disease transmission in an area, and thus informs the best control measure to perform based on that risk. Respondents also mentioned that surveillance of a multitude of habitat types is important to assessing disease risk and understanding some mosquitoes' preferred habitat types. Respondents expressed frustration with the lack of uniformity of surveillance measures across the Commonwealth and reiterated the importance of a coordinated surveillance plan and the importance of communicating what type of surveillance measures various MCDs are performing, as different types of surveillance measures may yield different outcomes. For example, one respondent noted that depending on the types and locations of the mosquito traps they use, surveyors could be more likely to catch a certain mosquito species. The respondent used this example to emphasize the importance of Commonwealth-wide surveillance and mapping to conduct a coordinated response and have a complete understanding of potential disease risks during a mosquito season.

Summary reports and academic articles wrote at length on the **benefits of Open Marsh Water Management** as a first step in a comprehensive mosquito control program, and as a strong alternative to any pesticide use. OMWM was developed in New Jersey in the mid-1960s and is now a major source reduction technique used in coastal mosquito control agencies in New Jersey and around the country. OMWM has been proven to effectively control mosquitoes in salt marshes through a combination of biological control and habitat manipulation (U.S. Environmental Protection Agency, 1997). Wetlands management techniques, developed for OMWM are also applicable to other potential mosquito breeding or habitat sites such as freshwater wetlands, stormwater facilities, and river floodplains (State of New Jersey, 1997). In some areas, OMWM and marsh restoration eliminates the need for chemical control measures entirely (James-Pirri et al., 2009). While OMWM projects have high upfront costs, they may provide long-term savings compared to the continued use of pesticides. Although the specific design of an OMWM system can vary, the purpose and main idea behind the practice emphasizes source reduction and water exchange to eliminate standing water sources that could be breeding grounds for infectious mosquito populations (State of Connecticut, 2013). While OMWM is suggested as a best practice for mosquito control, it may not be applicable to all states. It is important to note that Massachusetts had an OMWM plan, however all MCDs except for Plymouth Count MCD ended their OMWM projects due to stringent regulations that required MCDs to monitor the OMWM sites. MCDs were unable to perform the required monitoring and therefore had to seek alternate mosquito control methods. Respondents and summary documents recommended the following other best practices for state mosquito control:

- **Relationship building (two out of 10 respondents).** Respondents noted that smaller MCDs or programs that might lack staff capacity can benefit from strong relationships with other MCDs or other state entities that might be able to fill the capacity gap or provide support or information that smaller programs may lack.

- **Biological control (six out of 33 reports).** Summary documents and reports recommended using natural predators such as predacious fish and copepods. However, these organisms should only be introduced if they are indigenous to the area, or in closed bodies of water, as they have been known to trigger algal blooms after consuming algae-eating organisms in a system (Beyond Pesticides/National Coalition Against the Misuse of Pesticides, 2012).

- **Additional best practices as recommended by summary documents** included performing mosquito larvae source reduction, capacity building and training for mosquito control agencies, and conducting larviciding and adulticiding.

4.2.2 Best Practices from Other States

Based on information from documents reviewed, as well as perspectives of respondents from within the beyond the Commonwealth, ERG identified mosquito control similarities and differences between Massachusetts and three other northeastern and mid-Atlantic states. Table 4-4 compares mosquito control in Connecticut, New York, New Jersey, and Massachusetts and highlights potential transferrable best practices (from interviews and documents) that the Commonwealth could consider from the other states.

Table 4-4. Summary of State Mosquito Control Programs, with Recommended Best Practices

	Massachusetts	Connecticut	New York	New Jersey
Primary Responsible Entity	• MCDs • Local boards of health	• Local health departments	• Local (county-level) health departments[a]	• County Mosquito Control Commissions
State-Level Control Entity	• SRB • DPH	• WHAMM • Department of Public Health • Department of Agriculture • CAES • University of Connecticut, Department of Pathobiology and Veterinary Science	• New York State Department of Health	• SMCC
Guiding Legal Framework	• Massachusetts General Law Ch. 252, MCD Enabling Legislation	• Legislative Act PA 97-289	• New York State Public Health Law • New York State Sanitary Code	• New Jersey Health Statutes
Best Practices	*See Reports5 and 6 for a thorough articulation of best practices used in Massachusetts.*	• Statewide mosquito trapping and surveillance • Tiered, four-phase response model for mosquito control based on: (1) public health notification, (2) public health alert, (3) public health warning, and (4) public health emergency • Veterinary surveillance and active mosquito surveillance[b] data are also collected through statewide trapping efforts	• Centralized state testing labs • Strong public health campaigns that encourage residents to use personal protection measures • Promotion of animal vaccination, primarily of horses, to protect against EEE	• State Equipment-Use Program • State Airspray Program • OMWM for source reduction and habitat improvement • New Jersey Light Trap for adult mosquito surveillance, with collections made daily during mosquito season to inform surveillance and response operations

[a] While these departments are referred to as local departments, they serve the whole county, not just one town or municipality.

[b] Passive mosquito surveillance relies on human and animal disease reports to gather information in mosquito-related infections, while active mosquito surveillance relies on trapping mosquitoes and testing them for presence of disease (Marin/Sonoma Mosquito and Vector Control District, 2021).

4.3 Strategies for Policy and Management Improvement

To better understand the existing structure for mosquito control in Massachusetts, the evaluation drew on summary documents and respondent perceptions to answer the following questions:

- Is the structure of the SRB appropriate for fulfilling mosquito control goals?
- What potential changes could be made for these entities to better fulfill mosquito control goals?

4.3.1 Structural Strengths and Weaknesses of the SRB

Overall, respondents offered mixed perspectives on the strengths and weaknesses of the existing structure of the SRB. Over half (seven out of 12) highlighted some of its benefits. For instance, some respondents (four out of 12) indicated that its **diverse composition** with robust representation from key agencies—including environmental interests through DEP—is a strength of the existing structure. A few respondents who praised the structure, however, noted DPH's lack of involvement in the SRB as a gap—particularly given the Department's strong role in mosquito surveillance.

One quarter (three out of 12) of respondents indicated another strength of the SRB: the **resources**—such as technical expertise and data—that they can provide to others in the Commonwealth, like the MCDs. For instance, one respondent described how the SRB helps the MCDs develop BMPs for mosquito control, in addition to providing opportunities to get expert opinion from key people such as the Commonwealth's chief apiarist. Two respondents also highlighted the **oversight role** that the SRB provides to the MCDs, noting advantages such as the need for the SRB to approve MCD budgets each year and the requirement for the districts to provide annual reports to the SRB. Informants also noted that as a public body subject to the Commonwealth's open meeting laws, the SRB is usefully transparent and open to public involvement. A final benefit noted by one respondent was the need for a statewide body to coordinate large, emergency responses—such as for aerial spraying—when needed.

Despite the strengths of the SRB, respondents suggested many potential changes to its structure. Over two thirds of them noted that a membership update could strengthen the SRB's ability to fulfill the goals of the mosquito control program. For instance, they suggested adding representation from DPH (as mentioned above), as well as at least one subject matter expert—such as a university or state scientist expert in mosquito biology and control—who could play a more active role in coordinating testing, research, and efficacy of interventions. A few respondents questioned the role of DCR on the SRB and noted that it could be useful to replace DCR with another agency that has a stake in mosquito control activities, such as the Division of Ecological Restoration or the Division of Fisheries and Wildlife.

4.3.2 Recommended New SRB Structures

Four out of 10 of informants suggested completely overhauling the SRB and creating a more centralized system to handle mosquito control activities. These informants suggested having a more centralized authority to oversee all mosquito control activities, including those within the districts themselves.

The respondents recommended establishing a new agency or division, housed within an existing department (such as MDAR or DEP) or at the secretariat level (EEA). This new agency, they noted, would have the following advantages:

- It would **allow more planning for oversight** of mosquito control activities within the Commonwealth. It could allow for more standardized statewide control measures and management, helping overcome some issues with the areas in the Commonwealth that are not part of any MCDs and thus receive limited surveillance and control, except in the event of an emergency. Some respondents also noted that a more standardized system could minimize the use of private control services by cities and towns. Respondents expressed concern that private entities that conduct mosquito control activities have limited oversight and requirements to disclose their activities, resulting in the potential application of unwanted control measures. According to respondents, more standardized Commonwealth measures could help decrease the need for municipalities or individuals to turn to private services.

- **MCD employees would become staff of the new agency,** helping simplify and streamline many of the administrative issues the SRB currently deals with and creating more standardized personnel and budgeting processes. This would also help ensure that the district-level staff have easy access to Commonwealth experts for guidance on surveillance and control, BMPs, and more.

- **MCDs could more easily share resources and equipment** with neighboring MCDs and municipalities. Currently, though respondents cited some instances of ad hoc coordination between MCDs (e.g., sharing of planes for spraying between the Bristol and Plymouth MCDs), MCDs are technically only allowed to spend their resources on their member communities and must document any services that they share with each other. A centralized agency could house useful equipment, such as excavators for open water management activities or planes for spraying, that districts could use as needed based on a shared equipment schedule. This type of system would mirror successful processes used in other states—such as New Jersey, which has a statewide equipment use program administered by its OMCC that allows counties to lease state-owned equipment (see Section 3.4.3 above for more information).

Respondents' recommendations for a more centralized mosquito control program echo recent legislation proposed in February 2021—Senate Bill S.556, "An Act Providing for the Public Health by Establishing an Ecologically Based Mosquito Management Program in the Commonwealth." The bill proposes a new mosquito management office administered by the EEA Secretary, which would have a staff and board responsible for regulating and overseeing "all disease vector mosquito and related nuisance organisms management activities in the commonwealth," including preparing ecologically based mosquito management plans and arbovirus response plans. In addition to including existing agencies that are represented on the SRB, such as MDAR and DEP, the legislation proposed that the management office board include representatives from DPH, the Division of Fisheries and Wildlife, and the Division of Ecological Restoration. This type of broader oversight structure could address some of the respondents' concerns about not currently having DPH representation or enough representation from environmental agencies on the SRB. The legislation also has the support of environmental groups such as Massachusetts Audubon, which recommended similar legislative reform in a

2021 position paper (Mass Audubon, 2021a) that calls for broadening the membership of the SRB and broadening statewide mosquito surveillance to include districts that are not currently part of MCDs. Notably, passing legislations to form a new mosquito management office— such as that proposed by Senate Bill S.556 or as proposed by Massachusetts Audubon—would require repealing and replacing M.G.L. c. 252, as well as the enabling legislation for the nine MCDs established through their own legislation.

4.4 Challenges in Mosquito Control on State, Federal, and Private Lands

As described in Section 3, the Commonwealth and MCD's authority to conduct mosquito control activities is limited on certain types of lands, such as federal property (e.g., National Parks, land owned by the Department of the Interior, Air Force bases), state lands such as DCR-managed state parks, state penitentiaries, and certain private properties that can request MCD exclusions from mosquito control activities or opt-outs for Commonwealth-wide aerial spraying activities. These differences in mosquito control options on these lands can fragment mosquito control activities and create challenges for ensuring cohesive management approaches. To better understand these challenges, ERG investigated the following evaluation questions, for which the following sections summarize results:

- What are the unique and prevalent barriers to effective mosquito control on private and public (federal, state, local) property?
- What strategies can the states, MCDs, and other entities use to address challenges to mosquito control on private and public lands? Are there any success stories or best practices to draw on?

4.4.1 Key Challenges

About half of respondents (seven out of 13) indicated that concern about treatment—particularly larviciding and adulticiding—on private property is a major barrier to chemical control efforts. Even for non-chemical treatment options, respondents cited difficulties coordinating with public and private landowners to ensure consistent approaches. Respondents noted that while many landowners are eager and willing to have spraying on their properties, there are notable instances of large property owners that have excluded their properties from wide-area MCD spraying and/or opted out of SRB spraying. Multiple informants cited land owned by the Trustees of Reservations (Trustees of Reservations, 2021) and Massachusetts Audubon as main examples of properties that either request exclusions from MCDs or opt out of SRB spraying. (See Table 4-5 below for a summary of all land areas that requested spraying exclusions from MCDs in 2020.) Additionally, some land trusts will also not permit MCDs to conduct surveillance on their properties. Respondents felt that exclusion of these lands from treatment and surveillance, as natural areas with mosquito habitat, could compromise the overall efficacy of mosquito control efforts in surrounding areas.

Other respondents offered contrasting perspectives: while they are pleased that they can request exclusions/opt-outs, the current exclusion/opt-out system is burdensome and requires more effort than it should. In general, their comments mirror the Commonwealth's divided opinion on spraying, where many have strong and entrenched perspectives about mosquito control activities and their benefits vs. harm. These perspectives were also reflected in the MCTF May 3 public listening session, where public commenters were strongly divided on spraying.

Analysis of MCD annual reports and the annual number of requests for spraying vs. the requests for exclusions also demonstrates a great variation in preferences across the Commonwealth (Table 4-5).

Table 4-5. Number of Exclusion and Service Requests by MCD in 2020

Project/District Name	Number of Service Requests	Number of Exclusion Requests
Berkshire County MCP	96	198
Bristol County MCP	12,979	128
Cape Cod MCP	Not listed	55
Central Mass. MCP	16,831	660
East Middlesex MCP	102	114
Nantucket MCP	1	0
Norfolk County MCD	9,107	295
Northeast Massachusetts Mosquito Control and Wetlands Management	1,917	285
Plymouth County MCP	17,923	453
Suffolk County MCP	27	5

Source: Annual MCD reports.
Duke County MCP and Pioneer Valley MCP reported n/a for the number of exclusion and service requests in their 2020 annual reports as they do not perform larviciding or adulticiding.

ERG also asked respondents what they perceive to be the largest barriers to mosquito control (both chemical and non-chemical) and surveillance on public lands. The 17 responses were mixed, but respondents noted a variety of challenges including the following:

- **Difficulty in conducting mosquito control and surveillance (five out of 17).** As with private land, respondents expressed concerns about challenges conducting a variety of mosquito control activities on public lands—particularly federal lands—that may host key mosquito habitat and become EEE or WNV hotspots. Multiple respondents shared anecdotes about federally owned land in their districts—including Hanscom Air Force Base, Veterans Affairs hospitals, wildlife refuges, and national parks—where the MCDs could not conduct mosquito control activities because landowners did not allow MCDs to enter or conduct activities on their land, including non-spray activities like water management and surveillance. Respondents noted that the inability to even monitor in these areas and better understand the mosquito populations and their levels can undermine mosquito control in their districts.

- **Issues surrounding endangered species and critical habitat protections (three out of 17).** Relatedly, a few respondents stated that some areas that are prime mosquito habitat are also home to endangered or sensitive species. Federal and state regulations limit mosquito control activities in these areas, even when the area may also serve as a major breeding ground for disease-carrying mosquitoes.

- **Restrictions under the Children and Families Protection Act (three out of 17).** Some respondents also discussed the restrictions surrounding the Act and the restrictions regarding pesticides applications on daycare and school properties. While schools are allowed to have spraying on their properties if the practices fall within their IPM plans and they provide the required notice to families, respondents noted, the restrictions can make it difficult to spray on or near schools in emergencies or high-risk situations—when time between detection and spraying is of the essence.

ERG also asked respondents what barriers they have encountered, if any, to effective mosquito control on state lands. Respondents did not comment on challenges with mosquito control on state lands, with the exception of one respondent who encountered a challenge performing mosquito control in a DCR state park within their MCD. The respondent mentioned that the local rangers were proponents of mosquito control and permitted the MCD to perform control measures in the park, but there was pushback from higher levels of management within the DCR who did not want mosquito control measures taken on the property.

4.4.2 Recommended Solutions

To overcome challenges in both public and private lands, two main themes emerged: the importance of education and outreach and building relationships with landowners. Respondents indicated that outreach and education could help build understanding among landowners and managers and those responsible for mosquito control and surveillance. In describing the potential benefits of relationship-building and education and outreach, they brought up:

- **Increased awareness of management options.** Respondents stressed that increased outreach and education activities for the public on mosquito control—at both the MCD level and the state level—could give landowners and managers a better understanding of mosquito control, what it entails, and what options landowners have. A few respondents discussed the strengths of their MCDs' outreach and education programs, which have been a part of fostering robust community support and less pushback on operations. One respondent suggested developing more specific question responses and FAQ sheets that could serve as a resource for the public to address common concerns and misinformation.

- **Strengthened understanding of public perspectives.** While many respondents highlighted the need for a more informed public, they also noted that it could be useful to get more information *from* the public so that those responsible for mosquito control could better understand stakeholders' perspectives and consider how mosquito control activities (e.g., pesticide spraying) could harm livelihoods and the economy. Respondents noted that if MCD representatives and others at the state level had more opportunities to discuss major concerns and impacts with the public, it would be easier to find mutually agreeable solutions.

- **Relationships.** Some respondents discussed how their MCDs had formed relationships with landowners and managers, which made it easier to discuss mosquito control options and determine the best solutions for various lands.

Other potential solutions mentioned by respondents included:

- Granting the Commonwealth and MCDs the ability to enter private property and abate particularly problematic mosquito sites.

- More staff capacity and funding for outreach and education.

- A standardized Commonwealth-wide surveillance system that would grant authority for trapping and reporting on private lands.

- A Commonwealth-level technical advisor who could serve as a liaison, helping coordinate control on state and federal lands where control and access is currently difficult.

- Lessening the burden on landowners by switching to an opt-in instead of opt-out system for spraying.

- Strengthening the focus of MCDs on non-spray control activities, including removing culvert blockages to allow fish passage and increasing fish predation on mosquito larvae, restoring abandoned cranberry bogs to wetlands, and improving wetland health.

4.5 Evaluation Summary

Overall, perspectives on Massachusetts' current policy structure for mosquito control are deeply divided. Some feel that the current policy structure functions well and meets the Commonwealth's goals for safe and effective mosquito control. Conversely, others feel that significant aspects of the structure—such as the composition of the SRB, the SRB's level of power, and regional variations with the MCDs—could benefit from considerable revisions. Respondents were also divided on the existing structure of the SRB: some felt that the existing structure is diverse and provides robust representation from key agencies with a stake in mosquito control, while others suggested completely overhauling the SRB and creating a more centralized structure for mosquito control throughout the Commonwealth. Some respondents noted that a more cohesive structure (e.g., a new agency or division responsible for mosquito control) could help create a uniform approach to coordination with some of the federal, state, and private entities where the Commonwealth does not have the jurisdiction to perform management activities.

Respondents' divided perspectives on the mosquito control policy structure were reflected in some of the literature reviewed (e.g., Mass Audubon (2021b), Trustees of Reservations (2021)), as well as in the MCTF public listening session held on May 3, 2020. These divisions often stemmed from a strong opposition to aerial spraying that the SRB conducts at the Commonwealth level and truck-based spraying that the MCDs conduct within their member municipalities. Multiple respondents expressed frustration with what they perceived as the lack of clarity over these processes, the burdensome nature of the opt-out process, and the limited uniformity regarding spraying across MCDs. As recommended by respondents, a policy structure that creates consistency across control and surveillance actions at the regional level could create a stable baseline that would be easier for the public to understand than the current structure. Transparency about the decision-making process at the regional and Commonwealth level, abundant communication about processes and decisions, agreement on the scientific basis for decision-making in mosquito control (e.g., triggers, methods, options), and greater effort to promote understand between the opposing perspectives could also strengthen support for mosquito control actions within the Commonwealth

5. Works Cited

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Appendix A

INTERVIEW GUIDE

1. ABOUT THIS DOCUMENT

The interview guide outlined in this document will inform the Massachusetts Mosquito Control Task Force Study. Eastern Research Group, Inc. (ERG) will use this document during semi-structured interviews with key stakeholders in mosquito control efforts in Massachusetts and in other northeastern states. Interviewees will include key contacts from Mosquito Control Districts (MCDs), Massachusetts Department of Environmental Protection (MDAR), Massachusetts Department of Public Health, Local Boards of Health, Massachusetts Audubon, and other regional experts.

Text in *italics* indicates information the interviewer will share with the informant, while information in **[brackets and bold]** is an internal note for the interviewer and will not be communicated to the informants.

1.1 Interview Objectives

The interviews will gather insight on the effectiveness of the current structure and practices for mosquito control in Massachusetts, including the following areas:

- **Objective 1:** The benefits and drawbacks of the existing mosquito control policy structure in Massachusetts
- **Objective 2:** Best practices and lessons learned in mosquito control in Massachusetts and in other northeastern states
- **Objective 3:** Challenges to effective mosquito control on private and public property and potential solutions
- **Objective 4:** Public water system laws regarding pesticide use

2. INTERVIEW GUIDE FOR TASKS D AND F

Opening Script:
Thank you for taking the time to speak with me today; your thoughts and opinions will be very valuable to this project. We are excited to have the opportunity to speak with you today as part of an evaluation of the effectiveness of the current structure and practices for mosquito control in Massachusetts. As you may know, the Mosquito Control for the 21st Century Task Force (MCTF), chaired by the Executive Office of Energy and Environmental Affairs (EEA), is legislatively mandated to commission a study which will provide a complete a comprehensive evaluation of the Commonwealth's mosquito control processes. Findings from the study will be used by the Task Force to make a set of recommendations to inform legislation that may lead to changes to the existing structure and processes related to mosquito control in the Commonwealth. The MCTF tasked ERG with conducting this study.

As part of this study, we are eager to hear today about your thoughts on the benefits and drawbacks of the existing mosquito control policy structure in Massachusetts, specific changes that would enhance mosquito control management decision-making, lessons learned from the Commonwealth's control program and programs in other northeastern states, and challenges to effective mosquito control on private and public property and their potential solutions.

Before we begin, I want to let you know that we expect the interview to take no more than one hour of your time. All information you share today is confidential. Responses across all respondents will be aggregated before sharing with MCTF, EEA, and their partners so that no information will be attributable to you.

Do you have any questions before we begin?

2.1 Background

1. To begin, please tell us about yourself:
   a. What is your position at [organization/company name]?
   b. How long have you been employed there?
2. Please briefly describe your background in mosquito control.
3. Currently, in Massachusetts [or other state depending on the informant], could you please describe your role in relation to mosquito control?

2.2 Existing Mosquito Control Policy Structure

- ***Evaluation Question Set 1—Structure***: *Does the current structure of the mosquito control program reflect a balanced representation of the interests and issues that need to be addressed?*
- ***Evaluation Question Set 2—Decision-making effectiveness****: Is the decision-making process efficiently executed and effectively communicated? Are there inconsistencies that need to be addressed?*
- ***Evaluation Question Set 3—Management effectiveness****: How effective is mosquito control program management in relation to oversight of activities, finances, public participation, ensuring local options and choices in services received, and in control of nuisance mosquito populations? What past and present barriers have prevented Massachusetts cities and towns from joining regional mosquito control districts or pursuing other local or regional approaches?*

As part of our first set of questions, we are interested in understanding the effectiveness of the existing mosquito control policy structure and how well it performs.

4. The aim of Massachusetts' mosquito control program is to ensure mosquito control is safe and effective, resulting in decreased prevalence of mosquito borne illness in humans and animals, as well as decreased prevalence of disease carrying mosquitoes. Given your knowledge of the Commonwealth's mosquito control program, do you feel that it's designed in a manner to achieve these goals? Please explain your response.
5. What do you see as the major strengths of Massachusetts' mosquito control program?
6. What do you see as the major weaknesses of Massachusetts' mosquito control program?
7. Does the program reflect a balanced **set of interests** (e.g., reflecting the interest of multiple stakeholders, geographies)? If yes, how so?
   a. [**If no**] What could be done to improve the interests reflected in the program?
8. Does the program represent a balanced **set of issues** (e.g., public health needs, ecological impacts, etc.)? If yes, how so?
   a. [**If no**] What could be done to improve the issues reflected in the program?

9. Based on your knowledge of the program and its components, on a scale of 1 to 5, where 1 = not at all effective and 5 = highly effective, how effective do you think the decision-making process for mosquito control activities is in relation to the following (please explain your response for each):
    a. When to conduct spray operations?
    b. When to survey mosquito populations?
    c. Establishing MCDs?
    d. Funding MCDs?
    e. Activities conducted by MCDs?
10. For the components discussed above, what part of the decision-making process do you think could be improved, and how?
    a. Are decisions communicated in an efficient manner to constituents? Please explain.
        i. **[If no**] What could be done to strengthen the communication of decisions to constituents?
11. On a scale of 1 to 5, where 1 = not at all effective and 5 = highly effective, how would you rank the following components of mosquito control program management? Please explain your rankings. [**Modify list below based on informant's experience.**]
    a. Oversight of activities?
    b. Finances?
    c. Public participation?
    d. Ensuring local options and choices in services received?
    e. Control of nuisance mosquito populations?
12. Are you aware of any past and present barriers that have prevented Massachusetts cities and towns from joining regional mosquito control districts or pursuing other local or regional approaches? If so, please explain these barriers.
    a. What do you think could be done to overcome these barriers?
13. How would you describe the existing coordination between MCDs (e.g., coordination on activities, resource sharing, etc.)?
    a. What do you see as opportunities to strengthen coordination between MCDs?
    b. Do you see any opportunities for strengthening coordination between neighboring towns that are not part of MCDs and MCDs?

2.3 Best Practices and Lessons Learned

- ***Evaluation Question Set 4—Best practices**: What lessons and best practices (e.g., tiered mosquito control) can Massachusetts learn and adopt from other programs in states with robust mosquito control programs (e.g., other northeastern states like Connecticut's tiered program, Michigan)? How feasible is implementing these types of practices in Massachusetts?*
- ***Evaluation Question Set 5—Strategies for improvement**: Is the structure of the SRB appropriate for fulfilling program goals? What potential changes could be made for these entities to better fulfill mosquito control goals?*

14. [**For out-of-state informants only**] At a high level, could you please describe the structure of your state's mosquito control program?
    a. What do you see as best practices from your state's program that could be of use to other states, such as Massachusetts?

   b. What are the major challenges your state has encountered in relation to mosquito control?
   c. What strategies has your state used to overcome these challenges?
15. What do you see as some of the major lessons learned from the Commonwealth's mosquito control program?
16. Are there any best practices at the local level that you think could be useful for the Commonwealth to adopt? If so, what are these practices?
17. The State Reclamation and Mosquito Control Board oversees mosquito control in the Commonwealth, including oversight of the 11 MCDs and establishment of administrative and technical policies, guidelines, and best management practices to ensure mosquito control programs are safe and effective. What do you think currently functions well for the SRB structure?
    a. What do you see as potential opportunities to modify the SRB structure to better fulfill mosquito control goals?

2.4 Challenges to Effective Mosquito control on Private and Public Property

- ***Evaluation Question Set 6—Public and private land challenges and solutions****: What are the unique and prevalent barriers to effective mosquito control on private and public (federal, state, local) property? What strategies can the states, MCDs, and other entities use to address challenges to mosquito control on private and public lands? Are there any success stories or best practices to draw on?*

18. What would you say are the major barriers to effective mosquito control on private property?

    a. Do you have any suggestions for the Commonwealth to address these challenges on the local or state level?

19. What would you say are the unique and prevalent barriers to effective mosquito control on public property (including federal, state, and local)? Consider in your response DOD facilities, public schools, penitentiaries, local parks, etc.

    a. Do you have any suggestions for the Commonwealth to address these challenges on the local or state level?

20. Specific to challenges to mosquito control on private and public lands, are there any success stories or best practices you think Massachusetts could learn from looking at:

    a. Programs within the Commonwealth?
    b. At other states?

2.5 Public Water Laws

21. Do you have any concerns about the current systems for protecting public drinking water systems from pesticides? [If not, that's okay.]
22. Do you have any recommendations for ensuring protection of public water systems from pesticides (to treat mosquitoes)? [If not, that's okay]

2.6 <u>Wrap Up</u>

That brings us to the end of our discussion.

23. Is there any additional feedback or information that you would like to share today before we end our call?

Thank you again for taking the time to speak with me today; we greatly appreciate your insights as part of this project. In terms of our next steps, we will be analyzing data collected through these interviews and using them to develop a portion of the full draft report that our ERG team will deliver to the MCTF by mid-July. The report should be finalized by mid-August and will be publicly available.

Appendix B

LIST OF ADDITIONAL DOCUMENTS REVIEWED

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Report 3: Opt-Outs and Exclusions

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1. EXECUTIVE SUMMARY

The Commonwealth of Massachusetts offers residents the option to opt out of mosquito control pesticide spraying performed by the SRB or request an exclusion from wide area applications of pesticides such as those performed by MCDs. Opt-out requests apply to SRB activities and exclusions apply to other entities (i.e., MCDs). In 2020, the last year with complete data, more than 2,000 residents and property owners submitted requests for opt-out or exclusion. In 2021, the first year of municipal opt-outs, 35 municipalities submitted complete, timely applications to opt out of state activities. Residents can also sign up to be notified in advance of planned spray events.

No comparable opt-out programs were identified in other northeastern states. Outside the northeast, Michigan, which has emerging mosquito issues somewhat similar to Massachusetts and has an opt-out process for residents that is very similar to the individual exclusion/opt-out request process in Massachusetts.

Certain aspects of the opt-out/exclusion program appear to cause difficulties. This includes exclusions made under 333 Code of Massachusetts Regulations (CMR) 13.03, which requires exclusion requests be made by the private property owner or someone in legal control of the property. Additionally, the process of annually submitting applications to MDAR and placing required “no spray” markers along the perimeter of a property can be time-consuming, particularly for organizations owning multiple parcels. Multiple concerns have been raised regarding the possibility of a property being sprayed despite an exclusion request, either by accident or due to spray drift, although applicators take measures to prevent this. The public has also expressed concerns regarding the state’s ability to waive exclusion requests in the event that DPH determines an application is needed to protect public health, potentially impacting individuals with chemical sensitivities and farms that follow organic practices but do not have organic certification (certified organic farms are excluded even in the event of a public health hazard certification). Opt-outs made under Massachusetts General Law (M.G.L.) chapter (c.) 252, Section 2A may only be made by the property owner and follow the same process for requesting as set forth in 333 CMR 13.03. Opt-outs are also waived in the event that DPH determines an application is needed to protect public health.

In addition to allowing property owners and tenants to request exclusions or opt outs for their properties, municipalities can apply to opt out of aerial spraying or wide area emergency operations conducted by the SRB. The 2020 legislation *An Act to Mitigate Arbovirus in the Commonwealth,* which expanded the SRB’s authority to conduct mosquito control operations across the commonwealth, established the municipal opt-out process, which will sunset at the end of 2022. Concerns expressed about this new program may be related to its novelty. The amount of time provided for municipalities to complete the application and requirements was frequently criticized as being inadequate. Several individuals also expressed concern or confusion regarding the exact requirements for an application to be accepted, such as what needs to be included in an alternative mosquito management plan. Many view the opt-out process, especially the requirement to develop an alternative mosquito management plan, as burdensome, particularly for smaller municipalities with limited resources.

In Massachusetts, residents can sign up to be notified by email in advance of aerial spraying or wide area emergency operations conducted by the SRB by submitting a notification request form to MDAR. This process was created by the 2020 Act and will sunset at the end of

2022. All New England states, as well as New York and New Jersey, have some requirements regarding notification in advance of planned pesticide applications, although some states' notification requirements apply only to limited groups of people.

The Task Force requested an analysis of the impacts, risks, and benefits of providing a range of mosquito control options, including opt-out programs. However, no published studies that analyze and quantify these impacts, risks, and benefits are available. As a result, the assessment of impacts, risks, and benefits presented herein is qualitative, based on input received from stakeholders. As Report 8: Impact of Mosquitoes, Mosquitoes as Disease Vectors and Mosquito Control Measures discusses, mosquito control pesticide applications have some demonstrated public health benefits due to their reduction of mosquito populations, and allowing exclusions and opt-outs limits pesticide applications. Conversely, exposure to pesticides may result in adverse human health effects and ecological toxicity. Subsequently, many residents and municipalities have made clear that they do not want to be subject to mosquito pesticide spraying. However, some of these residents and municipalities may support non-chemical mosquito control methods or mosquito surveillance, which may provide public health benefits. Allowing exclusions and opt-outs allows these residents and municipalities to obtain these services without being subjected to unwanted chemical controls.

2. SCOPE OF WORK

This section performs the following, as requested by the Mosquito Control Task Force:

Analyze and summarize mosquito control opt-out programs.

1. *Summarize existing practice in Massachusetts, particularly as it pertains to community opt-out and property owner opt-out and notification.*
2. *Analyze the impacts, risks, and benefits of providing a range of options for mosquito control pesticide use, including opt-out.*
3. *Summarize opt-out programs in other states, including lessons learned if possible.*
4. *Address options for making opt-out more time-efficient and cost-effective for pesticide administrators, communities, and property owners. Address feasibility of implementing global positioning system (GPS) mapping systems.*

The content of this section is based on reviews of mosquito control regulations and laws of Massachusetts and other states; conversations with employees of the Massachusetts Department of Agricultural Resources (MDAR), employees of the Executive Office of Energy and Environmental Affairs (EEA), and one mosquito control district (MCD) superintendent; public comments; issues that Task Force members raised at Task Force meetings; reviews of relevant literature; and reviews of select MDAR, State Reclamation and Mosquito Control Board (SRB), and EEA documents.

3. HOW IS THE EXCLUSION/OPT-OUT PROGRAM CURRENTLY OPERATING IN MASSACHUSETTS AND OTHER STATES?

3.1 Current Operation of the Exclusion/Opt-Out Program in Massachusetts

Massachusetts allows three main types of opt-outs from pesticide spraying. First, tenants and property owners may submit an exclusion request to exclude their properties from wide area application of pesticides. Second, property owners may request to opt out of spraying conducted by the SRB. Third, municipalities may apply to opt out of activities conducted by the SRB. This section describes each program in more detail. Further, the SRB excludes surface drinking water supply areas, commercial fish hatcheries and aquaculture, and priority habitats for endangered and threatened species, based on GIS information provided by the Department of Environmental Protection, the Department of Fish and Game, and MDAR. MDAR also maintains a list and map of hemp farms and certified organic growers in the state, and "the SRB will make every effort to exclude these properties from any emergency mosquito control efforts that could impact the status of their crops" (State Reclamation and Mosquito Control Board, 2019). These last two land types are not automatically excluded from spraying conducted by MCDs.

3.1.1 Individual Property Exclusion/Opt-Out

Property owners or residents can exclude individual properties from wide area spraying or opt out of spraying activities performed by the SRB. This process is called "opt-out" or "exclusion" depending on the regulatory or statutory authority that the request pertains to. Property owners may opt out, request an exclusion, or both, while tenants may only request exclusions.

- The regulation 333 CMR 13 provides for exclusions, which the property owner or tenant can request. Exclusions under 333 CMR 13.03 pertain to wide area applications, which are primarily performed by MCDs. Wide area applications are defined as "all aerial applications made for the control of Public Nuisance Pests, and all ground applications made for the control of Public Nuisance Pests which cross property lines or are made to areas that exceed one acre" (*333 CMR 13.00: Standards for Application (2017)*).
- MGL c. 252, Section 2A provides for opt-outs, which only the property owner can request. Opt-outs under MGL c. 252, Section 2A pertain to aerial spray or wide area emergency operations performed by the SRB. MGL c. 252, Section 2A does not further define wide area applications. The opt-out process is new and temporary, lasting only from 2021 through 2022.

The processes for requesting an exclusion or an opt-out are the same, and they can be requested simultaneously. Requests become effective 14 days after submittal and expire on December 31 of that year, requiring annual resubmittal to continue to exclude the property. Individual opt-outs and exclusions that have been granted for individual properties can be waived if the Commissioner of Public Health certifies that the pesticide application is to be made to protect public health, the Commissioner of the Department of Conservation and Recreation has certified that the application is necessary to contain an infestation of a recently introduced pest, or the Commissioner of MDAR has certified that the application is necessary to contain an infestation of a pest that is a significant threat to agriculture. The main differences between opt-outs and exclusions are legal distinctions in the origins of each process, what pesticide applications each applies to, and who can submit the request (Massachusetts Department of Agricultural Resources, 2020). As of the writing of this report, in 2021, 100 percent of people requesting to opt out under MGL c. 252, Section 2A also requested an exclusion under 333 CMR, and the majority of the requests were for exclusions from both adulticiding and larviciding. Individuals can also request notification by email of upcoming spray events conducted by the SRB. Notification requirements may be altered or waived in the event of an emergency, and were created by the 2020 Act and sunset at the end of 2022 (The Commonwealth of Massachusetts Executive Office of Energy and Environmental Affairs, n.d.).

Opt-out, exclusion, and notification requests are made by submitting an online or paper form to MDAR, which maintains a database and forwards each request to the local MCD, if applicable. In 2020, 2,062 individual opt-out/exclusion requests were received for properties in MCDs. Another 287 requests for exclusions were received for properties not in MCDs. The number of exclusion requests received has been increasing since 2017, for properties both within and outside MCDs, as shown in Table 3-1.

Table 3-1. Requests Submitted, 2017–2020

Year	Requests in an MCD	Requests Outside an MCD	Total
2017	1,067	8	1,075
2018	1,634	7	1,641
2019	1,765	30	1,795
2020	2,062	287	2,349

The number of individual exclusion requests varies from district to district, but there can be hundreds of requests in some MCDs. In 2020, exclusion requests in the eight MCDs that conducted adulticide spraying ranged from a minimum of five in heavily urban Suffolk County to a maximum of 660 in the Central Massachusetts district; the median number of exclusions reported by these eight districts for 2020 was 242. Two MCDs that do not engage in pesticide applications reported receiving no exclusion requests (i.e., Dukes County and Pioneer Valley). It is not clear whether the districts engaging in larviciding but not adulticiding (i.e., as of 2020, Cape Cod and Nantucket) have operations that meet the definition of "wide area applications." Table 3-2 presents the number of exclusion requests reported by each district for 2020, as reported by MCDs.

Table 3-2. Exclusion Requests Received in 2020 as Reported by MCDs

Project/District Name	Exclusion Requests Reported	Number of Municipalities in District
Central Massachusetts Mosquito Control Project	660	44
Plymouth County Mosquito Control Project	453	28
Norfolk County MCD	295	25
Northeast Massachusetts Mosquito Control and Wetlands Management District	285	33
Berkshire County Mosquito Control Project	198	10
Bristol County Mosquito Control Project	128	20
East Middlesex Mosquito Control Project	114	26
Cape Cod Mosquito Control Project	55	15

Project/District Name	Exclusion Requests Reported	Number of Municipalities in District
Suffolk County Mosquito Control Project	5	2
Nantucket Mosquito Control Project	0	1
Dukes County Mosquito Control Project	N/A	6
Pioneer Valley MCD	N/A	15

Source: 2020 Annual Reports from 12 MCDs.
Note: The Dukes County and Pioneer Valley districts, which do not perform pesticide applications, reported "N/A" for the number of exclusion requests received.

3.1.2 Municipal Opt-Out

MCDs perform most routine mosquito control in Massachusetts. However, when public health hazards arise, the SRB may perform spraying. The SRB may spray in any municipality in the commonwealth regardless of whether the municipality is a member of an MCD. In 2020, *An Act to Mitigate Arbovirus in the Commonwealth* (*Michigan Administrative Code, R 285.637.11 - Commercial notification and posting requirements (2008)*) created a new requirement for EEA to provide a means for municipalities to opt out of mosquito control spraying conducted by the SRB if the municipality demonstrates an alternative mosquito management plan, subject to EEA approval. Unlike individual property opt-outs, approved municipal opt-outs from SRB spraying are not waived in the event of a certification of a public health need. The municipal opt-out process is temporary, lasting only from 2021 through 2022 (*Michigan Administrative Code, R 285.637.11 - Commercial notification and posting requirements (2008)*). To apply to opt out of SRB spraying for the 2021 season, first a municipality must develop an alternative mosquito management plan in consultation with its board of health. The municipality must vote to opt out of SRB spraying at a meeting of the city council or select board that includes input on the alternative plan and allows for public comment. The municipality then provides a copy of the certified vote with an application for approval of its plan to EEA. The alternative mosquito management plan must include at a minimum a detailed public outreach and education component. A plan is effective through December 31 of the year in which it is approved (Commonwealth of Massachusetts Executive Office of Energy and Environmental Affairs, 2021b).

As of June 1, 2021, 35 municipalities, shown in Figure , submitted opt-out applications for SRB spraying to the EEAopt-out@mass.gov email inbox. Two additional municipalities submitted applications in the weeks thereafter and were received too late for consideration. Applications were reviewed to assess the regional impact of excluding the municipality from spraying, including risk of EEE, strength of the alternative mosquito management plan, and ability to implement the plan. Regional impact is considered because mosquitoes and birds are not confined by municipal boundaries, so mosquito management activities in one municipality can impact arbovirus risk in nearby municipalities (Commonwealth of Massachusetts Executive Office of Energy and Environmental Affairs, 2021a). Some of the applications received demonstrate a misunderstanding of the municipal opt-out process; Section 4 discusses these issues.

Of the 35 municipalities that submitted complete, timely opt-out applications, six municipalities (17 percent) are members of an MCD, and 29 municipalities (83 percent) are not, as of 2020. For comparison, as of July 19, 2021, 229 of all 351 municipalities in Massachusetts

(65 percent) were in MCDs. Of the six MCD-member municipalities applying to opt out, five are members of the Pioneer Valley MCD, which does not currently conduct any spraying, and one (Beverly) is a member of the Northeast Massachusetts Mosquito Control and Wetlands Management District but requires board of health approval for any adulticiding or barrier treatments. Although some municipalities requesting opt-out are MCD members, none currently receive routine adulticiding services from their respective districts.

On July 12, 2021, EEA announced opt-out decisions. Of the 35 applications under consideration, 24 applications rated as having minimal or low regional risk levels were approved and 11 applications rated as moderate regional risk level were denied, shown in Figure 3-1. No applications submitted in 2021 were rated as having high or very high regional risk levels.

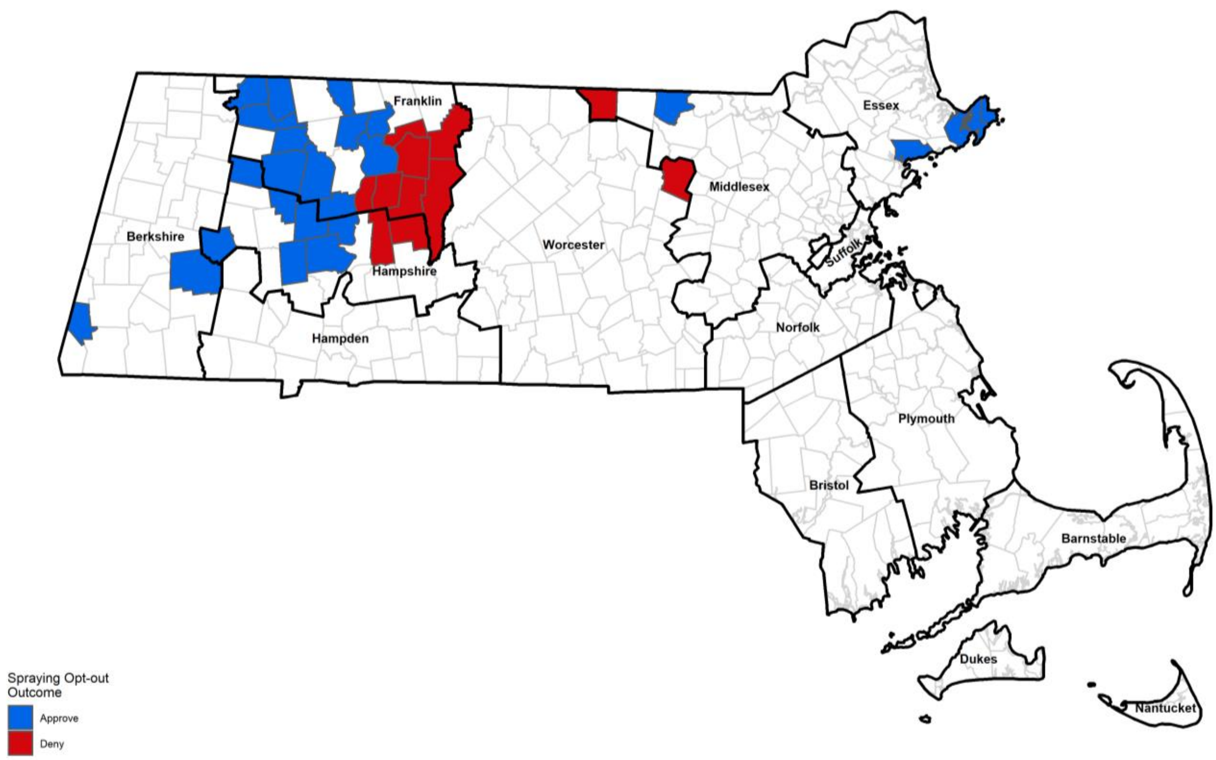


Figure 3-1. Map of municipalities that applied to opt out by June 1, 2021.

3.1.3 Notification Policy in Massachusetts

As of passage of the 2020 Act in the summer of 2020, through the end of 2022, Massachusetts residents may request to be notified of aerial spray or wide area emergency applications conducted by the SRB. When a request is made, the SRB will notify the requestor by email at least 48 hours prior to an aerial application or other wide area emergency operations (The Commonwealth of Massachusetts Executive Office of Energy and Environmental Affairs, n.d.). The pesticide regulations require that public notification be done through a local newspaper used for legal notices, prior to any aerial applications. This notice is to be done no sooner than 10 days prior to the application and contains information about the application. Aerial larviciding operations conducted by MCDs can be exempted from these requirements if a notice of proposed application is published between February 1st and March 1st of that year. Notification requirements may also be waived given certification of a public health hazard. Districts typically provide their own additional notifications about their adulticiding and larviciding activities to local residents. For example, the Central Massachusetts Mosquito Control Project lists potential spray areas on its website and on a phone answering service by 3:30 p.m. each day (Central Massachusetts Mosquito Control Project).

3.2 Current Exclusion/Opt-Out and Notification Policies in Other States

3.2.1 Exclusion/Opt-Out Policies in Other States

Exclusions and opt-out policies in other northeastern states were reviewed per the scope of this report. In this report, "northeastern states" includes all of New England, plus New York and New Jersey.

No other northeastern states have opt-out policies comparable to those of Massachusetts. Most northeastern states have exclusions for certain land uses, such as organic farms, schools, water supplies, or endangered species habitats. Sometimes the exclusion is applied by default, but sometimes the business must request it. For example, in New Hampshire, aerial application of pesticides cannot normally be made in "sensitive areas" such as school buildings and associated properties, nurseries and daycare centers, rest homes, and hospitals and clinics, although these areas are not necessarily excluded in the event of a public health emergency.

Residential opt-outs are available in Michigan, the U.S. state with the second-most eastern equine encephalitis (EEE) cases in recent years after Massachusetts. Michigan allows residents to opt out of spraying with a process similar to that of Massachusetts. In Michigan, residents can opt out of spraying up to 48 hours before spraying begins. The department of public health can override opt-outs in the case of an emergency declaration (*Michigan Administrative Code, R 285.637.11 - Commercial notification and posting requirements (2008)*).

3.2.2 Notification Policies in Other Northeastern States

Opt-outs, notification requirements, and similar regulations in most states are written to apply to pesticide applications in general. No other northeastern states have opt-out programs, but they do have requirements for notification, information on which is included here. Although notification policies in other states were not included in the original scope of this report, this information provides valuable context on other states' operations. Note that states may have provisions altering notification requirements in situations such as operations of mosquito control agencies or emergency applications made to protect human health.

The notification options in other northeastern states vary widely. In several other northeastern states including Rhode Island, New York, and New Jersey, no notification requirements are specific to mosquito control operations, but general pesticide application notification requirements apply. Although no other northeastern state allows municipal or individual opt-out similar to Massachusetts, in New Hampshire and Maine, mandatory public hearings or public comment periods allow community input on each planned spray event; in New Hampshire, cities and towns perform mosquito control, so municipalities may de facto opt out of mosquito control by simply not performing mosquito control. It is important to consider that other northeastern states have fewer cases of EEE than Massachusetts (Centers for Disease Control and Prevention, 2020a).

Notification requirements for wide area pesticide applications in northeastern states include:

- Public notice, which can take multiple forms, most commonly publication in a local newspaper. Public notice is normally required for applications in New Hampshire, aerial applications in Maine, and applications in New York (alternatively, all owners or residents of buildings in the treatment area may be informed in writing).
- An opportunity for residents to provide public comment or attend a public meeting, which is normally required for all applications in Vermont and for applications in residential areas in New Hampshire.
- Mandatory notice to owners/residents of nearby properties, which the applicator or hiring entity must provide in three states, specifically:
  - New Hampshire: Notice must be given to property owners within 1,320 feet of the treatment areas for aerial application of pesticides in rural areas.
  - New York: Notice must be given to the owners, owners' agents, or occupants of all buildings and structures on the premises of the pesticide application area, unless newspaper publications provide prior notice.
  - Maine: Residents who have signed up for the notification registry can request notification from any or all of their neighbors, who must then provide notice before applying pesticides on their properties.
- Notification registries, which require residents/property owners to sign up, register, or take other measures to be notified. Registries are included in mosquito control efforts for three states:
  - Connecticut: Residents can sign up for a registry to be notified of pesticide applications to abutting properties by commercial applicators when the pesticide application is within 100 yards of their property (applicators must check the registry and notify neighbors).
  - Maine: Residents can sign up for a notification registry and request notification from neighbors for pesticide applications made to their properties.
  - Rhode Island: School staff members and parents/guardians of students can request notification for pesticide applications to be made at the school.
- Other notification requirements. Applicators in Maine must notify the Maine Poison Control Center. In New Jersey, any publicly sponsored or funded mosquito adulticiding must provide information on the pesticides proposed for use to each municipality to be sprayed; the information must be provided annually in March or as soon as possible after the decision to spray is made, and the notification must be provided prior to the application.

Notification requirements in Massachusetts and other northeastern states are summarized in Table 3-3; this table lists only requirements for notification and does not include any optional notification activities.

Table 3-3. Summary of Notification Requirements for Pesticide Applications in Northeastern States

State	Public Notice	Public Comment/ Meeting	Notice to Owners/ Residents	Notification Registry	Other
Massachusetts	Yes	No	No	Yes	No
Maine[9]	Yes	No	Yes	Yes	Yes
New Hampshire[10]	Yes	Yes	Yes	No	No
Vermont[11]	No	Yes	No	No	No
Rhode Island[12]	No	No	No	Yes	No
Connecticut[13]	No	No	No	Yes	No
New York[14]	Yes	No	Yes	No	No
New Jersey[15]	No	No	No	No	Yes

While the details on notification requirements and waiving those requirements vary, all New England states have some regulations for providing notice to certain potentially affected individuals in advance of pesticide spraying. The burden of notification most commonly falls on the pesticide applicator, although in some cases, the person or entity hiring a commercial applicator is responsible for notification.

[9] Notice of Aerial Pesticide Applications, § 026 (n.d.-a). ; Notification Provisions for Outdoor Pesticide Applications, (n.d.).

[10] State of New Hampshire. (2008). *Mosquito Control and Pesticides in New Hampshire*. ; Restriction on the Application of Pesticides by Commercial Applicators and Permittees, (n.d.). http://www.gencourt.state.nh.us/rules/state_agencies/pes500.html

[11] Mosquito Abatement, § Chapter 85: Mosquito Abatement (n.d.).

[12] Pesticide applications and notification of pesticide applications at schools, § Section 23-25-37 (n.d.-b). http://webserver.rilin.state.ri.us/Statutes/TITLE23/23-25/23-25-37.HTM

[13] Connecticut Department of Energy and Environmental Protection. (2016, December 23, 2016). *Pre-Notification of Pesticide Application to Abutting Property*. Retrieved April 28 from https://portal.ct.gov/DEEP/Pesticides/Pre-Notification-of-Pesticide-Application-to-Abutting-Property

[14] Pesticide Applicator Certification, § 33-0905 (n.d.-c). https://newyork.public.law/laws/n.y._environmental_conservation_law_section_33-0905

[15] Pesticide Exposure Management, § Chapter 30. Pesticide Control (n.d.). https://www.nj.gov/dep/rules/rules/njac7_30.pdf

4. CURRENT STRENGTHS AND WEAKNESSES OF THE EXCLUSION/OPT-OUT PROGRAM

Assessment of the exclusion/opt-out process and program is predicated on the different goals of stakeholders. Issues raised in this section are based on public comments, comments from members of the Task Force, interviews with and reports from MCD supervisors, and discussions with state government employees. Many aspects of the individual exclusion and opt-out processes and the municipal opt-out are defined in MDAR regulations and changes would require changes to these regulations.

4.1 Feedback on the Individual Opt-Out Process

For individual property owners or tenants seeking an exclusion or opt-out, barriers in the application process exist. Each year, some requests are received with incorrectly filled forms, indicating individuals may have had difficulty understanding how to fill out the form, although MDAR has stated that these errors are normally resolved after receipt (Orth, 2021). One commonwealth employee noted that some individuals are not proficient in using the internet to access the form, and distrust in the government may cause hesitation in providing information for exclusion/opt-out or notification requests. At the time of this report, no other comments have been received from private individuals indicating difficulty with the process to opt out.

Further, individuals have expressed other reasons to be dissatisfied with the opt-out/exclusion program. In particular, individuals with organic home gardens or beehives have expressed dissatisfaction with the possibility of spray drift (i.e., from truck spraying) or emergency aerial spraying that can occur with little notice. Minimum buffer zones to avoid spray drift are provided on the label of pesticide products, which all pesticide applicators are legally required to follow. An MDAR employee stated that districts are generally cautious in spray operations to ensure they do not unintentionally spray an excluded property. At least one MCD reports using GPS technology to ensure buffer zones are provided: in its 2020 report, Plymouth County noted that it does not spray within 300 feet of excluded properties, and spray equipment notifies applicators when they are within 500 feet of an excluded property. Some individuals have expressed concern that despite wanting or requesting spraying, their property may not be sprayed due to being within the buffer zone for a neighbor's opt-out/exclusion request.

Owners and operators of organizations, such as certified or non-certified organic farms, land trusts, and commercial beekeepers, as well as individuals with chemical sensitivities or preexisting conditions, have reported that the opt-out process can be burdensome and confusing and that the requirements to mark the property may pose a real barrier. At a recent meeting of the Task Force (Mosquito Control for the Twenty-First Century Task Force, 2021b), members raised several concerns:

- For organizations owning multiple parcels of land, and for beekeepers with hives on many properties they do not own, submitting opt-out/exclusion requests annually for every parcel and posting markers every 50 feet is time-consuming and burdensome. These organizations as well as farms whose mailing addresses are not the same as the property locations must submit the requests and then provide maps or geographic information system (GIS) files once contacted by MDAR or the district, rather than providing all the information at once with the initial submission.

- Because published maps of spray areas do not show exclusions (for privacy reasons), it is not always clear to persons requesting exclusions that their properties will not be sprayed. One Task Force member voiced concern that excluded properties could be accidentally sprayed despite exclusions.
- Spray drift is of particular concern for beekeepers. Spray drift from truck-based spraying could reach hives even if the hives are not directly sprayed. Notification periods may be too short for beekeepers to access and cover hives ahead of planned spraying.
- Although certified organic farms are not sprayed even in the event of a public health hazard, many farms in Massachusetts follow organic practices but do not have certification, and they could be sprayed if their opt-outs are waived due to a public health hazard.

MCDs and the commonwealth have taken measures to address some of these concerns. Unless otherwise noted, these measures are examples of steps taken by at least one district and it is not known whether all districts use these protocols:

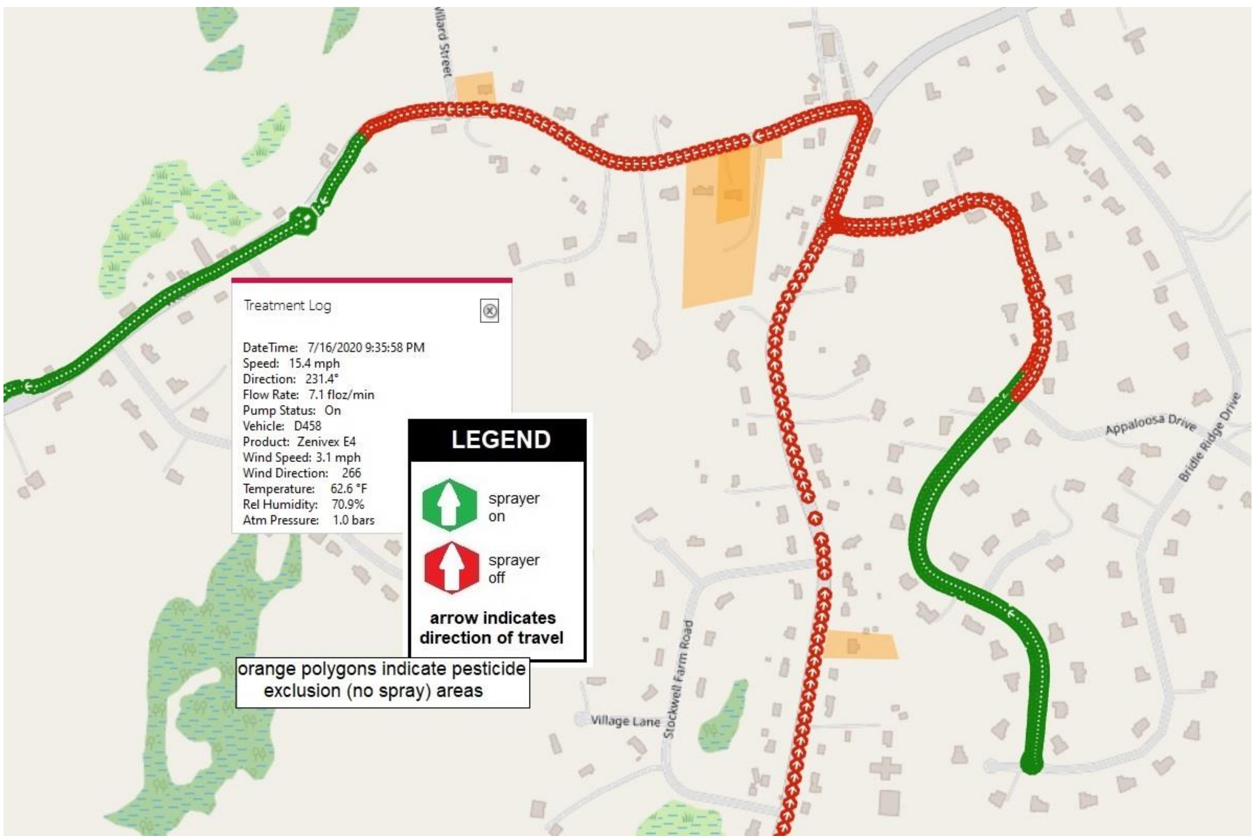
- All MCDs that conduct spraying use GIS mapping together with GPS units, smartphones, or other portable technology, reducing the odds of accidentally spraying an excluded area. One MCD superintendent described the measures they take to ensure excluded properties are not sprayed, which include having technicians drive a route in advance during daylight hours to identify excluded properties, using a GPS system that provides audio and visual notifications when approaching an excluded property, and printing paper records of all exclusions in case of a technological problem.
- Although exact buffer zones are not known for all districts, MCD operations do account for spray drift. Buffer zones can be variable based on weather or can be a fixed distance, and they can be incorporated into GPS systems to notify applicators to turn off spray equipment.
- Districts do not rely on the physical markers to identify excluded properties, and compliance with the marking requirement is low in most districts. Physical markers may serve as a backup in case of technological failure. The requirement for physical markers is required by regulation that was developed before GIS and GPS technologies were readily available for use by MCDs.

4.2 Impact of Exclusions/Opt-Outs on MCD Operations

In some cases, processing exclusion requests can be burdensome for districts to manage. In 2020, six districts each received more than 100 exclusion requests. An automated system managed by MDAR processes web forms submitted by residents. The system then forwards each request to the MCD in which the property is located, if the municipality indicated by the property owner is an MCD member. Each district is then responsible for managing the requests in a database or spreadsheet. Tracking requests can be a burden for the MCDs, but best practices can help minimize this. For example, tools available in most email clients can help districts keep incoming exclusion requests organized. While management may vary across districts, commercial software is available to plan spray routes. Some districts have weather monitors on spray trucks, which can be used to determine the buffer needed for an exclusion. Commercial

GPS software can then give audio and visual notifications to technicians when they need to turn off the sprayer, creating minimal additional effort for applicators.

In some cases, exclusions can impact MCD operations. Plymouth County uses 300 foot buffer zones, with equipment notifying operators when they are within 500 feet of an excluded property. The district received 453 exclusion requests for 2020, and estimated that exclusion of these properties with 300-500 foot buffers resulted in 4,500-19,000 households being impacted. (Plymouth County Mosquito Control Project, 2021). Other districts may use weather information (i.e., wind speed and direction) to calculate necessary buffer distance, often allowing smaller buffer zones than the 300-500 foot standard, reducing the number of impacted properties. For example, this spray map published by the Central Massachusetts Mosquito Control Project, which uses wind conditions to determine buffer zones, shows that the application did not use a buffer at a fixed distance from excluded areas (Central Massachusetts Mosquito Control Project, n.d.). The number of exclusion requests received by most districts is much fewer than the number of requests for service and should therefore be less burdensome than managing spray requests.



Source: Central Massachusetts Mosquito Control Project.

Figure 4-1. Map of spray application in Central Massachusetts Mosquito Control District.

4.3 Feedback on the Municipal Opt-Out Process

4.3.1 Concern Around Creation of a Municipal "Opt-Out" Instead of "Opt-In" Process

The municipal opt-out process is a new process, and several concerns have been commonly reported. One major concern is that municipalities viewed the status quo as an "opt-in" system, while the 2020 act created an opt-out system. This perception appears to be based in the reasoning that municipalities can choose whether or not to participate in an MCD and, depending on the district, may be able to choose which services they receive from that MCD. However, mosquito control activities within municipalities that join an MCD is a different policy structure than mosquito control activities that are authorized and initiated by the SRB.

Some districts offer significant control to member municipalities. For example, Marblehead is part of the Northeast Massachusetts Mosquito Control and Wetlands Management District. In Marblehead, broadcast spraying requires approval from the Board of Health and must show that it will substantially reduce the risk of humans contracting diseases, outweighing the adverse health effects of spraying. Broadcast spraying in Marblehead also requires holding a public meeting, which only a locally acquired case of West Nile virus can trigger. The Northeast Massachusetts Mosquito Control and Wetlands Management District does not perform adulticiding in Marblehead except with Board of Health approval (Northeast Massachusetts Mosquito Control and Wetlands Management District, 2021). However, not all districts are the same in the services they offer or require for members, and municipalities cannot choose which district to join. For example, Pioneer Valley does not perform any mosquito control activities, so municipalities in these districts cannot access mosquito control. The funding structure for all districts except East Middlesex and Pioneer Valley requires municipalities to pay the same amount regardless of actual services received. Therefore most municipalities must pay for all services provided by their district regardless of actual services received if they are members of a district (Pioneer Valley Mosquito Control District, 2021). MDAR reported that some municipalities have attempted to contract for other mosquito control independent of MCDs, but this has generally not been successful.

The opt-out process created by the 2020 act does not change the ability of municipalities to join or choose not to join an MCD. The act creates a new opt-out process allowing municipalities to opt out of spraying specifically conducted by the SRB. Prior to the creation of this opt-out process, municipalities did not have this ability. Some concerns appear to be rooted in a misunderstanding of the 2020 act; the SRB already had authority to conduct spraying in response to a public health hazard, and this authority predates the municipal opt-out process. Prior to the implementation of the municipal opt-out process, municipalities could not be excluded from spraying conducted by the SRB.

4.3.2 Other Concerns with the Municipal Opt-Out Process

At a May 3 public listening session of the Task Force, many individuals, including several individuals affiliated with local government agencies, expressed concern about the municipal opt-out process. In general, these individuals were concerned with the perceived expanded authority the 2020 act grants the SRB to conduct additional emergency activities and with the difficulties municipalities were encountering with the new municipal opt-out process. Commonly expressed opinions and concerns included:

- There was insufficient notice of policy changes, and municipalities would not have time to complete the requirements to opt out. Interested parties who were unaware of the change in process, such as organizations representing lobstermen, also expressed these concerns. A few attendees stated that although their local governments or local residents desired to opt out, there was not enough time for them to do so.
- Developing an alternative plan for mosquito management and completing the opt-out requirements were too difficult or burdensome, particularly for smaller towns and cities.
- There was confusion about whether membership in an MCD was adequate to fulfill the requirement for an alternative mosquito management plan.
- There was a lack of information and evidence, such as evidence of the efficacy of spraying and information on unnamed inert pesticide ingredients, for municipalities to make decisions.
- There was concern about not knowing what the criteria for spraying will be and whether municipal officials will be notified of planned spray events.

In response to concerns around the short time frame, EEA extended the deadline for municipal opt-out to May 28. Many other questions and concerns are related to the newness of the SRB spraying and municipal opt-out process and may not continue to be concerns. However, it is clear that many municipalities, especially smaller municipalities, find the opt-out process burdensome and confusing; do not approve of a perceived expansion of state powers; and have concerns about either the impact of spraying or data gaps regarding efficacy, off-target impacts, and unknown formulation components or contaminants in pesticides. It is worth noting that although the process for municipal opt-out is new, the state has previously conducted spraying without an option for municipalities to opt out.

The questions submitted to EEA and municipal opt-out applications received indicate that some municipalities attempting to opt out do not fully understand the process and requirements. For example, one municipality filled out a residential opt-out/exclusion request form (intended for property owners or tenants) and included it with its application. At least one municipality failed to check the required boxes acknowledging certain conditions. It may be that these municipalities did not understand the requirements of the opt-out process or that they lacked the resources to review and correctly complete the application in the time frame required.

5. WHAT ARE SOME OF THE RISKS AND BENEFITS OF PROVIDING A RANGE OF OPTIONS FOR MOSQUITO CONTROL PESTICIDE USE, INCLUDING OPT-OUT?

Both municipal and individual opt-outs carry certain risks. As has been previously discussed, mosquito control pesticide use has the benefit of reducing the number of mosquitoes. Because mosquitoes travel, individuals or municipalities opting out can impact neighboring areas as mosquitoes move from an untreated area to a treated area. Conversely, areas that are not sprayed because of an opt-out or exclusion may still benefit, as fewer mosquitoes may move into the area from neighboring treated areas. Allowing individual property owners to opt out can create a patchwork of exclusions that can impact plans to spray. In 2014, Bill Mehaffey, Jr., superintendent of the Northeast Massachusetts mosquito district, told *The Boston Globe* that opt-outs complicate the district's plans for spraying and "there are some communities where it doesn't even make sense to spray because so many residents have chosen not to participate" (Wade, 2014).

Another clear case of opt-outs and exclusions impacting operations recently occurred in Michigan. In 2019, Michigan suffered a EEE outbreak. The state announced plans for aerial spraying in several counties, including Kalamazoo County, but the governor did not declare an emergency to allow waiving exclusion requests. According to news reports, more than 3,800 individual property exclusion requests were received from all counties for the spraying (Shamus, 2019). The spraying of Kalamazoo County was cancelled due to the large number of opt-outs in the county, making aerial adulticiding "no longer an effective treatment option for Kalamazoo County," according to County Health Officer James Rutherford (Johnson, 2019). In September 2020, the Michigan Department of Agriculture and Rural Development promulgated a finding of emergency, signed by the governor, that allowed the department to disregard opt-out requests for the next six months (Michigan Department of Agriculture and Rural Development, 2020).

The benefits of providing a range of options for mosquito control are difficult to quantify, but certain benefits can be inferred. One potential benefit of allowing municipalities to opt out of spraying is that more municipalities may join MCDs/mosquito control projects. Some municipalities do not want to pay for or just do not want pesticide spraying. If their local MCDs provide a range of options, including the ability to opt out of spraying, they can join MCDs for the benefits of surveillance, education programs, and other services, without signing up for spraying, although the funding structure in most districts means municipalities pay a set amount to participate in an MCD regardless of services received. For example, the Northeast Massachusetts district does not typically spray in Marblehead, where spraying is not allowed except with approval from the Board of Health. Allowing member municipalities to choose to receive only certain services encourages municipalities to join MCDs, without forcing them to change municipal regulations or receive services local residents do not want.

Providing the option for local residents and property owners to opt out benefits groups such as beekeepers, gardeners, farmers, and sensitive populations, who may want to avoid pesticides. In Massachusetts, certain farms follow organic practices but are not certified; while certified organic farms are not sprayed, these non-certified farms are not covered under that exclusion (Mosquito Control for the Twenty-First Century Task Force, 2021a). There are no exclusions in policy to cover gardens, apiaries, and sensitive individuals, and these groups can avoid pesticide contact by opting out their properties or by signing up for notification of pesticide applications, covering gardens or beehives, and staying indoors. Having options for opt-out could reduce political opposition to wide area pesticide application by allowing concerned individuals to avoid the impacts of spraying.

6. OPTIONS FOR IMPROVING THE EXCLUSION/OPT-OUT PROGRAM AND IMPLEMENTATION

Recommendations in this section are based on feedback received from numerous stakeholders, including the Task Force and members of the public, but they may not reflect all issues faced by all stakeholders. Changes to the individual exclusion process require regulatory changes to 333 CMR 13 by MDAR under authority of M.G.L. c. 132B with approval from the Pesticide Board and following M.G.L. c. 30A as it pertains to regulatory changes. Municipal opt-out and notification requirements are legislative items scheduled to sunset at the end of 2022.

6.1 Improvements to Individual Exclusion/Opt-Out Processes

As of 2020, all seven MCDs that engaged in wide area adulticiding used GIS mapping to mark areas that were not to be sprayed, and all but one (Northeast Massachusetts, which reported unanticipated information technology issues) used GPS equipment to ensure the spraying did not occur in excluded areas. Buffer zones vary across districts (i.e., some districts have consistent buffer distances, while others vary buffer distance based on weather conditions) but can be incorporated into GIS or GPS technologies. Although management may vary among districts, exclusion requests can be easily managed with available software incorporating GIS information. One district superintendent said in an interview that technicians in their district are encouraged to travel their routes ahead of time in daylight to see where exclusions are located, although the GPS software used by the district provides audio and visual alerts to the technician. This district did not consider managing exclusions to be burdensome and does not rely on the posting of "no spray" markers to identify excluded areas, although the signage serves as a backup in case of technological failure. In fact, the superintendent reported that the majority of excluded properties in the district already do not post the required signage. Mapping exclusions/opt-outs using GIS technology and integrating them into GPS technology used for spraying, which has recently become standard practice in most districts, could alleviate concerns around accidental spraying of excluded areas, spray drift, and opt-out markers. This should be better communicated to individuals opting out.

In many cases, particularly those of land trusts, organic farms, and conservation organizations, organizations report submitting the same requests every year. This can be time- and cost-intensive for these organizations. A more efficient option for submitting opt-out requests may be possible, especially when one organization owns many parcels and when supporting information such as maps is needed. The requirement to resubmit requests annually was added because exclusions accumulated; for example, when residents moved, they rarely removed the exclusion from their former property. This resulted in a buildup of exclusion requests, significant extra work for MCDs if they tried to confirm residents still wanted to be excluded, and residents who may not have wanted to be excluded being excluded because of a request submitted by a former resident of the property. There is a clear tradeoff between maintaining an up-to-date list of residents who want exclusions and making the process efficient for large organizations who have to resubmit many parcels annually. A middle ground may exist, such as allowing individuals or organizations to automatically renew the prior year's submissions without resubmitting all information for each parcel or sending reminder notifications to residents who submitted requests the prior year.

6.2 Improvements to the Municipal Opt-Out Process

Mosquito control issues in Massachusetts, with its relatively mild climate but high incidence of EEE, are unique. In recent years, Massachusetts has had more human cases of EEE than other U.S. states (Centers for Disease Control and Prevention, 2020a). Other states may not serve as good models regarding the use of opt-outs and exclusions to balance mosquito management with other health, environmental, and economic concerns. The commonwealth can learn from its own experiences and the experiences of citizens. Experience has shown that although many residents desire and even request mosquito control activities, many other residents do not want to be subjected to pesticide spraying, for a variety of reasons. These residents may take advantage of residential opt-outs and exclusion requests. The structure of the opt-out process in Massachusetts allows residents who do not want to be subject to spraying to opt out, while maintaining the ability of other residents to receive these services and allowing the state to conduct emergency operations unhindered by individual property opt-outs. However, due to measures to prevent spray drift and the mobile nature of mosquitoes, exclusions and opt-outs will always have effects beyond the individual or municipality desiring the exclusion/opt-out.

6.3 Communication with the Public and Municipalities

Individuals and municipalities show clear misunderstandings of the structure and operations of mosquito control in Massachusetts. Examples include individuals and municipalities making errors in exclusion and opt-out forms; individuals outside of MCDs requestions exclusions/opt-outs from pesticide applications (which do not generally occur outside MCDs); and public comments and opt-out requests submitted by municipalities in areas where EEE and WNV activity is low and are therefore unlikely to be sprayed by SRB (and have not been sprayed by SRB in the past). While some misunderstandings are inevitable, improved communication could reduce some of these misunderstandings. Possible areas for improved communication include providing additional information and transparency around the criteria for spraying, policies for buffer zones, and frequency of past spray operations by MCDs and the SRB in each municipality. To specifically reduce misunderstandings of the individual opt-out/exclusion process, this information could be published with the opt-out/exclusion request form, such as in the associated FAQ document.

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Report 4: Chemical Composition and Toxicity of Pesticides Used in Ground and Aerial Spraying in Massachusetts

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1. EXECUTIVE SUMMARY

ERG was tasked with providing the Task Force with information on the chemical composition and toxicity (human health and ecological) of pesticides used by mosquito control districts and projects (MCDs) and the State Reclamation and Mosquito Control Board (SRB) in Massachusetts, including the amounts used. Information was also requested on per- and polyfluoroalkyl substances (PFAS) in pesticides, pesticide resistance, and considerations related to pesticide efficacy and pesticide toxicity. Accordingly, ERG interviewed experts, conducted literature reviews, and evaluated U.S. Environmental Protection Agency (EPA) registration documentation for pesticides.

Key takeaways include:

- All pesticides used in the United States must be registered under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). Registrants must provide EPA with information on the requested action, the identity and quantity of all chemicals in the product, data on potential risks to human health and the environment, proof that the product manufacturing process is reliable, and labeling (including directions for use, contents, and appropriate warnings).
- Although EPA receives the full list of all ingredients in pesticide products, this information is not available to the public due to concerns related to trade secrets.
- Before pesticides are used in Massachusetts, they must first be registered with not only EPA but the Massachusetts Department of Agricultural Resources (MDAR).
- MDAR only receives information on pesticides' active ingredients, not the full list of pesticide ingredients (which would also include inert compounds).
- Pesticides used in the United States that target mosquitoes can fall into the category of adulticides, larvicides, pupicides, or ovicides.
- Massachusetts MCDs use bacterial insecticides, spinosyns, methoprene, and mineral oils as larvicides.
- Adulticides used by Massachusetts MCDs and the SRB are currently all pyrethroid insecticides.
- Most active ingredients evaluated have properties that indicate a high potential for bioaccumulation. The main toxicological concern for all the products used in Massachusetts is ecological, with pyrethroids demonstrating the highest acute ecological toxicity. The specific toxicity is related to effects in the aquatic environment.
- Per- and polyfluoroalkyl substances (PFAS) have been detected in pesticide products used in Massachusetts for mosquito control. EPA identified the source of the contamination to be from the containers in which the product is packaged. However, there is some debate as to whether other pesticides contain PFAS through the products ingredients. EPA and EEA are continuing to work on this ongoing issue.

- Pesticide resistance has not been widely studied in the mosquitoes of concern in Massachusetts. However, two species of concern, Culex pipiens and Aedes vexans, have shown resistance to pyrethroid insecticides—the type of adulticide used by MCDs. To reduce pesticide resistance, MCDs may rotate insecticides from different mode of action (MoA) groups, minimize chemical pesticide usage by using non-chemical integrated pest management strategies, and monitor local mosquito populations for resistance.

2. INTRODUCTION

This report was developed in response to the Task Force's request for information on the chemical composition of pesticides used in ground and aerial spraying throughout the United States and in Massachusetts. The scope outlined by the request for responses stated "Describe the chemical composition of pesticides used in ground and aerial spraying throughout the United States and in Massachusetts, including identification of per- and polyfluoroalkyl substances, and including frequency of use in aerial and ground-based spraying applications.

- Summarize best-available data on toxicity of ingredients used in spraying, including on bio-accumulative tendencies, ecological persistence, trophic transfer, and use of synergists. Report shall summarize best-available data on insecticide resistance to the active ingredients.

- Describe the efficacy of the primary pesticide ingredients in controlling nuisance mosquito populations, as it compares to the risk profile of the pesticides on human and ecological health.

- If ingredients are non-identifiable, report shall describe any barriers to identification of chemical composition."

This report is organized as follows:

- Section 3 outlines the basic approach to registering pesticides in the United States and explains the chemical composition of pesticides used to control mosquitoes in the United States.

- Section 4 provides information on the products used by the Commonwealth since 2009, with further information on the amount of each product that has been used since 2016.

- Section 5 provides the methods and results of the evaluation of the pesticides' human health and ecological toxicity.

- Section 6 details the issue of PFAS in pesticides.

- Section 7 summarizes current research on pesticide resistance.

- Section 8 comments on the tradeoffs between pesticide toxicity and efficacy.

3. OVERVIEW OF PESTICIDES USED TO CONTROL MOSQUITOES IN THE UNITED STATES AND MASSACHUSETTS

EPA has the authority to register and regulate pesticides under FIFRA. To register a pesticide with EPA, a company must first submit an application containing information on the requested action; the identity and quantity of all chemicals in the product; data on potential hazards to human health and the environment; proof that the product manufacturing process is reliable; and labeling, including directions for use, contents, and appropriate warnings (USEPA, 2021a). The data that the registrant submits are the toxicity and environmental fate studies that need to be conducted according to strict guidelines. The study results are reviewed by EPA and, if determined of acceptable quality, used by EPA in risk assessments for human health and ecological risks. Note that while EPA receives the full list of inert ingredients in pesticides, this information is not often available to the public due to concerns about protecting trade secrets.

> **Some Terms Used in This Report**
>
> - **Pesticides** are chemicals used to kill a wide range of "pests": insects, snails, weeds, plant diseases, weeds, etc.
> - **Insecticides** are a subset of pesticides that kill insects. Insecticides registered for use against mosquitoes in the United States are used to control both nuisance and vector-bearing mosquitoes.
> - **Larvicides** are insecticides that target the larval stage of mosquitoes.
> - **Adulticides** are insecticides that are designed to kill adult mosquitoes.

EPA reviews this information along with peer-reviewed scientific data to develop comprehensive environmental and human health risk assessments for the pesticide product (USEPA, 2021a). These risk assessments assess the potential for harm to humans, wildlife, fish, and plants, including endangered species and non-target organisms, and the potential for surface water or groundwater contamination from leaching, runoff, and spray drift (USEPA, 2021a). Risk is a product of hazard (i.e., toxicity) and exposure. Therefore, these risk assessments encompass comprehensive toxicity evaluations, not just of manufacturer submitted data but also data from the peer reviewed literature. This is done to identify the exposure levels at which adverse effects will occur in both humans and the environment. In addition, EPA uses complex fate and transport computer models to estimate, based on defined application procedures, how much of the pesticide will reach a given organism and the exposure timeframe. Combining this information EPA evaluates if the application procedures will result in exposures above or below levels of concern. If results indicate exposures may be above levels of concern EPA may work with the manufacturer to modify application procedures to minimize the risk before full approval. EPA also reviews the product's label which has the product's application protocols. EPA must review all label language before the product can be used or sold (USEPA, 2021a). If a pesticide is used in a way that keeps the risk of negative health effects in humans or the environment low despite the toxic nature of the pesticide (due to minimal exposure), EPA may approve the pesticide for that use. Note that EPA only approves a pesticide for specific uses, which are described on the label. To use a pesticide in a way that is not described on the label is a violation of federal law.

There are certain situations in which pesticides do not undergo the typical registration review process. For example, FIFRA Section 3(c)(7) empowers EPA to conditionally register pesticides without reviewing all of the health and safety information because an identical or similar product is already registered (USEPA, N.D.-a). Additionally FIFRA Section 18 allows emergency exemptions for unregulated pesticides to be used during a public health emergency (USEPA, 2021j).

The practice of larviciding includes applying insecticides in water where mosquitoes breed. These products are applied by various means: by hand, with a backpack sprayer, from all-terrain vehicles or trucks, and by aircraft. The most used larvicides are microbial, specifically various species of *Bacillus thuringiensis israelensis* (Bti) and *Bacillus sphaericus* (Bs) that are toxic to larval mosquitoes. Another type of larvicide, neonicotinic insecticides, attacks the nicotinic receptor in mosquito brains, resulting in larval death. Other compounds that are registered with EPA and used for larviciding include methoprene, which inhibits the growth of the mosquito by mimicking a hormone that assists in mosquito growth, and mineral oil, which creates a film on the water surface and prevents larvae from getting out of the water to breathe (California Department of Health Services, 2005b; Telford, 2009).

Adulticide chemicals are most often applied through ultralow volume (ULV) spraying. The goal of ULV is to allow the compound to interact with an adult mosquito in flight, ultimately resulting in its death. ULV spraying releases a fine mist into the air, which is carried by air currents and kills mosquitoes that come into contact with the airborne material. It allows for a small amount of liquid to be used in a given area (California Department of Health Services, 2005a). ULV application should only be conducted when environmental conditions are appropriate: the ULV spray must move properly through the air to come into contact with the flying adult mosquitoes. Liquid adulticides may also be sprayed on vegetation or on buildings and allowed to dry. This approach, termed a "barrier treatment," kills mosquitoes in locations where they are most likely to land. According to the Centers for Disease Control and Prevention, this type of spraying is most often used by pest control professionals rather than local governments or MCDs (CDC, 2020) and tend to be more residual. Table 3-1 summarizes categories of adulticide compounds used in the United States.

Table 3-1. Adulticide Pesticide Categories Used in the United States

Pesticide Category	Description
Pyrethrin	Compound extracted from chrysanthemum flowers that can kill insects by altering nerve function. These compounds do break down quickly in the environment.
Pyrethroids	Synthetic pyrethrin-like compounds that have been engineered to not break down as easily in the environment as pyrethrin. Pyrethroids kill mosquitoes by altering nerve function. Example active ingredients include d-phenothrin and permethrin. Pyrethroids are often used in conjunction with a synergist, such as piperonyl butoxide (PBO), which enhances the effect of the pesticides by inhibiting the enzyme that breaks down the pesticides.
Organophosphates	Synthetic compounds designed to kill mosquitoes by altering nerve function. Major organophosphate ingredients used in the United States include malathion and naled.

4. Pesticides Used for Mosquito Control in Massachusetts by MCDs and the SRB

Before a pesticide is used in Massachusetts, it must be registered with MDAR as well as EPA. For product registrations that include active ingredients that that are already in products registered in Massachusetts, MDAR staff conduct a technical review of the products. A technical review includes:

- Assess adherence to the labeling requirements as outlined in EPA's Pesticide Label Manual. Particular attention to primary label content sections requirements, missing label elements, etc. In case of a distributor product label, evaluate consistency with the primary registrant's product label.
- Determine if the product contains a new active ingredient that has never before been registered in MA. If so, product is pulled and placed in queue for special review. Special reviews of new active ingredients are only conducted for conventional pesticides, not for antimicrobials.
- Determine if active ingredient is included on the groundwater protection list and whether the product label indicates a wide area use pattern, such as agricultural uses or turf uses. If so, reclassification of use is considered. If not already federally restricted, the product will be registered as a state-restricted use product.
- Consideration of other active ingredients to be reclassified based on previous actions by the Subcommittee. Currently, 2,4-D (an herbicide) products containing more than 20% are reclassified to state restricted use.
- Consideration of new use pattern(s) of active ingredients that may be of concern for unreasonable adverse effects to the environment and may require evaluation by the Subcommittee.

Special reviews are conducted when there is an active ingredient in a product that has not been registered before. MDAR reviews information submitted to EPA and provides an overview of EPA's Final Registration Decision to the Pesticide Board Subcommittee.

MCDs choose which registered pesticides to use for routine applications in their districts. MCDs are expected to ensure that the products are registered by both EPA and MDAR and that they use the products according to label directions and all applicable laws and regulations ERG evaluated which insecticides have been used by MCDs and the SRB from 2009 to 2020. During this time frame, the MCDs used 44 different pesticide products and the SRB used one pesticide (Anvil 10+10).

To evaluate more recent information on pesticide use, ERG also extracted data from MCD and SRB reports on the quantity of each pesticide used by the MCDs and the SRB from 2016 to 2020. The most commonly used pesticides since 2016 are summarized in Table 4-1.

Table 4-1. Most Used Pesticides by MCDs, 2016–2020

Product	Pesticide Category; Active Ingredient	Total Amount, 2016–2020[a]
Vectobac 12AS	Larvicide; Bti	180,799 pounds
Vectobac GR	Larvicide; Bti	157,056 pounds
Altosid Pellets	Larvicide; methoprene	114,782 pounds

Product	Pesticide Category; Active Ingredient	Total Amount, 2016–2020[a]
Zenivex E4	Adulticide; pyrethroid	96,735 pounds
Anvil 10+10	Adulticide; pyrethroid	85,093 pounds

Source: MCD annual reports, 2016–2020.

[a] Data were provided in a variety of units and were translated to pounds (the most common unit) for comparison. The method used is summarized in Appendix A.

When aerial spraying is determined to be necessary due to the risk of an Eastern equine encephalitis (EEE) outbreak, the Commonwealth convenes state agencies including MDAR, the Department of Environmental Protection (DEP), the Department of Public Health (DPH), and the Department of Fish and Game (both the Division of Fisheries and Wildlife (DFW) and the Division of Marine and Fisheries (DMF)) to review and approve an adulticide for spraying, considering both public health and environmental impacts (Bharel & Cranston, 2020a). Since 2006, the Commonwealth has chosen Anvil 10+10 for use in these aerial spraying events. The SRB, operating within MDAR, works with the MCDs and DPH to implement these spraying events (MDAR, 2010). Between 2009 and 2020, the SRB requested spraying due to EEE outbreaks in four years: 2010, 2012, 2019, and 2020. The table below summarizes the amount of Anvil 10+10 used in these spraying events, along with the area sprayed and the counties included in the spray areas.

Table 4-2. Aerial Spraying Due to an EEE Outbreak, 2009–2020

Year	Number of Spray Events	Acres Sprayed[a]	Total Amount Anvil 10+10 Sprayed (Gallons)	Counties Included in Spray Area[b]
2010	1	288,143	1,395	Bristol, Plymouth
2012	2	494,000	1,785	Bristol, Plymouth
2019	6	2,048,865	9,939	Bristol, Hampden, Hampshire, Middlesex, Norfolk, Plymouth, Worcester
2020	1	178,823	985	Bristol, Plymouth
Total	**10**	**3,009,831**	**14,104**	

[a] If more than one spray event occurred in a year, the number of acres may include the same area of land being sprayed on more than one occasion.

[b] Inclusion of a county in this table does not imply the whole county was sprayed, only that at least one town in a county was sprayed.

4.1 Larvicides

Since 2009, MCDs have used six different categories of larvicide:

- Bacterial insecticides
- Spinosyns
- Methoprene (and s-methoprene)
- Mineral oil
- Ethoxylated alcohols

- Organophosphates

However, the commonwealth has phased out the use of both the ethoxylated alcohols and the organophosphate larvicide. In 2009, the Commonwealth reported the use of 5% Skeeter Abate, which had the active ingredient temephos (CASRN 3383-96-8), the only organophosphate larvicide on the market in the United States at that time. In 2011, though, EPA issued a cancellation order for temephos (USEPA, 2011). No reports of using temephos in Massachusetts were found after 2009. Therefore, it is not discussed further in this report. Additionally, the Commonwealth also previously used larvicidal products that contained or were 100 percent ethoxylated alcohol (Agnique MMF, Agnique MMF PAK). These products were last reported used by any MCD in 2014. EPA cancelled the registration of these products in 2016 (USEPA, N.D.-b).

The table below lists all the compounds that were used by MCDs or the SRB in the time frame of ERG's analysis (2009–2020), but have been discontinued in more recent years.

Table 4-3. Larvicides Reported as Previously Used by Massachusetts but Discontinued

Product	Larvicide Category	Last Year of Reported Use
Agnique MMF	Ethoxylated alcohol	2014
Agnique MMF PAK	Ethoxylated alcohol	2014
Teknar G	Bacterial insecticide	2009
Teknar HPD	Bacterial insecticide	2014
5% Skeeter Abate	Organophosphate	2010

Source: MCD annual reports, 2009–2015.

The subsections below describe the MoAs of the larvicide categories, along with the amounts of pesticides used by MCDs.

4.1.1 Bacterial Insecticides

Bacterial insecticides rely on naturally occurring rod-shaped soil bacteria to kill mosquito larvae (USEPA, 2015a; Washington State Department of Health, N.D.). These insecticides contain the bacterial active ingredient and other inert substances. The main active ingredients that fall into this category are Bti and Bs and subspecies of these microbes.

Both Bti and Bs kill mosquito larvae by releasing toxins in the larval mosquito's gut that cause the mosquito to stop eating and die (California Department of Health Services, 2005a; IRAC, 2020). Specifically, as the bacteria sporulate, they produce inclusion bodies that are toxic to mosquito larvae. However, they are not toxic to mosquito pupae or adults because they need an alkaline environment—unique to the larval mosquito—to produce the toxic compound (California Department of Health Services, 2005a; Telford, 2009). The bacterial insecticide products used by MCDs, and the amounts of those products used, are presented in Table 4-4.

Table 4-4. Overview of Bacterial Insecticides Used in the Commonwealth of Massachusetts

Chemical Name	EPA Reg. #	Active Ingredient (% of Product)	Listed Inert Ingredients (% of Product)	MCD That Reported Use	Amount Applied (Pounds)[a]					
					2016	2017	2018	2019	2020	Total
AquaBac G	62637-3	Bti strain BMP 144 (2.86%)	None listed	Cape Cod, Central Mass., Nantucket	1,947	903	11,276	8,473	12,439	**35,038**
AquaBac XT	62637-1	Bti strain BMP 144 (8%)	None listed	Bristol, Cape Cod	2,015	3,476	2,544	1,114	—	**9,148**
FourStar Bti briquets	83362-2-89549	Bti (7%)	Plaster of paris (70–80%)	Cape Cod	5	—	—	—	—	**5**
FourStar Bti CRG	85685-4	Bti strain BMP 144 (10%)	4-aminobenzoic acid (0.2%), crystalline silica—quartz (69.25%)	Central Mass., Norfolk, Northeast	907	545	733	1,687	1,770	**5,642**
FourStar CRG	85685-2	Bs 2362 serotype H5a5b, strain AML614 (9%), Bti strain BMP 144 (1%)	4-aminobenzoic acid (0.3%), crystalline silica—quartz (68.79%)	Bristol, Central Mass.	3,759	3,537	3,059	4,029	4,240	**18,624**
FourStar WSP (FourStar MBG)	85685-3	Bti strain BMP 144 (3%), Bs 2362, serotype H5a5b, strain AML614 (3%)	Crystalline silica—quartz (70–90%)	Northeast, Central Mass., Plymouth	—	—	—	463	170	**633**
FourStar microbial briquets	83362-3	Bs 2362 serotype H5a5b, strain AML614 (6%), Bti strain BMP 144 (1%)	Plaster of paris (60–80%)	Berkshire, Central Mass., East Middlesex, Nantucket, Norfolk, Northampton, Northeast, Plymouth, Suffolk	1,596	587	599	1,131	665	**4,578**
Spheratax WSP	84268-2	Bs 2362 (4.75–5.25%)	None listed	Bristol, Cape Cod, East Middlesex, Plymouth, Suffolk	298	866	337	12	11	**1,524**

Chemical Name	EPA Reg. #	Active Ingredient (% of Product)	Listed Inert Ingredients (% of Product)	MCD That Reported Use	Amount Applied (Pounds)[a]					
					2016	2017	2018	2019	2020	Total
Summit briquets	6218-47	Bti strain BMP 144 solids, spores, and insecticidal toxins (10.31%)	None listed	Plymouth	48	101	149	134	90	**522**
Teknar G	70051-73, 73049-403	Bti strain SA3A (1.7%)	None listed	Northeast	No reported use since 2009					
Teknar HPD	70051-51	Bti strain SA3A (1.6%)	None listed	Suffolk	No reported use since 2014					
VectoBac 12AS	73049-38 275-102	Bti (1.2%)	None listed	Bristol, Cape Cod, East Middlesex, Norfolk, Northeast, Plymouth, Suffolk	42,929	33,970	28,061	40,416	35,424	**180,799**
VectoBac CG	73049-19	Bti (4.95%)	None listed	Berkshire, Northeast, Plymouth	8	—	—	—	—	**8**
VectoBac G (VectoBac GS)	73049-10, 275-50	Bti (2.8%)	None listed	Bristol, Berkshire, Cape Cod, Central Mass., East Middlesex, Nantucket, Norfolk, Northeast, Plymouth, Suffolk	10,000	9,800	—	—	—	**19,800**
Vectobac GR	73049-486	Bti (2.8%)	None listed	Norfolk, Suffolk	42,320	44,476	24,800	23,340	22,120	**157,056**
Vectolex WDG	73049-57	Bs 2362, ABTS 1743 (51.2%)	None listed	Bristol, Northeast	—	4.7	31.6	—	—	**36**
Vectolex WSP	73049-20	Bs 2362 (7.5%)	None listed	Bristol, Berkshire, Cape Cod, Central Mass., East Middlesex, Nantucket, Norfolk, Northeast, Plymouth, Suffolk	2,767	1,890	4,988	5,519	4,701	**19,865**

Chemical Name	EPA Reg. #	Active Ingredient (% of Product)	Listed Inert Ingredients (% of Product)	MCD That Reported Use	Amount Applied (Pounds)[a]					
					2016	2017	2018	2019	2020	Total
VectoMax WSP (VectoMax FG)	73049-429	Bti (4.5%), Bs 2362 (2.7%)	None listed	Bristol, Berkshire, Cape Cod, East Middlesex, Northeast, Plymouth	514	680	714	823	1,805	**4,536**

Source: MCD annual reports, 2016–2020.
— = data not available.
[a] Data were provided in a variety of units and were translated to pounds (the most common unit used) for comparison. The method used is summarized in Appendix A.

4.1.2 Spinosyns

Spinosyns act as pesticides by modulating the nicotinic acetylcholine receptor in an insect's brain. The active ingredient in the spinosyn pesticides used in Massachusetts is Spinosad. Spinosad is derived from fermentation of a culture of a bacterial organism called *Saccharopolyspora spinosa*. Spinosad is made of two related active ingredients: Spinosad factor A (about 85 percent of the active ingredient) and Spinosad factor D (about 15 percent of the active ingredient). Spinosad is registered to control "lepidopteran pests, Colorado potato beetles, dipteran leafminers, fleas, fruit flies, house flies, fire ants, mosquito larvae, sawfly larvae, stable flies, and thrips…termites and certified for use in organic agricultural production" (USEPA, 2018c). In 2012, Spinosad represented only 2 percent of the pesticide market for mosquito control in the United States (USEPA, 2018c).

The products used by the MCDs that contain Spinosad are summarized in Table 4-5.

Table 4-5. Quantity of Spinosyn Insecticides Used in Massachusetts, 2016–2020

Chemical Name	EPA Reg. #	Active Ingredient (% of Product)	Listed Inert Ingredients (% of Product)	MCD That Reported Use	Amount Applied (Pounds)[a]					
					2016	2017	2018	2019	2020	Total
Natular DT	8329-602	Spinosad (7.5%)	Anhydrous citric acid (<5%)	Northeast	—	—	—	3	—	**3**
Natular G	8329-80	Spinosad (0.5%)	Granulated corncob (>95%)	Central Mass.	6	118	26	169	19,567	**19,886**
Natular G30	8329-83	Spinosad (2.5%)	Sand (quartz, aluminum oxide, calcium oxide, titanium oxide) (68%)	Berkshire, Central Mass.	195	10.5	110	518	5,803	**6,637**
Natular XRT	8329-84	Spinosad (6.25%)	None listed	Bristol, Norfolk	2	—	—	—	—	**2**
Natular T30	8329-85	Spinosad (8.33%)	None listed	East Middlesex, Norfolk	—	—	—	5	—	**5**
Natular G30 WSP	8329-91	Spinosad (2.5%)	Quartz, aluminum oxide, calcium oxide, titanium oxide (68%)	Central Mass., Norfolk	—	—	—	1	43	**44**

Source: MCD annual reports, 2016–2020.
— = data not available.
[a] Data were provided in a variety of units and were translated to pounds (the most common unit used) for comparison. The method used is summarized in Appendix A.

4.1.3 Methoprene (CASRN: 40596-69-8) and S-Methoprene (CASRN: 65733-16-6)

Methoprene is a larvicide that works by mimicking juvenile hormones in mosquitoes. This prevents the larvae from transitioning to adulthood (IRAC, 2020). The methoprene-containing products used in Massachusetts from 2016 to 2020 are summarized in Table 4-6.

Table 4-6. Quantity of Methoprene Insecticides Used in Massachusetts, 2016–2020

Chemical Name	EPA Reg. #	Active Ingredient (% of Product)	Listed Inert Ingredients (% of Product)	MCD That Reported Use	Amount Applied (Pounds)[a]					
					2016	2017	2018	2019	2020	Total
Altosid briquets	2724-375	s-methoprene (8.62%)	None listed	Cape Cod, Norfolk	—	22	24	0.2	4	**50**
Altosid XR	2724-421	s-methoprene (2.1%)	None listed	Bristol, Central Mass., East Middlesex, Norfolk, Northeast, Plymouth	527	353	289	528	784	**2,481**
Altosid pellets	2724-448	s-methoprene (4.25%)	Plaster of paris (69.16%), crystalline silica—quartz (0.7%), activated carbon (9.26%)	Bristol, Berkshire, Cape Cod, Central Mass., East Middlesex, Norfolk, Northeast, Plymouth, Suffolk	45,606	45,920	3,021	2,744	17,491	**114,782**
Altosid Pro-G	2724-451	s-methoprene (1.5%)	Crystalline silica—quartz (90.6%)	Norfolk	—	—	3	—	—	**3**
MetaLarv SPT	73049-475	s-methoprene (4.25%)	None listed	Norfolk	—	—	—	—	160	**160**
Altosid P35	89459-95	s-methoprene (4.25%)	Amorphous, precipitated, and gel silica (5.4–6.3%), calcium(II) sulfate, dihydrate (1:1:2) (67.9–71.5%)	Bristol, East Middlesex, Plymouth	—	—	—	—	4,095	**4,095**

Source: MCD annual reports, 2016–2020.

— = data not available.

[a] Data were provided in a variety of units and were translated to pounds (the most common unit used) for comparison. The method used is summarized in Appendix A.

4.1.4 Mineral Oil (CASRN: 8012-95-1) and White Mineral Oil (8042-47-5)

Mineral oils act as a larvicide by reducing the surface tension of the water, making it difficult for mosquito larvae, pupae, and emerging adult mosquitoes to attach to the surface of the water and causing them to drown. The products are most effective for pupae and emerging adult mosquitoes, which interact with the water surface and the mineral oil (Northeast Massachusetts Mosquito Control and Wetlands Management District, n.d.). The mineral-oil-containing products Massachusetts used from 2016 to 2020 are summarized in Table 4-7.

Table 4-7. Quantity of Mineral-Oil-Containing Insecticides Used in Massachusetts, 2016–2020

Chemical Name	EPA Reg. #	Active Ingredient (% of Product)	Listed Inert Ingredients (% of Product)	MCD that Reported Use	Amount Applied (Pounds)[a]					
					2016	2017	2018	2019	2020	Total
CocoBear oil	8329-93	White mineral oil (10%)	None listed	Cape Cod, Central Mass., Plymouth	19	80	25	69	54	**247**
BVA2 oil	70589-1	Mineral oil (includes paraffin oil) (9.7%)	Base oil may be a mixture of the following (>95%): heavy paraffin hydrotreated distillate, light paraffin hydrotreated distillate, hydrotreated neutral oil, white mineral oil	Cape Cod, Central Mass., Plymouth	6,217	5,811	4,220	5,842	5,242	**27,331**

Source: MCD annual reports, 2016–2020.

[a] Data were provided in a variety of units and were translated to pounds (the most common unit used) comparison. The method used is summarized in Appendix A.

4.2 Adulticides

Since 2009, MCDs and the SRB have only reported using pyrethroid compounds for adulticiding. No organophosphate compounds have been used, so this report discusses only pyrethroids. It has been estimated that pyrethroids account for approximately 25 percent of the global market for insecticides (ATSDR, 2018). Pyrethroids can be divided into type I and type II compounds: type II compounds, also referred to as "CS" pyrethroids, contain a cyano-group, whereas Type I compounds do not. Both Type I and Type II pyrethroids act as insecticides through the same MoA (IRAC, 2020). As described by IRAC (2020), pyrethroids operate by "keeping sodium channels open, causing hyperexcitation, in some cases, nerve blockage." That is, insects exposed to pyrethroid-based insecticides experience an alteration of nerve function that causes paralysis and eventually death. A summary of the adulticide products used by MCDs and the SRB to control mosquitoes in Massachusetts is presented in Table 4-8.

Table 4-8. Pyrethroid-Containing Products Used by the Commonwealth of Massachusetts Since 2016

Product	EPA Registration Number	Pyrethroid (% of Product)	Other Listed Ingredients (% of Product)	MCD That Reported Use	Amount Used (Gallons)					
					2016	2017	2018	2019	2020	Total
Anvil 10+10[a]	1021-1688-8329	d-phenothrin (10%)	PBO (10%), petroleum distillates (10%), mineral oil (50–75%)	Bristol, Berkshire, Central Mass., East Middlesex, Norfolk, Northeast, Suffolk	140	125	203	10,004	1,027	**11,499**
Duet[a]	1021-1795-8329	d-phenothrin (5%), prallethrin (1%)	PBO (5%), petroleum distillates, hydrotreated light (10–20%), white mineral oil (50–75%)	Bristol, Berkshire	564	738	851	1,928	1,419	**5,500**
Flit 10EC	8329-67	Permethrin (10%)	Petroleum distillates, hydrotreated light (82%), nonylphenol ethoxylate (4.4%)	Berkshire, Plymouth, Suffolk	3	3	7	—	—	**13**
Mavrik (Mavrik Perimeter)	2724-478	Fluvalinate (22.3%)	Ethylene glycol (8%), Sodium alkylnaphthalenesulfonate, formaldehyde condensate (2.2%)	Bristol, Berkshire, Central Mass., East Middlesex, Norfolk, Plymouth, Suffolk	—	0.008 (1 oz)	0.008 (1 oz)	0.26 (33 oz)	0.05 (7 oz)	**0.326**
Suspend Polyzone	432-1514	Deltamethrin (4.75%)	None listed	Northeast	—	—	—	—	2	**2**
Suspend SC	432-763	Deltamethrin (4.75%)	None listed	East Middlesex, Northeast, Plymouth, Suffolk	75	43	102	7	—	**227**
Zenivex E20	2724-791	Etofenprox[b] (20%)	Isopropyl myristate (79.38%)	Central Mass.	243	247	—	—	—	**490**
Zenivex E4	2724-807	Etofenprox[b] (4%)	Isopropyl myristate (35%)	Bristol, Cape Cod, Central Mass., Norfolk, Northeast	2,516	2,331	3,452	3,150	1,449	**12,898**

Source: MCD annual reports, 2016–2020

[a] Product also reports containing PBO, a synergist.

[b] Etofenprox is a pyrethroid-like ether compound (as opposed to an ester compound, which is typical for pyrethroids).

5. TOXICITY EVALUATION FOR PESTICIDES USED BY MCDS AND THE SRB IN MASSACHUSETTS

The following sections provide toxicity data on the pesticide products used in the Massachusetts. Human health and ecological toxicity data are included for active ingredients. Although pesticide formulations also include inert ingredients, their toxicity is not evaluated in this section. See Section 5.5 for a brief discussion of inert ingredients. Given the magnitude of data on many of the active compounds, ERG mainly focused on EPA human and ecological hazard assessments conducted for registration of these compounds. In most instances, the data were very timely (published between 2015 and 2020). However, ERG also reviewed other data (e.g., literature reviews, toxicity databases) to cover the full spectrum of potential hazards associated with the active ingredients.

5.1 Method to Collect Data on Human Health Toxicity

For each chemical, ERG extracted a range of data from EPA hazard assessments and registration eligibility decision documents. For human-health-related toxicity, ERG collected information on:

- Acute toxicity classifications
- Carcinogenicity classifications
- Endocrine disruption potential

If available in EPA's hazard assessments, information was also extracted on sub-chronic and chronic duration toxicity for human health. Scans of the literature were also conducted to evaluate additional endpoints of potential concern for inclusion in this report. For quality assurance, ERG ran each of the CASRNs through a database, Pharos Project, that automates the process of comparing chemical CASRNs to more 40 authoritative lists to aggregate toxicity concerns highlighted by governments across the world (Healthy Building Network, 2021). If any government source had indicated concern for an endpoint not included in ERG's analysis, these data were also extracted, as was any information on the compounds being included on any list of concern by government agencies.[16]

EPA classifies pesticides into six categories for acute toxicity based on a set of standard toxicological evaluations, often conducted in mice or rats, evaluating the dose (or concentration) of a compound that results in the death of 50 percent of organisms tested. These are referred to as the LD_{50} (or LC_{50}). The higher the LD_{50}/LC_{50}, the less acutely toxic a compound is considered. In addition, the potential for the compound to cause skin or eye irritation and dermal sensitization is also routinely evaluated for each active pesticide ingredient. EPA's classification scheme is presented in Table 5-1.

[16] For some endpoints, Pharos also indicates hazard potential as determined by various NGOs. We did not include this data in this report.

Table 5-1. EPA's Acute Toxicity Classification Scheme for Pesticides

Classification	Acute Oral LD_{50} (mg/kg)	Acute Dermal LD_{50} (mg/kg)	Acute Inhalation LC_{50} (mg/L)	Eye Irritation	Skin Irritation	Dermal Sensitization
Category I	≤ 50 mg/kg	≤ 200 mg/kg	≤ 0.05 mg/L	Corrosive (irreversible destruction of ocular tissue) or corneal involvement or irritation persisting for more than 21 days	Corrosive (tissue destruction into the dermis and/or scarring)	
Category II	> 50 to 500	> 200 to 2,000	> 0.05 to 0.5	Corneal involvement or irritation clearing in 8–21 days	Severe irritation at 72 hours (severe erythema or edema)	
Category III	> 500 to 5,000	> 2,000 to 5,000	> 0.5 to 2	Corneal involvement or irritation clearing in 7 days or less	Moderate irritation at 72 hours (moderate erythema)	
Category IV	>5,000	> 5,000	> 2	Minimal effects clearing in less than 24 hours	Mild or slight irritation (no irritation or slight erythema)	
Positive						Product is a sensitizer or is positive for sensitization
Negative						Product is not a sensitizer or is negative for sensitization

Regarding the carcinogenicity information collected, EPA's cancer classification process is based on a weight of evidence evaluation of the literature; ultimately EPA classifies compounds into one of five categories:

- Carcinogenic to humans
- Likely to be carcinogenic to humans
- Suggestive evidence of carcinogenic potential

- Inadequate information to assesses carcinogenic potential
- Not likely to be carcinogenic

Further, given that EPA is planning to screen all pesticides through its endocrine disruption screening program (EDSP), ERG also gathered available data from EPA on the potential of the compounds to cause endocrine disruption (USEPA, 2021c). EPA's EDSP is a tiered program. Tier 1 chemicals are screened "to identify substances that have the potential to interact with the endocrine system": specifically, they are evaluated on whether they interact with estrogen, androgen, or thyroid hormone receptors. If so, they proceed to Tier 2 for testing (USEPA, 2021c). Tier 2 testing is used to establish a quantitative relationship between the dose and the adverse effect.

ERG supplemented data from EPA with information from the EU, which also has a comprehensive database on endocrine disruption potential of thousands of compounds.

The data collected through this process have been compiled in an accompanying spreadsheet to this document to allow the Task Force to filter and compare conclusions as needed. The data are also summarized below.

5.2 Results of Human Health Toxicity Evaluation

When reviewing the information presented in this section, it is important to understand that many toxicological studies involve doses higher than people are expected to be exposed to when mosquito control products are applied. Therefore, an association between a hazard and a specific compound does not necessarily imply that human health is at risk, as risk is a product of hazard and exposure. EPA develops application protocols for pesticides to keep exposure levels in the human populations below levels of toxicological concern. However, if the science on the fate, transport, or toxicity of a compound evolves, updated application practices may be needed. EPA is required by law to periodically review every pesticide to ensure that it continues current regulatory standards and is based on most current science. Additionally, if a product is used improperly (a violation of federal law) this could result in exposure above levels of toxicological concern.

Table 5-2 summarizes the acute mammalian toxicity data and EPA's carcinogenicity classifications, as collected by ERG. This information makes it clear that the larvicides have minimal acute human health toxicity concerns, but concerns do exist with some of the adulticide compounds.

Table 5-2. Summary of Data on Acute Toxicity and Carcinogenicity Classification from EPA

Active Ingredient	CASRN	Subcategory	Acute Oral	Acute Dermal	Acute Inhalation	Eye Irritation	Skin Irritation	Dermal Sensitization	Carcinogenicity
Larvicides									
Bti	68038-71-1	Bacterial insecticide	IV	IV	IV	Not reported[a]	Not reported[a]	Not reported	Not likely to be carcinogenic
Bs ABTS 1743	143447-72-7	Bacterial insecticide	IV	IV	IV	IV	Potential[b]	Potential[b]	Not stated
Bs AM614	143447-72-7	Bacterial insecticide	IV	IV	IV	III	IV	Potential[b]	Not stated
Spinosad	131929-60-7; 131929-63-0	Spinosyn	IV	III	IV	III	IV	Negative	Not likely to be carcinogenic
Methoprene	40596-69-8; 65733-16-6	Methoprene	IV	IV	IV	IV	IV	Negative	Not an oncogenic compound[c]
Mineral oil	8012-95-1; 8042-47-5	Mineral oil	IV	IV	IV	III/IV	IV	Negative	Not classifiable as to human carcinogenicity
Adulticides									
d-phenothrin	26002-80-2	Pyrethroid (Type I)	IV	III	IV	III	IV	Negative	Not likely to be carcinogenic
Etofenprox	80844-07-1	Pyrethroid	IV	III	IV	IV	IV	Positive	Not likely to be carcinogenic
Deltamethrin	52918-63-5	Pyrethroid (Type II)	II to IV[d]	III	II/III	III	IV	Negative	Not likely to be carcinogenic
Fluvalinate	69409-94-5	Pyrethroid (Type II)	II	III	Testing not required	III	IV	Negative	Not likely to be carcinogenic
Prallethrin	23031-36-9	Pyrethroid (Type I)	II	IV	II	IV	IV	Negative	Not likely to be carcinogenic
Permethrin	52645-53-1	Pyrethroid (Type I)	III	III	IV	III	IV	Negative	Suggestive of carcinogenic potential
PBO	51-03-6	NA	III	III	IV	IV	IV	Positive	Not likely to be carcinogenic

[a] The registration review document for Bti states: “Primary dermal irritation (81-5, 870.2500) and primary eye irritation (81-4, 870.2400) were not required under the 1988 Registration Standard because these studies are not required for the TGAI (40 CFR 158.740). These studies are required and will be reviewed for the manufacturing-use and the end-use products. In general, slight to moderate skin irritation has occasionally been observed in product tests, which may be attributed to other ingredients in the formulation, and occasionally eye irritation has been seen in primary eye irritation tests. This is often associated with dry, anhydrous forms of the product and may be due to physical irritation effects as might be caused by sand or drying agents rather than caused by traditional toxicity” (USEPA, 1998). An updated summary of the acute toxicity endpoints could not be found.

[b] The registration review document for Bs states: “primary dermal irritation and dermal sensitization indicated that products containing ABTS 1743 may be potential dermal sensitizers…For AM614… a dermal sensitization study conducted with an end-use product containing AM614 indicating that products containing AM614 may be potential dermal sensitizers…While the Agency does have positive dermal sensitization data performed with end-use products containing *Bacillus sphaericus*, no such effect has been demonstrated with the active ingredient only” (USEPA, 2019a).

[c] The language used in the registration review document for methoprene varies from the standard cancer classification categories used by EPA (USEPA, 2021h).

[d] This range is a result of different results in different tests in rats (USEPA, 2020a).

Beyond what is presented in Table 5-2, the available data in EPA's registration review documents demonstrate that bacterial insecticides and mineral oils are not expected to pose toxic threats to human health (USEPA, 1998, 2007, 2019a).

As for the other larvicide compounds used by MCDs for mosquito control, EPA's human health risk assessment for Spinosad noted that the primary toxic effect observed in available toxicological studies was histopathological changes in multiple organs (e.g., epididymides, thymus, thyroid, larynx). Anemia was also noted in several studies (USEPA, 2016f). Effects were observed in rats, mice, and dogs, with dogs being the most sensitive species. Further, according to EPA, "In the [spinosyn] rat reproduction toxicity studies, offspring toxicity was seen in the presence of parental toxicity …(75–100 mg/kg/day)" (USEPA, 2016f). Parental toxicity was evidenced by increased organ weights, mortality, and histopathological findings in several organs. Offspring effects included decreased litter size, survival, and body weights with Spinosad. Dystocia and/or other parturition abnormalities were also observed (USEPA, 2016f). EPA models estimate that, if products containing Spinosad are applied as directed, exposure levels in the general public will be at least 100 times lower than those where adverse effects may occur (USEPA, 2016f).

For methoprene, EPA has reported possible mild irritation to the skin with sub-chronic exposures, as well as possible chemical pneumonitis if ingestion leads to aspiration to the lung. Longer-term exposures may result in dermatitis (USEPA, 2021g). A review of the Pharos database indicated that the Danish EPA Advisory List for Self-Classification of Hazardous Substances, under the globally harmonized classification system, lists methoprene as H361: suspected of damaging fertility to the unborn child (see Table 5-4, Danish Environmental Protection Agency, 2010). Note that this conclusion is based on modeled data. Specifically, the advisory list developed by the Danish EPA is based on quantitative structure activity relationship modeling, which has inherent uncertainty (Danish Environmental Protection Agency, No Date).

Unlike the larvicides, some of the pyrethroid compounds do pose human health toxicity concerns. EPA's Health Effects Division has categorized permethrin as suggestive of carcinogenic potential based on evidence of increased lung adenomas in female mice (USEPA, 2020c). The one product MCDs have used in the last four years that contains permethrin, Flit 10EC, has not been used in the last two years and has been used minimally in the prior years (3 to 7 gallons applied). D-phenothrin, the main active ingredient in Anvil 10+10, is the least acutely toxic of the pyrethroids to mammals. To understand the relative toxicity of the pyrethroid compounds, values were extracted from EPA's Human Health Based Benchmarks for Pesticides; these data are summarized in Table 5-3. EPA developed the lifetime human health benchmarks to be used "as screening levels for use by states and water systems in determining whether the detection of a pesticide in drinking water or a drinking water source may indicate a potential health risk" (USEPA, 2017c). The lower the benchmark, the greater the toxicity of a compound.

From the information summarized in the table, the most toxic of the pyrethroid compounds used by MCDs for mosquito control is fluvalinate. Data are not available for chronic toxicity for all the pyrethroid compounds related to chronic exposure, but permethrin is considered slightly less toxic than fluvalinate. Although permethrin has a benchmark for chronic exposure that is much higher than phenothrin's, the concentration in drinking water associated with a 1 in 10,000 to 1 in 1,000,000 risk of cancer is 3 to 334 ppm.

Table 5-3. Human Health Benchmarks for Pyrethroid Compounds

Active Ingredient	Acute or One-Day Human Health Benchmark (ppb)	Chronic or Lifetime HHBP (ppb)	Carcinogenic HHBP (E-6 to E-4) (ppb)
Fluvalinate	30	30	Not applicable
Deltamethrin	30	-[a]	Not applicable
Prallethrin	50	-	Not applicable
d-Phenothrin	800	40	Not applicable
Etofenprox	-	240	Not applicable
Permethrin	1,700	1,600	3.3–334.4
PBO	42,000	992	Not applicable

- = value not provided in the HHBP database (USEPA, 2017c)

[a]EPA determined that a chronic HHBP was not needed for deltamethrin compounds as it was determined the acute endpoint is protective of repeated exposures (USEPA, 2019b)

With high enough doses, Type I pyrethroids are known to produce behavioral arousal, aggressive sparring, increased startle response, and tremors. Type II pyrethroids produce salivation, coarse tremors, and clonic[17] seizures (ATSDR, 2018).

Deltamethrin, fluvalinate, and permethrin all behave as standard pyrethroid-type compounds. In addition, the California Environmental Protection Agency has listed fluvalinate on Proposition 65 due to developmental toxicity concerns. Fluvalinate, along with prallethrin, is also on Minnesota's Chemicals of High Concern and Priority Chemicals List, and Oregon has listed deltamethrin as a priority, persistent pollutant.

D-phenothrin and etofenprox do not produce the effects known to be associated with pyrethroids. For example, in a study with a dose of 2,000 mg/kg of d-phenothrin, neurological effects were not seen in rats, dogs, or mice (USEPA, 2016b). Instead, according to EPA, the most sensitive endpoint associated with exposure to d-phenothrin is liver toxicity, as characterized by increased liver weight, hepatocellular vacuolization, and hypertrophy; this occurred at a dose of 26.8 mg/kg/day and no effects were observed at 7.1 mg/kg/day. In addition, a 90-day inhalation study showed histopathological changes in nasal turbinates at 0.291 mg/L, with no effects being seen at 0.104 mg/L (USEPA, 2016b).

Etofenprox is grouped in the pyrethroid category. IRAC (2020) designates it as having the same MoA as the other compounds in this group. However, EPA's draft human health risk assessment states the data are not available to make this conclusion (USEPA, 2017b). EPA does not elaborate on its MoA. Etofenprox differs from the pyrethroid class of compounds in that it has an ether moiety, rather than the ester moiety that define pyrethroids. The major targets for etofenprox are the liver, thyroid, kidney, and blood system. Etofenprox is characterized as having low acute toxicity via oral, dermal, and inhalation routes of exposure. All sub-chronic and chronic studies showed adverse effects in two or more of the target systems, but at high levels of exposure (i.e., over 180 mg/kg/day). Studies indicate that thyroid impacts get progressively worse with increasing exposure levels to etofenprox (USEPA, 2016b). The Australian and EU

[17] Sustained rhythmic jerking.

governments have listed Etofenprox as H362 under the globally harmonized classification system, indicating it may cause harm to breastfed children.

A 2008 article raised concerns about the potential association between pyrethroids/ pyrethrins and asthma and allergy (Center for Public Integrity, 2008). Subsequently, EPA conducted a weight of evidence evaluation on this topic. It concluded that the evidence of an association was lacking, but stated that it would continue to evaluate new data on this issue as they became available (USEPA, 2009).

In addition to the EPA documents, ERG reviewed the published literature on pyrethroids and health effects. Given the magnitude of data on this topic, ERG focused on a recent review by Saillenfait, Ndiaye, & Sabaté (2015). This article's authors note that exposure to pyrethroids is widespread in the general population, as indicated by detection of metabolites of pyrethroid compounds in urine. They note that the main sources of exposure to pyrethroids is ingestion of food with residual pesticide and dermal contact with house dust that has been contaminated following domestic use for pest control. The authors conclude that effects related to accidental exposures (acute, high dose) are well described and reference effects including irritation of the respiratory system, skin and eyes and paresthesia.[18] As for low-level chronic exposures, the authors describe recent epidemiological studies as "limited and controversial." These studies have observed potential associations between pyrethroid exposure and adverse effects on sperm quality, sperm DNA, reproductive hormones, pregnancy outcomes, and neurobehavioral outcomes (e.g., ADHD) after in utero exposure.[19] However, the authors also note that these findings are not conclusive and that further research is needed to determine the potential risks associated with long-term, low-level exposure to pyrethroids.

The data collected on endocrine disruption potential and any additional indications of concern from government sources, as listed in the Pharos database, are included in Table 5-4. The data indicate that, although EPA is requiring all pesticides to go through its EDSP, the only active ingredient used by the MCDs or the SRB that has gone through this program is PBO, for which the screening results do not indicate endocrine disruption potential (USEPA, 2015b). Although not considered final and available only for public comment, data are available for etofenprox from EPA's Estrogen Receptor Bioactivity assays, none of which indicated activity with etofenprox (USEPA, 2015c). Reviewing the current registration eligibility documents or workplans for registration review, EPA has stated final approval of the pesticides will only occur with additional data related to endocrine disruption (this could include scientific justification that the screening is not warranted) (USEPA, 2015a, 2016b, 2016g, 2017b, 2019a, 2020a, 2020c, 2021g).

The EU data provide some additional information on the endocrine disruption potential for these insecticides (European Commission, 2000). These data indicate that deltamethrin has the strongest evidence indicating potential for endocrine disruption with exposure. d-phenothrin, fluvalinate, and prallethrin also all have some evidence for endocrine disruption (European Commission, 2000). The EU data support the findings that etofenprox and PBO are not endocrine disruptors.

[18] A burning or prickling sensation in the body.

[19] Summaries of all studies evaluated by Saillienfait et al. (2015) are included in Table 1 (male hormonal and reproductive effects) and Table 2 (health effects of pyrethroids during pregnancy) of the publication.

Lastly, the synergist used with pyrethroids, PBO, has its own toxicity profiles but is not designed to be a pesticide on its own. Instead the use of PBO increases the toxicity of pyrethroid compounds by blocking enzymes needed to break down pyrethroids in the body. Therefore, when considering the risk of adverse effects from pesticide exposure, it is useful to understand whether the compound is used in conjunction with PBO. The target of PBO toxicity is the liver: toxicological studies have shown that toxicity to result in increases in liver weight, cholesterol and enzyme activity, and various histopathological changes (USEPA, 2006). These effects were observed at doses over 50 mg/kg/day. In addition, inhalation exposure studies in rats demonstrated an increase in laryngeal hyperplasia and metaplasia in rats after exposure to 3.91 mg/kg/day (0.015 mg/L) (USEPA, 2006).

Table 5-4. Summary of Data on Endocrine Disruption Potential and Additional Concerns from Government Sources

Active Ingredient	CASRN	Category	Subcategory	EPA EDSP	EU Endocrine Disruption Category for Human Health[a]	Additional Noted Human Health Concerns from Government Sources
Bti	68038-71-1	Larvicide	Bacterial insecticide	—	—	None
Bs ABTS 1743	143447-72-7	Larvicide	Bacterial insecticide	—	—	None
Bs AM614	143447-72-7	Larvicide	Bacterial insecticide	—	—	None
Spinosad	131929-60-7; 131929-63-0	Larvicide	Spinosyn	—	—	None
Methoprene	40596-69-8; 65733-16-6	Larvicide	Methoprene	—	—	Listed by the Danish EPA as H361: suspected of damaging fertility to the unborn child (based on modeled data)
Mineral oil	8012-95-1; 8042-47-5	Larvicide	Mineral oil	—	—	None
d-phenothrin	26002-80-2	Adulticide	Pyrethroid (Type I)	—	2	None
Etofenprox	80844-07-1	Adulticide	Pyrethroid	—	3	Listed by Australia and EU as H362: may cause harm to breastfed children
Deltamethrin	52918-63-5	Adulticide	Pyrethroid (Type II)	—	1	Listed by Oregon DEQ as a priority, persistent pollutant
Fluvalinate	69409-94-5	Adulticide	Pyrethroid (Type II)	—	2	Listed in the California EPA's Proposition 65 due to developmental toxicity concerns; listed on the Minnesota Department of Health's Chemicals of High Concern and Priority Chemicals List
Prallethrin	23031-36-9	Adulticide	Pyrethroid (Type I)	—	2	Listed on the Minnesota Department of Health's Chemicals of High Concern and Priority Chemicals List
Permethrin	52645-53-1	Adulticide	Pyrethroid (Type I)	—	—	None
PBO	51-03-6	Synergist	NA	Negative	3b	None

Sources: (European Commission, 2000; Healthy Building Network, 2021; USEPA, 2015a, 2016b, 2016g, 2017b, 2019a, 2020a, 2020c, 2021g).
— = data not available.
[a] Category 1: evidence of endocrine disrupting activity in at least one species using intact animals; Category 2: at least some in vitro evidence of biological activity related to endocrine disruption; Category 3a: studies available but no indication of endocrine disruption effects; Category 3b: no or insufficient data available.

5.3 Method to Evaluate Ecological Toxicity of Pesticides Used by MCDs and the SRB in Massachusetts

To summarize the data on bioaccumulative tendencies, ecological persistence, and trophic transfer potential, physical/chemical property information was extracted for each chemical. The variables for which ERG extracted data, along with the data source used, are:

- **Octanol/water partition coefficient (logK_{ow}, log P).** Data extracted from the International Union of Pure and Applied Chemistry's (IUPAC's) Pesticides Properties Database (PPDB) (Lewis et al., 2016).
- **Bioconcentration factor (BCF).** Data extracted from EPA's CompTox Chemical Dashboard (USEPA, 2017a).
- **Bioaccumulation Factor (BAF).** Data extracted from EPA's CompTox Chemical Dashboard (USEPA, 2017a).
- **Half-life in soil.** Data extracted from the IUPAC PPDB (Lewis et al., 2016).
- **Half-life in water.** Data extracted from the IUPAC PPDB (Lewis et al., 2016).
- **Half-life on plant surfaces.** Data extracted from the IUPAC PPDB (Lewis et al., 2016).
- **Biotransformation half-life in fish (kM).** Data extracted from EPA's CompTox Chemical Dashboard (USEPA, 2017a)

For consistency within each variable and direct comparability between values, sources were selected based on the availability of data in the two databases for each property. If information was not available in the referenced sources and a different source was used, this is indicated in the results.

To analyze ecological toxicity for the active ingredients of interest, ERG took a similar approach to the one it used for human health. That is, ERG:

- Extracted acute toxicity data from EPA registration documents or supporting files.
- Used endocrine disruption potential information from the EU.
- Evaluated other potential ecotoxicity concerns using the Pharos database, an ecotoxicity expert interview, and literature reviews.

EPA risk assessment for registration of active ingredients also categorizes compounds' acute ecological toxicity using LC_{50}/LD_{50} data, similar to the categorization process for human health. EPA's scheme is presented in Table 5-5.

Table 5-5. Summary of EPA's Classification Scheme for Acute Ecotoxicity

Category	Avian: LD_{50} Acute Oral Concentration (mg/kg Body Weight)	Avian: LD_{50} Dietary Concentration (mg/kg Diet)	Aquatic Organisms: LC_{50} Acute Concentration (mg/L)	Wild Mammals: LD_{50} Acute Oral Concentration (mg/kg Body Weight)	Non-Target Insects: LC_{50} Acute Concentration (µg/Bee)
Very highly toxic	<10	<50	<0.1 mg/L	<10	
Highly toxic	10–50	50–500	0.1–1	10–50	<2
Moderately toxic	51–500	501–1,000	>1–10	51–500	2–11
Slightly toxic	501–2,000	1,000–5,000	>10–100	501–2,000	
Practically nontoxic	>2,000	>5,000	>100	>2,000	>11

The physical/chemical property information, ecological toxicity data, and EPA conclusions are also in the accompanying spreadsheet.

5.4 Results of Ecotoxicity Evaluation

Table 5-6 compiles data on the physical/chemical properties of the active ingredients used by the MCDs and the SRB for mosquito control.

Table 5-6. Summary of Physical/Chemical Property Information

Chemical	CASRN	$\log K_{ow}$	BCF	BAF	Half-Life (Days) in Various Systems				
					Biotransformation in Fish (kM)	"Typical" Soil[a]	Water with Sediment	Water Only	On Plant Surfaces
Larvicides									
Bti	68038-71-1	—	—	—	—	120[b]	—	—	1–4[b]
Bs ABTS 1743	143447-72-7	—	—	—	—	—	—	—	—
Bs AM614	143447-72-7	—	—	—	—	—	—	—	—
Spinosyn A	131929-60-7	3.9	10.5	—	1.16	24.3	126	16	2–16
Spinosyn D	131929-63-0	4.3	27.4	—	1.17	45.2	126	11	2–16
Mineral oil	8012-95-1	12.3	—	—	—	65	—	—	—
White mineral oil	8042-47-5	5	—	—	—	87	—	—	—
Methoprene	40596-69-8	5	143	—	0.955	10	1–28[c]		1.4[d]
Adulticides									
d-phenothrin	26002-80-2	6.01	475	355	2.68	1–2	—	—	6.0
Etofenprox	80844-07-1	6.9	3,900	137,000	3.51	11	13.3	5.7	2.1[d]
Deltamethrin	52918-63-5	4.6	415	1,760	3.23	58.2	65	17	6.5
Fluvalinate	69409-94-5	3.85	3,810	664	4.68	7	—	—	3.0
Prallethrin	23031-36-9	4.49	45.9	86.2	0.256	—	—	—	—
Permethrin	52645-53-1	6.1	563	1,060	2.34	13	40	23	6.7
PBO	51-03-6	4.75	105	249	4.19	13		<1[e]	14.3

— = data not available

[a] IUPAC uses "typical" to describe soils that are "given in the general literature and are often a mean of all studies field and laboratory" (Lewis et al., 2016).

[b] Data are from the USEPA Registration document for Bti (USEPA, 1999)

[c] The data source for this value, the National Pesticide Information Center, did not indicate the water system from which these values were collated.

[d] Data were not available for on plant surfaces only. This value indicates on *and in* plant matrices

[e] This value is reported as "in an aqueous solution when illuminated with sunlight."

Table 5-6 demonstrates that all active ingredients used by MCDs and the SRB, larvicides and adulticides alike, have logK_{ow} values greater than 3.0, indicating high probability for bioaccumulation (University of Hertfordshire, 2020). However, not all compounds have BCFs or BAFs that would indicate high bioaccumulation potential. Chemical management programs often consider a BCF or BAF value of 5,000 or higher to indicate a compound is bioaccumulative (European Chemicals Agency, 2017). None of the evaluated larvicide active ingredients have BCF values this high. Of the adulticides active ingredients, etofenprox, deltamethrin, fluvalinate, and permethrin all have either BCF or BAF values greater than 5,000. d-phenothrin, the compound used for adulticiding by the SRB, has BCF and BAF values well below 5,000. The high logK_{ow} and lower BAF/BCF values are potentially explained by the short biotransformation times in fish, indicating organisms can break down some of the pyrethroid compounds through biological processes.

As for persistence, larvicides (which are applied to water systems to kill mosquito larvae) have minimal water half-life data. The compounds that make up Spinosad (Spinosyn A and Spinosyn D) have half-lives of about four months in water with sediment. Additionally, the data for methoprene indicate that half the compound should be gone from a water system in under one month.

Several of the compounds used for larviciding are lacking data to fully understand their persistence in the environment. EPA data indicate that Bti is easily degraded by sunlight and has a half-life of about one to four days when it is on foliage (USEPA, 1998). However, it may persist for several months in soil (USEPA, 1998). As with any compound, Bti's persistence properties vary based on field conditions, such as the type of vegetation present, amount of sunlight, and presence of organic matter (City of Boulder, 2018). Marcombe et al. (2011) found Bti had residual activity for 20 weeks. In addition, some studies have shown that bacterial insecticides can be recycled in the environment, though there is not scientific consensus on this issue. "Recycling" in this case refers to the process of the spores germinating, returning to vegetative growth, replicating, sporulating, and producing toxins. Some studies have observed this with Bti (Aly et al., 1985; Khawaled et al., 1990), but others have not (Duchet et al., 2014).

Adulticides, which are to be sprayed in the air and avoid water bodies, have data indicating half-lives in water and soil of less than a month in most cases. The exception to this is deltamethrin, which has a half-life in soil of about two months. All the adulticides except for PBO have half-lives on plants of less than one week. PBO, the synergist used in some pyrethroid formulations, may take more than two weeks to degrade to half its original amount.

As for acute toxicity, EPA's conclusions for each category evaluated are presented in Table 5-7. Data from the EU on the potential for the compounds to cause endocrine disruption in wildlife are presented in Table 5-8, along with conclusions from other governments on these compounds. Regarding chronic toxicity, the data is not as readily available but any information from EPA reports is included in the sections that follow.

Table 5-7. Summary of Acute Toxicity Classifications for Active Ingredients Used by MCDs and the SRB in Mosquito Control

Active Ingredient	Freshwater Fish	Freshwater Invertebrates	Estuarine/Marine Fish	Estuarine/Marine Invertebrates	Birds	Non-target Insects
Bti	Practically nontoxic to slightly toxic	Moderately toxic	Practically nontoxic	Practically nontoxic	Practically nontoxic	Practically nontoxic
Bs[a]	Practically nontoxic	Practically nontoxic	Practically nontoxic	Practically nontoxic	Practically nontoxic	Practically nontoxic
Spinosad	Moderately toxic	Slightly toxic	Moderately toxic	Highly toxic	Low toxicity with acute exposure, more sensitive with chronic exposure[b]	Highly toxic
Methoprene	Moderately to highly toxic[b]	Highly toxic	Data not presented	Very highly toxic	Practically nontoxic	Data not presented
Mineral oil	Practically nontoxic	Highly toxic	Not toxic	Moderately toxic	Practically nontoxic	Practically nontoxic
Pyrethroids[c]	Very highly toxic	Very highly toxic	Very highly toxic	Very highly toxic	Generally not expected[b]	Highly toxic

[a] Given the similar biochemical profile to AM614's, EPA assumed AM614 is likely also nontoxic in the environment.

[b] EPA's rationale documentation did not classify the impacts following the standard categorization. The range exists due to different LD_{50} values for different fish species (USEPA, 2019a).

[c] The categorizations in this table are based on the pyrethroid category, not individual pyrethroid compounds. This is because, in the most recent evaluation of data for registration of 19 pyrethroids, EPA focused on nine specific compounds (bifenthrin, cyfluthrins, cyhalothrins, cypermethrins, deltamethrin, esfenvalerate, fenpropathrin, permethrin, and the pyrethrins) and provide rationale that all 19 pyrethroids did not need to go through full risk evaluations.

Table 5-8. Summary of Data on Wildlife Endocrine Effects and Ecotoxicological Concerns as Reported by Other Governmental Agencies

Active Ingredient	CASRN	Category	Subcategory	EU Endocrine Disruption Category for Wildlife	Additional Noted Ecotoxicological Concerns from Government Sources
Bti	68038-71-1	Larvicide	Bacterial insecticide	—	None
Bs ABTS 1743	143447-72-7	Larvicide	Bacterial insecticide	—	None
Bs AM614	143447-72-7	Larvicide	Bacterial insecticide	—	None
Spinosad	131929-60-7; 131929-63-0	Larvicide	Spinosyn	—	None
Methoprene	40596-69-8; 65733-16-6	Larvicide	Methoprene	—	None
Mineral oil	8012-95-1; 8042-47-5	Larvicide	Mineral oil	—	None
d-phenothrin	26002-80-2	Adulticide	Pyrethroid (Type I)	3b	None
Etofenprox	80844-07-1	Adulticide	Pyrethroid	3	None
Deltamethrin	52918-63-5	Adulticide	Pyrethroid (Type II)	2	Listed by Oregon DEQ as a priority, persistent pollutant
Fluvalinate	69409-94-5	Adulticide	Pyrethroid (Type II)	3	None
Prallethrin	23031-36-9	Adulticide	Pyrethroid (Type I)	3	None
Permethrin	52645-53-1	Adulticide	Pyrethroid (Type I)	—	None
PBO	51-03-6	Synergist	N/A	2	Listed by Canadian EPA as bioaccumulative and inherently toxic to the environment

— = data not available.

Based on EPA's analyses, there is a range of acute ecotoxicity concerns across ecological categories and pesticides. Additionally, ecological toxicity is the risk driver for these pesticides in most cases. Therefore, exposure should be minimized to minimize potential risk.

5.4.1 Bacterial Insecticides

EPA has deemed these compounds minimally to moderately toxic with acute exposures. EPA also concluded that Bti and Bs did not need to have chronic toxicity data evaluated because the acute data indicate no potential for concern. Recently, the City of Boulder reviewed its approach to mosquito control and recommended "reduc[ing] the use of Bti as much as possible, while not compromising mosquito management outcomes by focusing on ecologically-sound treatment options"(City of Boulder, 2018). The City justified this approach with a literature review on the ecological effects of Bti that cited more complex or indirect effects on ecological systems.

For example, Pauley, Earl, and Semlitsch (2015) found that when predators were present, Bti treatment—specifically slow-release mosquito dunks (10.31 percent active ingredients) every 30 days—significantly decreased tadpole survival. The same was not observed with "quick-kill" mosquito bits (2.85 percent active ingredient) every 14 days. Further, a five-year study of adult *Odonata* by Jakob and Poulin (2016) found a fivefold reduction in abundance and a threefold reduction in richness in Bti-treated sites. The authors attributed this to the 87 percent reduction of aquatic flies, a food source to *Odonata*, due to Bti. Further, Poulin, Lefebvre, and Paz (2010) assessed the impact of Bti-treated sites on the diet of house martins. They found that Bti-treated sites had much smaller house martin prey (flying ants at treated sites versus spiders and dragonflies at untreated sites) and lower reproductive success for the birds, with decreased clutch size and fledgling survival.

In addition, the City of Boulder cited studies that found differential effects based on the life stage of the insect, which is not included in EPA's registration review. For example, Kastel, Allgeier, and Bruhl (2017) found first-instar larvae of the midge *Chironomus riparius* were much more susceptible to Bti toxicity than fourth-instar larvae. Additionally, changes in species turnover and colonization dynamics were also observed after Bti treatment (Lundström et al., 2010).

For s-methoprene, in addition to the data presented in the above tables, EPA also summarized information on chronic exposure effects. Disruptions to growth were observed at 0.051 mg/L in daphnia magna and reduced reproductive success in mysid shrimp with ≥0.002 mg/L. Additionally, La Clair, Bantle, and Dumont (1998) reported abnormal levels of deformations in amphibians with exposure to s-methoprene breakdown products. The authors found that although s-methoprene itself does not result in deformations in amphibians at a concentration of 1 µL/L; the addition of several of s-methoprene breakdown products resulted in deformities in juvenile amphibians. For methoprene.

More data are also available on Spinosad from EPA. As indicated above, Spinosad is moderately toxic to fish, both freshwater and estuarine/marine, when considering acute exposures (USEPA, 2016f). It is slightly toxic to freshwater invertebrates, but highly toxic to estuarine invertebrates. Interestingly, EPA also noted that chronic exposure increases the toxicity of Spinosad ten- to a thousandfold: rare for pesticides, which often have similar toxicity profiles regardless of exposure time frame. EPA suggests there may be a different MoA with chronic exposure (USEPA, 2016g). In addition, EPA noted that Spinosad is highly persistent in the environment and that toxic residues may remain in water columns for decades (USEPA, 2016f). One of the main toxicological concerns with Spinosad is its high acute toxicity to pollinators, specifically honey bees (USEPA, 2018c).

5.4.2 Pyrethroids

As is clear from the data presented in Table 5-7, pyrethroids are highly toxic to the aquatic environment. In fact, EPA has concluded that aquatic toxicity is the risk driver for pyrethroid compounds. Of note also is that pyrethroid aquatic toxicity increases with decreasing ambient temperature (Whiten & Peterson, 2016). EPA is in currently conducting a registration review for pyrethroid compounds (USEPA, 2020d) and has recently published additional mitigation measures as a result of its analysis. This is because the ecological risk assessment, which focuses on aquatic toxicity, demonstrated that concentrations exceeding levels of concern may be present after application of pyrethroids for a variety of uses, including aerial spraying events to control mosquitoes.

EPA assesses pyrethroids as a class, not chemical by chemical. The chemicals for which data were included in the EPA analysis include bifenthrin, cypermethrin, cyfluthrin, deltamethrin, esfenvalerate, fenpropathrin, cyhalothrin, permethrin, and pyrethrins. These are referred to as the pyrethroid working group (PWG) pyrethroids. EPA states that “the aquatic risk in the current assessment for these chemicals are representative of the non-PWG pyrethroids” (USEPA, 2016c), which includes the other active ingredients used by MCDs and the SRB in mosquito control (i.e. fluvalinate, prallethrin, d-Phenothrin, etofenprox). In addition, EPA focuses their risk assessment on aquatic animals because “their high toxicity of pyrethroids to aquatic animals and their potential chemical exposure in water are well established.”

Combining information on hazard and exposure (assuming high end exposure estimates) EPA concluded that using pyrethroids as adulticides may result in exceedance of acute and chronic levels of concern for freshwater and estuarine/marine fish, and for freshwater and estuarine/marine invertebrates. These exceedances can result in a potential reduction in survival, growth, and reproduction to non-target aquatic animals (USEPA, 2016e). EPA’s levels of concern and subsequent risk determinations from this assessment are provided in Appendix B. Subsequently EPA developed additional restrictions and label guidelines to minimize these effects. For details on the assumptions and methods used for the exposure assessment, see EPA’s *Preliminary Comparative Environmental Fate and Ecological Risk Assessment for the Registration Review of Eight Synthetic Pyrethroids and Pyrethrins (Part IV)* (USEPA, 2016c).

In general, when considering acute exposures, EPA states that aquatic invertebrates are orders of magnitude more sensitive to pyrethroids than fish (either freshwater or marine) (USEPA, 2020d). More specifically, benthic or sediment-dwelling invertebrates are especially sensitive to pyrethroids (USEPA, 2020d). Similarly, freshwater fish are more sensitive than estuarine/marine fish. For chronic exposures, though, it is not clear if there is a difference in susceptibility between freshwater and marine invertebrates or fish (USEPA, 2020d).

In EPA's pyrethroid assessment, only two of the five pyrethroids used as active ingredients by MCDs and the SRB for mosquito control are included in the quantitative evaluations. To provide more context, ERG conducted a query of EPA's ECOTOX database to extract relevant LC_{50} values for the five active ingredients in the pyrethroid class (USEPA, 2021b). This search resulted in more than 2,600 LC_{50} values in aquatic species, of which more than 2,400 were for permethrin and deltamethrin (all data are available in the accompanying spreadsheet). To understand the relative toxicity of the compounds used by the MCDs and the SRB for mosquito control, the lowest of the presented mean LC_{50} values was identified for each species group for each pesticide active ingredient. This is summarized in Table 5-9.

Table 5-9. Lowest Available LC_{50} (µg/L of Active Ingredient) Value by Aquatic Species Category and Pyrethroid Compound

Active Ingredient	Freshwater		Saltwater	
	Fish	Crustacean	Fish	Crustacean
d-phenothrin	1.4	4.4	38.3	0.025
Permethrin	0.62	0.02	2.2	0.018
Deltamethrin	0.021	0.003	0.36	0.00032
Fluvalinate	0.61	0.5	11	0.021
Etofenprox	2.36	0.29	No data	0.0188

Table 5-9 demonstrates the high toxicity of these compounds to crustaceans in both fresh and saltwater systems, with all compounds having LC_{50} values less than 1 µg/L of active ingredient. Deltamethrin is the most toxic of these compounds to aquatic systems. d-phenothrin (the compound most often used for aerial spraying for mosquito control in Massachusetts) and etofenprox are the least acutely toxic of the pyrethroid active ingredients used, based on available LC_{50} values.

Available data from ECOTOX also support EPA's conclusion that invertebrates are more vulnerable than fish or crustaceans to the effects of pyrethroids. Blackflies (LC_{50} = 0.6 µg/L), mayflies (LC_{50} = 0.1 µg/L), and midges (lowest LC_{50} = 0.06 µg/L) all have LC_{50} values lower than the mosquito LC_{50} for permethrin (0.7 µg/L). Backswimmers (LC_{50} = 0.012 µg/L), mayflies (lowest LC_{50} = 0.005), and certain midge species (LC_{50} = 0.000016 µg/L) all have lower deltamethrin LC_{50}s than the mosquitoes (0.02 µg/L). Unfortunately, no data were available for any invertebrates in ECOTOX other than mosquitoes and no reported LC_{50}s were available for mosquitoes for fluvalinate.

As well as affecting the aquatic environment, pyrethroids are considered highly toxic to honey bees based on the low doses that can result in death (USEPA, 2016e). EPA's risk assessment for pyrethroids only assessed the risk to pollinators due to agricultural uses, not adulticiding, making this a potential exposure route that has not been evaluated by EPA (USEPA, 2016e). (EPA has concluded that more data are needed to fully evaluate risks to pollinators from pyrethroids and has requested that these data be gathered before it finalizes its registration review for pyrethroids.)

In 2014, Sanchez-Bayo and Goka conducted a risk assessment of hundreds of pesticides on honey bees and bumble bees using LD_{50} information from available sources (e.g., ECOTOX) combined with data on pesticide residue in pollen, honey, and wax from several sources. Based on their analysis, of the pyrethroids reported as used by MCDs for mosquito control, deltamethrin poses the greater risk to honey bees based on contact exposure (Sanchez-Bayo & Goka, 2014). Flauvinate, permethrin, and d-phenothrin posed low risk (<1 percent estimated risk of death based on exposure levels) (Sanchez-Bayo & Goka, 2014). One important consideration is that the source of the pyrethroids in the residue data used is unknown and these products are used for a variety of purposes, not just mosquito adulticiding.

5.5 Inert Ingredients

Inert ingredients are any ingredients purposefully included in a pesticide formulation that are not the active ingredient; they act as emulsifiers, propellants, dyes, solvents, and more (USEPA, 2020b). As mentioned earlier, EPA receives a full list of all inert ingredients in pesticides seeking registration, but MDAR does not. EPA reviews the information for inert ingredients that are used in pesticide formulations. At a minimum, a basic set of toxicological and environmental data is considered in the review to be approved for use in pesticide formulations. On most pesticide safety data sheets, inert ingredients are not listed because they are considered trade secrets. For 19 of the 43 pesticides MCD used from 2009 to 2020, the safety data sheets listed some of the inert ingredients. The sheets for the other 24 listed none. In many instances, more than 80 percent of the pesticide's formulation is considered a trade secret. All inert ingredients for which ERG could find information are listed in the tables in Section 4 of this report.

6. PER AND POLYFLUOROALKYL SUBSTANCES (PFAS) IN PESTICIDES

PFAS are a group of human-made chemicals with non-stick, water-resistant, and stain-resistant qualities that have been manufactured and used in thousands of consumer goods—including non-stick cookware, water-resistant clothing, and cosmetics—since the 1940s (Gluge et al., 2020). PFAS are highly persistent in both the environment and humans due to their strong carbon-fluorine bond (Gluge et al., 2020). As a result, PFAS are widely detected in soil, water, and air and can persist in the environment (PEER, 2020). Exposure to PFAS is associated with a variety of human health issues, including suppressed immune function, thyroid disease, testicular and kidney disease, cancers, liver damage, lipid and insulin dysregulation, and reproductive and developmental problems (Fenton et al., 2021) (Fenton, Ducatman et al. 2021).

Recent investigations have identified PFAS in multiple pesticide products, and the source of PFAS is not always known. Thus far, pesticide manufacturers have indicated through communications with MDAR that PFAS is not used in the formulations. Furthermore, EPA has indicated through communications with MDAR that no PFAS is used as active or inert ingredients in currently registered pesticide products. In addition, EPA has indicated in communications with the State FIFRA Issues Research and Evaluation Group (SFIREG) and it's working committees, where MDAR is represented, that no longer-chain fluorinated compounds are approved for use in currently registered pesticides. Investigation on the source of contamination is ongoing, by EPA, state agencies, and various environmental and consumer advocacy groups. Use of products where PFAS was found was discontinued until which time new product was supplied in a non-fluorinated container and testing of the new product showed no measurable levels of PFAS. Analysis by state agencies indicates that for product applied prior to discontinued use, the PFAS levels in the products do not present health concerns in the communities in which it was applied (Massachusetts Executive Office of Energy and Environmental Affairs, 2021). The timeline of investigation into PFAS is detailed below:

- In December 2020, Public Employees for Environmental Responsibility (PEER) tested samples of the pesticide Anvil 10+10 and discovered PFOA and HFPO-DA at various levels in the pesticide formulation (PEER, 2020).

- In January 2021, EPA tested the barrels that Anvil 10+10 is shipped in and found unspecified levels of nine PFAS. EPA indicated that the fluorinated shipping barrels may be the source of PFAS and asked states to discontinue use of Anvil 10+10 in fluorinated HDPE containers to minimize public health risks (USEPA, 2021e).

- Due to EPA's findings, the manufacturer of Anvil 10+10 recalled the fluorinated containers and supplied Massachusetts with Anvil 10+10 in non-fluorinated containers. DEP samples have confirmed the Anvil 10+10 in non-fluorinated containers does not contain measurable PFAS and the manufacturer has switched to all non-fluorinated containers (Massachusetts Executive Office of Energy and Environmental Affairs, 2021).

- On March 5, 2021, EPA released testing data from a limited number of fluorinated HDPE containers used by one pesticide product supplier. The data showed the presence of eight PFAS compounds, with levels ranging from 20 to 50 parts per billion (USEPA, 2021e). EPA found the PFAS compounds PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, and PFUdA in the fluorinated barrels (USEPA, 2021e). A summary of the results is presented in Figure 6-1.

- On April 20, 2021, Massachusetts Sierra Club examined the active ingredients of pesticides registered in Massachusetts and list the following ingredients as PFAS: hexaflumuron, metofluthrin, novaluron, noviflumuron, pyrifluquinazon, tefluthrin, and tetraconazole (SierraClub, 2021). It should be noted that the MCDs used none of these active ingredients from 2009 to 2020. According to the Sierra Club, these seven PFAS are the active ingredients in 89 pesticide products currently registered in Massachusetts (SierraClub, 2021). Additionally, the Sierra Club identified 73 organofluorine pesticides registered in Massachusetts that do not fit the current EPA working definition of PFAS but may be considered PFAS under a broadened definition (SierraClub, 2021). EPA's current definition of PFAS is, "a structure that contains the unit R-CF2-CF(R')(R"), where R, R', and R" do not equal "H" and the carbon-carbon bond is saturated (note: branching, heteroatoms, and cyclic structures are included)" (USEPA, 2021h).

- On May 25, 2021, DEP and MDAR reported that they had tested eleven pesticides from containers of different sizes and materials for PFAS contamination (Massachusetts, 2021). MDAR and DEP found elevated PFAS levels in multiple pesticide formulations. These data are summarized below in Table 6-1. Based on these findings, MCDs immediately stopped use of Vectobac 12AS packaged in 2.5- and 30-gallon containers, which were the only two sampled products with positive test results reported to be in active use. Although these samples yielded results indicating that branched chain PFOS might be present, the Vectobac sample results are uncertain regarding the specific chemical nature of the detections due to unresolved analytical issues and potential sampling device contamination. These issues are undergoing further assessment. Some, but not all, test results from this sampling process show the presence of PFAS in formulations from fluorinated and, occasionally, from reportedly non-fluorinated containers.. (Massachusetts Executive Office of Energy and Environmental Affairs, 2021).

Currently, EPA is testing different brands of fluorinated containers to determine whether the containers contain or leach PFAS and how the leaching occurs (USEPA, 2021e). EPA and DEP are testing non-fluorinated containers to confirm findings and are testing different brands of fluorinated containers to determine whether they contain and/or leach PFAS (Massachusetts Executive Office of Energy and Environmental Affairs, 2021).

Of note and not limited to pesticides, while there are reportedly 9,200 PFAS, EPA's three methods to support the analysis of PFAS in drinking water, Methods 533, 537 and 537.1, yield results for only 29 PFAS (0.3% of PFAS) (USEPA, 2021d). Without ability to test for more PFAS, the full scope of the problem of PFAS generally may remain unknown.

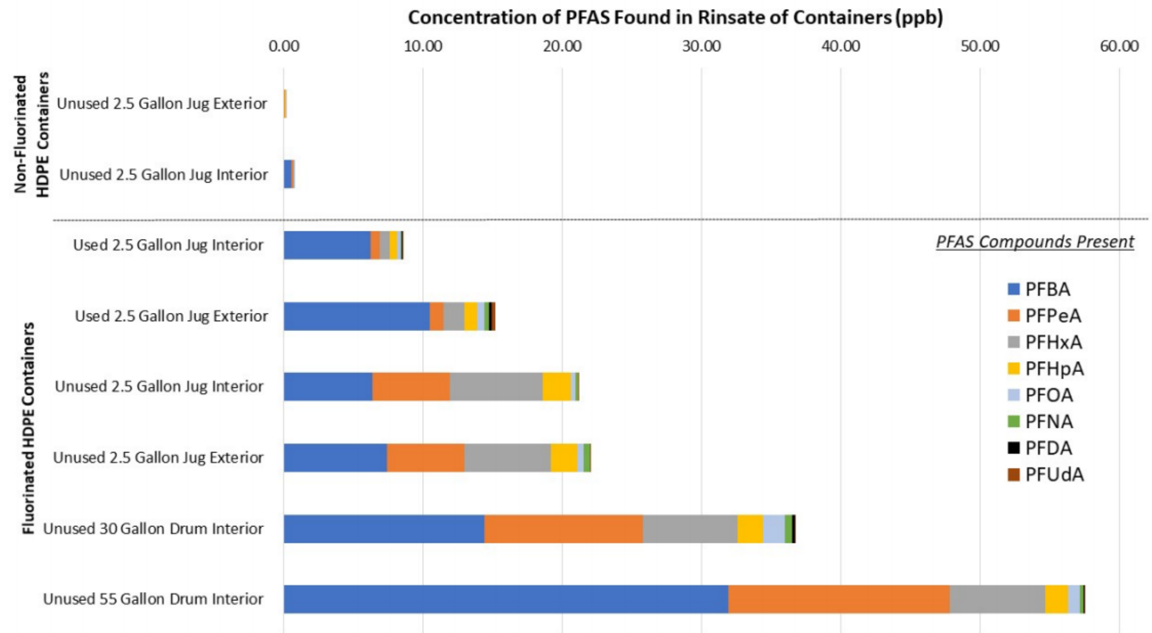

Figure 6-1. Results of EPA analysis on the amount of PFAS in rinsates from pesticide containers (USEPA, 2021e).

Table 6-1. DEP PFAS Test Results in Select Pesticides in Varying Container Types and Sizes; 5/13/2021

Pesticide Formulation	Number of Containers, Lots, and Samples	Summary of Results PFAS Analyte (ppt)	Notes
One PFAS above limit of quantification. Additional sampling needed to determine whether noted results are meaningful and reproducible.			
CocoBear 2.5-gallon	1 container	PFBA (193)	
Aqua Zenivex 2.5-gallon	2 containers, 2 lots	PFOA (3140; 410 J)	
Multiple PFAS consistently above limit of quantification. The elevated levels suggest an inadvertent source that may be preventable.			
Anvil 10+10 2.5-gallon	2 containers, 2 lots (fluorinated)	PFHpS (128–138; in all) PFOS (76 J–141; in all)	Fluorinated containers identified as a likely source
Anvil 10+10 55-gallon plastic	3 containers, 2 lots, 6 samples (fluorinated)	PFBA (171–716; in all) PFPeA (55 J–292; in all) PFHxA (24 J–132; in all) PFOA (22 J–99; in 3) PFHpS (52 J–107; in 3) PFUnA (14 J–184; in 3)	Fluorinated containers identified as a likely source
Mavrik Perimeter 8 oz.	2 containers; 1 lot	PFBA (6,820; 9,280) PFPeA (2,380; 3,610) PFHpA (287; 427) PFHpS (2,710; 2,060) PFOS (1,220; 1,240) Maximum total PFAS = 16,703	These containers are reported to be non-fluorinated, so a source has yet to be determined

Pesticide Formulation	Number of Containers, Lots, and Samples	Summary of Results PFAS Analyte (ppt)	Notes
Preliminary results: PFOS identification and quantitation for these samples are uncertain due to analytical issues. These are being discussed and assessed.			
Vectobac 12AS 2.5-gallon	3 containers; 2 lots	PFOS: tentative identification and preliminary quantitation suggest significant levels may be present (2,760–5,040; in all) PFUnA (169–272; in all) PFDA (62 J–124; in all) PFNA (74 J–226; in all) Preliminary maximum total PFAS = 5,682	These samples have presented significant analytical challenges, which may be attributable to surfactant additives The containers are reported to be non-fluorinated, so a potential PFAS source has yet to be identified
Vectobac 12AS 30-gallon	8 containers; 9 samples; 4 lots	PFOS: tentative identification and preliminary quantitation suggest significant levels may be present (2,320–2,720; in all) PFUnA (151–215 J; in all) Preliminary maximum total PFAS = 2,935 Note: 1 sample was below limit of quantification for all analytes; analytical issues may have compromised these results	These samples have presented significant analytical challenges, which may be attributable to surfactant additives The containers are reported to be non-fluorinated, so a potential PFAS source has yet to be identified

J = estimated value below the limit of quantitation but above the detection limit. Lowest J value noted if at least one sample had a detection greater than the limit of quantitation.

7. Pesticide Resistance in Mosquitoes

Resistance to insecticides is defined as a reduction in a pest population's susceptibility to insecticides, typically due to overuse or misuse of selected pesticides (IRAC, 2020). When the same pesticide is used repeatedly in an area, local mosquito populations naturally select for traits that resist the pesticide (IRAC, 2020). Additionally, resistance to one insecticide can confer resistance to other structurally similar pesticides, called cross-resistance (Nauen, 2007). Insects have multiple mechanisms of developing insecticide resistance. The two most common methods are metabolic resistance and target-site resistance. Mosquitoes with metabolic resistance can detoxify pesticides more quickly than non-resistant mosquitoes (IRAC, 2021). Mosquitoes with target-site resistance have developed a genetic mutation that prevents the pesticide from binding or interacting with its intended targets, reducing the pesticide's ability to act (IRAC, 2021).

In Massachusetts, seven mosquito species are involved or suspected to be involved in the spread of EEE and West Nile virus, either between animals or from animals to humans. However, only two of these seven species have been studied for their resistance to pesticides: *Aedes vexans*, a species suspected of transmitting EEE from birds to humans, and *Culex pipiens*, the primary vector of West Nile virus in Massachusetts.

Culex pipiens has shown resistance to pyrethroids, organophosphates, and bacterial insecticides (Johnson & Fonseca, 2016; Kioulos et al., 2013; Paul et al., 2005). This species has two methods of resistance to pyrethroids, metabolic resistance and target-site resistance (Scott et al., 2014). In 2016, researchers found that a genetic modification in *C. pipiens* that creates strong resistance to pyrethroid insecticides was widely distributed in New Jersey (Johnson & Fonseca, 2016). In 2005, a study in New York showed that *C. pipiens* had low resistance to methoprene, phenothrin, and Bs and high levels of resistance to Bti (Paul et al., 2005). However, in another study, *C. pipiens* displayed resistance to pyrethroids but showed no evidence of resistance to Bti (Kioulos et al., 2013). Researchers also found a positive correlation between resistance levels and amount of pesticide applied (Paul et al., 2005).

Studies of *Aedes vexans* mosquitoes have found no resistance to pesticides with the active ingredient Bti and some resistance to the active ingredient permethrin, a pyrethroid. *Aedes vexans* mosquitoes in Germany and France have shown no evidence of resistance to Bti after decades of use (Becker et al., 2018; Tetreau et al., 2013). A study in North Dakota found permethrin resistance in *A. vexans* mosquitoes in the region (Scott et al., 2014).

Insecticide resistance can also be conferred from exposure to insecticides from private companies and private agriculture (Richards et al., 2020). A 2017 study in South Dakota, found that *Ae. vexans* mosquitoes in agricultural communities with mosquito control programs had higher levels of resistance to pyrethroid insecticides (Dunbar et al., 2017). This finding suggests that when private agricultural mosquito management and public mosquito control programs use pesticides from the same MoA groups, pesticide resistance can increase (Dunbar et al., 2017). One solution to this issue is to ensure that private businesses and public mosquito control programs use insecticides from different MoA groups (Dunbar et al., 2017).

Mosquito control programs may monitor local mosquitoes for resistance regularly and update their mosquito control plans based on the results (Richards et al., 2020). The most effective strategy to avoid insecticide resistance is to alternate or rotate insecticides from different MoA groups (IRAC, 2020; Nauen, 2007). To rotate insecticides, programs may use an insecticide from one MoA group for a single generation of mosquitoes, then rotate to an insecticide from a different MoA group for the next generation of mosquitoes (Bethke, 2013). One study of *C. pipiens* demonstrated the effectiveness of rotating insecticidal agents. In 2005, a study in Lebanon found that *C. pipiens* had developed target site resistance to organophosphate insecticides after organophosphates had been used for a long period in the area (Osta et al., 2012). Due to the high levels of resistance, in 2006 most municipalities switched to pyrethroid insecticides (Osta et al., 2012). In 2012, researchers found a lower incidence of the target site mutation that gave the mosquitoes resistance to organophosphates (Osta et al., 2012).

Control programs can also reduce insecticide resistance by minimizing pesticide use, using non-chemical integrated pest management strategies, and avoiding the use of persistent chemicals, since prolonged exposure to a chemical can increase resistance (Bethke, 2013). Approximately half of Massachusetts MCDs reported undertaking some type of pesticide resistance testing in 2020. Refer to the Report 5: Integrated Pest Management and Non-Chemical Mosquito Controls report for more information on non-chemical mosquito control strategies.

8. EVALUATING PESTICIDE EFFICACY AND PESTICIDE RISK PROFILES

The main purpose for using pesticides for mosquito control is to reduce the number of mosquitoes in order to mitigate public health risks caused by mosquito-borne illness, and also to alleviate nuisance levels of mosquitoes that may or may not carry disease, based on complaints by the public. However, the efficacy of the products is highly dependent on many factors, such as the weather; time of year; vegetation cover; activity of mosquitoes; and water temperature, pH, and flow. Therefore, the efficacy of pesticides used in Massachusetts varies with each use. However, following label directions on the most appropriate application approach theoretically should result in an efficacious mosquito kill. Any efficacy claims made on a product is evaluated by the U.S. EPA (USEPA, 2021f). Table 8-1 outlines the efficacy data from Massachusetts mosquito aerial spraying operations in response to increased EEE risk.

According to the Massachusetts arbovirus surveillance and response plan (Bharel & Cranston, 2020a):

"*Key lessons learned from previous operations include:*

- *Any reduction in population is expected to be temporary, lasting no more than 2 weeks…*
- *The greater the mosquito activity, the greater the efficacy;*
    - *Mosquito activity is minimal at 60°F and increases with increasing temperature.*
    - *Mosquito activity generally increases with increasing humidity, but is reduced when raining.*
- *Coverage of large spray blocks improves efficacy over smaller, separate strips; and*
- *Coverage of the spray area in the shortest amount of time possible improves efficacy.*
- *The life cycle of the mammal-biting mosquito species of greatest concern is such that the majority of populations are gone by end of August/first week of September.*
- *Mosquito surveillance and weather pattern data are essential in helping to determine need and timing for aerial spray interventions*."

The available data show that the total reduction in the number of mosquitoes can range significantly—from 20 to 89 percent—after aerial spraying with pyrethroid compounds. But this reduction is expected to be temporary.

Table 8-1. Aerial Spray Efficacy: Percent Reduction in Mosquitoes Trapped

Aerial Intervention Location	Start Date	End Date	Total Reduction in Primary Mosquito Vector[a,b]	Total Reduction in Mosquitoes Trapped	Temperature Range (°F)[c]	Dewpoint Range (°F)[c]	Acres per Hour (Average Across All Hours of Spray)
Bristol/Plymouth	8/8/2006	8/9/2006	35–92%	59–86%	59–64	53–57	17,499
Bristol/Plymouth	8/22/2006	8/24/2006	0–94%	60–89%	57–69	55–62	34,191
Bristol/Plymouth	8/5/2010	8/7/2010	87–89%	77–87%	58–79	57–73	26,194
Bristol/Plymouth	7/20/2012	7/22/2012	14–84%	42–81%	56–73	54–61	30,701
Bristol/Plymouth	8/13/2012	8/14/2006	46–60%	36–47%	66–73	64–66	21,981
Bristol/Plymouth	8/8/2019	8/11/2019	66%	58%	55–72	50–70	20,112
Bristol/Plymouth	8/21/2019	8/25/2019	91%	25%	57–77	51–74	15,066
Middlesex/Worcester	8/26/2019	8/27/2019	38%	20%	53–64	45–57	16,212
Middlesex/Norfolk/ Worcester	9/10/2019	9/18/2019	—	—	52–70	42–69	16,975
Hampden/Hampshire /Worcester	9/16/2019	9/17/2019	—	—	48–58	47–51	14,388
Bristol/Plymouth	9/18/2019	9/24/2019	—	53%	54–70	51–67	12,125
Bristol/Plymouth	8/10/2020	8/11/2020	82%	70%	73-78	68-72	29,833

Source: (Bharel & Cranston, 2021a)

— = control not detected; calculations may be affected by small sample sizes.

[a] Primary mosquito vector is the mammal-biting species *Coquillettidia perturbans*, considered to be the mosquito most likely to spread EEE to humans.

[b] Data sources include DPH and the Bristol and Plymouth County MCDs. 2006–2012 data shown as ranges inclusive of all three data sources. 2019 combines data from all three sources into a single calculation.

[c] Weather data taken from Plymouth, Worcester, and Westover airports and may not accurately represent actual temperature and dewpoint at location of spraying.

The efficacy of these products can be considered in the context of the hazard profiles of the larvicides and adulticides used in Massachusetts. As the preceding sections discuss, although some toxicological studies indicate potential concern for human health, the major risk driver is ecological toxicity. As summarized in Table 5-7, pesticides used by MCDs and the SRB for mosquito control all have been found by EPA to be highly toxic in at least one ecological category, with pyrethroids demonstrating the greatest toxicity to the environment. EPA did evaluate potential alternative compounds to replace pyrethroids, but found that other chemical options were limited and that those alternatives—i.e., organophosphates—also have toxicity concerns; see USEPA (2018a). Therefore, exposure to these compounds should be minimized to limit risk. Larvicides used by the Commonwealth appear to have fewer toxic characteristics than the adulticides, but are still not without toxic properties.

There are also unknown ecological and human health risks that EPA is not evaluating. Not all ingredients in pesticide products are known, because companies protect their product formulations. Meanwhile, compounds may enter the products from containers, as demonstrated with the new issue related to PFAS.

Ultimately, pesticides must be used with caution and consideration to the tradeoffs—for example, the need to remove mosquitoes active at nuisance levels versus the ecological risk that may occur as a result of the application. The risk and benefits of mosquitoes and mosquito control are presented in Report 8: Impact of Mosquitoes, Mosquitoes as Disease Vectors and Mosquito Control Measures.

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Appendix A

ESTIMATING PESTICIDE WEIGHTS

FourStar Bti briquets were only used by one MCD, which did not report the weight of the tablets in its annual report. When ERG asked the MCD, the MCD reported using 45-day briquets (small briquets). The label for a small FourStar Bti briquet lists two possible weights, 10 or 12.5 grams. ERG estimated the briquet weight to be 11.25 grams, an average of the two possible weights.

Additionally, 12 of the pesticides used by MCDs are liquids and had usage values reported in volumes.

- For six of these 12 pesticides, the safety data sheets and labels had information on the total weight of active ingredient. For example, Zenivex E4’s label stated that it “Contains 0.30 lb Etofenprox/gallon” and listed etofenprox as the active ingredient, making up 4 percent of the total product. ERG assumed that 0.30 pounds was 4 percent of this product’s weight per gallon, meaning that the entire product weighed 7.5 pounds per gallon.

- For the remaining six pesticides, ERG used an average of the weights of the six calculated pesticides, 7.9 pounds/gallon, as the approximate weight per volume.

Appendix B

SELECT INFORMATION FROM THE EPA RISK ASSESSMENT FOR PYRETHROIDS

This appendix provides levels of concern used in EPA's risk assessment for pyrethroids (USEPA, 2016e) and the results of EPA's ecological risk assessment for pyrethroids when used in mosquito adulticiding. The data have been extracted directly from the report; no modifications have been made.

Table B-1. Summary of the Levels of Concern Used for the Risk Quotient Method

Risk Presumption	RQ	LOC
Birds and mammals		
Acute Risk	Diet-based EEC/LC_{50} or dose-based EEC/LD_{50}	0.5
Acute Restricted Use	Diet-based EEC/LC_{50} or dose-based EEC/LD_{50} (or LD_{50} < 50 mg/kg)	0.2
Acute Endangered Species	Diet-based EEC/LC_{50} or dose-based EEC/LD_{50}	0.1
Chronic Risk	Diet or dose-based EEC/NOAEC	1
Aquatic Animals		
Acute Risk	EEC/LC_{50} or EC_{50}	0.5
Acute Restricted Use	EEC/LC_{50} or EC_{50}	0.1
Acute Endangered Species	EEC/LC_{50} or EC_{50}	0.05
Chronic Risk	EEC/NOAEC	1
Terrestrial and Semi-Aquatic Plants, and Aquatic Plants		
Acute Risk	EEC/EC_{25}	1
Acute Endangered Species	EEC/EC_{05} or NOAEC	1
Terrestrial Invertebrates		
Acute risk to bees	EEC/LD_{50}	0.4
Chronic risk to bees	EEC/NOAEC	1

Table B-2. Summary of Risk Determinations for Adulticide Uses of Pyrethrins for Freshwater and Estuarine/Marine Fish and Invertebrates

	LOC Exceedances[1]											
	FW Fish		E/M Fish		FW Inverts		FW Benthic Inverts		E/M Inverts		E/M Benthic Inverts	
Scenarios	Acute	Chronic	Acute	Chronic	Acute	Chronic	Acute	Chronic	Acute	Chronic	Acute	Chronic
CA residential + impervious Aerial, 0.0025 lb a.i./A x 25 @ 3 days	*X*				*X*	**X**	*X*	**X**	*X*	**X**	*X*	
FL residential + impervious Aerial, 0.0025 lb a.i./A x 25 @ 3 days	*X*				*X*	**X**	*X*		*X*		*X*	
FL turf Aerial, 0.008 lb a.i./A x 25 @ 3 days	*X*		*X*	**X**	**X**	**X**	**X**	**X**	**X**	**X**	*X*	**X**
FL turf Aerial, 0.0025 lb a.i./A x 10 @ 7 days					*X*		*X*		*X*			
FL pepper Aerial, 0.008 lb a.i./A x 25 @ 3 days	*X*		*X*	**X**	**X**	**X**	**X**	**X**	**X**	**X**	*X*	**X**
FL pepper Aerial, 0.0025 lb a.i./A x 10 @ 7 days					*X*		*X*		*X*			
FL pepper Aerial, 0.008 lb a.i./A x 1 app	*X*				*X*				*X*			

[1]A light shaded and italics "*X*" means an exceedance of the acute listed species LOC (listed species LOC: acute = 0.05). A dark shaded and bolded "**X**" means an exceedance of the listed and non-listed species LOCs (non-listed species LOCs: acute = 0.5; chronic = 1.0).

According to EPA, the California and Florida turf scenarios represent uses such as parks, campsites, athletic fields, and golf courses. The Florida pepper scenarios represent agricultural uses in diverse areas of the United States.

Table B-3. Acute and Chronic RQs for Freshwater and Estuarine/Marine Fish Exposed to Pyrethrins

Scenario/Uses	Peak EEC (µg/L)	60-day EEC (µg/L)	FW Fish		E/M Fish	
			Acute RQ#	Chronic RQ#	Acute RQ#	Chronic RQ#
CA residen + impervious Aerial, 0.0025 lb a.i./A x 25 @ 3 days	0.337	0.248	*0.07*	0.13	0.02	0.35
FL residen + impervious Aerial, 0.0025 lb a.i./A x 25 @ 3 days	0.251	0.173	*0.05*	0.09	0.02	0.25
FL turf Aerial, 0.008 lb a.i./A x 25 @ 3 days	1.69	0.770	*0.33*	0.41	*0.11*	**1.1**
FL turf Aerial, 0.0025 lb a.i./A x 10 @ 7 days	0.150	0.0790	0.03	0.04	0.01	0.11
FL pepper Aerial, 0.008 lb a.i./A x 25 @ 3 days	1.63	0.714	*0.32*	0.38	*0.10*	**1.0**
FL pepper Aerial, 0.0025 lb a.i./A x 10 @ 7 days	0.144	0.0730	0.03	0.04	0.01	0.10
FL pepper Aerial, 0.008 lb a.i./A x 1 app	0.321	0.0309	*0.06*	0.02	0.02	0.04

Generally, numbers were rounded to three significant figures, except for the RQs, for which no more than two decimal places were used.

= LOC exceedances (acute RQ ≥ 0.05; chronic RQ ≥ 1.0, for listed species) are shaded. A light shaded and italics "*RQ*" means it exceeds the listed species LOC. A dark shaded and bolded "**RQ**" represents LOC exceedances of the listed species and non-listed species LOCs.

For freshwater fish, Acute RQ = use-specific peak EEC / 5.1 ppb [for Rainbow Trout, *Oncorhynchus mykiss*]. Chronic RQ = use-specific 60-day EEC / 1.9 ppb [for Fathead Minnow, *Pimephales promelas*].

For estuarine/marine fish, Acute RQ = use-specific peak EEC / 16 ppb [for Sheepshead minnow, *Cyprinodon variegatus*]. Chronic RQ = use-specific 60-day EEC / 0.7 ppb [for Sheepshead minnow, *Cyprinodon variegatus*].

Table B-4. Summary of Risk Determinations for Adulticide Uses of Deltamethrin for Freshwater and Estuarine/Marine Fish and Invertebrates

Scenarios	LOC Exceedances[1]											
	FW Fish		E/M Fish		FW Inverts		FW Benthic Inverts		E/M Inverts		E/M Benthic Inverts	
	Acute	Chronic	Acute	Chronic	Acute	Chronic	Acute	Chronic	Acute	Chronic	Acute	Chronic
CA residential + impervious Ground, 0.00134 lb a.i./A x 25 @ 3 days	**X**		*X*		**X**	**X**	**X**	**X**	**X**	**X**	*X*	**X**
FL residential + impervious Ground, 0.00134 lb a.i./A x 25 @ 3 days	**X**		*X*		**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
FL turf Ground, 0.00134 lb a.i./A x 25 @ 3 days	*X*				**X**	**X**	**X**	**X**	**X**	**X**	*X*	**X**
FL turf Ground, 0.00089 lb a.i./A x 10 @ 7 days	*X*				**X**	**X**	**X**	**X**	**X**		*X*	
FL pepper Ground, 0.00134 lb a.i./A x 10 @ 3 days	*X*				**X**	**X**	**X**	**X**	**X**	**X**	*X*	
FL pepper Ground, 0.00089 lb a.i./A x 10 @ 7 days	*X*				**X**	**X**	**X**	**X**	**X**		*X*	
FL pepper Ground, 0.00134 lb a.i./A x 1 app	*X*				**X**	**X**	*X*	**X**	**X**			
FL turf Aerial, 0.00134 lb a.i./A x 25 @ 3 days	*X*				**X**	**X**	**X**	**X**	**X**	**X**	*X*	**X**
FL residential + impervious Aerial, 0.00134 lb a.i./A x 25 @ 3 days	**X**		*X*		**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**

[1]A light shaded and italics "*X*" means an exceedance of the acute listed species LOC (listed species LOC: acute = 0.05). A dark shaded and bolded "**X**" means an exceedance of the listed and non-listed species LOCs (non-listed species LOCs: acute = 0.5; chronic = 1.0).

Table B-5. Acute and Chronic RQs for Freshwater and Estuarine/Marine Fish Exposed to Deltamethrin

Scenario/Uses	Peak EEC (µg/L)	60-day EEC (µg/L)	FW Fish Acute RQ#	FW Fish Chronic RQ#	E/M Fish Acute RQ#	E/M Fish Chronic RQ#
CA residen + impervious Ground, 0.00134 lb a.i./A x 25 @ 3 days	0.125	0.00248	**0.83**	0.15	*0.22*	0.10
FL residen + impervious Ground, 0.00134 lb a.i./A x 25 @ 3 days	0.183	0.00414	**1.2**	0.24	*0.32*	0.17
FL turf Ground, 0.00134 lb a.i./A x 25 @ 3 days	0.0128	0.00146	*0.09*	0.09	0.02	0.06
FL turf Ground, 0.00089 lb a.i./A x 10 @ 7 days	0.00818	0.000411	*0.05*	0.02	0.01	0.02
FL pepper Ground, 0.00134 lb a.i./A x 10 @ 3 days	0.0128	0.000717	*0.09*	0.04	0.02	0.03
FL pepper Ground, 0.00089 lb a.i./A x 10 @ 7 days	0.00832	0.000404	*0.06*	0.02	0.01	0.02
FL pepper Ground, 0.00134 lb a.i./A x 1 app	0.0120	7.89×10^{-5}	*0.08*	<0.01	0.02	<0.01
FL turf Aerial, 0.00134 lb a.i./A x 25 @ 3 days	0.0211	0.00242	*0.14*	0.14	0.04	0.10
FL residen + impervious Aerial, 0.00134 lb a.i./A x 25 @ 3 days	0.200 (0.390)*	0.00824	**1.3**	0.48	*0.34*	0.34

Generally, numbers were rounded to three significant figures, except for the RQs, for which no more than two decimal places were used.

* EECs marked with an asterisk were set to 0.200 ppb because they exceeded the limit of solubility of deltamethrin in the aquatic modeling.

= LOC exceedances (acute RQ ≥ 0.05; chronic RQ ≥ 1.0, for listed species) are shaded. A light shaded and italics "*RQ*" means it exceeds the listed species LOC. A dark shaded and bolded "**RQ**" represents LOC exceedances of the listed species and non-listed species LOCs.

For freshwater fish, Acute RQ = use-specific peak EEC / 0.15 ppb [for Rainbow trout, *Oncorhynchus mykiss*]. Chronic RQ = use-specific 60-day EEC / 0.017 ppb [for Fathead Minnow, *Pimephales promelas*].

For estuarine/marine fish, Acute RQ = use-specific peak EEC / 0.58 ppb [for Sheepshead minnow, *Cyprinodon variegatus*]. Chronic RQ = use-specific 60-day EEC / 0.024 ppb [for Sheepshead minnow, *Cyprinodon variegatus*].

Table B-6. Summary of Risk Determinations for Adulticide Uses of Permethrin for Freshwater and Estuarine/Marine Fish and Invertebrates

Scenarios	LOC Exceedances[1]											
	FW Fish		E/M Fish		FW Inverts		FW Benthic Inverts		E/M Inverts		E/M Benthic Inverts	
	Acute	Chronic	Acute	Chronic	Acute	Chronic	Acute	Chronic	Acute	Chronic	Acute	Chronic
CA residential + impervious Aerial, 0.007 lb a.i./A x 25 @ 3 days	*X*	**X**	*X*	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
FL residential + impervious Aerial, 0.007 lb a.i./A x 25 @ 3 days	*X*	**X**	*X*		**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
FL turf Aerial, 0.007 lb a.i./A x 25 @ 3 days	*X*	**X**	*X*		**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
FL turf Aerial, 0.0035 lb a.i./A x 10 @ 7 days	*X*		*X*		**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
FL pepper Aerial, 0.007 lb a.i./A x 25 @ 3 days	*X*	**X**	*X*		**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
FL pepper Aerial, 0.0035 lb a.i./A x 10 @ 7 days	*X*		*X*		**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
FL pepper Aerial, 0.007 lb a.i./A x 1 app	*X*		*X*		**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**

[1] A light shaded and italics "*X*" means an exceedance of the acute listed species LOC (listed species LOC: acute = 0.05). A dark shaded and bolded "**X**" means an exceedance of the listed and non-listed species LOCs (non-listed species LOCs: acute = 0.5; chronic = 1.0).

Table B-7. Acute and Chronic RQs for Freshwater and Estuarine/Marine Fish Exposed to Permethrin

Scenario/Uses	Peak EEC (µg/L)	60-day EEC (µg/L)	FW Fish		E/M Fish	
			Acute RQ#	Chronic RQ#	Acute RQ#	Chronic RQ#
CA residen + impervious Aerial, 0.007 lb a.i./A x 25 @ 3 days	0.349	0.155	*0.44*	**3.0**	*0.16*	**1.08**
FL residen + impervious Aerial, 0.007 lb a.i./A x 25 @ 3 days	0.307	0.105	*0.39*	**2.0**	*0.14*	0.73
FL turf Aerial, 0.007 lb a.i./A x 25 @ 3 days	0.308	0.113	*0.39*	**2.2**	*0.14*	0.79
FL turf Aerial, 0.0035 lb a.i./A x 10 @ 7 days	0.127	0.0235	*0.16*	0.45	*0.06*	0.16
FL pepper Aerial, 0.007 lb a.i./A x 25 @ 3 days	0.313	0.112	*0.40*	**2.2**	*0.14*	0.78
FL pepper Aerial, 0.0035 lb a.i./A x 10 @ 7 days	0.129	0.0233	*0.16*	0.44	*0.06*	0.16
FL pepper Aerial, 0.007 lb a.i./A x 1 app	0.225	0.00584	*0.28*	0.11	*0.10*	0.04

Generally, numbers were rounded to three significant figures, except for the RQs, for which no more than two decimal places were used.

= LOC exceedances (acute RQ $\geq$ 0.05; chronic RQ $\geq$ 1.0, for listed species) are shaded. A light shaded and italics "*RQ*" means it exceeds the listed species LOC. A dark shaded and bolded "**RQ**" represents LOC exceedances of the listed species and non-listed species LOCs.

For freshwater fish, Acute RQ = use-specific peak EEC / 0.79 ppb [for Bluegill sunfish, *Lepomis macrochirus*]. Chronic RQ = use-specific 60-day EEC / 0.052 ppb [for Bluegill sunfish, *Lepomis macrochirus*, based on an ACR].

For estuarine/marine fish, Acute RQ = use-specific peak EEC / 2.2 ppb [for Atlantic Silverside, *Menidia menidia*]. Chronic RQ = use-specific 60-day EEC / 0.143 ppb [for Atlantic Silverside, *Menidia menidia*].

Report 5: Integrated Pest Management and Non-chemical Mosquito Controls

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1. Executive Summary

Integrated Pest Management (IPM) involves integration of non-chemical mosquito controls, such as stormwater management, as well as use of larvicides and/or adulticides when warranted. IPM is considered best practice across the United States and is carried out by nine of the Massachusetts mosquito control districts (MCDs). To determine efficacy and summarize the best available science related to IPM and non-chemical mosquito controls, the ERG team reviewed MCDs' Annual Reports from 2009-2020, requested detailed information from MCDs on spending and what was known about the efficacy of various IPM activities they undertake, and conducted literature reviews.

The literature indicates that individual components of IPM are effective in reducing mosquito populations and reducing human contact with mosquitos. For example, a range of actions to remove of standing water (e.g., culvert rehabilitation) are available that can essentially eliminate mosquito larval habitats. In general, the engineering source reduction measures evaluated in this report are undertaken for reasons other than mosquito control, but they have the co-benefits of decreasing mosquito habitat. However, the team could not identify any studies that examined the efficacy of IPM as a whole on mosquito populations over a large geographic area, such as Massachusetts, nor evaluations that would help to optimize IPM programs to accommodate the unique characteristics of residents and ecosystems in smaller geographic areas, such as MCDs.

2. Overview

This report responds to the following requested research area in the scope outlined by the Mosquito Control Task Force (MCTF):

> "Summarize the best-available science on options for non-chemical mosquito control, which may include but is not limited to: Integrated pest management; Public education; Mosquito predator habitat; Stormwater management; River and wetlands restoration; Dam removal and culvert improvements; Rain gardens and bioswales; Other ecologically-based mosquito management techniques.
>
> - Report shall include information and data on practices currently employed by Massachusetts cities and towns, as well as practices employed by other states and/or cities/towns, including quantifiable data demonstrating program efficacy or lack of program efficacy.
> - Report must address costs of implementation of non-chemical mosquito control.
> - Report must address options for non-chemical mosquito control in surface water exclusion buffer zones."

The content in this report is based on reviews of current non-chemical mosquito control used in Massachusetts and other states; input from arbovirus, ecotoxicity, and pollinator experts; literature reviews; downloads of Massachusetts dam data; a public records request from the Massachusetts Office of Dam Safety; an interview with the Division of Ecological Restoration (DER) regarding dam removal; requests to the Executive Office of Energy and Environmental Affairs (EEA) for cost information (for aerial spraying and education/communication in recent years); and breakdowns of 2021 mosquito control district (MCD) budgets by integrated pest management (IPM) components requested from the nine Massachusetts MCDs carrying out IPM.

Section 3 of this report reviews Massachusetts' approach to IPM, which uses non-chemical controls, education, and surveillance to minimize the use of pesticides. The sections after that summarize five types of non-chemical mosquito controls:

- Education and public engagement (Section 4)
- Stormwater management, including rain gardens and bioswales (Section 5)
- River and wetlands restoration (Section 6)
- Mosquito predator habitat (Section 7)
- Dam removal and culvert management (Section 8)

For each category of non-chemical mosquito controls and for IPM, this report summarizes available information on:

- Current practices in Massachusetts
- Considerations for wetland resource areas and buffer zones under the Massachusetts Wetlands Protection Act (MGL c. 131 § 40)
- Costs
- Current practices in other states
- Best available science/best practices related to the approach

3. INTEGRATED PEST MANAGEMENT

The Massachusetts Pesticide Control Act (MGL c. 132 B, § 7) defines IPM as "a comprehensive strategy of pest control whose major objective is to achieve desired levels of pest control in an environmentally responsible manner by combining multiple pest control measures to reduce the need for reliance on chemical pesticides; more specifically, a combination of pest controls which addresses conditions that support pests and may include, but is not limited to, the use of monitoring techniques to determine immediate and ongoing need for pest control, increased sanitation, physical barrier methods, the use of natural pest enemies and a judicious use of lowest risk pesticides when necessary."

The basic components of IPM for mosquitoes are source reduction, surveillance of larval and adult mosquitoes, control of all mosquito life stages (using both chemical and non-chemical means), insecticide resistance testing, education, community involvement, and evaluation of actions taken (see Figure 3-1) (Centers for Disease Control and Prevention, 2020b; United States Environmental Protection Agency, 2017b). This section discusses IPM broadly; subsequent sections drill into the details on specific education, source reduction, and non-chemical control approaches called out by the MCTF in the scope of work.

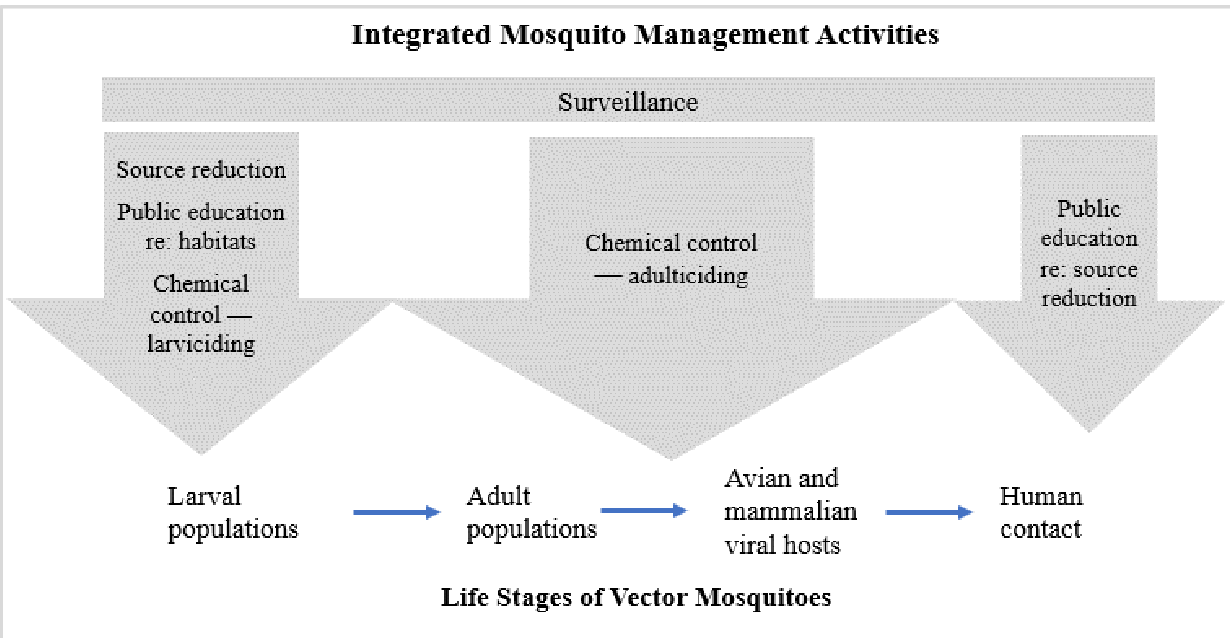


Figure 3-1. IPM activities and their effect on mosquito life stages.

3.1 Current Practices in Massachusetts

Figure 3-2 provides an overview of the prevalence of the IPM components that MCDs are currently using across the Commonwealth. In 2020, all 11 MCDs active in that year were involved with adult mosquito surveillance; 10 of the 11 undertook larval surveillance. Eight MCDs used adult mosquito controls and 10 used larval controls. Although 10 MCDs reported education and outreach efforts, details are not available to determine if these activities were related to source reduction, personal protection, or increasing awareness of the MCD program.

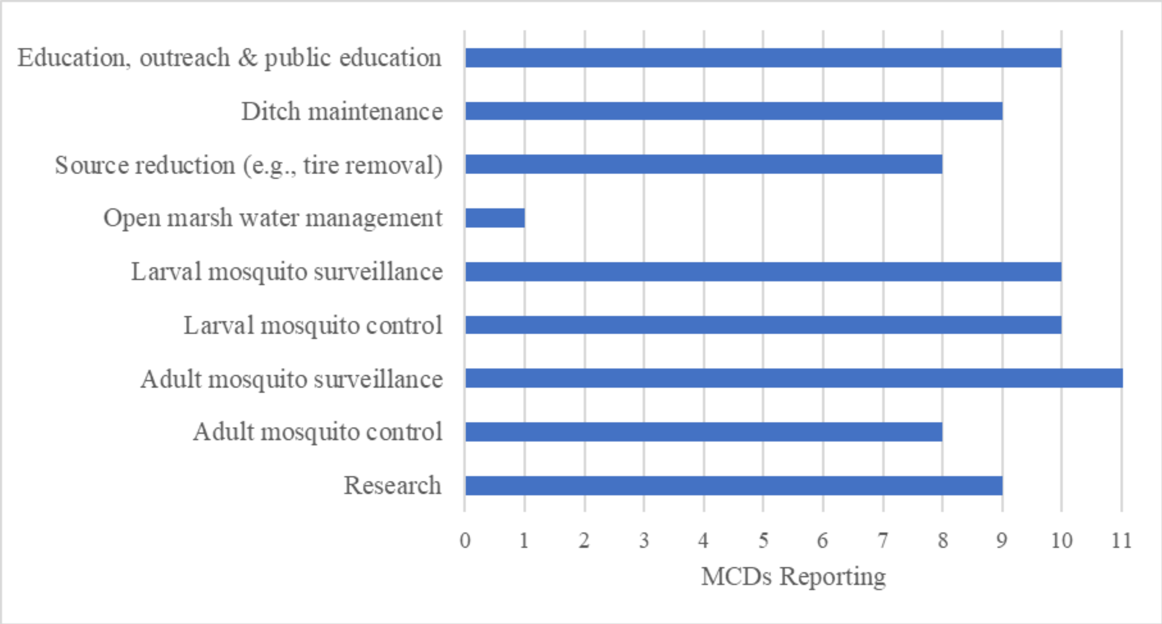


Figure 3-2. IPM components reported by MCDs in 2020.

While all 11 MCDs, along with other state agencies, participate in larval and adult mosquito surveillance efforts, there is a lack of detailed reporting on their specific IPM activities. Expenditures for each component of IPM are presented in Sections 3.1.2.1 and 3.1.2.2. To date, quantitative assessments of IPM's efficacy at reducing mosquito populations in Massachusetts (both nuisance and vector mosquitoes) and the human health risks from vector mosquitoes have not been undertaken (EEA, personal communication, July 2021).

MCDs' IPM-related efforts are complemented by the contributions of other state agencies as described in the *Massachusetts Arbovirus Surveillance and Response Plan:* for example, surveillance by the Department of Public Health (DPH); post-spray monitoring of honeybees by the Massachusetts Department of Agricultural Resources (MDAR); surface drinking water supply monitoring by the Department of Environmental Protections (DEP); and development of communications materials related to arbovirus risks, personal protection, and source reduction by DPH (Bharel & Cranston, 2020a).

IPM has been widely adopted and practiced across Massachusetts MCDs and supported by activities carried out by other state agencies (e.g., surveillance, review of toxicological profiles of pesticides, evaluation and mitigation of impacts on non-target receptors, and risk communication).

3.1.1 Considerations for Wetland Resource Areas and Buffer Zones

A number of IPM source reduction activities—specifically, stormwater management, dam removal, culvert management, and river and wetlands management—are expected to affect Wetlands Protection Act–protected areas or associated buffer zones. Therefore, the Wetlands Protection Action applicability and regulatory requirements are summarized in this section and then referred to in each of the following sections summarizing non-chemical controls.

The Massachusetts Wetlands Protection Act (MGL c. 131, § 40; 310 CMR 10.00) defines several types of wetland resource areas that are subject to protection in order to preserve wetland functions according to the eight statutory interests, which include water supply, wildlife habitat, flood control, fisheries, and shellfish. It also establishes requirements for the review of proposed projects that could alter wetlands including vegetation destruction, change in hydrology, or change in water quality. The Massachusetts Rivers Protection Act (MGL c. 131, § 40; 310 CMR 10.58) defines riverfront areas and regulates alteration of land or hydrology near Massachusetts rivers.

According to these two acts, the following areas are subject to protection:

- Inland wetlands, including bogs, swamps, marshes, wet meadows, land subject to flooding, banks, vernal pools, lakes, ponds, and riverfront areas (200 feet from most rivers; 25 feet from urban rivers).

- Coastal wetlands, including beaches, salt marshes, tidal flats, dunes, coastal banks, estuaries, rocky intertidal shores, barrier beaches, land subject to tidal action, land subject to coastal storm flowage, and creeks.

As well, 310 CMR 10.02.2(b) establishes a buffer zone of 100 feet from banks, freshwater and coastal wetlands, tidal flats, beaches and dunes.

Any activity—other than minor activities identified in 310 CMR 10.02(2)(b)2—proposed or undertaken within a wetland resource area or the buffer zone of a resource area, if applicable, that will remove, fill, dredge, or alter that area, is subject to regulation under MGL c. 131, § 40 and requires the filing of a Notice of Intent. Minor activities include, for example, maintenance of existing structures (e.g., culverts), if such structures were constructed to current standards.

Before undertaking any of these source reduction activities, a municipality or private property owner would need to prepare a Notice of Intent for submission to and review by the local conservation commission. Under Mass. Gen. Laws Ch. 131, § 40, Massachusetts MCDs have an exemption from these Wetlands Protection Act requirements if the activities are undertaken for the purposes of mosquito control. Nonetheless, MCDs generally communicate with conservation agents and local conservation commissions when such activities are being planned.

While there is no direct action that would be subject to the Wetlands Protection Act, public outreach related to removal of mosquito habitats on private property should inform residents of buffer zones and identify source reduction actions that may require preparing a Notice of Intent with the local conservation commission.

3.1.2 Costs

All 11 MCDs, along with other state agencies, participate in larval and adult mosquito surveillance and control efforts. Actual and anticipated future budgets are reported by MCDs in their annual reports. In June 2021, EEA provided more details on the state’s costs for aerial spraying and communications. EEA also requested that each MCD that was carrying out IPM provide a breakdown of its 2021 budget according to IPM components. This section summarizes budget details from these information sources.

3.1.2.1 MCD Costs

In general, the magnitude of MCD spending correlates with the number of participating municipalities (Table 3-1).

Table 3-1. Budgets for MCDs in 2020/2021

Project/District Name	Budget Year	Budget ($)	Member Municipalities (2020)	Land Area of Member Municipalities (Square Miles)
Berkshire County	2021	$295,582	10	225
Bristol County	Fiscal year 2020	$1,532,339	20	571
Cape Cod	2021	$2,587,259	15	412
Central Massachusetts	Fiscal year 2020	$2,577,745	44	834
Dukes County	2020	$6,177	6	93
East Middlesex	2021	$821,476	26	303
Norfolk County	2021	$2,001,629	25	382
Northeast Massachusetts Wetlands Management	2021	$1,884,100	33	466
Pioneer Valley	Fiscal year 2021	$55,000	15	376
Plymouth County	2021	$1,991,602	28	702
Suffolk County	2021	$289,860	2	52

Sources: MCD budget requests; MCD annual reports (member municipalities); property (MassGIS Bureau of Geographic Information, 2016). (land area).

The aggregate budgets for the nine MCDs carrying out IPM total $13.9 million.[20] As shown in Figure 3-3, the largest expenditures were for (pesticide-based) larval and adult mosquito control (36 percent) followed by water/habitat management (including, for example, ditch maintenance, culvert repair and maintenance, stormwater infrastructure) and source reduction (e.g., tire removal). Surveillance costs account for 19 percent of these MCDs' budgets with education and public engagement, research (e.g., resistance testing) and other IPM activities accounting for 14 percent of budgets. These budgets are unlikely to include the full costs of construction and maintenance of, for example, water management in the districts as these are often undertaken for reasons other than mosquito control and may be funded by separate state and municipal budgets.

[20] IPM breakdowns exclude Dukes County, Nantucket, and Pioneer Valley MCDs.

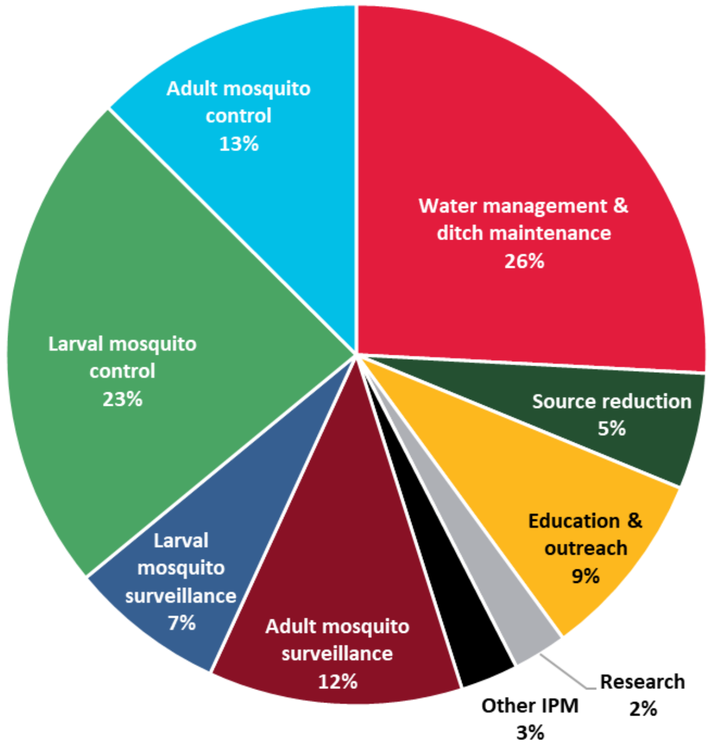


Figure 3-3. IPM components in MCD 2021 budgets.

MCDs report that the distribution of spending across IPM components is dependent on a wide range of factors, including requests for control due to nuisance, the amount and types of mosquito habitats (where larval surveillance and control may occur), and viral disease risks. Figure 3-4 illustrates MCD spending by each component of IPM for the nine MCDs that carry out the major components of IPM (as Dukes County and Pioneer Valley have not been utilizing chemical controls, they are not considered to follow IPM). Four MCDs spend more than 35 percent of their budgets on water management and source reduction (Norfolk, Central Massachusetts, Cape Cod, and Plymouth). East Middlesex and Cape Cod MCDs are notable in dedicating the most to education and public engagement. All MCDs except Cape Cod (which does not carry out adulticiding) spent between 35 and 62 percent of their budget on larval and adult mosquito controls, primarily for larval controls (three MCDs reported that their larval surveillance costs are included with larval control costs, which would overstate larval control costs and understate the cost of larval surveillance); Norfolk and Bristol MCDs spent proportionately more on adult mosquito controls.

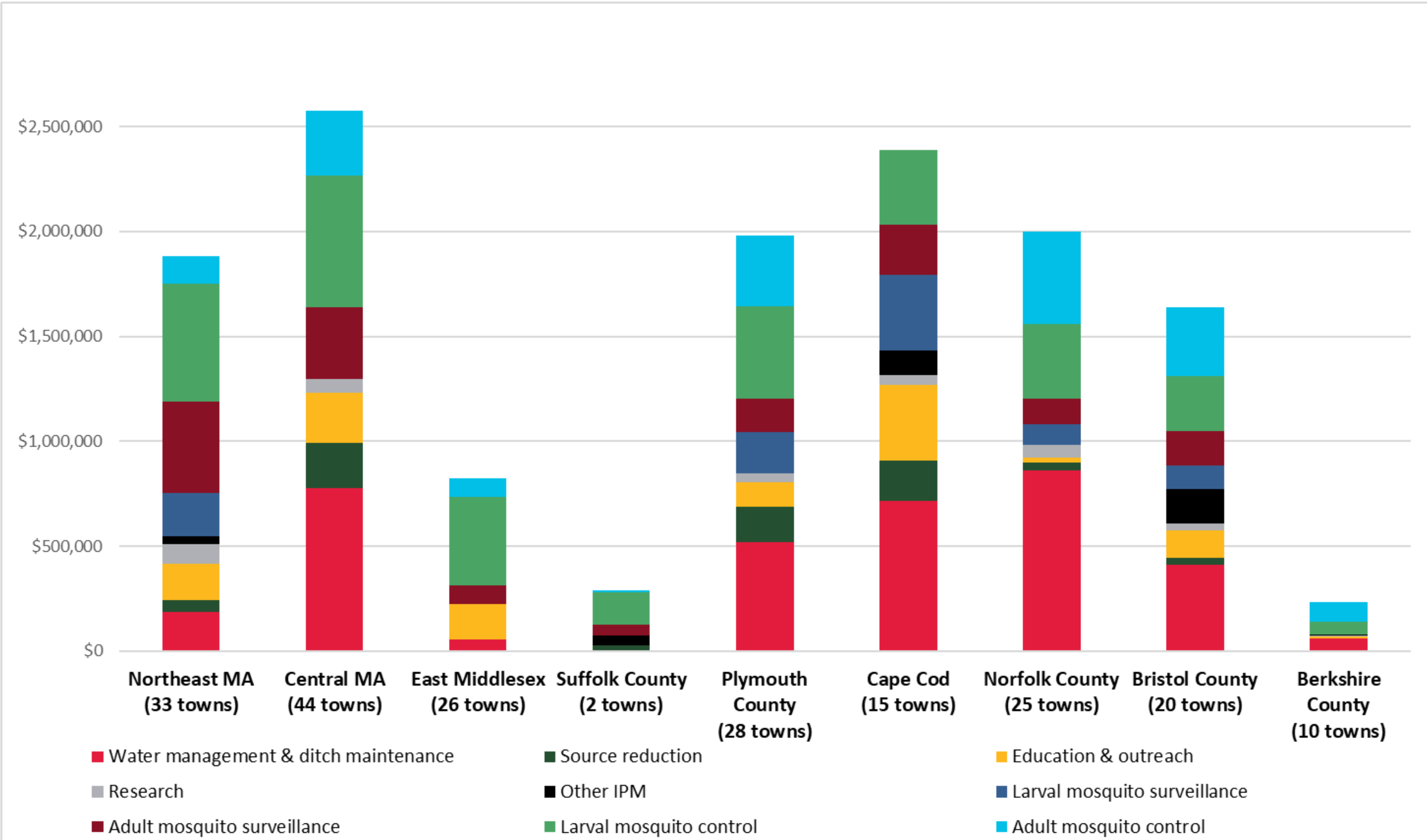


Figure 3-4. 2021 MCD budgets by IPM components.

3.1.2.2 Other State Agencies in Massachusetts

While a number of state agencies beyond the MCDs support the Commonwealth's mosquito surveillance, control and public engagement, these costs are not generally identifiable in available budget reports. Communications spending that ERG could identify as directly related to mosquito control efforts undertaken by other state agencies is summarized in Table 3-2. State Agencies, primarily DPH, may undertake media campaigns to raise awareness of the public health risks associated with arboviruses, as well as, the Commonwealth's surveillance and response activities. The cost of communications activities such as the purchase of advertising to notify the public of increased arbovirus risk or aerial spray events, for the most recent three years is summarized in the table below. These figures do not include staff time spent responding to media and other inquiries, which was significant in 2019 when news coverage was high.

Table 3-2. Commonwealth Costs Associated with Arbovirus Health Emergency and Aerial Spraying

Year	Aerial Spraying	Aerial Spray Cost	Communications Costs
2020	One spray event; 178,823 acres	$518,911	$500,000
2019	Six spray events; 2,048,865 acres	$5,085,636	—
2018	No aerial spraying	—	$80,000

Sources: 2018, 2019, 2020 State Reclamation and Mosquito Control Board annual reports; correspondence with EEA re: 2020 costs.

3.1.2.3 Costs in Other States

In addition to the budgeted and actual costs incurred by MCDs and other state agencies, informal guidance on costs of several IPM components (surveillance and truck spray by private contractors) for various-sized municipalities is published by the New Hampshire Department of Health and Human Services:

- "Small rural towns that have fewer than 1,000 catch basins and do not have salt marshes may spend between $25,000-$35,000 for annual mosquito surveillance and control (larvicide and spot adulticide). Control only may cost between $10,000 -$20,000.

- Large towns that have between 2,000 to 5,000 catch basins and salt marshes or extensive wetlands may spend between $55,000-$105,000 for annual mosquito surveillance and control (larvicide and spot adulticide). Control only may cost between $40,000-$90,000. Town-wide road spraying will add approximately $25,000-$35,000 per year.

- Cities that have over 5,000 catch basins and freshwater swamps may spend between $84,000-$114,000 for annual mosquito surveillance and control (larvicide and spot adulticide). Control only may cost between $70,000-$100,000. Town-wide road spraying will add approximately $20,000-$30,000 per treatment" (New Hampshire Arbovirus Task Force & New Hampshire Arboviral Illness Task Force, 2021)."

3.2 Current Practices in Other States

The following table summarizes the IPM activities that other New England states are carrying out.

Table 3-3. IPM Activities in Other States

State	IPM Practices in Other States
Connecticut	Connecticut's Mosquito Control Program is a collaborative effort involving the Department of Energy and Environmental Protection (DEEP), Connecticut Agricultural Experiment Station, and Department of Public Health, together with the Department of Agriculture and the University of Connecticut's Department of Pathobiology and Veterinary Science. The Wetland Habitat and Mosquito Management Program uses water management, including open marsh water management (OMWM), as its preferred approach to source reduction and biological control of mosquitoes. Connecticut carries out most the major components of IPM centrally and not via local MCDs. Educational efforts appear to be limited to providing local governments and residents with resources on the DEEP website (Department of Public Health, 2020).
Maine	Responsibility for mosquito control is distributed across several state agencies and collaborating organizations. The Maine Department of Agriculture and Conservancy Forestry undertakes mosquito surveillance (and oversees IPM initiatives in the state), as does the Maine Medical Center Research Institute. The University of Maine Cooperative Extension offers education and some technical support. Maine uses some of the major components of IPM (surveillance, limited larviciding and adulticiding, research, and education/engagement), but these agencies do not appear to be involved in source reduction (Division of Disease Surveillance; University of Maine Cooperative Extension, 2020).
New Hampshire	While the state has an arboviral illness surveillance, prevention, and response plan, its government is involved in surveillance, providing technical advice to municipalities, and offering educational materials. Source reduction and pesticide usage are left to municipalities. Decentralized control and limited funding prevent IPM from being consistently adopted across New Hampshire municipalities (New Hampshire Arbovirus Task Force & New Hampshire Arboviral Illness Task Force, 2021).
Rhode Island	In Rhode Island, mosquito control is administered centrally by state agencies. They use some of the major components of IPM (surveillance, larviciding, adulticiding; education/engagement is limited to Department of Environmental Management and Department of Public Health websites), but they do not appear to be involved in source reduction (Rhode Island Department of Environmental Management, 2021).

3.3 Best Available Science Related to Integrated Pest Management

According to the American Mosquito Control Association (2017), best practices based on literature reviews and experiences of local and state mosquito control programs consist of the following elements:

- Surveillance
- Mapping
- Setting action thresholds
- Larval source reduction

- Biologic controls
- Chemical controls of larvae
- Chemical controls of adult mosquitoes
- Monitoring for efficacy and resistance
- Community outreach
- Recordkeeping

While not as detailed, the Centers for Disease Control and Prevention (CDC) and EPA have also published IPM overviews and support collaboration among states and MCDs, such as the following resources:

- CDC's "Integrated Mosquito Management" website explains the basic components of IPM and links resources such as ArboNET and MosquitoNET for the public. https://www.cdc.gov/mosquitoes/mosquito-control/professionals/integrated-mosquito-management.html
- CDC's Zika communication toolkits offer educational outreach and communication materials that can be customized for different organization to distribute. https://www.cdc.gov/zika/comm-resources/toolkits.html
- EPA's "Success in Mosquito Control: An Integrated Approach" site explains IPM and the collaboration between EPA and the CDC to provide best practice guidance for mosquito control. https://www.epa.gov/mosquitocontrol/success-mosquito-control-integrated-approach#main-content

MCD representatives reported differing perspectives on measuring the effectiveness of IPM. Five MCDs noted that they do not quantify its effectiveness; instead, they emphasize following best management practices with available resources as efficiently as possible. Four MCDs measure program effectiveness using surveillance (i.e., dip counts for larvae and trap counts for adult mosquitoes) before and after pesticide applications (Executive Office of Energy and Environmental Affairs & Eastern Research Group Inc., 2021a).

DPH's aerial spray efficacy work and the research summarized in the previous sections show that each component of IPM can reduce mosquito populations and arbovirus risks. For example, source reduction (e.g., container and tire removal) and the range of stormwater management actions can reduce or even eliminate certain stagnant water habitats, reducing larval populations and thereby reducing adult populations. Another component of IPM, adulticiding, can quickly and dramatically reduce populations of adult mosquitoes.

Table 3-4, below, presents aerial spray efficacy in reducing adult mosquito populations along with application rates and climatic conditions for public health aerial spraying in Massachusetts since 2006. The other sections of this report address efficacy of several other IPM components, including education, outreach, and several water management activities.

Table 3-4. Aerial Spray Efficacy: Percent Reduction in Mosquitoes Trapped, Comparing Pre-spray Trapping Numbers to Post-spray Trapping Numbers

Aerial Intervention Location	Start Date	End Date	Reduction in Primary Mosquito Vector[a,b]	Reduction in Mosquitoes Trapped	Temperature Range (°F)[c]	Dewpoint Range (°F)[c]	Average Acres per Hour
Bristol/Plymouth	8/8/2006	8/9/2006	35–92%	59–86%	59–64	53–57	17,499
Bristol/Plymouth	8/22/2006	8/24/2006	0–94%	60–89%	57–69	55–62	34,191
Bristol/Plymouth	8/5/2010	8/7/2010	87–89%	77–87%	58–79	57–73	26,194
Bristol/Plymouth	7/20/2012	7/22/2012	14–84%	42–81%	56–73	54–61	30,701
Bristol/Plymouth	8/13/2012	8/14/2006	46–60%	36–47%	66–73	64–66	21,981
Bristol/Plymouth	8/8/2019	8/11/2019	66%	58%	55–72	50–70	20,112
Bristol/Plymouth	8/21/2019	8/25/2019	91%	25%	57–77	51–74	15,066
Middlesex/Worcester	8/26/2019	8/27/2019	38%	20%	53–64	45–57	16,212
Middlesex/Norfolk/ Worcester	9/10/2019	9/18/2019	ND	ND	52–70	42–69	16,975
Hampden/Hampshire/ Worcester	9/16/2019	9/17/2019	ND	ND	48–58	47–51	14,388
Bristol/Plymouth	9/18/2019	9/24/2019	ND	53%	54–70	51–67	12,125
Bristol/Plymouth	8/10/2020	8/11/2020	82%	70%	73-78	68-72	29,833

Source: Bharel and Cranston (2020a, 2021b)

ND = control not detected (calculations may be affected by small sample sizes)

[a] The primary mosquito vector is the mammal-biting species *Coquillettidia perturbans*, considered to be the mosquito most likely to spread Eastern equine encephalitis to humans.

[b] Data sources include DPH and the Bristol and Plymouth County MCDs. 2006–2012 data shown as ranges inclusive of all three data sources. 2019 combines data from all three sources into a single calculation.

[c] Weather data are taken from Plymouth, Worcester, and Westover airports and may not accurately represent actual temperature and dewpoint at location of spraying.

In implementing IPM, mosquito control organizations prioritize and invest in a range of activities they believe are most suitable for given geographies, communities, expected and surveilled mosquito populations, and arboviral risk levels. This complexity may make it difficult to undertake efficacy studies of IPM (by either finding comparable areas to serve as controls with no IPM or comparing the baseline conditions for an area before adopting IPM). Most MCDs reported that measuring the effectiveness of IMM as a whole was difficult and not undertaken (EEA, personal communication, July 2021). Therefore, where efficacy data are available, ERG has summarized those data for each of the non-chemical control methods included in this report.

The American Mosquito Control Association (2017) references efficacy studies for various IPM components but not for IPM as an integrated approach. CDC reports, “IPM is a comprehensive, systems-based approach to pest management with the goal of providing the safest, most effective, most economical, and sustained remedy to pest infestations. IPM reduces the risk from pests while also reducing the risk from the overuse or inappropriate use of hazardous chemical pest-control products” (Centers for Disease Control and Prevention, 2020b).

4. Education and Public Engagement for Mosquito Control and Personal Protection

This section focuses on education and public engagement associated with source reduction and personal protection. These two topics pertain to different phases of the mosquito life cycle (see Figure 4-1). Proactive education and public engagement can reduce larval mosquito habitats on private property (source reduction) and reduce human contact with virus-bearing mosquitoes. Educating residents on efforts to eliminate container-breeding mosquito habitats on personal property is best for reducing the risk of West Nile virus (WNV), given that this is their preferred breeding habitat. Educating residents about personal protection to avoid exposure to mosquitoes (e.g., mosquito repellents, long sleeves and pants, altering time outside) is suitable for reducing risks of both WNV and Eastern equine encephalitis (EEE).

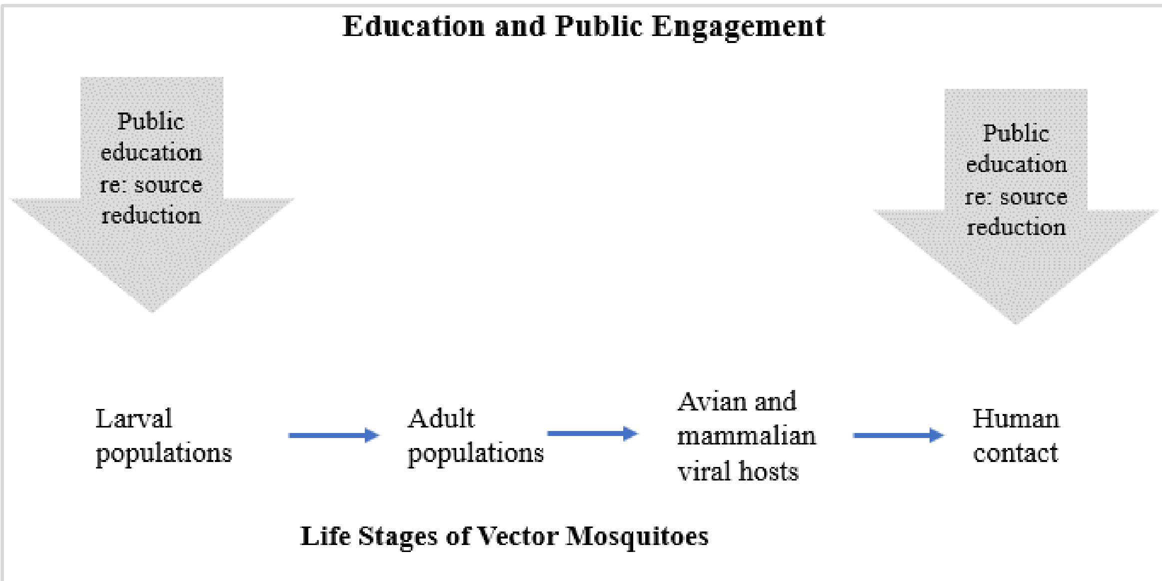


Figure 4-1. Education and public engagement and their effect on mosquito life stages.

4.1 Current Practices in Massachusetts

MCDs and other local organizations, such as boards of health, schools, DPH, and MDAR, undertake a range of education and public engagement activities for various purposes:

- Increasing awareness and acceptance of mosquito control programs
- Encouraging residents to participate in source reduction
- Promoting personal protection from mosquitoes

DPH's *Massachusetts Arbovirus Surveillance and Response Plan* (Bharel & Cranston, 2020a) and their website[21] identify educational resources for MCDs and local governmental and

[21] https://www.mass.gov/lists/arbovirus-surveillance-plan-and-historical-data

non-governmental organizations (NGOs) to use. In addition, the plan calls for a coordination of efforts with MCDs and local Boards of Health (Bharel & Cranston, 2020a).

This section summarizes education and public engagement activities undertaken by MCDs (Section 4.1.1) and Massachusetts government agencies (Section 4.1.2). No information was found quantifying the level of use of the DPH-published resources or their efficacy in altering Massachusetts residents' awareness, perceptions, or behaviors. Municipalities may undertake additional education and public engagement efforts independently or in coordination with MCDs, NGOs, and/or other governmental agencies. In correspondence, several MCD representatives stated that they rely on optional feedback from their community to gauge effectiveness and level of use after public education and outreach activities (EEA, personal communication, July 2021). They also noted that quantification of effectiveness is difficult because there is no way to verify the efficacy of activities such as traditional media outreach, brochure distribution, and website resources. While website visitors, social media post likes/shares/comments, and presentation attendees can be counted, these metrics do not reflect a change in source reduction practices or personal protection measures taken by the target audience.

4.1.1 MCD Activities

The 2020 *Massachusetts Arbovirus Surveillance and Response Plan* calls for MCDs to have the primary role in education and outreach to residents (Bharel & Cranston, 2020a; Massachusetts MCDs, 2021). According to their annual reports, all MCDs undertake education and public engagement, although the levels and types of their activities vary. A summary of these activities, extracted from the MCD annual reports, is presented in Figure 4-2. The most prevalent types of education and outreach activities undertaken by MCDs are presentations to groups (such as boards of health and public meetings) and distribution of written materials to residents directly or via news media. More than half of MCDs actively engage in door-to-door canvassing or school programs, which are expected to reach many more residents.

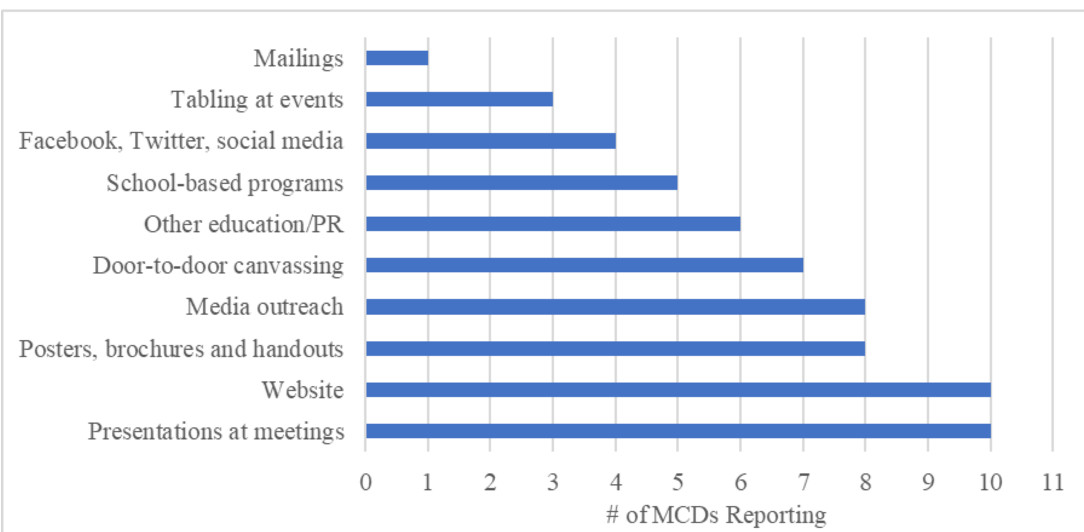


Figure 4-2. Types of education and engagement activities undertaken by MCDs in 2020.

MCDs use a variety of sources for educational content and collaboration. Six of the 11 MCDs active in 2020 had an educator on staff. Most MCDs reported that their education efforts involved collaboration. Figure 4-3 shows that MCDs most frequently collaborated with other state agencies including other MCDs (Bharel & Cranston, 2020a; Massachusetts MCDs, 2021).

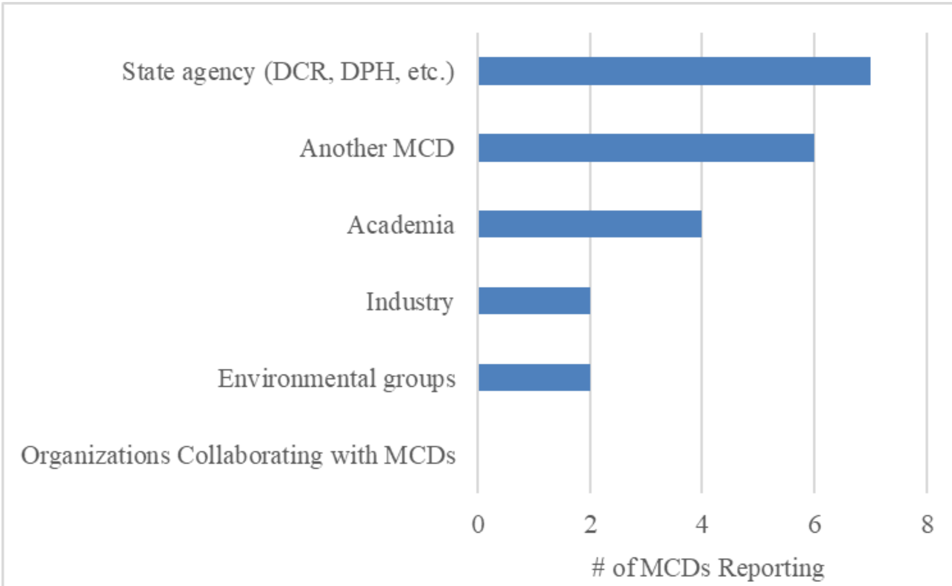


Figure 4-3. Organizations collaborating on education and engagement activities with MCDs in 2020.

4.1.2 State Agency Activities

ERG reviewed the MDAR, Department of Environmental Protection (DEP), and DPH websites, as well as DPH's 2020 *Massachusetts Arbovirus Surveillance and Response Plan* and the State Reclamation and Mosquito Control Board's *Massachusetts Emergency Operations Response Plan for Mosquito-Borne Illness* to locate educational activities related to mosquito control that were conducted by entities beyond MCDs. The *Massachusetts Arbovirus Surveillance and Response Plan* specifies that DPH provide information relevant for education and public engagement programs carried out by MCDs and boards of health. It also has recommendations for risk communication and educational efforts for both personal protection and source reduction, tiered according to DPH-determined risk levels (Bharel & Cranston, 2020a).

DPH publishes a range of materials related to mosquito control, current risk levels, personal protection, and risk communications (e.g., example press releases) customized to various audiences (e.g., local boards of health), videos, and factsheets (Bureau of Infectious Disease and Laboratory Sciences & Department of Public Health, n.d.). Disseminated educational materials consist of brochures and posters, including Spanish and Portuguese language versions. An overview of the guidance and resources is presented below.[22]

- Fact sheets and frequently asked questions on mosquitoes in Massachusetts

[22] More details are available online: https://www.mass.gov/info-details/mosquito-borne-disease-prevention

- — WNV
- — EEE
- — Mosquito control and spraying
- — Mosquitoes in Massachusetts
- — Aerial spraying of mosquitoes for EEE

- Educational materials for teachers

  - — Mosquito-borne disease educational materials
  - — Mosquito repellent guidance for school staff

- Resources for local boards of health

  - — Arbovirus information for local boards of health

- Prevention tips

  - — Brochures on preventing mosquito bites
  - — Guidance for applying EPA-approved mosquito repellent to prevent EEE
  - — Frequently asked questions about mosquito repellent
  - — Kid-friendly mosquito repellent posters in English, Spanish, and Portuguese
  - — A mosquito bite prevention poster for parents/caregivers in English, Spanish, and Portuguese

- Testing and data

  - — Current WNV and EEE activity and risk maps (June–October)
  - — Arbovirus surveillance plan and historical data
  - — Mosquito control projects and districts

ERG could not identify information describing how much these materials are used, or their effectiveness in changing behaviors that would reduce mosquito-borne arboviral risks.

4.1.3 Considerations for Wetland Resource Areas and Buffer Zones

Education and public outreach activities are not expected to have any direct or indirect impact on wetland resources areas or buffer zones.

4.1.4 Costs

While all MCDs carried out education and public engagement activities, budget information on education and public engagement activities was requested only for the nine MCDs carrying out IPM. Table 4-1, below, summarizes this information.

Table 4-1. MCD Budgets for Education and Public Engagement

Project/District Name	Education and Public Engagement Budget (2020/2021)	% of MCD Annual Budget
Berkshire County	$8,867	3%
Bristol County	$131,195	8%
Cape Cod	$358,538	15%
Central Massachusetts	$239,473	9%
Dukes County	Information not requested	
East Middlesex	$169,142	21%
Norfolk County	$20,016	1%
Northeast MA	$169,569	9%
Pioneer Valley	Information not requested	
Plymouth County	$119,496	6%
Suffolk County	$0	0%
Total	$1,207,428	10%

Source: annual MCD reports and supplemental request for budget breakdown (June 2021).
[a] Nantucket was no longer an MCD as of 2020; this historical budget information was not requested of Nantucket.

State Agencies beyond the MCDs, primarily DPH, may undertake media campaigns to raise awareness of the public health risks associated with arboviruses, as well as, the Commonwealth's surveillance and response activities. The cost of communications activities such as the purchase of advertising to notify the public of increased arbovirus risk or aerial spray events, for the most recent three years is summarized in the table below. These figures do not include staff time spent responding to media and other inquiries, which was significant in 2019 when news coverage was high.

Table 4-2. Other State Agencies' Costs Associated with Communications Related to Arbovirus Risk and Health Emergency

Year	Communications Costs
2020	$500,000
2019	$0
2018	$80,000

Source: (EEA, personal communication, July 2021).

4.2 Education and Public Engagement Activities in Other States

Based on a review of nine states' websites and their referenced resources, the types of DPH-sponsored education and public engagement related to source reduction and personal protection are fairly consistent and available to users navigating to state government resources. While some initiatives, mainly related to Zika, involved community-level education and support (e.g., provision of mosquito repellent), ERG could not identify documents or descriptions of the level of implementation or efficacy of other states' education and public engagement activities related to source reduction and personal protection from arboviruses.

Representing 13 northeastern states and the District of Columbia, the Centers for Disease Control and Prevention (CDC) and Cornell University have created the Northeast Regional Center for Excellence in Vector-borne Diseases, which offers free trainings and resources specific to the Northeast (Northeast Regional Center for Excellence in Vector-Borne Disease, 2021). This collaboration focuses on training, applied research, and creating community partnerships to increase awareness of mosquito- and tick-borne diseases.

Notable education and public engagement efforts from other states include the following examples (see Table 4-3 for more detailed information):

- Virtually all states reviewed provide downloadable/printable brochures, posters, and links to other resources on awareness of arbovirus and the value of personal protection.
- One state provides guidance for personal protection that emphasizes EEE is "preventable."
- Boulder Colorado uses online storymaps to describe all aspects of mosquito control program.
- States offer a range of curricula and materials for primary schools. (Several states have developed and used school-based curricula to educate as many people as possible within the community, and to reach out indirectly to others—such as parents—who may take action.)

Table 4-3. Education and Public Engagement Activities in Other States

State	Education and Public Engagement in Other States
Connecticut	Background on arboviruses and human health is presented on both DEEP and Connecticut DPH websites (awareness material downloads and links to other organizations and resources). The websites also offer guidance on source reduction and personal protection. The state's EEE plan includes risk communication activities (primarily notification) based on surveillance results and associated risk levels (Connecticut Mosquito Management Program, 2019b; Department of Public Health, 2020).
New Hampshire	The Arboviral Illness Task Force coordinates the mosquito management plan, including education and outreach on mosquito-borne illness (New Hampshire Arbovirus Task Force & New Hampshire Arboviral Illness Task Force, 2021). The Division of Public Health Services website offers background on arboviruses and human health (and material downloads), as well as guidance on source reduction and personal protection (New Hampshire Division of Public Health Services, 2016).
Vermont	The Vermont Department of Health offers background on arboviruses and human health, as well as guidance on source reduction and personal protection (Vermont Department of Health, 2021).
Rhode Island	The Rhode Island DPH website offers background on arboviruses and human health (an introductory video and links to other organizations and resources), as well as guidance on source reduction and personal protection (Rhode Island Department of Health).
Maine	The Maine Centers for Disease Control provide background and resources (other state and federal agency sites) related to arboviral illness and personal protection (Division of Disease Surveillance). Printed materials can be ordered through www.maine.gov/dhhs/order, frequently asked questions are answered at www.maine.gov/dhhs/mosquitofaq, and the agency has made an offer for epidemiologists to conduct trainings and give presentations on arboviral diseases. The *Surveillance, Prevention, and Response Guidance for Maine Towns and Communities* document establishes roles for municipalities to support personal protection but does not provide details on educational activities (Maine Center for Disease Control and Prevention, 2020).

State	Education and Public Engagement in Other States
Iowa	Background on arboviruses (primarily WNV), including information and downloadable posters on personal protection, is available at https://idph.iowa.gov/cade/disease-information. The state offers a "Mosquitoes and Me" curriculum for upper elementary students with 28 lessons (Urban Ecosystem Project).
Minnesota	The Minnesota Department of Health website offers background on arboviruses and human health (and material downloads), as well as guidance on source reduction and personal protection (Minnesota Department of Transportation, 2021). The site also offers live and recorded webinars on health risks associated with mosquito-borne diseases and personal protection (Minnesota Department of Transportation, 2020).
Wisconsin	The Department of Health Services has guidance for personal protection, emphasizing that EEE is "preventable," at https://www.dhs.wisconsin.gov/mosquito/bite-prevention.htm (Wisconsin Department of Health Services, 2021).
Colorado	Education and public engagement efforts are often developed and delivered at the municipal, county, or MCD level. Boulder developed a full description of its mosquito management program and materials, intended to raise public awareness (City of Boulder, 2021). The Colorado Department of Public Health and Environment webpages provide resources on WNV risks and guidance on source reduction and personal protection.

4.3 Best Available Science Related to Education and Public Engagement Activities for Mosquito Control and Personal Protection

ERG's review of literature did not identify a suitable evaluation of comprehensive education or public engagement interventions related to mosquito control. However, ERG did locate evaluations of educational and engagement activities related to source reduction and personal protection, along with overarching practices that may result in a more effective educational campaign. MCDs reported that they did not measure whether outreach efforts (school-based curricula and programs; presentations to other governmental groups who contact residents (e.g., Boards of Health); websites; distribution of brochures, handouts, mailings; traditional media outreach; social media (e.g., Facebook, Twitter); door-to-door canvassing; and tabling at events) reached their target audiences nor did they measure the efficacy of outreach in changing behaviors (Executive Office of Energy and Environmental Affairs & Eastern Research Group Inc., 2021a).

Studies quantifying the effect of education initiatives to promote source reduction by homeowners have had mixed results. An evaluation of active community peer education in a source reduction program in New Jersey showed a significant reduction in container habitats in the sites where the volunteers actively engaged the community compared to untreated control counties (Healy et al., 2014). A public outreach campaign to reduce risk of dengue in Colima, Mexico, found that an outreach initiative consisting of printed materials on preventing vector proliferation, local discussion groups involving community leaders, visits to randomly chosen homes, and other engagement activities reduced dengue incidence from 30 percent in the control to 17 percent. In contrast, ground spraying with permethrin and piperonyl butoxide reduced dengue incidence to 14 percent, equivalent to the incidence in areas that combined outreach and pesticide sprays (Mendoza-Cano et al., 2017). These results suggest that active education using community peer educators can be an effective means of source reduction and a critical tool in the arsenal against mosquitoes.

Communication, education, and public engagement efforts intended to change personal protective behavior face a number of challenges related to the diversity of individuals' health-related beliefs. Each person holds different health-related beliefs, the combination of which affects their perception of arbovirus risks and perceived benefits and barriers to personally protective behavior changes. ERG's review of literature did not identify a suitable evaluation of comprehensive education and public engagement interventions related to changing behavior to improve personal protection again arbovirus. In one tangentially related study of public health message uptake in a WNV hotspot near Toronto, Canada, researchers found that efforts such as flyer and poster distribution may increase awareness of mosquito biology or mosquito control activities, but were not, by themselves, determined to be effective in changing behaviors (Elliott et al., 2008). In this instance, the lack of data does not imply educational campaigns do not work: information is just very limited. However, there is literature on constructing public health education interventions that recognize and build on complex health and personal beliefs (Rakhshanderou et al., 2020). It was determined that outlining the basis of risk communication principles and instituting behavior change intervention on a broad scale were beyond the scope of this report.

In terms of efficacy, the references reviewed note several characteristics of educational interventions that make community members more likely to change their behaviors (e.g., remove standing water sources on their property and take measures to protect themselves and family members from mosquito bites) (Bharel & Cranston, 2020a; Bodner et al., 2016; Brunton et al., 2017; Urban Ecosystem Project, n.d.-a). These include:

- A written plan specifying communication and community engagement roles and responsibilities for state and local organizations. The *Massachusetts Arbovirus Surveillance and Response Plan* establishes community engagement roles for MCDs, as well as state and local organizations in Massachusetts).

- Consistent messaging from state-level organizations, including MCDs; municipal, residential, and educational organizations; and other stakeholders.

- Working with organizations and individuals in the community with the greatest number of community or individual contacts.

- Providing educational materials in the language most used by the intended audience.

- Reducing barriers to behavior change by providing complimentary services (e.g., tire removal for source reduction and distribution of mosquito repellent).

- Coordination of activities throughout the year.

- Feedback and knowledge sharing about what is working and what is not working.

5. STORMWATER MANAGEMENT FOR MOSQUITO CONTROL

Traditionally, stormwater management is thought of as the process of implementing engineering controls or other infrastructure that reduces the runoff of rainwater or melted snow from streets, lawns, and other impervious surfaces in an effort to improve water quality (United States Environmental Protection Agency, 2020a). Considering mosquito control specifically, stormwater management can be used to:

- Minimize areas of standing water that mosquitoes use as breeding grounds.
- Direct runoff to permanent standing water bodies such as wetlands and rivers, which may be habitats for mosquito predators.

All cities and municipalities in Massachusetts have existing stormwater infrastructure maintained and inspected by local authorities. However, there is a lack of data on the efficacy of stormwater management for mosquito control in Massachusetts; several studies from other states such as California are discussed later in this section. Because mosquito control best practices can be incorporated into existing infrastructures and maintenance routines, stormwater management for mosquito control is a widely applicable, effective aspect of IPM that addresses mosquitoes at both the larval and adult stages (see Figure 5-1).

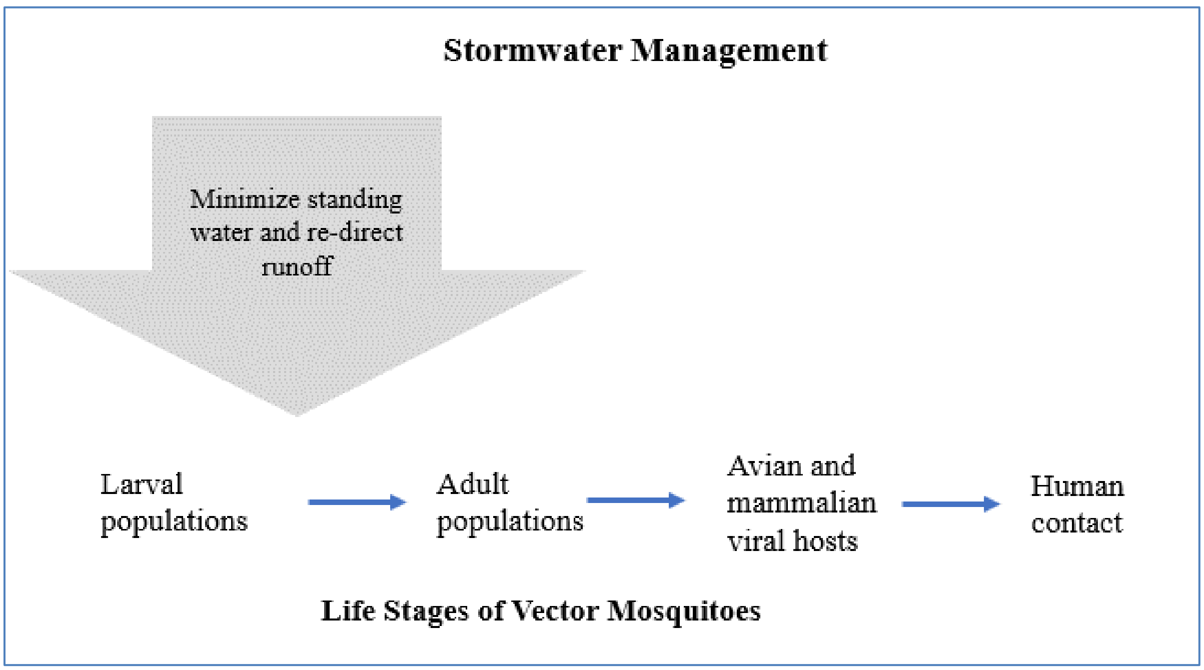


Figure 5-1. Stormwater management activities and their effect on mosquito life cycles.

5.1 Current Stormwater Management Practices for Mosquito Control in Massachusetts

In Massachusetts, the management of stormwater pollution and runoff is governed through provisions of the wetland protection regulations, 310 CMR 10.00. The Commonwealth has developed a handbook describing both the legal framework of stormwater management in

Massachusetts and the elements of stormwater management with a focus on best management practices (Massachusetts Department of Environmental Protection, 2008).

Several agencies and departments within the Commonwealth play a role in stormwater management and may be involved in management activities related to mosquito control. Table 5-1 describes these agencies and their roles in stormwater management activities.

Table 5-1. Massachusetts Agencies and Their Roles in Stormwater Management

Agency	Role
DEP	Issued the policy that established the stormwater management standards. Educates the public and government employees on federal, state, and local stormwater permits. Provides resources for the public to engage in their own stormwater management activities.
Department of Conservation and Recreation	Detects and eliminates illicit discharges in stormwater from DCR-managed areas. Educates the public on good housekeeping methods for stormwater management, such as cleaning streets and drainage systems. Manages the construction of stormwater management controls and oversees post-construction maintenance (Department of Conservation & Recreation).
Local departments of public works and regional water management entities	Manages drainage systems, identifies leaks and other issues along stormwater lines and devices, and oversees the cleaning and maintenance of municipal separate storm sewer systems (United States Environmental Protection Agency, 2021). May coordinate with MCDs to manage areas of potential concern (e.g., excess sedimentation, clogged culverts, general drainage issues).
Local conservation commissions	Advises municipal officials and local boards on stormwater management. Reviews DEP and DPW stormwater plans before submission. Manages rain gardens, discharge collection, and catch basin cleaning. Issues permits under the Conservation Commission Act (MGL Chapter 40 section 8C), the Wetlands Protection Act (MGL Chapter 131 section 40), and the home rule provisions for non-zoning wetlands bylaws (Massachusetts Association of Conservation Commissions, n.d.).
Department of Transportation	Creates management plans to meet state and federal regulations related to stormwater runoff. Ensures that its drainage systems are regularly inspected and well maintained (MassDOT Environmental Services, n.d.).
MCDs	Oversee mosquito control, public education, and mosquito-borne disease surveillance. Determine management methods to address both vector mosquitoes and nuisance mosquitoes in their member communities.

Other organizations in the Commonwealth contribute to stormwater management activities as well, though not all explicitly incorporate or discuss mosquito control. For example, schools and universities can be involved in the creation of rain gardens. Non-governmental organizations (NGOs) have published resources on creating rain gardens and bioswales with native plants, and have collaborated with Massachusetts communities to build rain gardens (Clark, 2011; Fialkoff, 2018; Fontaine et al., 2011).

Table 5-2 shows which MCDs reported a selection of stormwater management activities on their annual reports between 2016 and 2020.

Table 5-2. Massachusetts MCDs and Projects That Reported Stormwater Device Management Activities Between 2016 and 2020

Project/District Name	Ditch Maintenance[a]	Catch Basin Cleaning	Detention Pond Planning	Identify Clogged Ditches and Culverts with Department of Public Works and Department of Transportation	Review Structural Plans for New Developments (Stormwater)	Work with Conservation Administrators on Stormwater Management
Berkshire County	✓	✓		✓		
Bristol County	✓					
Cape Cod	✓					✓
Central Massachusetts	✓					
Dukes County						
East Middlesex	✓			✓	✓	
Norfolk County	✓	✓		✓		✓
Northeast Massachusetts Wetlands Management	✓	✓	✓	✓	✓	✓
Pioneer Valley						
Plymouth County	✓			✓	✓	
Suffolk County	✓	✓		✓		

Source: annual MCD reports.

[a] The annual reports use a yes/no field for ditch maintenance; the columns to the right of "Ditch Maintenance" were filled according to free-text comments in annual reports, responding to questions about additional source reduction activities in which the MCDs participate.

5.1.1 *Considerations for Wetland Resource Areas and Buffer Zones*

As stated in section 3.1.1, MCDs have an exemption under Mass. Gen. Laws Ch. 131, § 40 and do not need to submit a Notice of Intent for activities which would otherwise require one under the Wetlands Protection Act. For other individuals and groups, a project with a stormwater management component may require:

- Preparing a Notice of Intent with the local conservation commission and permitting if the project is in a wetland area.
- Preparing a Surface Water Discharge General Permit for general construction or multi-sector general permits in outstanding resource waters (MassDOT Environmental Services, n.d.).

While the activity itself may not take place within an area subject to protection, many stormwater management activities alter the collection and flow of water to areas that may be subject to protection. Because the purpose of stormwater management devices is to either reduce standing water by improving stormwater drainage or rerouting stormwater to larger water bodies, these activities are unlikely to be prohibited so long as the proper permits are attained.

5.1.2 *Costs*

Water management and ditch maintenance costs accounted for the largest portion of MCD budgets for 2021. Table 5-3 shows that these activities accounted for 1–43 percent of the total budget across nine MCDs. For this table, water management and ditch maintenance activities include ditch maintenance, culvert repair and maintenance, and maintenance of other stormwater infrastructure.

Table 5-3. MCD Costs for Water Management and Ditch Maintenance in 2021

Project/District Name	Water Management and Ditch Maintenance	Percent of 2021 Budget
Norfolk County	$860,700	43%
Central Massachusetts	$777,190	30%
Cape Cod	$717,075	30%
Plymouth County	$517,817	26%
Bristol County	$409,984	25%
Northeast Massachusetts	$188,410	10%
East Middlesex	$54,135	7%
Suffolk County	$2,899	1%
Berkshire County	$ 59,116	20%

For 2021, Norfolk County MCD reported the highest budget for water management and ditch maintenance activities and designated the largest percentage of its budget to these activities compared to the other MCDs. See Section 3.1.2.1 for more information on MCD budgets and activity costs.

The following table, abbreviated from Houle et al. (2013), describes the installation, labor, and maintenance costs per hectare of treated area. The authors documented the costs after observing the construction and maintenance needs for various stormwater treatment devices during the first two to four years of operation. All six systems below were in New Hampshire and are considered conventional stormwater management.

Table 5-4. Costs of Stormwater Treatment Devices Adjusted to 2012 Inflation

Cost per Hectare	Vegetated Swale	Wet Pond	Dry Pond	Sand Filter	Gravel Wetland	Bioretention (Bioswale)
Original capital cost	$29,700	$33,400	$33,400	$30,900	$55,600	$53,300
Inflated 2012 capital cost	$36,200	$40,700	$40,700	$37,700	$67,800	$63,200
Annual operations and maintenance cost ($/year)	$2,280	$7,830	$6,150	$7,210	$5,550	$4,940

Modified from Houle et al. (2013).

The costs of stormwater treatment devices are highly site-specific; the table above demonstrates the range of costs associated with each system. Ekka et al. (2021) hypothesize that the capital costs for bioretention systems may be four times higher than the capital costs for vegetated swales due to more complex engineering and specialized construction materials.

Factors such as natural topography, pre-existing infrastructure, utility conflicts, and permitting needs also influence capital and maintenance costs. Table 5-5 below describes maintenance activity cost estimates published by the United States Environmental Protection Agency (2009), based largely on actual cost data and bid proposals from the Maryland region in 2005. The table highlights several common maintenance activities.

Table 5-5. Estimated Costs of Stormwater Management Device Maintenance Activities

Maintenance Item	Unit Price ($)	Unit	Mobilization Cost ($)
Clogging: debris removal (preventative)	$350	Event	$0 (none)
Clogging: clear outfall channel of sediment	$130	Cubic yard	$0
Clogging: clogged low flow	$750	Event	$800
Vegetation: install wetland plant	$6	Each	$800
Vegetation: repair low spots in dry pond bottom	$25	Square yard	$1,500
Vegetation: remove woody vegetation from dry pond bottom	$1,700	Event	$0
Dredging: dredge wet ponds (jobs larger than 1,000 cubic yards) and haul offsite	$60	Cubic yard	>$2,500
Dredging: dry pond sediment removal	$7,600	Event	$0
Dredging: dewater and remove sludge from underground facilities	$1	Gallon	$0
Channels: remove and replace riprap or pea gravel	$160	Square yard	$1,500
Channels: shoreline protection	$50	Linear foot	$1,500
Channels: erosion repair	$1,100	Event	$0

Modified from United States Environmental Protection Agency (2009).

For stormwater treatment devices that may affect wetlands, rivers, or other wetland resource areas and buffer zones, costs associated with permitting must also be considered.

5.2 Stormwater Management for Mosquito Control in Other States

Virtually all states have state regulations and guidelines for stormwater management; however, mosquito control is not always incorporated into stormwater management plans. Table 5-6 describes resources on stormwater best practices and whether mosquito control is integrated into these best practices for states in New England.

Table 5-6. Stormwater Management Activities for Mosquito Control in Other States

State	Stormwater Management for Mosquito Control
Connecticut	The Mosquito Management Program does not report any stormwater management activities as part of its IPM approach (Connecticut Mosquito Management Program, 2019b). Stormwater guidance materials discuss mosquito control practices in relation to sump basins, underground retention, dry detention, filters, and swales (Connecticut Department of Energy and Environmental Protection, 2004).
Maine	The state does not report any stormwater management activities as part of its mosquito management program at the state level (Department of Agriculture Conservation and Forestry & Department of Health and Human Services, 2013; Division of Disease Surveillance). The Maine Department of Environmental Protection (2016) briefly mentions mosquito control in state-issued stormwater guidance.
New Hampshire	The Department of Health and Human Services does not report stormwater management activities in its response plan for mosquito control (New Hampshire Division of Public Health Services, 2008a, 2016).
Rhode Island	The Department of Environmental Management reports "cleaning gutters and other such housekeeping measures to eliminate habitat" as part of its Mosquito Response Protocol (Rhode Island Department of Environmental Management, 2001). The protocol reports visits to catch basins, roadside ditches, and detention basins in order to distribute larvicides, but stormwater maintenance is not reported during these visits.
Vermont	The Agency of Agriculture, Food, and Markets does not report stormwater management activities at the state level as part of its mosquito response (Vermont Agency of Agriculture, n.d.). Neither of the state's two MCDs (BLSG Insect Control District and Lemon Fair Insect Control District) report stormwater management activities, although both report using an IPM approach (Brandon-Leicester-Salisbury-Goshen-Pittsford Insect Control District, 2021; Lemon Fair Insect Control District, 2020).

5.3 Best Available Science Related to Stormwater Management for Mosquito Control

Several studies have investigated how common stormwater infrastructure relates to the presence of mosquitoes and mosquito breeding areas. Overall, these studies stress the importance of two factors in the effectiveness of stormwater management in controlling target mosquitoes:

- Designing the system to make runoff inaccessible to mosquitoes after a storm event and/or drain completely after a short period.
- Maintaining the system over time.

The California Department of Transportation conducted a five-year study (2004–2009) to evaluate sites with stormwater treatment technology and identify improvements that would reduce the occurrence of standing water. Standing water was observed during 22 percent of site inspections from June 2004 to December 2006 (Metzger et al., 2018). After major structural repairs and modifications, the monthly percentage of sites observed with standing water fell to approximately 10 percent. Uneven basin grade and loose rock riprap were the most common structural causes of standing water. Re-grading basin floors, cutting low-flow channels, and replacing riprap were effective structural changes that significantly reduced the presence of standing water after storm events (Metzger et al., 2018).

Table 5-7 and Table 5-8 abbreviated from the study, describes the structural and non-structural causes of standing water identified between June 2004 and December 2006, as well as the corrective actions later taken by the California Department of Transportation:

Table 5-7. Common Structural and Non-structural Causes of Standing Water in Stormwater Management Devices

Structural Cause	Corrective Measures
Uneven basin grade	Re-graded basin floor; cut low-flow channel between inlet and outlet
Loose rock riprap energy dissipater	Replaced with boulders embedded in a concrete apron, boulders resting on top of a concrete apron, or molded concrete blocks
Uneven grade in conveyance pipe	Re-sloped pipe; replaced plastic pipe with concrete pipe
Concrete pads not sloped	Re-poured and re-sloped concrete weir pads
Malfunctioning skimmer outlet	Modified outlet float valve; modified flexible outlet tube to prevent "pinching"
Outlet clog	Repaired, modified, and/or cleaned outlet
Trash/debris accumulation/blockage inside gross solids removal device	Cleaned out gross solids removal device
Scour depressions	Modified inlets and/or energy dissipaters
Non-structural Cause	**Corrective Measures**
Sediment accumulation at inlet	Removed sediment accumulation; modified inlet area to minimize sediment loading
Non-stormwater flow	Traced and eliminated sources; installed subsurface perforated PVC drain pipe conveyance between inlet and outlet; constructed a bypass channel to divert non-stormwater around stormwater treatment system

Modified from (Metzger et al., 2018).

Vegetated swales and bioswales are installed to filter stormwater runoff and route stormwater into a specific drainage area. However, if improperly maintained, they have the potential to collect and retain standing water for extended periods of time. Gingrich (2006) demonstrated this in a study of 17 bioswales from three Delaware counties, performing mosquito dips, water quality measurements, and larval identification over four months. Gingrich's analysis found that about 60 percent of bioswales hosted significant mosquito breeding over the study period. Most were designed to use riprap (artificially placed stones or concrete rubble). The riprap created ideal mosquito breeding conditions (small pockets of water left after drainage).

Ekka et al. (2021) conducted a scientific literature review to provide guidance for modern swale design. The table below summarizes their findings regarding peak-flow mitigation to increase the efficiency of stormwater conveyance and stormwater volume reduction. The study also references supporting literature for each design component and provides several other tables with more specific swale guidance, which is not summarized here.

Table 5-8. Design Guidance for Swales and Other Stormwater Management Devices

Design Component	Common Design Guidance
Main channel	Increase the cross-sectional area to provide higher conveyance capacity. This can be achieved by a trapezoidal channel. If right-of-way space is limited, a longer section of triangular channel with side slopes of 6:1 (horizontal:vertical) or shallower is better.
Vegetation type	Choose a blend of species with tall and stiff grass blades.
Grass density	Use dense, non-clumping grasses to prevent concentrated flow. Aim for grass cover of good–excellent (3,000–9,000 stems/square meter) for selected species.
Channel roughness	Ensure channel roughness (Manning's roughness coefficient) is between 0.26 and 0.35 for different grass types. Significantly lower at high flows when water depth exceeds grass height.
Check dams	Add earthen or rock structures (60 centimeters high at most) at the downstream end of the swale or at the drop inlet.
Underdrains (optional)	Install perforated pipe systems in permeable soils with a minimum infiltration rate of 1 centimeter (0.5 inches) per hour; maintain sufficient separation from the groundwater table.
Construction technique	Minimize compaction in the main swale channel to maintain soil permeability.

Modified from Ekka et al. (2021).

Several of the design components above, such as vegetation type and construction technique, are relevant to the construction of rain gardens. Like swales and other stormwater management devices, rain gardens should be designed to collect and retain water for no more than 72 hours after a storm event to discourage mosquito breeding. The best available science for swales and rain gardens compiled by Ekka et al. (2021) indicates that regular maintenance of plants and landscaping materials is necessary to ensure timely drainage.

6. RIVER AND WETLANDS RESTORATION FOR MOSQUITO CONTROL

6.1 Overview

The Commonwealth of Massachusetts considers rivers and wetlands to be vital resource areas for both the community and local ecology. About 590,000 acres, or 12 percent of the state area, are composed of wetlands and there are about 8,229 miles of river in Massachusetts (Association of State Wetland Managers, 2013; National Wild and Scenic Rivers System). Common approaches to mosquito control in wetlands and river areas include vegetation control, ditch maintenance, and other topographical changes, which affect both the larval and adult stages of the mosquito lifecycle (see Figure 6-1 below).

- **Vegetation control** involves the removal of excess vegetation, whether native or non-native, and the selective removal of certain plant species to reduce area that mosquitoes use for oviposition and larval development.

  — It increases predator access to larvae and mosquito resting areas and allows better coverage by other mosquito control agents, such as aerial sprays (Thullen et al., 2002).

- **Ditch maintenance** involves modifying and/or maintaining channels that regulate water flow to reduce standing water areas.

  — It increases predator access to larvae and mosquito resting areas, flushes out larval food resources (plant detritus, bacteria, algae, etc.), and increases dynamic water flow to discourage mosquito oviposition.

- **Other terrestrial mosquito control activities** include creation of artificial hummocks (raised mounds with vegetation such as sedges) and steepening embankments at the water's edge.

  — These activities are usually undertaken to improve water circulation and water depth.
  — Open marsh water management (OMWM), one example of a terrestrial mosquito control activity, uses multiple topographical changes—such as deep-water areas connected by channels—to facilitate tidal flooding, prevent mosquito breeding habitat, and facilitate presence of mosquito predators.

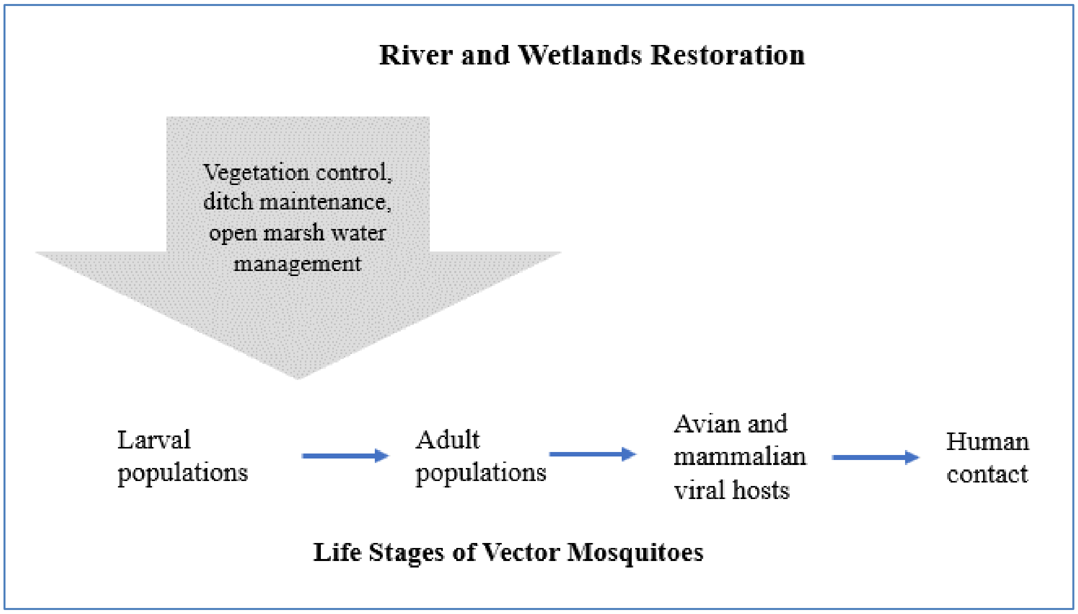


Figure 6-1. River and wetlands restoration activities and their effect on mosquito life cycles.

6.2 River and Wetlands Restoration Activities in Massachusetts

Many Massachusetts communities employ some degree of vegetation control and ditch maintenance as part of general maintenance programs. These activities also have aesthetic benefits and can make areas more accessible to the public and to municipal maintenance workers. Local mosquito control agencies can collaborate with municipalities to maintain vegetation control and ditches to reduce mosquito habitat.

OMWM methods are applicable in coastal Massachusetts, where tidal ranges can reach up to 11 feet depending on the season (J. Rey et al., 2012). Employing OMWM to facilitate the movement of high and low tides helps maintain deep-water areas and flush out shallow areas which would otherwise be standing water.

Between 2016 and 2020, five Massachusetts MCDs reported river and/or wetlands management activities in their annual reports. Table 6-1 shows which MCDs reported open marsh management, restoration activities, and vegetation control.

Table 6-1. Massachusetts MCDs and Projects That Reported River and Wetlands Activities between 2016 and 2020

Project/District Name	OMWM	Wetlands/Marsh Restoration	Vegetation Control	Ditch Maintenance[a]
Berkshire County		✓		✓
Bristol County	✓			✓
Cape Cod				✓
Central Massachusetts				✓
Dukes County				
East Middlesex				✓
Norfolk County	✓			✓

Project/District Name	OMWM	Wetlands/Marsh Restoration	Vegetation Control	Ditch Maintenance[a]
Northeast Massachusetts Wetlands Management	✓	✓	✓	✓
Pioneer Valley				
Plymouth County	✓	✓		✓
Suffolk County				✓

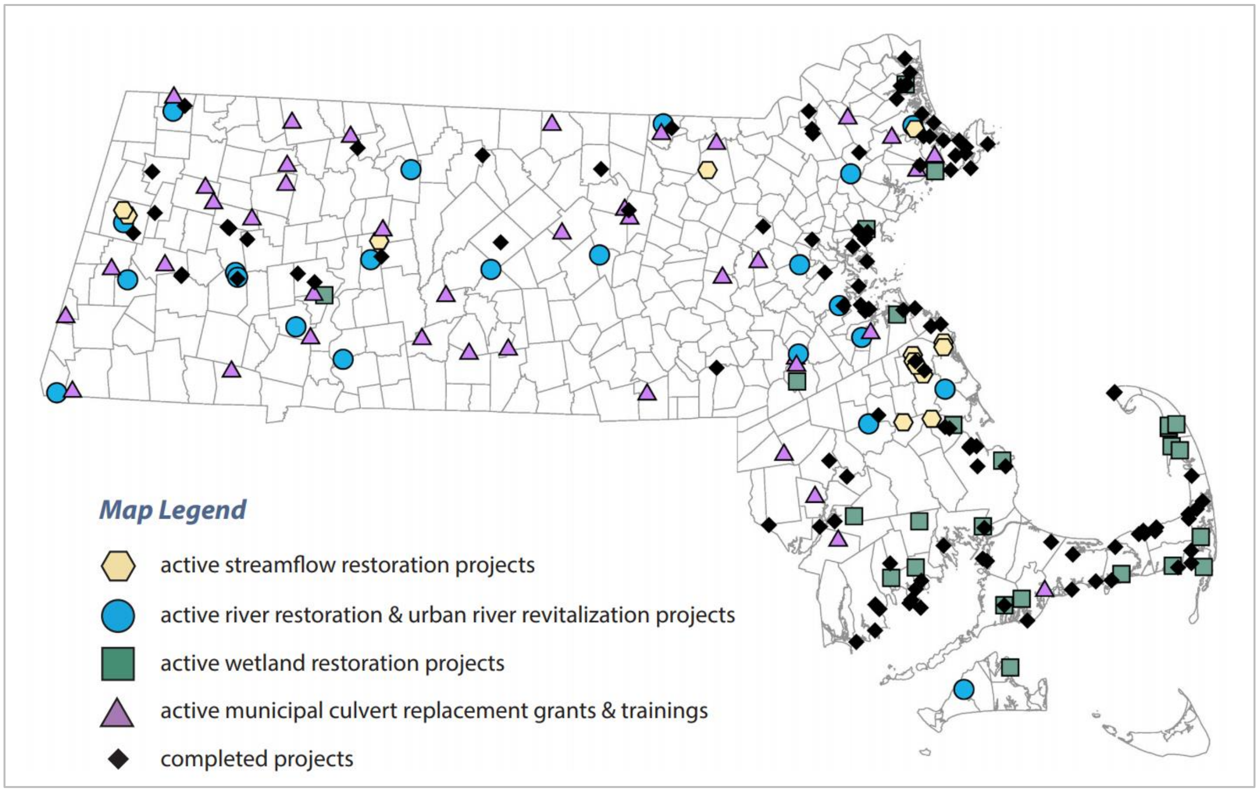
[a] The annual reports use a yes/no field for ditch maintenance; the columns to the left of "Ditch Maintenance" were filled according to free-text comments in annual reports, responding to questions about additional source reduction activities in which the MCDs participate. This includes MCDs that either initiated projects or performed maintenance (e.g., maintaining vegetated areas created during a previous restoration project).

Two examples of the type of work being done in river and wetland restoration to assist with mosquito control in Massachusetts:

- In January 2013, the Northeast Massachusetts Wetlands Management MCD and Division of Ecological Restoration (DER) finished construction on a restoration project at the Castle Neck River Estuary in Essex and Ipswich, Massachusetts. Tidal drainage improved and salt marsh mosquito habitat was reduced by removing three flow obstructions across 130 acres of wetland ("Castle Neck River Estuary Restoration Project," 2013).

- The Herring River Tidal Restoration Project in Wellfleet and Truro, Massachusetts, is restoring tidal flow using OMWM. Hydrologic and ecological research have suggested that restoring the natural tidal flow will reduce mosquito populations and have many other community, ecosystem, and health benefits (National Park Service, 2011). Mosquito populations may be reduced because of increased tidal flushing and restored habitats for mosquito predators.

DER has been involved with over 100 wetlands and river restoration projects in multiple cities and municipalities. Communities and MCDs looking to begin restoration projects as part of their IPM can reach out to DER for planning assistance and funding resources (Commonwealth of Massachusetts, 2021g). Figure 6-2 shows the locations of active and completed projects supported by DER (Division of Ecological Restoration, 2021a).



Source: (Division of Ecological Restoration, 2021a).

Figure 6-2. Map of active and completed ecological restoration projects supported by DER.

6.2.1 Considerations for Wetland Resource Areas and Buffer Zones

According to the Wetlands Protection Act's definitions (summarized in Section 3.1.1), river and wetlands alterations qualify as activities regulated in Wetlands Protection Act–protected areas and buffer zones. As stated in section 3.1.1, MCDs have an exemption under Mass. Gen. Laws Ch. 131, § 40 and do not need to submit a Notice of Intent for activities which would otherwise require one under the Wetlands Protection Act. For other individuals and groups, wetland and river restoration activities may require preparing a Notice of Intent with the local conservation commission for permitting decisions (called an "Order of Conditions"). Many Massachusetts cities and municipalities also have local bylaws which regulate activities near wetlands, rivers, and other local water bodies.

Wetlands restoration projects can receive technical assistance for preparing necessary permits under state and federal law from DER.

6.2.2 Costs

Costs of vegetation control, ditching, and other activities vary widely depending on the area and region. Annual 2021 budget information provided by MCDs did not include costs of river and wetlands activities. Many rivers and wetlands restoration projects rely on several sources of funding, including local, state, and federal grants. Because these projects often apply for multiple sources of funding over different periods of time, there is limited research available on the average cost of a single river or wetlands restoration project in Massachusetts.

Table 6-2 describes wetlands maintenance activity cost estimates published by the United States Environmental Protection Agency (2009), based largely on costs from the Maryland region in 2005. Note that the data did not specify if mosquito control was a motivating reason or focus for these projects and maintenance items.

Table 6-2. Estimated Costs of River and Wetland Maintenance Activities

Maintenance Item	Unit Price ($)	Unit	Mobilization Cost ($)
Vegetation: install wetland plant	6	Each	800
Vegetation: repair low spots in dry pond bottom	25	Square yard	1,500
Vegetation: remove woody vegetation from dry pond bottom	1,700	Event	0
Dredging: dredge wet ponds (jobs larger than 1,000 cubic yards) and haul offsite	60	Cubic yard	>2,500
Dredging: dry pond sediment removal	7,600	Event	0
Dredging: dewater and remove sludge from underground facilities	1	Gallon	0
Channels: remove and replace riprap or pea gravel	160	Square yard	1,500
Channels: shoreline protection	50	Linear foot	1,500
Channels: erosion repair	1,100	Event	0

Modified from United States Environmental Protection Agency (2009)

6.3 River and Wetlands Restoration Activities in Other States

The table below describes mosquito control activities in rivers, wetlands, and marshes for states in New England.

Table 6-3. River and Wetlands Restoration for Mosquito Control in Other States

State	River and Wetlands Restoration for Mosquito Control
Connecticut	The Wetland Habitat and Mosquito Management (WHAMM) program integrates OMWM into Connecticut's IPM strategy (Connecticut Mosquito Management Program, 2019b). The WHAMM program uses selective pool and ditch networks to reduce the negative effects of traditional ditching and restore natural water flow, thereby reducing mosquito habitats in saltwater marshes (Connecticut Mosquito Management Program, 2019a).
Maine	The Department of Environmental Protection does not list any river or wetland restoration programs on its website (Maine Department of Environmental Protection, 2016). The Division of Disease Surveillance does not list any river or wetlands activities at the state level as part of its mosquito response (Division of Disease Surveillance).
New Hampshire	The Department of Health and Human Services does not report river or wetlands activities as part of its response plan for mosquito control (New Hampshire Division of Public Health Services, 2016). The Arboviral Illness Task Force identified wetlands and marsh lands on private property as a working subject area, stating that these areas should be identified so that "the fish and game department and the department of environmental services [can] determine if the standing water hazard can be removed" (NH Department of Health and Human Services, 2021).

State	River and Wetlands Restoration for Mosquito Control
Rhode Island	The Department of Environmental Management reports saltmarsh water management projects as part of its Mosquito Response Protocol (Rhode Island Department of Environmental Management, 2001). These projects are intended to reduce mosquito habitat for saltwater species that can carry WNV and/or EEE.
Vermont	The Agency of Agriculture, Food, and Markets does not report river and wetlands activities at the state level as part of its mosquito response (Vermont Agency of Agriculture, n.d.). The BLSG Insect Control District, one of two MCDs in Vermont, reports river and stream monitoring as part of its IPM strategy (Brandon-Leicester-Salisbury-Goshen-Pittsford Insect Control District, 2021). The Lemon Fair Insect Control District reported that a wetlands restoration project undertaken in 2014 had positive effects on frog and tadpole populations, which are natural predators of mosquito larvae, but has not reported river or wetland activities since (Lemon Fair Insect Control District, 2020).

6.3.1 Other States

In New Jersey, the Edwin B. Forsythe National Wildlife Refuge employed OMWM techniques in a project that used pond construction and connecting channels to facilitate tidal flow and create both open water and deep-water areas. These activities reduced mosquito larvae population and density by over 90 percent in the two years following OMWM treatment (James-Pirri et al., 2009).

6.4 Best Available Science Related to River and Wetlands Restoration for Mosquito Control

Several studies compared methods of vegetation thinning and ditch maintenance to discourage mosquito breeding habitats in wetland and river areas, and many studies have researched the efficacy of OMWM as mosquito control. Overall, the studies stress two factors as necessary to the effectiveness of river and wetlands restoration for mosquito control:

- Eliminating shallow, standing water by either improving drainage (ditch maintenance) or creating deep-water zones.
- Maintaining the system over time.

6.4.1 Vegetation Control

Thinning of vegetation, especially at the waterline, includes mechanical removal of plants, burning, and selective removal of species. In a published literature review, J. R. Rey et al. (2012) laid out several studies suggesting that periodic vegetation thinning was less effective at reducing mosquito habitat than limiting vegetated areas to create deep-water zones along rivers and in wetlands. One of the studies referenced in Rey et al.'s review (Walton and Jiannino (2004)) determined that even with 50 percent reduction in vegetation, the treatment wetland had no significant difference in reduction of larval abundance or adult mosquitoes. The authors hypothesized that controlled thinning of vegetation does not remove mosquito breeding areas at water depths less than a meter, as shallow areas of standing water are still present.

A study by Thullen et al. (2002) compared the mosquito production of wetland areas with thinned vegetation or artificial hummocks to untreated wetland. The hummock wetland areas produced approximately 98 percent fewer mosquitoes in terms of egg rafts and larvae, while areas with generally thinned vegetation produced approximately 75 percent fewer mosquitoes than the untreated wetland. While general thinning of vegetation did significantly reduce mosquito activity in this study, the authors found that emergent vegetation regrew quickly and would need more consistent maintenance to be effective in the long term. The hummocks limited emergent vegetation to the hummocked areas and increased predator access to egg rafts and larvae in the areas between hummocks.

6.4.2 Ditch Maintenance

Ditching, a formerly widespread method of mosquito control, disrupts natural water flow and topography with artificial ditches and channels. This method is no longer common in New England. However, these states still maintain some ditch systems and channels as a routine part of mosquito control; in Massachusetts, road sand, yard waste, and sediment loads from developed areas often obstruct water flow in the ditches and need constant removal to maintain ditch efficacy (State Reclamation and Mosquito Control Board, 1998a).

Research on the effectiveness of ditch maintenance for mosquito control has indicated that the method is only effective if water is kept at least 1 meter deep. Walton (2011) notes that ditches and water channels that are kept deeper than 1 meter form deep-water zones and reduce the amount of standing, shallow water for mosquito breeding. Deep water also allows fish and other mosquito predators to move through different areas and access mosquito larvae and egg rafts.

6.4.3 Other Topographical Changes

OMWM "represents the least deleterious and most efficient non-pesticidal method for controlling saltmarsh mosquitoes," according to the State Reclamation and Mosquito Control Board (1998a).

The previously mentioned study by James-Pirri et al. (2009) examined the effectiveness of OMWM in two wetlands: the Edwin B. Forsythe National Wildlife Refuge in New Jersey and the Parker River National Wildlife Refuge in Massachusetts. At both refuge sites, the wetland areas treated with OMWM approaches saw a significant decrease in number of larvae and larval density. These effects were still significant two years after treatment. A system of pond construction and radial ditches was implemented in 2003 at the Forsythe wetland and in 2005 no larvae were detected in the treatment area. A comparison of the two years before and after treatment showed a 92.9 percent reduction in larvae. The Parker River wetland in Massachusetts was treated with deepening and sloping of ditch edges, pond creation, and selective ditch plugging. This approach created a closed tidal system with permanent deep-water areas. The study found a significant 99.8 percent reduction in larvae in the two years after treatment compared to the two years before.

7. MOSQUITO PREDATOR HABITAT

7.1 Overview

Potential mosquito predators that are native to Massachusetts include:

- Insects (e.g., dragonflies, damselflies, midges, backswimmers)

- Bats (e.g., little brown bats, big brown bats)
- Copepods
- Fish (e.g., fathead minnow, golden shiner, American eel, mummichog, tilapia[23])

The improvement of predator habitat to manage mosquito populations is a form of biological control. Habitat improvement creates a theoretical possibility that predators may increase and the adult and larval mosquito populations may decrease (see Figure 7-1 below). However, there is limited to no peer-reviewed data on the efficacy of altering predator habitat, or simply increasing predators, to decrease nuisance or vector mosquitoes relevant to Massachusetts.

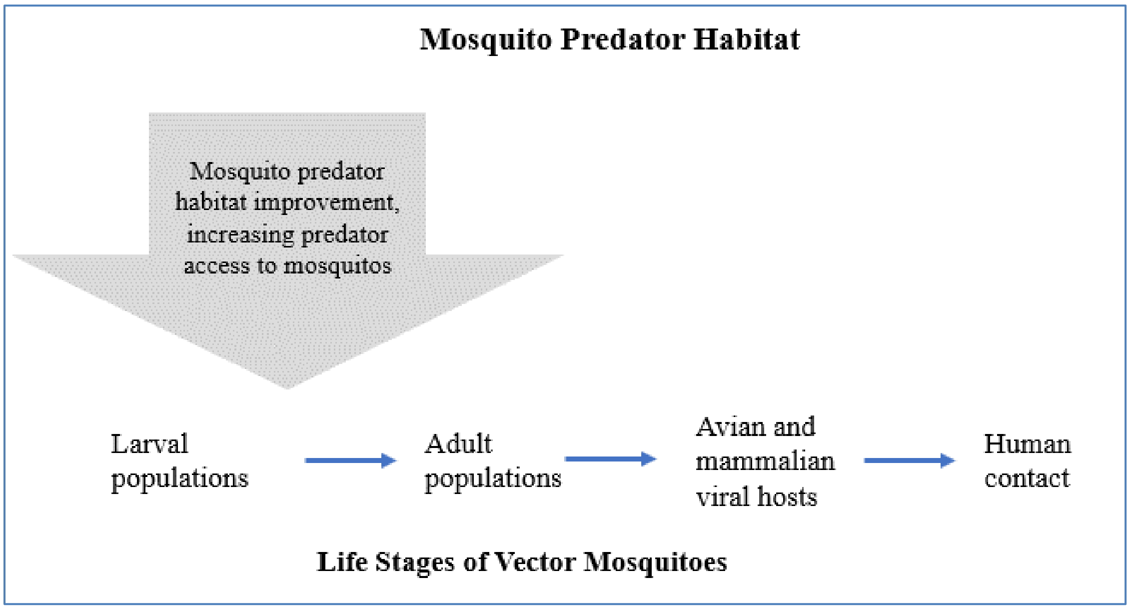


Figure 7-1. Mosquito predator habitat activities and their effect on mosquito life cycles

Other IPM practices such as river and wetlands restoration and stormwater management may affect existing predator populations. The restoration of river and wetlands ecosystems can indirectly improve the effectiveness of mosquito predators such as dragonflies and local fish by increasing access to mosquito larvae. For example, ditching activities that result in deep-water zones and open water make habitats better for fish populations and allows fish better access to mosquito larvae and egg rafts at the water’s edge. These topics are described in detail in Section 6; this section focuses on the concept of using mosquito predators to control mosquito populations.

7.2 Current Practices in Massachusetts

No MCD has reported increasing the number of mosquito predators directly, but two (Berkshire County and Northeast Massachusetts Wetlands Management) have reported mosquito

[23] Tilapia, while not native to Massachusetts, are commonly found in Massachusetts waters and are permitted in Massachusetts aquaculture facilities.

predator habitat activities. Between 2016 and 2018, the Northeast Massachusetts Wetlands Management MCD reported that several of its water management activities, including ditch maintenance and stream cleaning, are intended to promote predator habitat and access to mosquito larvae. Similarly, Berkshire County reported ditch maintenance and water quality improvements specifically aimed at improving fish access to larvae and enhancing the success of other native predators.

The Massachusetts state website suggests that homeowners consider adding minnows such as *Gambusia*, koi, or guppies to ornamental pools and aquatic gardens as a form of preventative mosquito control (Massachusetts Mosquito Control Services, n.d.). *Gambusia* are non-native fish, but they are unlikely to pose a risk to local wildlife when contained in ornamental pools and aquatic gardens. Containment of the non-native fish is critical, and the Massachusetts Division of Fisheries and Wildlife prohibits the release of fish or spawn to inland waters without a permit (Division of Fisheries and Wildlife, n.d.).

7.2.1 Considerations for Wetland Resource Areas and Buffer Zones

Alteration of mosquito habitat through stormwater control or river and wetlands restoration is discussed in Sections 5.1 and 6.2.1. As stated in section 3.1.1, MCDs have an exemption under Mass. Gen. Laws Ch. 131, § 40 and do not need to submit a Notice of Intent for activities which would otherwise require one under the Wetlands Protection Act.

The introduction of mosquito predator species and/or encouragement of mosquito predator habitat do not necessarily qualify as activities regulated in Wetlands Protection Act–protected areas and buffer zones, and therefore may not require permitting or a Notice of Intent with the local conservation commission. In situations where a resource area must be filled, dredged, or altered to accommodate or encourage predator species, a Notice of Intent may need to be prepared. Mosquito predator habitat activities that affect continuous or intermittent stream flows will, by definition, affect Wetlands Protection Act–protected areas and buffer zones; these will be subject to permitting under state and federal law, and local conservation commissions and state authorities will need to be notified.

Individuals or groups interested in stocking fish as a predator species in public waters must submit justification and supporting documentation to the Massachusetts Division of Fisheries and Wildlife in order to obtain a Class 2 Public Stocking license under 321 CMR 4.00: Fishing.

Additionally, proposed alterations to wetlands habitats regulated under the Wetlands Protection Act are reviewed by the National Heritage and Endangered Species Program (NHESP), which inventories rare and endangered species in Massachusetts (State Reclamation and Mosquito Control Board, 1998a). The NHESP will help determine whether the introduction and/or encouragement of mosquito predators may affect rare or endangered species in terms of food and resource competition, predation, and habitat changes. The NHESP maintains a series of habitat maps showing wetland habitat for state-listed species and will determine whether the proposed alterations affect key habitats.

7.2.2 Costs

There are limited studies describing the costs of introducing mosquito predators or encouraging predator habitat as a form of mosquito control. Mosquitofish such as *G. affinis* cost about $1.50 per fish but are not considered suitable for introduction in Massachusetts (Massachusetts Open Marsh Water Management Workgroup, 2010). No other cost information on mosquito predators or habitat improvements was identified.

7.3 Current Practices in Other States

None of the five other New England states reported recent activities or projects that involved adding mosquito predators or improving mosquito predator habitats. The table below describes mosquito-predator-related information and activities for states in New England.

Table 7-1. Mosquito Predator Habitat Activities in Other States

State	Mosquito Predator Habitat Management for Mosquito Control
Connecticut	The Mosquito Management Program defines biological control as "the control of a pest by the introduction of a natural enemy of predator" and states that mummichogs *(Fundulus heteroclitus),* fathead minnows, sunfish, and top minnows are acceptable to introduce as mosquito predators. Mosquitofish *(Gambusia),* guppies, and dragonfly nymphs are also listed as mosquito predators (Connecticut Department of Energy and Environmental Protection, 2020). The Program acknowledges that certain bats and birds will eat mosquitoes and "encourages the placement of bat and birdhouses for the conservation of these species but does not endorse the use of them solely for the control of mosquitoes" (Mosquito Management Program, 2019). **Note:** introduction of non-native organisms in open waters is prohibited in Connecticut (Connecticut General Assembly - Environment Committee, 2003).
Maine	The Forest Service reports dragonflies, bats, birds, frogs, and mosquito-eating fish as providing some natural control against mosquitoes, but does not report any state-level activities regarding mosquito predators as part of its mosquito response (Maine Forest Service, 2003). **Note:** In the case of mosquito-eating fish, the "introduction of fish into any body of water is regulated" and requires a permit with the Department of Inland Fisheries and Wildlife (Maine Forest Service, 2003).
New Hampshire	The Department of Health and Human Services does not report mosquito predators as a means of mosquito control (New Hampshire Division of Public Health Services, 2008b). No other studies were identified regarding mosquito predator habitat control in New Hampshire. **Note:** New Hampshire regulations require a permit for the importation of certain species, including certain fish species (New Hampshire Fish and Game Department, 2016).
Rhode Island	The Department of Health does not report mosquito predator activities as part of its Mosquito Response Protocol (Rhode Island Department of Health).One study published by Couret et al. (2020) investigated the effectiveness of common bladderwort, a carnivorous plant from Rhode Island, as mosquito control. The laboratory study suggested that common bladderwort can effectively control mosquitoes at the larval stage, but no field studies have been conducted as of 2020.
Vermont	The Department of Health and the Agency of Agriculture, Food, and Markets do not report mosquito predator activities as part of their mosquito response (Vermont Agency of Agriculture, n.d.; Vermont Department of Health, 2021). No other studies were identified regarding mosquito predator habitat control in Vermont.

7.4 Best Available Science Related to Mosquito Predator Habitat

This section summarizes the results of several studies that quantified the effectiveness of mosquito predators at reducing larval and adult mosquito counts in various experimental settings. Note that the results are not exhaustive, and the original studies provide more details about the experimental setup, methods, and limitations of the results.

7.4.1 Dragonflies and Damselflies (Odonata)

Several studies have confirmed that dragonflies and other odonates are important predators of mosquito larvae (Telford, 2009). Data quantifying the effect of dragonfly predation in New England are limited. In simulated experiments, dragonfly naiads reduced *Culex pipiens* and *Culiseta longiareolata* mosquito populations by 32–78 percent (Stav et al., 2005), but a study of *Aedes* mosquitoes in Thailand indicated that in the field, predation rates by odonates are lower and negatively related to predator density (Weterings et al., 2015). Other studies emphasized that odonate mosquito consumption is highly dependent on the presence of other prey (Saha et al., 2009).

7.4.2 Copepods and Others (Crustacea)

Data quantifying the effect of copepod predation in New England are limited. In a laboratory study, copepods reduced mean larval survival from 92.2 percent (control, no copepods) to 29.8 percent in the presence of 1 to 10 copepods (Rey et al., 2004). A UK study of cyclopoid copepod predation on *Aedes albopictus mosquito larvae found that the median predation efficiency of* cyclopoid copepods was 22 percent, with copepod body mass positively related to predation efficiency (Russell et al., 2021). Copepods used in this study were collected from lakes in the UK and placed in lab colonies for the duration of the study. This study also tested the predation efficiency of copepods at temperatures between 15–25°C and found that, in this range, temperature did not have a significant effect on predation when mosquito larvae were the only food source present..

7.4.3 Fish (Various)

Many studies have quantified the effect of mosquitofish *(Gambusia)* predation on mosquito larvae. In a laboratory study, *G. affinis* predation reduced the number of mosquito larvae by 98.7–100 percent within 24 hours (Chobu et al., 2015). However, the Massachusetts Open Marsh Water Management Workgroup noted that despite high predation efficiency, mosquitofish have shown aggressiveness and invasive behavioral patterns that make them unsuitable for introduction in Massachusetts (Massachusetts Open Marsh Water Management Workgroup, 2010). In a field study, tilapia predation reduced the average number of mosquito larvae by 53 percent (Mohamed, 2003). No studies were identified regarding the predation efficiency of common Massachusetts fish (fathead minnow, golden shiner, American eel, mummichogs) with the exception of tilapia.

7.4.4 Bats (Mammalia, Chiroptera)

No studies on the effect of bat predation in New England were identified. In a study in Michigan, wild bats were captured and placed in cages with access to *Culex* mosquito oviposition basins. Bat predation resulted in a significant 32 percent reduction in egg-laying activity (Reiskind & Wund, 2009). No other studies were found on the quantification of bat predation on mosquitoes.

8. DAM REMOVAL AND CULVERT IMPROVEMENTS FOR MOSQUITO CONTROL

This section presents available information on dam removal and culvert management as source reduction techniques to reduce mosquito egg-laying and larval development habitats (see Figure 8-1). Generally, dam impoundments are open water habitats, which are not associated with WNV or EEE transmitting mosquitoes (Telford, 2009).

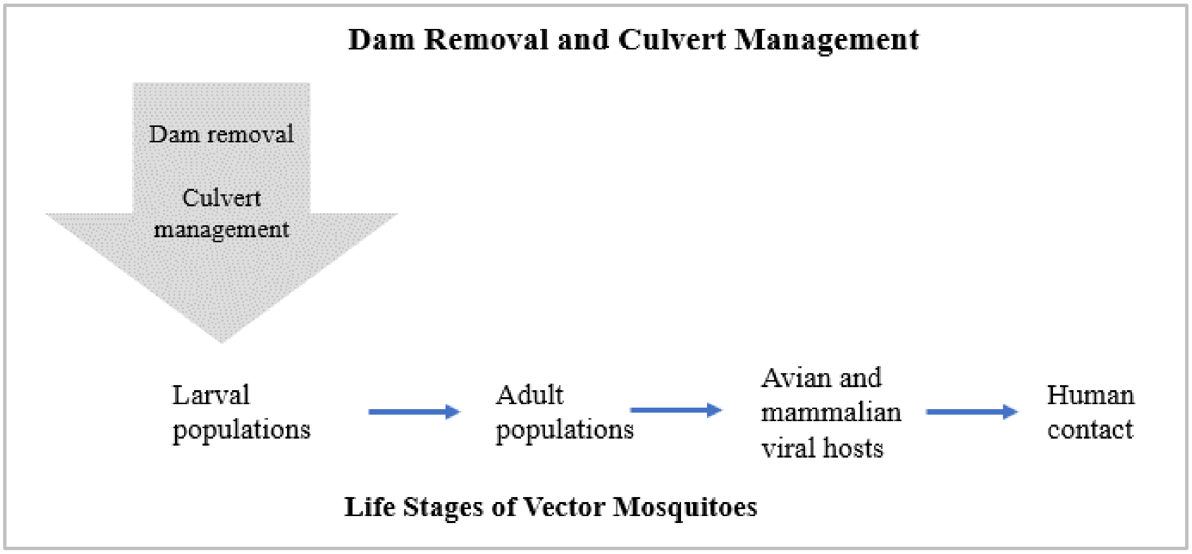


Figure 8-1. Dam removal and culvert management and their effect on mosquito life stages.

A dam is defined as any artificial barrier that impounds or diverts a natural watercourse (302 CMR 10.03). Dam impoundments can create habitats for mosquito larvae by (1) increasing the area of water amendable to egg deposition and larval development and (2) replacing river water flows with stagnant conditions in the impoundment area (Division of Ecological Restoration, 2021b). When dams are removed, source water flows more freely through the river course; the mosquito breeding and larval development habitat in the impoundment is virtually eliminated. The open water habitat associated with dams is not typically associated with mosquitoes transmitting WNV in Massachusetts (primarily *Culex pipiens*), though dams in Massachusetts' urban areas may provide standing water as habitat. Many dam impoundments are located in areas of Massachusetts (upper Cape and Bristol County) where EEE virus is more commonly detected, although only two of the more commonly EEE-carrying mosquitoes have larval habitats that might be associated with dam impoundments: *Coquillettidia perturbans* (which breeds principally in cattail/water-willow ponds) and *Culex salinarius* (which is a permanent pool breeder) (Bharel & Cranston, 2020a).

Culverts are engineering structures (pipes or short tunnels built transversely under a road, railway, or embankment) that convey a stream or stormwater. While culverts are critical structures needed to move water downstream, and sometimes to provide continuous passage of aquatic wildlife, improper design (i.e., culvert sizing, height, slope) or maintenance (remedying impeded flow due to debris) may result in pooling on the upstream or downstream side of the culvert, which provides habitat for mosquito egg laying and larval development.

8.1 <u>Current Practices in Massachusetts</u>

Dam Removal

Massachusetts has 2,903 dams. These were built for a variety of reasons, including water supply, agricultural use, and flood control; the majority were built before 1900 to power saw and textile mills and have outlived their original purpose. Federal agencies (i.e., the U.S. Army Corps of Engineers, the U.S. Fish and Wildlife Service, or the Federal Energy Regulatory Commission) regulate 73 of these pre-1900 dams, so they are not considered candidates for dam removal by the Commonwealth. The Office of Dam Safety has oversight responsibility for 1,536 dams. Three quarters of the remaining 1,284 dams are on private property MassGIS Bureau of Geographic Information (2020) . Table 8-1 summarizes the number of dams, the approximate waterline they are associated with, and jurisdictional authority. The 2,830 dams in Massachusetts that are not under federal control are associated with as much as 1,900 miles of waterline mosquito habitat.

Table 8-1. Summary of Number of Dams and Amount of Waterline Habitat by MCD and Jurisdictional Oversight

Project/District Name	Regulatory Oversight			
	Office of Dam Safety[a]		Non-Jurisdictional[b]	
	Number of Dams	Waterline Habitat (Miles)	Number of Dams	Waterline Habitat (Miles)[c]
Berkshire County	34	38	13	—
Bristol County	100	83	54	—
Cape Cod	25	14	32	—
Central Massachusetts	242	187	149	—
Dukes County	6	0	11	—
East Middlesex	72	43	36	—
Norfolk County	100	56	36	—
Northeast Massachusetts Wetlands Management	113	79	91	—
Pioneer Valley	61	34	61	—
Plymouth County	132	67	221	—
Suffolk County	3	5	2	—
Not in an MCD	648	464	578	—
Total	1,536	1,072	1,284	890 [d]
Private owner	645		925	
Public owner	891		359	

Source: MassGIS Bureau of Geographic Information (2016).

[a] The Massachusetts Office of Dam Safety oversees (1) dams that are 25 feet or more in height from the natural bed of the stream or watercourse measured at the downstream toe of the barrier, (2) dams with impounding capacities at maximum water storage elevation of 50 acre-feet or more, and (3) any artificial barrier or appurtenant works whose breaching the Commissioner Department of Conservation and Recreation deems could endanger property or safety.

[b] Non-jurisdictional dams include any appurtenant works that temporarily impounds or diverts water used on land in agricultural use as defined pursuant to MGL c. 131, § 40; any barrier or appurtenant works that has a size classification of small or low hazard potential that is used on land in agricultural use as defined in MGL c. 131, §

40; and any barrier that is not in excess of 6 feet in height, regardless of storage capacity, or that has a storage capacity at maximum water storage elevation not in excess of 15 acre feet, regardless of height.

[c] Waterline habitat calculated as the circumference of a circular shape the area of the pool surface area. For this discussion, ERG assumes that the circumference of impoundments is an approximation of the larval habitat, as effective egg laying occurs along the edge of the impoundment where water depth is 3 feet or less. Dam removal eliminates mosquito habitat by replacing stagnant or low-flow water conditions with moving water and lower water temperatures, which are less conducive to egg-laying and larval development. The relative contribution of dam impoundments to mosquito populations in Massachusetts, and the aggregate benefits of this type of source reduction within Massachusetts, have not been determined.

[d] Information on pool surface area, from which waterline habitat was derived, is not available for non-jurisdictional dams. Waterline habitat for non-jurisdictional dams was derived using the average waterline habitat per dam from Office of Dam Safety dams.

Dam removal is currently an active program within DER. DER has helped remove 40 dams since 2005; the Commonwealth is expected to continue its support for dam removal into the future, though the rate and likely locations of future dam removals are not known. The DER dam removal program is primarily intended to restore natural river systems and ecosystems and is not currently being done for mosquito control. Based on review of the MCD annual reports (2009–2020), MCDs have not undertaken any dam-removal-related activities except beaver dam management.

Culvert Management

The Massachusetts Department of Transportation Road Inventory includes 55,977 miles of road; the Department’s culvert data identify 5,582 culverts, which are primarily associated with perennial or intermittent flow streams (Massachusetts Department of Transportation, 2020; Slovin, 2019). There are many more culverts, intended to handle stormwater flows on both public and private property, that are not included in this inventory. Many stormwater culverts are present in every municipality and MCD in the Commonwealth. While the extent of design problems and conditions that lead to pooling of water for several days are not quantified, remedies and replacement are feasible and regularly undertaken by local and state public works programs, particularly when storm events indicate a culvert is insufficient to handle storm flows. Repairs and replacement that meet the Commonwealth’s construction standards will include features that improve draining and often eliminate pooling (Massachusetts Department of Environmental Protection, 2008).

The Massachusetts DER culvert replacement program provides technical assistance and grants for replacement of culverts that meet the Stream Crossing Standards (i.e., those that provide for continuous stream flow). This program does not cover drainage and stormwater culverts, but replacement, rehabilitation, and maintenance of culverts and roadside drainage ditches is often part of municipal stormwater plans and an element of road maintenance and rehabilitation. 2020 MCD annual reports indicate that nine of the 11 MCDs carry out a variety of the best management practices established in the *Massachusetts Stormwater Handbook,* primarily culvert and drainage ditch cleaning and streamflow improvement (Massachusetts Department of Environmental Protection, 2008).

8.1.1 Considerations for Wetland Resource Areas and Buffer Zones

Section 3.1.1 summarizes Wetlands Protection Act definitions of wetland resource areas and activities subject to protection. As stated in section 3.1.1, MCDs have an exemption under Mass. Gen. Laws Ch. 131, § 40 and do not need to submit a Notice of Intent for activities which would otherwise require one under the Wetlands Protection Act. For other individuals and groups, dam removals are subject to Wetlands Protection Act regulations and require preparing a Notice of Intent and submitting it to the local conservation commission, as well as permitting. DER has prepared guidance for owners interested in dam removal and also provides technical assistance in preparing necessary permits under state and federal law (Division of Ecological Restoration, 2021b; Executive Office of Energy and Environmental Affairs, 2007).

Culverts associated with continuous or intermittent stream flows will, by definition, affect Wetlands Protection Act–protected areas and buffer zones; entities installing them will be required to notify local conservation commissions and state authorities and will be subject to permitting under state and federal law. There are additional requirements for stormwater management in certain types of locations, such as drinking water wellhead protection areas, shellfish growing areas, and bathing beaches. The number, location, and condition (related to pooling) of stormwater or drainage culverts in Massachusetts are unknown.

8.1.2 Costs

Dam Removal

According to DER, dam removal typically costs several hundred thousand dollars, but this cost can range widely: it depends on both site characteristics and complexity of the removal (Division of Ecological Restoration, 2021a).

DER has compiled and published several examples of dam removals, each of which includes removal costs. These are presented in Table 8-2.

Table 8-2. Dam Removal Costs

Project	Removal Costs	Contextual Information	DER Contributions
Bartlett Pond Dam Removal (Lancaster)	$100,000	$600,000–$1.0 million estimated for repair/replacement	Loan from EEA Dam and Seawall Repair and Removal Fund; DER provided $45,000 cash and technical assistance
Briggsville Dam Removal (North Adams)	$920,000		95% of costs from state, federal, and nonprofit sources
Millie Turner Dam Removal (Pepperell)	$330,000	$2.8 million to repair	Match from Hurricane Sandy Resilience Program and DER
Tack Factory Dam Removal (Norwell/Hanover)	$382,000		Approximately 95% of the cost came from state, federal, and nonprofit sources

Culvert Management

While the cost of culvert/small bridge replacement is site-specific, Massachusetts does provide summary costs for 102 culvert/small bridge replacements that were eligible for DER assistance (those with perennial streams) and would comply with Stream Crossing Standards upon completion (Massachusetts Culverts and Small Bridges Working Group, 2020). Design and permitting costs ranged between $30,000 and $70,000. The median construction cost for these projects was $680,000. Replacement costs for simpler drainage culverts range from $2,500 to $5,500. These are summarized in Table 8-3.

Table 8-3. Existing Round Culverts Replaced

Number and Diameter	Length of Culvert Replaced (Feet)	Installation Cost Every 10 Years ($)	Maintenance Cost Every Nine Out of 10 Years ($/Year)
Two 2.5'	60	3,780	600
One 3.5'	44	4,752	600
One 3'	30	2,460	600
One 4'	40	5,360	600

Source: Natural Resources Conservation Service (2009).
Costs are listed in 2007 dollars.

In addition to culvert replacement, there are costs associated with creating small, dry bioswales and protective features on both sides of culverts. No information sources on the cost of creating these swales and water diversion features for individual small culverts were identified. Costs for larger bioswales are presented in Section 6.2.2.

8.2 Current Practices in Other States

No New England states reported conducting dam removal for mosquito control (Multiple states, personal communication, July 2021).

Engineering best management practices for culvert design and stormwater controls are consistent across Connecticut, New Hampshire, and Maine (Connecticut Department of Energy and Environmental Protection, 2004; Maine Department of Environmental Protection, 2016; McCarthy, 2008).

8.3 Best Available Science Related to Dam Removal and Culvert Improvements

Dam Removal

As a source reduction measure for mosquitoes, dam removal essentially eliminates the egg-laying and larval habitat created by impounded water. However, a review of the literature outlining the efficacy of dam removal for mosquito control did not locate any relevant literature.

Culvert Management

Improved culvert design, retrofit construction, and regular maintenance to remove debris are key to removing mosquito egg-laying and larval habitats associated with poorly performing culverts. The duration and amount of storm-event pooling can be minimized with three modifications: appropriate sizing of the culverts to handle anticipated stormwater flows; appropriate height from “collection levels” on both upstream and downstream sides of the culvert; and, for stormwater culverts, use of dry bioswale features (e.g., soil bed of native soils or highly permeable fill material, underlain by an underdrain system, native plantings). Details on the studies that evaluate the efficacy of stormwater management and culverts associated with mosquito control are presented in Section 5.3.

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Report 6: Best Practices to Maximize Impact of Pesticide Use on Mosquito Populations and Minimize Non-target Impacts of Mosquito Pesticides

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1. EXECUTIVE SUMMARY

The State Reclamation and Mosquito Control Board (SRB) and mosquito control districts and projects (MCDs) use integrated pest management (IPM) approaches, which combine non-chemical and chemical controls. There may be opportunities to make the chemical control part of these approaches more effective. More focused timing over the course of the mosqutio season and greater spatial precision of pesticide applications can increase efficacy and target specific mosquito species, which may reduce both risk from mosquito-borne disease and pesticide usage. To identify opportunities for refining chemical controls, this report compares best practices for chemical control to current practices in Massachusetts.

A related concern for the Mosquito Control Task Force (MCTF) is avoiding inadvertent exposure and adverse impacts of pesticide application on non-target receptors: vulnerable human populations, aquatic species, pollinators, and drinking water supplies. Several important measures reduce pesticide risks for these non-target receptors.

- The U.S. Environmental Protection Agency (EPA) reviews all commercially available pesticides and approves their use for specific pests and end uses. Pesticide label instructions provide applicators with instructions for appropriate use and restrictions, which are generally protective of non-target receptors and must be followed according to federal law.

- Current practices in Massachusetts include several protective activities and mechanisms to confirm protective measures are being followed.

The first section of this report covers current practices in place. The second section of this report examines pesticide choice, decisions about locations and timing of pesticide application, and other practices that have been determined to be protective of non-target receptors.

2. OVERVIEW

This report addresses the following request from the MCTF:

> "Summarize best practices to maximize impact of pesticide use on mosquito populations and minimize non-target impacts of mosquito pesticides, including but not limited to effects on persons with respiratory or immune system illnesses, drinking water supplies, pollinators and aquatic life."

Section 3 of this report compares best practices for maximizing the impact of pesticide applications on mosquitoes to current practices related to pesticide application in Massachusetts. Section 3.1 identifies practices that have been shown to minimize the impact of mosquito control pesticides on a number of non-target receptors. IPM, an approach taken by all MCDs and the SRB, uses a range of both non-chemical and chemical controls, with a goal of minimal pesticide use. Non-chemical controls and IPM as a whole are discussed in Report 5: Integrated Pest Management and Non-chemical Mosquito Controls.

3. COMPARISON OF BEST PRACTICES TO MAXIMIZE IMPACT OF PESTICIDE USE ON MOSQUITO POPULATIONS TO CURRENT PRACTICES IN MASSACHUSETTS

Table 3-1, starting on the next page, presents an overview of best practices established by the American Mosquito Control Association (AMCA) for maximizing the impact of pesticide use on mosquito populations (American Mosquito Control Association, 2017). The information presented in the table excludes some components of IPM programs, such as source reduction and education and outreach (discussed in detail in Report 5: Integrated Pest Management and Non-chemical Mosquito Controls). These best practices are juxtaposed against current practices in the Commonwealth. The characterization of the current practices in Massachusetts is taken from MCD annual reports, the SRB's *Emergency Operations Response Plan for Mosquito-Borne Illness*, the Department of Public Health's (DPH's) Surveillance and Response Plans for 2020 and 2021, and a questionnaire completed by MCDs in July 2021. Data were collected from 2009 to present, building on 2009 Generic Environmental Impact Report on the Commonwealth's mosquito control program (Telford, 2009).

Table 3-1. Comparison of Best Practices to Maximize Impact of Pesticide Use on Mosquito Populations to Current Practices in Massachusetts

Selected AMCA Recommendations Related to Maximizing Impact of Pesticide Use on Mosquito Populations	Current Practices in Massachusetts
Surveillance: Surveillance results should be used to inform decisions about 1) the most appropriate timing for pesticide application and 2) targeting geographic areas where specific mosquito species (arbovirus-bearing and nuisance mosquitoes) are found and/or arboviral disease risk levels are high (American Mosquito Control Association, 2017).	• All MCDs carry out larval and adult surveillance (location, species identification, and viral presence). • Testing by DPH ensures consistency and that DPH is aware of testing results across the state. • Towns and MCDs may conduct surveillance and arbovirus testing independent of DPH. Currently, here are no testing standards to ensure comparability to testing carried out by DPH and DPH does not utilize test results other than those produced by its own laboratory. Sharing of independent testing results among towns, MCDs, DPH is limited.
Mapping: Geographic information systems (GIS) should be used to identify mosquito habitats and plan ground and aerial pesticide application routes for maximum effectiveness (American Mosquito Control Association, 2017).	• MDAR provides MCDs, DPH, the Department of Environmental Protection (DEP), and other agencies with detailed mapping information (including exclusion areas), which MCDs and SRB use to plot application routes and to program GIS-based spray controls for truck and aerial spraying. (State Reclamation and Mosquito Control Board, 2019). • Some MCDs maintain geographic information systems with mosquito habitat, which is used for targeting applications. (Massachusetts MCDs, 2021)
Setting action thresholds: Response plans should set thresholds for specific control measures based on surveillance data of larval and adult mosquito populations and species, as well as arbovirus infection rates in mosquitoes, birds, mammals, and humans (American Mosquito Control Association, 2017).	• For 2020, all MCDs that carried out larviciding reported using surveillance-based action thresholds (i.e., larval dip counts) to decide when to apply larvicides. • Seven of the eight MCDs that carried out adulticiding in 2020 reported using surveillance-based action thresholds (i.e., light trap data) to decide when to apply adulticides (Massachusetts MCDs, 2021). • All but one MCD reported that because virtually all habitats harbor more than one mosquito species, their larviciding and adulticiding is not targeted specifically toward nuisance or arbovirus-bearing mosquitoes (EEA, personal communication, July 2021). • The Commonwealth's decision on when to use aerial adulticiding is based on DPH's determination of the Eastern equine encephalitis risk levels for focal areas (i.e., multiple adjacent municipalities) throughout the state. DPH's Surveillance and Response Plan does not provide specifics on how human health risk levels (high, medium, low) are defined (Bharel & Cranston, 2021b).

Selected AMCA Recommendations Related to Maximizing Impact of Pesticide Use on Mosquito Populations	Current Practices in Massachusetts
Chemical controls of larvae: The decision to apply larvicides should involve selection of pesticides and application technology and strategy (e.g., briquets, truck-mounted spraying, aerial spraying) that are known to be effective against the target mosquito species habitats. Surveillance and GIS have been demonstrated to be effective in focusing larviciding on areas with target larval and pupal mosquito populations (American Mosquito Control Association, 2017).	• MCDs must use EPA-registered larvicides that are also registered with the Commonwealth. The larvicides used in Massachusetts are presented in Report 4: Chemical Composition and Toxicity of Pesticides Used in Ground and Aerial Spraying in Massachusetts. • No information was identified on how MCDs and municipalities not part of MCDs decide which larvicides to use. • Total amounts of products applied by each MCD are recorded in annual reports, but details on each application event (i.e., pesticides and forms used, application locations, timing) are not automatically reported to the Commonwealth or in the MCD annual reports. • The SRB has not undertaken statewide larviciding during the 2009–2020 time period.
Chemical controls of adult mosquitoes: The decision to apply adulticides should involve selection of a pesticide and application technology and strategy (e.g., truck-mounted, aerial spraying with ultralow volume application, and lethal ovitraps for container-inhabiting mosquitoes) that are known to be effective against the target mosquito species and their locations. Surveillance and GIS have been demonstrated to be effective in focusing adulticiding on areas with target adult mosquito populations (American Mosquito Control Association, 2017).	• MCDs must use EPA-registered adulticides that are also registered with the Commonwealth. The adulticides used by MCDs are reported to the SRB and presented in Report 4: Chemical Composition and Toxicity of Pesticides Used in Ground and Aerial Spraying in Massachusetts. • No information was identified on how MCDs and municipalities not part of MCDs decide which adulticides to use. • Total amounts of products applied by each MCD are recorded in annual reports, but details on each application event (i.e., pesticides and forms used, application locations, timing) are not automatically reported to the Commonwealth or in the MCD annual reports. • In the spring of each year, MDAR, in consultation with DPH and other state agencies, reviews the most up-to-date toxicity information and available products and recommends and adulticide to be used by the SRB. Currently, for any high-risk public health event, Anvil 10+10 is used for aerial spray adulticiding over focus areas with high human health risks. • Before aerial sprays, MDAR publishes information on the locations and timing of the spray.

Selected AMCA Recommendations Related to Maximizing Impact of Pesticide Use on Mosquito Populations	Current Practices in Massachusetts
Monitoring for efficacy and resistance: The procedures for pesticide resistance testing outlined by the Centers for Disease Control and Prevention (CDC) should be followed (American Mosquito Control Association, 2017).	• Most MCDs have staff who attended Northeast Regional Center for Excellence in Vector-Borne Diseases or CDC workshops and are trained on or familiar with pesticide resistance testing. About half of MCDs reported they undertook some type of pesticide resistance testing in 2020. In general, MCDs' pesticide resistance results are not widely shared. • DPH conducts pesticide resistance testing. • Several MCDs and DPH track pre- and post-spray mosquito population surveys to determine knock-down efficacy of the pesticide application events (EEA, personal communication, July 2021). • Most MCDs reported that measuring the effectiveness of IPM as a whole was difficult and not undertaken (EEA, personal communication, July 2021).
Recordkeeping: All organizations applying pesticides should keep records of each application event (pesticide used, application rate, amount used, date, time, weather conditions, locations where application occurs); applicator certifications; mosquito surveillance reports, by species (American Mosquito Control Association, 2017).	• While MCDs appear to keep track of some of the recordkeeping information recommended by AMCA, there are no data standards or requirements for submitting data to a centralized data system, which could support tracking of mosquito control activities, analysis of, for example, overall MCD program efficacy, and identification of best practices. • DPH publishes information related to the Commonwealth's aerial spray events, including pre- and post-spray effectiveness, but does not compile operational details of MCDs' programs or effectiveness studies.

3.1 Other Considerations

DPH documented lessons learned from aerial spray operations during previous years that might affect the options for adjusting aerial spray protocols to protect non-target receptors, including the following (Bharel & Cranston, 2021b):

- "*Any reduction in population is expected to be temporary, lasting no more than 2 weeks.*
- *Factors affecting efficacy:*
    - *the greater the mosquito activity, the greater the efficacy;*
    - *coverage of large spray blocks improves efficacy over smaller, separate strips; and*
    - *coverage of the spray area in the shortest amount of time possible improves efficacy.*
- *The majority of mammal-biting mosquito species of greatest concern are typically gone by September.*
- *Mosquito surveillance and weather pattern data are essential in helping to determine need and timing for aerial spray interventions*."

4. Best Practices to Minimize Non-target Impacts of Pesticide Use for Mosquito Control

Risk of adverse effects from pesticide exposure is a product of two components: the inherent hazard of the pesticide and the amount of exposure to the pesticide. Therefore, there are two groups of strategies for minimizing impacts on non-target receptors: choosing less hazardous compounds (see Section 4.1) and reducing the amount of exposure to these compounds (see Section 4.2). Non-chemical approaches to mosquito control are addressed in Report 5: Integrated Pest Management and Non-chemical Mosquito Controls.

Again, the scope of work defines non-target receptors as:

- Vulnerable individuals, including, but not limited to those with respiratory or immune system illnesses

- Drinking water supplies

- Pollinators

- Aquatic life

These are representative categories: many other receptors are also of concern and warrant protection. In general, the best practices described in this section can be protective of a wider range of receptors. For example, minimizing spray drift can be beneficial to all sensitive non-target receptors.

4.1 Best Practices and Tools for Selecting the Least Hazardous Pesticide

The University of Nevada Pesticide Safety Education Program suggests asking the following questions when selecting a pesticide for use: "what is the toxicity level of the pesticide (measured by LD_{50} (lethal dose for 50% of study population)—the higher the LD_{50} number, the less toxic); how mobile is the pesticide and in what fashion can it be distributed (through air, soil, water, etc.); what is the residual life of the pesticide?" (Pesticide Safety Education Program, n.d.).

Best practices for choosing the least hazardous pesticide are presented below. These considerations often apply regardless of the non-target receptor. Practices that are specific to a particular non-target receptor are noted.

Additionally, California's best management practices for mosquito control state that a plan based on thresholds for chemical control is integral. Specifically, thresholds "provide a range of predetermined actions based on quantified data. Thresholds also establish expectations and boundaries for responses that ensure appropriate mosquito control activities are implemented at the appropriate time" (California Department of Public Health & Mosquito and Vector Control Association of California, 2012).

- To choose pesticides with the lowest toxicity, the National Pesticide Information Center recommends looking for the signal word "CAUTION." Signal words are required to be on pesticide labels and are there to describe the acute toxicity of a product. "CAUTION" indicates the product is slightly toxic. Other signal words include "WARNING," which indicates moderate toxicity, and "DANGER," which indicate high toxicity through at least one route of exposure. (National Pesticide Information Center and United States Environmental Protection Agency (2008).

- To make an informed decision about the least hazardous pesticide to use for a given purpose, it is best practice for toxicity data to be collated and compared for non-target receptors of interest across pesticides under considerations. Some sources of data:

    - The **International Union of Pure and Applied Chemistry** maintains a pesticide properties database with data on human health, ecological toxicity, and physical/chemical properties of pesticide active ingredients. The underlying data come mainly from monographs produced as part of the European Union's pesticide review process, though other sources may be used to fill data gaps. The quality of the data is noted within the database.

    - For evaluation related to vulnerable individuals, data are available in **EPA's Human Health Benchmark for Pesticides database** (United States Environmental Protection Agency, 2017a). This database provides concentrations of a pesticide in drinking water that would result in potential adverse health effects for the identified sensitive population. The lower the concentration, the higher the toxicity.

    - For evaluation related to aquatic non-target receptors, **EPA's ECOTOX** database has data on the ecotoxicity of more than 12,000 chemicals to receptors including aquatic life, plants, and wildlife. Users can search compilations of LD_{50} data along with other toxicity measurements to inform the selection of the least toxic pesticide.

- For bees, the University of California's State Water Agricultural and Natural Resources Integrated Pest Management program has developed a database of "**Bee Precaution Pesticide Ratings,**" which allows a user to easily create a list of pesticides under consideration and compare bee precautions related to a specific active ingredient (Dreistadt et al., 2018). This database also indicates if an active ingredient is toxic to honey bees, honey bee brood, and other bee species.

- EPA Registration Eligibility Decisions and accompanying risk assessments (which can be accessed through the "docket" tab after searching for a compound in **EPA's pesticide chemical search database**) provide results of both human and ecological toxicity evaluations and categorize the compounds into toxicological categories ranging from I to IV (I = highly toxic; IV = practically nontoxic).

- EPA's **CompTox Chemicals Dashboard** (USEPA, 2017a) collates data on human health and ecotoxicity data (including LD_{50}s), existing regulatory values for contaminants established by federal and state agencies, and physical/chemical properties for hundreds of thousands of compounds.

Accompanying Report 4: Chemical Composition and Toxicity of Pesticides Used in Ground and Aerial Spraying in Massachusetts is a spreadsheet containing toxicity data for the pesticides used in Massachusetts, including reported LD_{50} values used in EPA risk assessments and the reported human health benchmarks.

Further considerations when choosing the least hazardous pesticide:

- Evaluate the toxicity of inert ingredients in a pesticide, if available.

- Consider whether the pesticide formulation contains a synergist, such as piperonyl butoxide (PBO). Synergistic interactions can increase non-target toxicity of some pesticides (Weston et al., 2006).

- Where possible, avoid pesticides known to have synergistic effects with common agriculture pesticides or miticides commonly used in hives.

- Consider possible sublethal effects that can, for example, decrease bees' ability to effectively travel and gather nectar without causing obvious bee kills (Ingram et al., 2015).

Considerations when choosing pesticides least toxic to pollinators include:

- The degradation rate of the pesticide (Center for Pollinator Research, 2017).

- How a pesticide may spread through a plant. If a pesticide can systemically enter a plant, it could contaminate the nectar and pollen of flowers (Center for Pollinator Research, 2017).

- The formulation of the pesticide. Different formulations of products may be more or less likely to kill forager bees in the field. While losing a colonies foraging force is detrimental, formulations that permit forager bees to bring pesticides to the colony, without killing them, can have much more negative, although sometimes more difficult to detect, effects on colony health. Dusts, which easily adhere to forager bees' bodies, and wettable powders are more hazardous than emulsifiable concentrates. Some research and expert experience indicate that given the high concentration of active ingredients in ultralow volume formulation they may be more hazardous than other liquid formulations (Devillers, 2002).

- Application rates. Larviciding operations, especially when using sustained-release formulations that may reach high concentrations of pesticide in the treated water, should avoid water sources known to be used by bees, as some larvicides may impact bees at these higher concentrations (Elbanoby & Abou-Shaara, 2019).

4.2 Application Procedures to Minimize Non-target Effects

Applications of pesticides for mosquito control should be conducted to maximize the mosquito kill while minimizing exposure to non-target receptors. Application strategies for pesticides are specific to the life stage of the mosquito being targeted and also the type of product being applied. It is critical for any pesticide applicator to follow label directions. Applying pesticides in a manner not consistent with label direction is a violation of federal and state law. These directions are developed to minimize exposure below levels of concern for the general population, sensitive individuals, and sensitive ecological receptors. In addition to following the label, applicators should follow best management practices, such as:

- Ensure that the pesticide product being used is registered with EPA and Massachusetts and is administered by a registered pesticide applicator.

- Ensure the pesticide is being applied at the rates listed on the label. If possible and effective, apply at the lowest rate allowed on the label.

- When using a backpack or conducting aerial spraying, ensure proper equipment calibration, including testing droplet size and using proper nozzles for spraying.

- Check surroundings for sensitive areas prior to the application.

    - Measure wind speed to ensure pesticide can be carried, and be aware of wind direction to minimize drift.

    - Add a buffer if these is possibility of pesticide drift onto a non-target area.

    - Ensure proper calibration and function of all pesticide application equipment. See the PES module on proper calibration at https://pesticidestewardship.org/calibration/.

Additional considerations to minimize non-target receptor effects include spray notification, location, precision, and timing considerations (see Section 4.2.1) and weather (see Section 4.2.2).

4.2.1 Spray Notification Location, Precision, and Timing

Overarching considerations for the notification, location, precision, and timing of pesticide application to minimize non-target effects:

- Consider "hot spot" treatments, which AMCA recommends for container-inhabiting mosquitoes. AMCA explains this approach relies on "ground larval surveillance, aerial photography or imagery, GIS modeling, and adult mosquito or ovitrap surveillance data to pinpoint hot spots within target communities" (American Mosquito Control Association, 2017). Targeting hot spots can reduce the amount of larvicide used and thus reduce exposure to non-targets. This is further supported by the Xerces Society, which suggests using GIS as a proactive, predictive tool to "help pinpoint habitat areas for more timely species-specific control to determine when treatment is necessary and to correlate centers of human population with mosquito production sites" (Mazzacano & Black, 2013).

- Establish buffer zones and document them scientifically to afford the required level of protection, considering fate and transport (and drift for aerial applications). Buffer zones can reduce the likelihood of spray drift encountering excluded properties, water bodies, and areas where pollinators forage.

- Calculate a buffer zone for each pesticide application. The appropriate zone depends on:
    - Pesticide (Hennessey et al., 1992)
    - Application equipment (Lahr et al., 2000)
    - Altitude of aerial application (Latham, 2004)
    - Wind speed, wind direction, humidity, and temperature (Desmarteau et al., 2019)

- Map spray routes with clear indication of areas not to spray (i.e., properties where people have opted out or requested exclusion from spraying, organic farms, drinking water sources), including buffer zones. Use a GPS that provides audio and visual notification when approaching an excluded area to precisely indicate these areas and notify the applicator.

- Drive the spray routes during the day to get familiar with the route and areas not to be sprayed.

- Carry a printed map during application in case of technology failure.

- Before spraying, notify the community so they can take actions (e.g., covering hives, being indoors) to reduce exposure. Community notifications can be done through news articles, social media, and listservs of potentially affected entities (e.g., beekeepers' associations, farmers, municipal contacts such as Boards of Health).

More specific considerations based on the non-target of interest are provided in the following sections.

4.2.1.1 Vulnerable Individuals

Vulnerable populations sometimes face distinctly different risks from larviciding and adulticiding, given differences in how they are applied. For certain types of larvicides (e.g., those in briquet or pouch form), vulnerable people are not very likely to be exposed, given these are placed directly into the aquatic environment in which the larvae reside. Additionally, the majority of larvicides used regularly for mosquito control across the Commonwealth (e.g., *Bacillus thuringiensis israelensis, Bacillus sphaericus,* mineral oil) have no indicated adverse health effects on humans. Therefore, applying these products according to label directions will likely have minimal impact on vulnerable human populations.

For pesticides applied by spraying or through aerial applications, the following best practices can be considered to protect vulnerable individuals:

- Spray at night when people are indoors to reduce exposure.

- Provide (and widely promote) guidance on how people might protect themselves during spray events. For instance, the following optional guidelines are published on the Massachusetts Mosquito Control and Spraying Fact Sheet (Bharel & Cranston, 2020b):

    - "Close windows and turn off fans in spray areas. In very hot weather, you can open the windows or turn fans back on soon after the aerial spraying is completed.

    - Air conditioners do not have to be turned off, because they circulate indoor air.

    - Keep pets indoors during spraying. Although pets that remain outdoors could be exposed to small amounts of Anvil 10+10, they are not expected to experience adverse health effects from the spraying. There are many pesticide products (e.g., flea collars, pet shampoo, dips) containing similar ingredients that are used directly on pets to control ticks and insects. The suggestion to keep pets indoors is to ensure that they do not get scared, since the planes fly approximately 300 feet above the ground.

    - If clothes or outdoor items are exposed during spraying, wash them with soap and water."

Other states have published similar advisory materials, some with additional protective actions residents can take. New York State more strongly recommends the following when aerial spraying is about to occur (New York State Department of Health, 2009):

- “Children and pregnant women should take care to avoid exposure when practical.

- If possible, remain inside or avoid the area whenever spraying takes place and for about 30 minutes after spraying. That time period will greatly reduce the likelihood of your breathing pesticides in the air.

- Close windows and doors and turn off window air-conditioning units or close their vents to circulate indoor air before spraying begins. Windows and air-conditioner vents can be reopened about 30 minutes after spraying.

- If you come in direct contact with pesticide spray, protect your eyes. If you get pesticide spray in your eyes, immediately rinse them with water. Wash exposed skin. Wash clothes that come in direct contact with spray separately from other laundry.

- Consult your health care provider if you think you are experiencing health effects from spraying.”

4.2.1.2 Pollinators

- Regarding notification specific to beekeepers, Penn State University’s entomology program (Center for Pollinator Research, 2017) states:

> “It is strongly recommended that applicators notify beekeepers with registered apiaries in the area prior to pesticide applications. Bees will forage across several miles. Therefore, pesticide applicators should identify and notify beekeepers within five (5) miles of a treatment site at least 48 hours prior to application or as soon as possible. Timely notification will help ensure ample time for the beekeeper and applicator to develop a mutually acceptable strategy to manage pests while mitigating risk to honey bees. This may include covering hives, moving hives, or choosing the time of day to apply. Notifying beekeepers does not exempt applicators from complying with pesticide label restrictions. Many insecticide labels prohibit use if pollinators (bees) are present in the treatment area or the crop is in bloom.”

- If allowed by label, apply pesticide “when pollinators are not foraging (either at dusk or when plants are not flowering)” (Center for Pollinator Research, 2017).

- Be aware of the presence of blooming plants. In some cases, the pesticide label (and therefore federal law) prohibits application of pesticides to blooming crops or weeds when bees are visiting the area. Pesticide applicators would benefit from knowing when and where crops or local flowers are in bloom in their regions.

- Perform outreach to beekeepers to increase sign-ups for spray notifications, and inform beekeepers how to respond when notified of an upcoming application event.

4.2.1.3 Aquatic Life

- Extended-release formulations of larvicides (e.g., briquets) may wash out of the original locations where they are applied. Avoid applications that will directly impact sensitive water bodies by using precise GIS and GPS systems.

- Location of application may be limited by label directions: for example, Anvil 10+10 may not be applied over bodies of water unless necessary to target areas where adult mosquitoes are present (Clarke Mosquito Control Products, 2015).

- EPA recommends: "[w]here possible, leave a vegetative buffer strip between the field and areas where wildlife may be present, including downhill aquatic habitats. Be sure to follow any label requirements related to buffers, as well" (United States Environmental Protection Agency, 2020b).

4.2.1.4 Drinking Water

- Before applying pesticides, it is critical to know the locations of groundwater wells and surface water supplies, the depth to groundwater, and the soil composition surrounding drinking water supplies (Cornell University Cooperative Extension, n.d.).
    - Soil composition (sand, clay, organic matter, etc.), porosity, pH of soil, and distance to tributaries determine how far pesticides travel in the subsurface and how rapidly they degrade over time.
    - MCDs may evaluate soil types in their area using tools such as the USGS Web Soil Survey, which allows for analysis of local soil profiles and provides information on drainage, slope, and depth to water table (Natural Resources Conservation Service, 2019). To minimize contamination of drinking water sources, a MCD may determine if additional precautions (such as keeping a wide berth around the buffer zone) are necessary given the slope and drainage class of the area.

- For aerial spraying, Massachusetts regulations prohibit spraying directly over surface water supplies. All MCDs use SRB mapping to inform spray routes and avoid protected areas.

- Understanding how past spraying activities have affected water supplies will inform future sprays and is a best practice. Currently, DEP and public water systems collaborate to collect water samples two days before and two days after an aerial spray event to evaluate potential contamination (MassDEP, 2020c).

4.2.2 Climate/Weather

Temperature, wind, and precipitation have implications for minimizing non-target impacts. Temperature is an important variable that has varying effects on spray efficacy, degradation of residues, and pesticide toxicity. Chemical reactions slow as temperature decreases, which affects the rate of degradation of pesticide residuals; in cooler weather, pesticide residues will degrade more slowly, increasing the chance for non-target organisms to be exposed over a longer period (Devillers, 2002). Additionally, the toxicity of pesticides may vary with different temperatures. For example, pyrethroids become more toxic to certain organisms in colder weather (Whiten & Peterson, 2016). In addition, lower temperatures reduce pollinator foraging activity. Wind is needed to carry adulticide formulations and create contact with adult mosquitoes. However, too much wind can result in drift of pesticides beyond the intended area of application. Higher humidity and higher temperature are also associated with increased drift (Desmarteau et al., 2019). Further, precipitation can wash away pesticides from their intended target area and carry contaminants to different areas if not considered during application.

General best practices for applying pesticides are outlined below, followed by subsections with specific considerations for the non-target receptors of interest.

- For adulticide applications, the Washington State Department of Ecology (Emmett, 2004) recommends that applicators:
    - Record wind speed and direction before spraying and be observant of all changes in direction and speed during the application.
    - Use appropriate wind indicators. Gauges are highly recommended for ground applications and smoke for aerial applications.
    - For aerial applications, check temperature at different elevations to decide if there is an inversion.
    - Spray only when wind is away from sensitive sites.
- If not specified on the label, apply when wind speed is between 3 and 10 mph (United States Environmental Protection Agency, 2020b).
- If the label does not prescribe specific maximum wind speeds or climatic factors, use EPA's AgDRIFT model to estimate the potential downward deposition of aerial sprays and maximize spray efficiency while avoiding protected areas (U.S. Forest Service, 2021). AgDRIFT uses parameters specific to each application, including weather conditions such as wind and temperature, aircraft characteristics, droplet size, spray heights, and other parameters (Teske et al., 2002).
- Avoid adulticide spray applications when precipitation is expected within the next 24–48 hours (Kruger & Nguyen, 2018; United States Environmental Protection Agency, 2020b).
- Minimize wind interference by applying the aerial spray 10 feet or less above the top of the highest vegetation in the area. Precipitation events and even irrigation can carry pesticides long distances through watersheds (Holland & Sinclair, 2004).

4.2.2.1 Vulnerable Individuals

- Follow the general best practices for all non-targets listed above to protect vulnerable individuals.

4.2.2.2 Pollinators

- Hot temperatures can cause bees to "beard," or cluster outside the hive entrance at night, which could leave them directly exposed to a pesticide spray (Pokhrel et al., 2018a). Be aware of when high temperatures are causing bearding in local bees and avoid spraying at these times if possible. If bees are bearding, beekeepers can take certain measures to protect hives if they are aware of the upcoming spraying and of the protective measures they can take (Massachusetts Department of Agricultural Resources, n.d.).

4.2.2.3 Aquatic Life and Drinking Water

- Avoid spraying during precipitation events to prevent the transport of pesticides to water bodies in surface water runoff (Gorgoglione et al., 2018).

- Use EPA's AgDRIFT tool, discussed above, to maximize spray efficiency and minimize spray drift over water systems and supplies (U.S. Forest Service, 2021).

4.2.3 Other Considerations

This section summarizes other ways to minimize non-target receptor effects. These best practices and recommendations are pulled from the "Pesticide Environmental Stewardship" (PES) website, which has a collation of resources on various aspects of mosquito control to minimize non-target impacts (*Pesticide Environmental Stewardship*, 2021).

- Use a closed system when mixing and loading pesticides. "More pesticide spills occur while the pesticide is being measured and mixed than during any other part of a pesticide application," PES notes, so:
    - Site mixing/loading locations away from wells, streams, and lakes.
    - Keep a distance of at least 100 feet (check the pesticide label for more specifics) between the mixing and loading sites and wellheads, ditches, streams, or other water sources.
    - Ensure a "spill kit" is readily available near the mixing loading area.

- Take measures to prevent pesticide backflow, if applicable. Use an anti-siphon device (check valve) that will prevent backflow (and source water contamination). Other proper anti-siphoning techniques include the use of a reduced pressure zone device or an air gap between the filler pipe and the tank.

- Lock pesticides in a fire-resistant, spill-proof facility.

- Properly dispose of all pesticide containers. PES recommends triple rinsing containers and never leaving containers outside. PES also recommends collecting all water from the rinsing and applying it the original site of the application (without exceeding maximum application rates).

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Report 7: Massachusetts Drinking Water Regulations Related to Pesticide Application

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1. EXECUTIVE SUMMARY

Multiple federal laws and Massachusetts statutes and regulations are designed to ensure the safety of our nation's drinking water from source to tap. These regulations are intended to ensure the safety of pesticides and prevent chemicals that pose a risk to groundwater from being applied near groundwater recharge areas. Additionally, local source water protection activities often supplement state and federal regulations to limit or mitigate any potential impacts of pesticide application in and around drinking water supplies.

This report broadly reviews regulations relevant to drinking water supplies, public water systems, and pesticide applications and specifically evaluates applications of mosquito pesticides used by mosquito control districts (MCDs) and the State Reclamation and Mosquito Control Board (SRB). It discusses findings from water quality monitoring and considers how the Massachusetts regulatory framework compares to other New England states. This report finds that while the existing layers of regulatory protection do not guarantee that mosquito pesticides will never enter drinking water, they provide a framework for adding or modifying requirements as information becomes available, as priorities change, and as new science evolves.

2. REPORT OVERVIEW

This report addresses the following area of research requested by the Task Force: "Summarize the Massachusetts public water system laws and regulations as they relate to pesticide use protections for Massachusetts and other Northeast states." Given this scope, this report focuses on groundwater and surface water used as public drinking water supplies (as opposed to all surface water and groundwater resources, regardless of use) and public application (versus private application) of pesticides.

ERG's approach to this topic consists of the following steps:

- Review statutes and regulations relevant to drinking water supplies, public water systems, and pesticide applications and interview key agency representatives. Identify and summarize key requirements, implementing authorities, and outcomes.

- Identify any applicable requirements specific to the chemicals applied for mosquito control in the Commonwealth (Massachusetts MCDs, 2021). (See Report 4: Chemical Composition and Toxicity of Pesticides Used in Ground and Aerial Spraying in Massachusetts for a complete list of the pesticides and their active and inert chemical ingredients.)

- Summarize and evaluate available monitoring data and outcomes.

- Based on the review of applicable statutes and regulations and expert interviews, identify areas for improvement and best practices from other states.

With this approach, ERG considered how the Commonwealth's regulatory framework provides a range of tools to protect the public from harmful exposures to contaminants in drinking water. This report does not constitute an independent evaluation of whether the regulations effectively protect public health from mosquito pesticides currently used by the SRB and MCDs.

3. Overview of Pesticide and Drinking Water Regulations

Applicable federal statutes and state regulations in Massachusetts protect public water supplies and public health from pesticides through several controls:

- Restricting which chemicals can be used.
- Restricting where chemicals can be applied (e.g., groundwater restrictions, buffers around surface water).
- Monitoring for levels of regulated contaminants in treated drinking water prior to delivery to consumers.

3.1 Federal Laws

Major federal laws related to pesticide application and pesticides in drinking water sources include:

- The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA).
- The Safe Drinking Water Act (SDWA).
- The Clean Water Act (CWA).

Sections 3.2 and 3.2.2 discuss the Commonwealth's laws and regulations that implement key components of these federal laws and establish further requirements.

FIFRA gives the U.S. Environmental Protection Agency (EPA) the authority to register pesticides and regulate the use, storage, and disposal of containers and manufacturing wastes. Under FIFRA, products used to manage pests may not be distributed within the United States unless they have been registered with EPA and within the state they will be used in. The registration process aims to ensure that when products are applied according to labels, they will pose the least amount of risk to the environment or human health. Labels are required to state whether the product can be applied to drinking water. (USEPA, 2019c). The pesticide products that are most often used in drinking water are disinfectants for drinking water treatment. Additionally, piscicides (fish killing) algaecides, bactericides and molluscicides may be used to pre-treat water that will eventually become drinking water.

The SDWA protects the quality of drinking water delivered by public water systems by establishing health-based standards and other protective measures. EPA sets national health-based standards for regulated contaminants. However, not all pesticides registered under FIFRA are regulated under SDWA (USEPA, 2019c).

The SDWA Amendments of 1996 (section 1453[a][2]) require states to establish state Source Water Assessment Programs (SWP). These state programs define public water system source water protection areas, identified known and potential contamination sources, determined water system susceptibility to these sources, and take other preliminary measures to protect public drinking water supplies. Massachusetts completed its assessments in 2004 (Commonwealth of Massachusetts, 2021i). State SWPs can also provide technical and financial assistance (e.g., through EPA's Drinking Water State Revolving Fund). However, local authorities are primarily responsible for land use decisions in source water protection areas, and local zoning and non-zoning bylaws may not consider drinking water systems.

The CWA gives EPA the authority to regulate the discharge of pollutants into waters of the United States and implement pollution control programs (USEPA, 2020e). Section 402 of the CWA establishes the National Pollutant Discharge Elimination System (NPDES), which prohibits discharge of pollutants to waters of the United States without a permit. In Massachusetts and a few other states, EPA is the NPDES permitting authority. A NPDES permit is generally required for mosquito control "by any means" or for "chemical and biological insecticides and larvicides into or over water to control insects that breed or live in, over, or near waters of the United States" (USEPA, 2016a). In the event that aerial spraying is needed in Massachusetts, the Massachusetts Department of Agricultural Resources (MDAR) works with EPA to obtain a permit (State Reclamation and Mosquito Control Board, 2019). MCDs must also obtain a NPDES permit to comply with the CWA if their activities result in discharges to waters of the United States (USEPA, 2016d). Those permits require Section 401 certification by the Massachusetts Department of Environmental Protection (DEP) to ensure state water quality standards are met.

3.2 Massachusetts Legal and Regulatory Framework

The Commonwealth also has the authority to develop new guidance and regulations on chemicals as needed. Figure 3-1 presents these controls (with the associated law or regulation, implementing authority, and outcome), and the following sections explain them in detail.

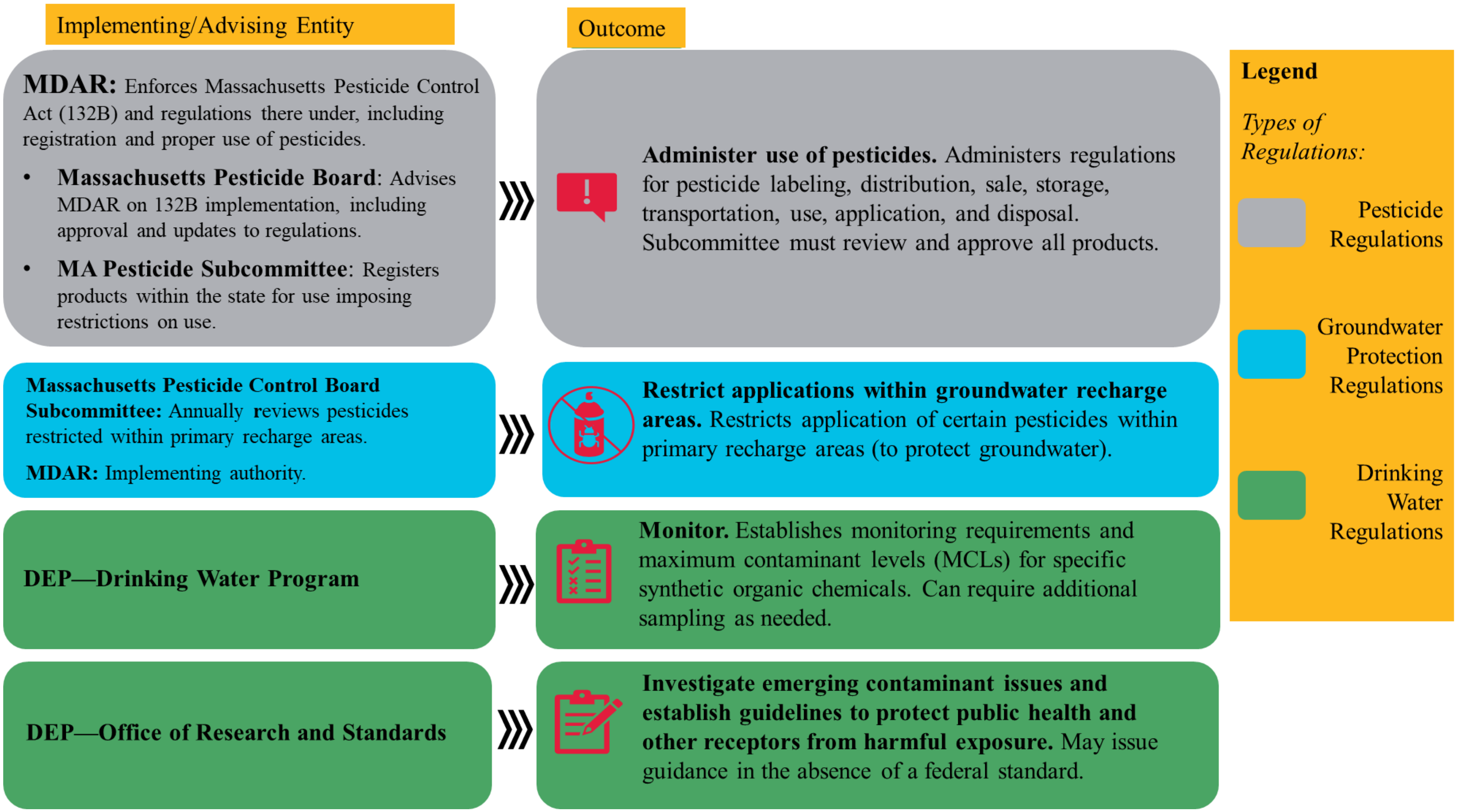

Figure 3-1. Overview of Massachusetts water quality and pesticide regulations.

3.2.1 Pesticide Laws and Regulations

Massachusetts regulates pesticides under the authority of the Massachusetts Pesticide Control Act (MPCA; Chapter 132B of the Massachusetts General Laws, enacted in 1978) (Commonwealth of Massachusetts, 2021h) and regulations promulgated thereunder at 333 CMR 2.00 through 14.00. MDAR is the lead agency for implementing and administering federal pesticide laws in the Commonwealth and has exclusive jurisdiction over pesticides under state law. Its duties include (Commonwealth of Massachusetts, 2021h):

- Establish requirements for licensing and supervising pesticide applicators.
- Conduct inspections and investigations to ensure that the requirements of MPCA and its regulations are being adhered to.
- Issue enforcement actions if violations of the rules and regulations have occurred.
- Form the Massachusetts Pesticide Board, which advises the MDAR commissioner with respect to the implementation and administration of MPCA and approves regulation development and updates
- Form the Massachusetts Pesticide Board Subcommittee, with the responsibility of registering all pesticides for use in the Commonwealth of Massachusetts, reviewing new active ingredients, and issuing all experimental use permits (Commonwealth of Massachusetts, 2021f).

The MPCA regulations do not establish a ban on applying pesticides (via aerial spraying or other methods) to surface waters of public drinking water sources, nor a designated setback when making applications around these areas. However, pesticides labels include such restrictions if needed. In addition, MassDEP's "Mosquitocide Aerial Spraying Water Resources Sampling Guidance" provides a protocol for ensuring a "no-spray" setback of 500 feet from active public drinking water reservoirs during aerial spray events (MassDEP, 2020b).

3.2.2 Drinking Water Regulations

Massachusetts has primary enforcement authority, or "primacy," to implement and enforce SDWA regulations within the Commonwealth (USEPA, 2020f). DEP has established state drinking water regulations that are at least as stringent as the equivalent EPA regulations. These regulations specify monitoring, reporting, and other requirements associated with every regulated contaminant, including regulated pesticides in drinking water. Mosquito pesticides used in Massachusetts since 2009 are not regulated contaminants. The following sections outline the broader system of health-based standards and regulations, in case they should apply to a mosquito pesticide in the future.

3.2.2.1 Health-Based Standards and Water Monitoring Requirements

Drinking water regulations specify health-based standards—maximum contaminant levels (MCLs) or other health-based limits—depending on the regulated contaminant. An MCL is "the maximum permissible level of a contaminant in water which is delivered to any user of a public water system" (MassDEP, 2017). Massachusetts can set MCLs that are more stringent than those EPA sets and/or that regulate contaminants that EPA does not.

EPA's Chemical Phase II/V rules establish MCLs for inorganic chemicals, volatile organic chemicals, and synthetic organic chemicals. Federally regulated synthetic organic chemicals include numerous pesticides. SDWA does not regulate any of the active ingredients or listed inert ingredients in the 44 pesticides used by the SRB or MCDs since 2009.

As part of the regulatory development process required under SDWA, EPA assesses, requires monitoring for, and evaluates for possible regulation a subset of unregulated contaminants known or anticipated to be detected in public water supplies. For example, from 2018 to 2020, EPA required drinking water system distribution entry point monitoring for total permethrin (the active ingredient in the product Flit 10EC; CASRN 52645-53-1), among the 30 contaminants under the agency's fourth Unregulated Contaminant Monitoring Rule (UCMR 4). Flit 10EC has been applied in Berkshire, Plymouth, and Suffolk County MCDs between 2011 and 2018 (Massachusetts MCDs, 2021). UCMR monitoring provides nationally representative data on contaminant occurrence and can also help EPA understand the extent and level of human exposure to these contaminants. UCMR monitoring also informs EPA's development of the Contaminant Candidate List, which is published every five years. Out of approximately 5,000 public water systems across the United States (including Massachusetts) with total permethrin monitoring results from that period reported to EPA as of April 2021, only 13 public water systems had concentrations of total permethrin above the established minimum reporting level (USEPA, 2021i). None exceeded the "reference concentration," a concentration below which adverse health effects are not expected). The specific locations of these water systems were not disclosed. Total permethrin is now on EPA's Contaminant Candidate List 4, a list of chemicals that may require further SDWA regulation following UCMR 4 monitoring (EPA, 2021).

UCMR 1, 2, and 3 did not include any of the active ingredients or listed inert ingredients in the 44 pesticides used by the SRB or MCDs since 2009 (USEPA, 2021i).

Although there are no federal or state drinking water monitoring requirements or health-based standards for the 44 pesticides used by the SRB or MCDs since 2009, DEP has the regulatory authority to ask any drinking water provider in the state to monitor for any contaminant at any time. Under 310 CMR 22.03-2:

> A Supplier of Water, upon request by the Department, shall sample and analyze its water for any parameter, at any location and frequency, deemed necessary to prevent the pollution of and secure the sanitary protection of waters used as sources of water supply and to ensure the delivery of a fit and pure water supply to all consumers, in accordance with 310 CMR 22.00.

As such, DEP has the authority to request monitoring for any chemical, should a suspected issue arise, or for purposes of study/investigation.

3.2.2.2 Health Advisories and Office of Research and Standards (ORS) Guidelines

If a mosquito pesticide's ingredients were identified as an issue in the future, DEP has the authority to provide guidance to water systems on emerging public health issues through EPA

Health Advisories (estimates of acceptable drinking water levels for chemicals), if available, and through DEP's ORS Guidelines (known as ORSGs). ORS' role within DEP is to provide scientific expertise in environmental health, toxicology, standard-setting, ecological and human health risk assessment, chemistry, and statistics (Commonwealth of Massachusetts, 2021a). ORS issues guidance for chemicals that pose risks from the state's perspective, including those in drinking water, providing DEP with the ability to respond to concerns over contaminants as they arise or where federal regulations are deemed insufficient (Commonwealth of Massachusetts, 2021c). DEP establishes its ORSGs for specific chemicals, using risk assessments consistent with those applied by EPA's Office of Water. DEP will enforce ORSGs when necessary, allowing itself to set more stringent requirements than those established through federal MCLs, or establish a standard in the absence of a federal MCL (Commonwealth of Massachusetts, 2021d).

While ORS has not developed an ORSG for an active mosquito pesticide chemical to date, this process has been used for many chemicals in the past—such as perchlorate and, more recently, per- and polyfluoroalkyl substances (PFAS)—and could be used for other emerging contaminants in the future. The process enables the Commonwealth to respond and regulate faster than waiting for EPA to do so.

ORS has been studying and issuing guidance on PFAS over the past several years. In January 2020, DEP updated its PFAS6 ORSG, and in October 2020, it issued a Massachusetts MCL for these compounds (MassDEP, 2020a). Report 4 discusses PFAS contamination in pesticides used in Massachusetts.

3.2.3 Groundwater Protection Regulations

Groundwater protection regulations regarding pesticide applications (333 CMR 12.00) are intended to prevent non-point source contamination of public drinking water supply wells from pesticide products on the Groundwater Protection List. The Groundwater Protection List is a list of pesticide products containing active ingredients that US EPA and/or the Pesticide Board Subcommittee identify as potentially impacting groundwater based on their chemical characteristics and toxicological profiles. The list is updated annually. The SRB or MCDs have not used the insecticides on the current list since at least 2009.[24]

Land managers, MCDs, or other entities seeking to apply one of the chemicals on the Groundwater Protection List must verify that they are not in a regulated primary recharge area. The regulated primary recharge area is designated as "Zone II" if it is delineated based on a hydrogeological study or as an "interim wellhead protection area" if the zone of contribution is approximated by drawing a half-mile radius (2,640 feet) around the wellhead (Massachusetts Executive Office of Environmental Affairs, 1988).[25]. If an individual wants to use a product that

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[24] Active insecticide ingredients currently on the Groundwater Protection List are aldicarb, carbofuran, dinotefuran, disulfoton, fenamiphos, fonofos, lindane, methoxyfenozide, pentachlorophenol, propoxur, terbufos, and thiamethoxam (MDAR, 2021a).

[25] Under Massachusetts drinking water regulations (310 CMR 22.21), Zone II must encompass all of Zone I, which is defined as "the protective radius required around a public water supply well or Wellfield. For Public Water System wells with approved yields of 100,000 gpd or greater, the protective radius is 400 feet. Wellfields and infiltration galleries with approved yields of 10,000 gpd or greater require a 250-foot protective radius. Protective radii for all other Public Water System wells, Wellfields, and infiltration galleries are determined by the following

is on the Groundwater Protection List and they are within a Zone II or IWPA, they must submit a pest management plan to the Department for review. Under the groundwater regulations (333 CMR 12.00), MDAR will only accept the plan under the following conditions:

a) The anticipated use site is not a highly vulnerable site.

b) The acceptance of the pesticide management plan is not likely to cause an unreasonable adverse effect on the environment.

c) There is no viable alternative control method other than the use of the product on the Groundwater Protection List. This is determined through confirmation of University of Massachusetts Extension services or the equivalent.

d) Implementation of an [MDAR]-approved [integrated pest management] or pesticide management plan will minimize to the extent possible the application of products on the Groundwater Protection List.

e) That no product on the Groundwater Protection List has been detected as a result of the groundwater monitoring program. Said detection shall result in the prohibition of the product's use within the primary recharge area of a public water supply well in which the pesticide has been detected (333 CMR 12.04).

As noted above, these rules do not apply to the mosquito pesticides in use in Massachusetts, as the pesticides currently in use do not contain chemicals on the Groundwater Protection List. Rather, these rules outline the existing framework and process for addressing pesticides with groundwater concerns, should concerns arise in the future. For those pesticides not containing chemicals on the Groundwater Protection List, there are not restrictions on use specific within primary recharge areas (unless related to pesticide label instructions). The ERG team was unable to identify groundwater monitoring data on whether any of the mosquito pesticides in use are present in groundwater sources.

3.2.4 Source Water Protection

As noted in Section 258, Massachusetts completed required source water assessments in 2004. Assessments identified the following top threats to public water sources: (1) residential lawn care/gardening, (2) residential septic systems and cesspools, (3) residential fuel oil storage, (4) stormwater discharge, and (5) state-regulated underground storage tanks. The assessment identified a need to expand groundwater protection to all Massachusetts communities.

DEP uses these findings to target technical assistance and outreach to public water systems, watershed groups, and others. DEP still considers the assessment a useful resource for understanding potential sources of contamination in local water supply protection planning and for developing a surface water source water protection plan or wellhead protection plan (Commonwealth of Massachusetts, 2021i). The program has not focused on mosquito pesticides

equation: Zone I radius in feet = (150 x log of pumping rate in gpd) - 350. This equation is equivalent to the chart in the *Guidelines and Policies for Public Water Systems.* A default Zone I radius or a Zone I radius otherwise computed and determined by the Department shall be applied to Transient Non-community Water System (TNC) and Non-transient Non-community Water System (NTNC) wells when there is no metered rate of withdrawal or no approved pumping rate. In no case shall the Zone I radius be less than 100 feet."

to date. However, the program is flexible—it can deliver technical assistance based on need, support updates to source water assessments as needed, and otherwise support local source water protection activities. The program provides education, technical or financial assistance, and other support which may be targeted to mosquito pesticides if identified as a priority.

4. REVIEW OF PESTICIDE MONITORING DATA

As established in the discussion of health-based standards and water monitoring requirements in Section 3.2.2.1, there is no requirement for public water systems to monitor for chemicals used by MCDs since 2009 in their water supplies or treated drinking water.

While individual public water systems may opt to conduct additional monitoring, this information is not reported on publicly accessible state platforms, such as in the Massachusetts Environmental Public Health Tracking Drinking Water Contaminant Data, and a system-by-system data search is beyond the scope of this report. Two key monitoring events related to mosquito pesticides included a) mandated monitoring of total permethrin from 2018 to 2020 (as discussed in Section 3.3.2.2.1) and b) DEP's decision to monitor drinking water during aerial application of Anvil 10+10.

With support from public water systems, DEP has monitored mosquito control aerial events, specifically water quality monitoring for Anvil 10+10, which the SRB has used for aerial treatments, since 2006. The SRB used Anvil 10+10 (containing sumithrin and piperonyl butoxide [PBO]) for aerial treatment of mosquitoes in 2006, 2010, 2012, 2019, and 2020 in response to Eastern equine encephalitis virus outbreaks.[26] DEP and public water systems collaborated to collect raw and finished water samples before and directly after the aerial spray event, drawing from active surface water sources within the aerial spray zones (the surface water itself is excluded) to monitor for potential contamination due to drift or runoff. The samples are collected and analyzed for the pesticide formulation's active pesticide and synergist. Key findings from the 2019 spray events were as follows:

> Sumithrin was detected in 4 of 84 raw water (prior to drinking water treatment) samples collected from water treatment plants; these concentrations were thousands of times below the U.S. EPA Guidance Levels for Human Health. Sumithrin was not detected in any sample collected from a finished (post-treatment) drinking water supply; all results from finished water samples were below the Limit of Detection (0.01 ug/L) for Sumithrin and, therefore, well below the Guidance Levels for Human Health, which range between 23 and 800 ug/L. The synergist, PBO, was detected in 54 of 84 raw drinking water samples and in 12 of 84 finished drinking water samples from water treatment plants; these were also at concentrations thousands of times below the U.S. EPA Guidance Levels for Human Health (MassDEP, 2020c)

Monitoring results from 2012 did not detect sumithrin. PBO was detected in the raw water of some of the public water systems sampled in the first spray event of the 2012 season and, in one, case several days after application. The maximum concentration of PBO measured was 150,000-fold lower than US EPA's acute human health exposure limit for drinking water. PBO was not detected in finished drinking water samples (MassDEP, 2012). These limits are

[26] MCDs also use Anvil 10+10 for ground-based mosquito treatment (Massachusetts DEP, 2020b).

developed to indicate a potential risk to human health. Exposure to concentrations below these defined reference concentrations are not expected to result in any adverse health effects.

These findings indicate that concentrations of sumithrin and PBO during 2019 aerial spraying were thousands of times below EPA's Guidance Levels for acute and chronic human health exposure. Summary findings from MassDEP are not reported according to pre- and post-spray detections. It should be noted that PBO is an active ingredient in more than 2,500 pesticide products used both in and outside of homes. For example, it is included in some flea and tick treatments for pets and some headlice treatments for humans (Cross, 2017). As such, there could be several sources of the detected PBO.

Monitoring data is not available to assess whether the pesticides used by MCDs are reaching surface water or groundwater.

5. Comparison and Lessons from Other New England States

Massachusetts' regulatory framework for drinking water protection is similar to those of other New England states. In interviews with drinking water program staff in Rhode Island and Connecticut, as well as representatives from regional and national drinking water organizations in the region (New England Waterworks Association, New England Interstate Water Pollution Control Commission, Association of State Drinking Water Administrators), interviewees reported that New England states have developed similar pesticide and groundwater regulations, health-based standards, drinking water monitoring requirements, and source water assessment programs.

The New England Waterworks Association reported that Massachusetts has been a leader in establishing health-based standards for drinking water. For example, Massachusetts was one of the first states to issue guidance on controlling manganese in water supplies (Wright-Pierce, 2018). In addition, Massachusetts has been one of the first states to establish an MCL for PFAS compounds (Coppinger et al., 2020).

The New England Waterworks Association suggested that clear communication between pesticide applicators and water systems is an area for improvement in managing pesticide applications and protecting drinking water across New England states. If applicators communicate their spray plans to water systems, water system managers can temporarily shut down pumps and intake valves. This can create an extra line of defense (King & Berry, personal communication, June 16, 2021).

6. Conclusion

Federal and state laws and regulations are designed to protect the public from harmful exposures to contaminants in drinking water. The regulatory framework offers multiple prongs of protection. Pesticide spraying restrictions minimize the amount of toxic chemicals that may enter surface waters used for drinking water supplies and their tributaries. Groundwater regulations protect recharge areas of public supply wells to prevent well water contamination by a range of anthropogenic activities, including pesticide applications. While these layers of protection do not guarantee that mosquito pesticides will not enter drinking water and pose health risks, they provide a framework for adding or modifying requirements as information becomes available, as priorities change, and as new science evolves.

ERG identified several areas of opportunity for improvement. These include:

- Leveraging existing programs, such as water quality monitoring and SWP, to encourage collaborative partnerships with local watershed organizations. Partnerships might include sampling efforts to increase data availability, as well as increased public outreach, education, and control efforts.

- Establishing a system whereby pesticide applicators communicate their spray plans to water system managers, so that managers can temporarily shut down pumps and intake valves if there is potential for increased risk. Such a system would be a significant undertaking in order to be inclusive all types of pesticides applicators—the SRB, all MCDs, and all 10,000 licensed applicators.

- Conducting additional research on impacts of household pesticide use, pesticide use by private entities, and truck-based spraying activities on water quality.

- Assessing public awareness/education around pesticide use and processes for making mosquito control exclusion requests.

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Report 8: Impact of Mosquitoes, Mosquitoes as Disease Vectors, and Mosquito Control Measures

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1. EXECUTIVE SUMMARY

Public health. ERG created a model to estimate the number of symptomatic West Nile virus (WNV) and Eastern equine encephalitis (EEE) infections that would take place under different levels of mosquito control. The model incorporates three steps. First, ERG used historical county-level infection data over the past 12 years to estimate the business-as-usual scenario. ERG used this scenario, along with mosquito control efficacy from the literature, to estimate the number of infections that would have occurred under scenarios in which additional or fewer mosquito control tiers were applied. Second, ERG used a decision tree model for WNV and EEE to estimate the outcomes of each infection. Third, ERG created distributions of healthcare costs of each infection outcome and applied these to each infection.

From ERG's model, the business-as-usual scenario would see an annual average of 12 (95 percent confidence interval [CI]: 3 to 28) symptomatic cases of WNV in Massachusetts, costing just over $13 million annually (95 percent CI: $0.1 to 38.9 million). By county, Middlesex and Suffolk counties had the largest number of cases for each scenario.

According to ERG's model, there is an annual average of four symptomatic cases (95 percent CI: one to nine cases) of EEE in the business-as-usual scenario, costing an average of $63.5 million annually (95 percent CI: $25.4 to 110.7 million).

Based on the ERG model, if chemical controls were halted in Massachusetts, there would be a 150 percent increase in WNV cases and a 275 percent increase in EEE cases, compared to the business-as-usual scenario. Alternatively, if Massachusetts increased its mosquito control practices and performed larviciding and adulticiding throughout the state, WNV cases would drop 25 percent, and EEE cases would remain the same compared to the business-as-usual scenario.

Commerce. ERG performed a literature review to find studies of mosquito impacts on tourism and recreation in Massachusetts. ERG did not find any Massachusetts-based studies, so it prioritized nearby states and studies with similar mosquito species. Nuisance levels of biting mosquitoes and outbreaks of mosquito-borne illness can both impact recreation. In a study in New Jersey, 59.5 percent of individuals stated that nuisance mosquitoes prevented them from enjoying outdoor activities. Another study, conducted in Madison, Wisconsin, found that residents were not willing to pay for mosquito control programs that targeted disease-transmitting mosquitoes when the disease risk of WNV was 10 in every 250,000 residents. Specifically, at this risk level, residents were willing to pay ($147) for a control program that targeted nuisance mosquitoes.

Agriculture. In this report, ERG also examines the agricultural impacts of mosquitoes and mosquito-borne diseases. Mosquitoes have been documented to cause EEE and WNV infections in Massachusetts livestock and other domesticated animals. Horses are particularly affected—between 2004 and 2019, 44 EEE infections and nine WNV infections were documented in Massachusetts horses, according to data from the Massachusetts Department of Public Health (DPH).

Furthermore, the use of pesticides for mosquito control may impact agriculture by harming pollinators. In Massachusetts, it is estimated that more than 45 percent of Massachusetts' agricultural commodities are dependent on pollination services. ERG found that pollinators contribute $134 million in value to 19 different Massachusetts crops. While ERG was not able to quantify the exact impact of mosquito control applications on pollinator health, detectable levels of pesticides used for mosquito control in Massachusetts have been found in honey bees. Though ERG did not find evidence of bee mortality due to pesticides in Massachusetts honey bees after aerial spraying events in 2019 and 2020, the active ingredients in some pesticides used in Massachusetts can be toxic to bees, and sublethal effects cannot be ruled out.

Ecosystem health. ERG also performed literature searches for the impacts of mosquitoes and mosquito control on ecosystem health. In response to public concern, ERG investigated the potential for mosquito control to adversely impact mosquito predators. ERG researched the diets of mosquito predators, particularly bats and fish in New England, and found little evidence of this. When mosquitoes were found to be part of an animal's diet, specifically bats, they were not in a large enough proportion to impact the population of that species. Moreover, ERG examined the potential for mosquito control chemicals to be toxic to aquatic ecosystems and avian species. ERG found that pyrethroids are highly toxic to aquatic ecosystems and that some chemicals used in mosquito control could have indirect impacts on avian species in Massachusetts.

2. THE IMPACT OF MOSQUITOES, MOSQUITO-BORNE DISEASES, AND MOSQUITO CONTROL IN MASSACHUSETTS

This section of the report was developed in response to the Task Force's request to research, analyze, and report on the current quantifiable impacts of mosquitoes (native, nuisance, and exotic), mosquito-borne diseases, and chemical-based mosquito control in Massachusetts. The scope further clarified that ERG should consider the following topics when characterizing impacts: public health, tourism, recreation, commerce, agricultural land (including organic farms), apiaries, ecosystem health, and native wildlife species (including birds, invertebrates, fish, other pollinators, and mosquito predators). In addition, the Task Force requested that ERG address current quantifiable impacts in a scenario with no mosquito control, a tiered scenario with community choice options, and a scenario that assumes business as usual.

Given the scale of this research area, ERG took a multifaceted approach to quantify as much information as possible. ERG categorized the requested information into four topic areas: public health, commerce (including tourism and recreation), agriculture (including pollinators and livestock), and ecosystem health. For each of these topics, ERG aimed to evaluate, where appropriate, the impact of mosquitoes (which includes mosquito-borne diseases) and the impact of mosquito control. For each of the research areas, ERG took a different approach to provide as much quantitative information as possible while working within the constraints of the available data. Some areas of the report refer to other sections, as the relevant information is discussed in detail elsewhere. Table provides an overview of the approaches to this section's topic areas.

Table 2-1. Overview of Approaches Used to Address Each Topic Area Requested

Research Area	Mosquitoes (Including Mosquito-Borne Diseases)	Mosquito Control
Public health	ERG created a model to estimate the average number of EEE and WNV cases that occur under the current levels of mosquito control (i.e., business as usual) and used mosquito control efficacy data from the literature to model the impacts of adding or retracting various tiers of mosquito control measures. This model includes an analysis of the types of outcomes associated with EEE and WNV infections (i.e., morbidity outcomes and mortality) along with the total estimated healthcare costs from the modeled infection outcomes.	Report 4: Chemical Composition and Toxicity of Pesticides Used in Ground and Aerial Spraying in Massachusetts report summarizes available data on the toxicity of the pesticides used by mosquito control districts (MCDs) or the State Reclamation and Mosquito Control Board (SRB) for mosquito control. Therefore, this section briefly summarizes the data. Refer to Report 4 for additional details.
Commerce	ERG focused on recreation and tourism as the main aspects of commerce. Data for this section were limited, and a quantification of impacts was not possible. Therefore, ERG presents a qualitative review of the available literature.	Data for this section were not available, and therefore this report does not discuss mosquito control.
Agriculture (including pollinators, livestock, and domesticated animals)	ERG summarizes the number of cases of EEE and WNV the Commonwealth reported for livestock, farm animals, or other domesticated animals.	ERG developed a baseline estimate of the monetary value of agriculture in Massachusetts and the proportion of that value attributable to pollinators, both bees and others. Data were evaluated on exposure and toxicity, but it was not possible to quantify the impacts of mosquito control. Therefore, ERG qualitatively describes findings from the literature on the different threats to pollinators in the Commonwealth, including pesticides and common pests. See Report 4: Chemical Composition and Toxicity of Pesticides Used in Ground and Aerial Spraying in Massachusetts for more information on pesticide impacts to pollinators.

Research Area	Mosquitoes (Including Mosquito-Borne Diseases)	Mosquito Control
Ecosystem health	Mosquitoes are a food source for several bat and fish species in the Commonwealth. Data to quantify the impacts of mosquitoes on these species were not available. Therefore, this section provides a qualitative discussion outlining the importance of mosquitoes to the diets of mosquito predators and how reduced mosquito populations (due to mosquito control activities) would not impact these animals.	Report 4: Chemical Composition and Toxicity of Pesticides Used in Ground and Aerial Spraying in Massachusetts presents available data on the toxicity of the pesticides used by MCDs or the SRB for mosquito control to ecosystem health. Therefore, this section only summarizes these data.

2.1 Public Health Impacts of Mosquitoes and Mosquito Control

Mosquitoes are vectors for many infectious diseases worldwide, including malaria, dengue fever, and Zika, with the specific diseases of concern varying from one region to the next. In Massachusetts, the two infectious diseases of greatest public health concern are WNV and EEE (Report 1: History of Arboviruses contains additional information on the history of arboviruses in Massachusetts). The public health impacts of these arboviruses are a product of many factors, including the climate, activity patterns of individuals, and mosquito control approaches. Focusing on mosquito control approaches, ERG developed a model to estimate the number of WNV and EEE infections (and type of infections) in Massachusetts under various tiers of control by county. Section 2.1.1 presents the method and results of the analysis.

To minimize the public health impacts of vector mosquitoes, chemical pesticides may be applied, either through deposition or spraying of larvicides in mosquito habitats or through spraying of adulticides in areas with active adult mosquitoes. Insecticides are designed to kill their targets and therefore are inherently toxic. As a result, there is concern about the public health implications of mosquito control as well. The Report 4: Pesticides used in mosquito control presents a full summary of toxicity data for the active ingredients used in the pesticides applied by the SRB and MCDs. Section 2.1.2 summarizes this information for context.

2.1.1 Impact of Mosquito-Borne Diseases on Public Health in Massachusetts

ERG developed a model that incorporates data from DPH and available scientific literature and uses Monte Carlo quantification to estimate how the number of cases of EEE and WNV will vary under different levels of mosquito control. The model results indicate that with increasing levels of control, there are decreasing amounts of mosquito-borne diseases—but with diminishing returns as each level of control is added.

2.1.1.1 Methods

ERG used a three-step modeling process to estimate the impact of mosquito-borne infections in Massachusetts. Figure 2-1 shows the model framework. The same general three-step framework was used for both EEE and WNV with different input data. The approach began by estimating the number of infections that are estimated to occur under business as usual and then under various levels of mosquito control (step 1). After modeling the total number of cases, ERG then used a decision tree model to estimate the number of infections resulting in the possible outcomes associated with each disease (e.g., encephalitis, meningitis, fever, death, or others) (step 2). Lastly, ERG calculated the healthcare costs of all infections based on the sum of each infection’s outcomes (step 3). These models were developed to recognize symptomatic cases only. Asymptomatic cases are rarely discovered but are thought to account for around 80 percent of WNV cases (Lindsey et al., 2010), while up to 96 percent of EEE infections may be asymptomatic (Morens et al., 2019).

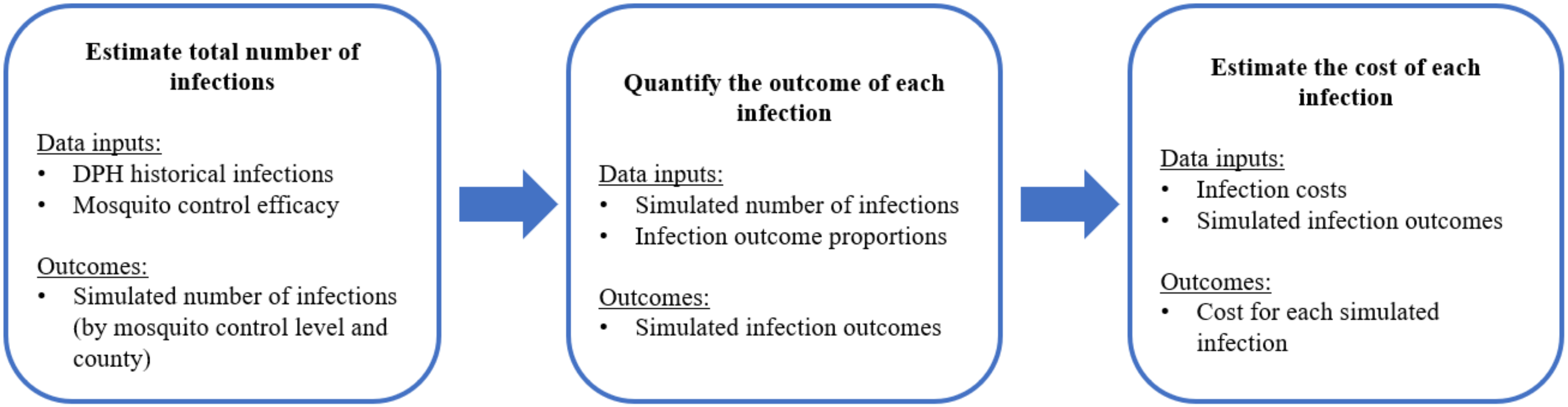

Figure 2-1. Model framework for WNV and EEE.

2.1.1.2 Estimating the Number of Infections Under Various Control Levels

ERG's model uses historical infection data from the past 12 years to estimate the number of EEE or WNV cases under different levels of mosquito control in each county. This is done using a Monte Carlo approach to account for the wide variability in the available input data and to show the various possible outcomes. The data from the past 12 years, provided by DPH, represent ERG's business-as-usual scenarios, which involve various levels of control across each Massachusetts county. ERG also modeled four additional mosquito control scenarios ranging from the least amount of control to the greatest amount of control, as Figure 2-2 shows. The first scenario is no mosquito control. The second scenario is larviciding only, referred to hereafter as Tier 1. The third scenario is adulticiding, which encompasses truck-mounted and backpack ground spraying, and larviciding, referred to as Tier 2. The fourth scenario includes larviciding, adulticiding, and aerial spraying, referred to as Tier 3.

ERG also investigated source reduction as a mosquito control method. Source reduction is the active removal of mosquito breeding sites, such as old tires and artificial containers. ERG found that source reduction can be highly effective at reducing mosquito populations over small areas (Fonseca et al., 2013; Unlu et al., 2013), but data are lacking on its efficacy over large areas such as counties. Therefore, the available data could not be incorporated into the current model (see the Report 5: Integrated Pest Management and Non-chemical Mosquito Controls for additional information about the best available science on non-chemical control methods).

No Mosquito Control	Tier 1	Tier 2	Tier 3
• No control methods	• Larviciding	• Larviciding • Adulticiding	• Larviciding • Adulticiding • Adulticiding using aerial application methods

Figure 2-2. Mosquito control levels in ERG's research model.

To estimate how the number of cases may change under the different tiers of control, ERG evaluated the literature and located data on the percent reductions in mosquito populations with various control approaches. These available data were used as a proxy for efficacy in reducing vector-borne infections, as data directly relating control approaches to changes in disease prevalence were not available. Table 2-2 shows the data used as inputs in the model for the efficacy in decreasing WNV and EEE. To calculate the change in the number of infections from one tier to another, ERG used Equation 2-1 to calculate additional mosquito controls (higher tiers) and Equation 2-2 to calculate fewer mosquito controls (lower tiers).

Equation 2-1. Reduced cases from additional levels of control.

$$Additional\ control\ cases = cases * (1 - efficacy)$$

Equation 2-2. Additional cases from reduced levels of control.

$$Reduced\ control\ cases = cases * \frac{1}{1 - efficacy}$$

Data for larviciding and adulticiding efficacy in Massachusetts MCDs were not available, except for adulticiding using aerial application methods from the Arbovirus Surveillance Plan (Bharel & Cranston, 2021b). However, ERG found studies that were specific to the disease-transmitting mosquito species and products used in Massachusetts when possible. In addition, the insecticide used in each study is an insecticide that MCDs or the SRB use for mosquito control. Many factors impact mosquito control efficacy, including vegetation, meteorology, droplet size, spray timing, and more (Bonds, 2012). The ranges shown in Table 2-2Table demonstrate the wide variability in spray efficacy due to these factors. For example, Barber et al. (2007) found that mosquito mortality was 95.2 percent for open sites, while it was only 50.7 percent for vegetated sites.

Table 2-2. Efficacy of Different Mosquito Control Practices Against WNV and EEE

Control Type	Arbovirus	Efficacy Range	Source
Larviciding	EEE	24–76%	(Luo, 2019; Sun et al., 2014)
	WNV		
Adulticiding—ultra-low-volume truck spraying	EEE	26–85%	(Barber et al., 2007)
	WNV		
Adulticiding—aerial spraying	EEE	38–91%	(Bharel & Cranston, 2021b)
	WNV	20–82%	

The 2021 Arbovirus Surveillance and Response Plan has data on its aerial spraying effectiveness. For this efficacy value, ERG used the range of the total reduction in mosquitoes trapped after aerial spraying events in 2006, 2010, 2012, and 2019 (Bharel & Cranston, 2021b). When the report presented a range, ERG opted to use the average value of the range.

According to the 2021 Arbovirus Surveillance and Response Plan, aerial spraying is effective for two weeks after a spray event takes place (Bharel & Cranston, 2021b). Since infections primarily occur in August and September (Bharel & Cranston, 2021b), ERG rounded this to eight weeks and assumed that each aerial spray event was effective for one quarter (two out of eight total weeks) of the season where individuals could be infected. For example, if there were three spray events in a county, ERG assumed that aerial spraying was effective for three-quarters of the period where individuals could be infected. When ERG added Tier 3 mosquito control to its model, it assumed that two spray events occurred that year.

ERG used Monte Carlo methods with mosquito infection data to assess a range of possible outcomes from the infection model. ERG used data from over the last 12 years because it had both the number of infections by county (CDC, 2021) and whether each MCD enacted each mosquito control practice referenced in Figure 2-2. ERG conducted 10,000 simulations of a single year of infections for each county in Massachusetts.[27] For each simulation, ERG randomly selected a year from the historical dataset, which represented the business-as-usual scenario. From there, ERG considered the impact of additional or fewer mosquito control practices on this business-as-usual scenario. To do this, ERG drew random efficacy values from within the ranges in Table . corresponding to each mosquito control practice added or removed. For example, if ERG selected a year in which there were 10 WNV cases in Middlesex County and larval and adult control had been reported as utilized (Tier 2 control), 10 cases would represent the business-as-usual scenario. To get the number of infections that would have occurred under a

[27] Using 10,000 simulations is common when using Monte-Carlo modeling methods. This reduces the impact of rare events impacting the average scenario (such as a year in which 50% of WNV cases die, when the average should be less than 10%).

Tier 1 scenario, ERG used Equation 2-2 along with an efficacy value sampled from the efficacy range for adulticiding inTable . If the randomly sampled efficacy was 50 percent, then ERG assumed that there would have been 20 WNV cases in the Tier 1 scenario.

The available infection data were at the county level. Therefore, ERG scaled the mosquito control methods used from MCD level to county level. To do this, ERG assumed that the efficacy of a mosquito control practice would scale with the proportion of municipalities within each county that that were part of an MCD. For example, if half of the municipalities within a county belong to an MCD and the MCD used larval control, the efficacy would be halved in calculating the number of cases resulting from taking that control away.

The one minor difference at this step between the approaches for EEE and WNV is that ERG limited its EEE model to years when infections occurred to simulate a year of an outbreak.

2.1.1.3 Defining the Outcome of Each Infection

Given that both EEE and WNV infections can result in a range of outcomes, ERG used a decision tree model to estimate the types and number of outcomes for each infection. For each decision tree, ERG used point estimates derived from the available data (Lindsey et al., 2010; Silverman et al., 2013).

WNV Decision Tree

Figure 2-3 summarizes WNV outcomes, along with the percentages that they represent (Lindsey et al., 2010). Nonneuroinvasive infections comprise 59.1 percent of cases, and the vast majority of those are transient. Of the cases that are neuroinvasive, encephalitis is the most common outcome, of which 12 percent of cases result in mortality. While transient cases are mild, they still result in symptoms and therefore are not asymptomatic cases.

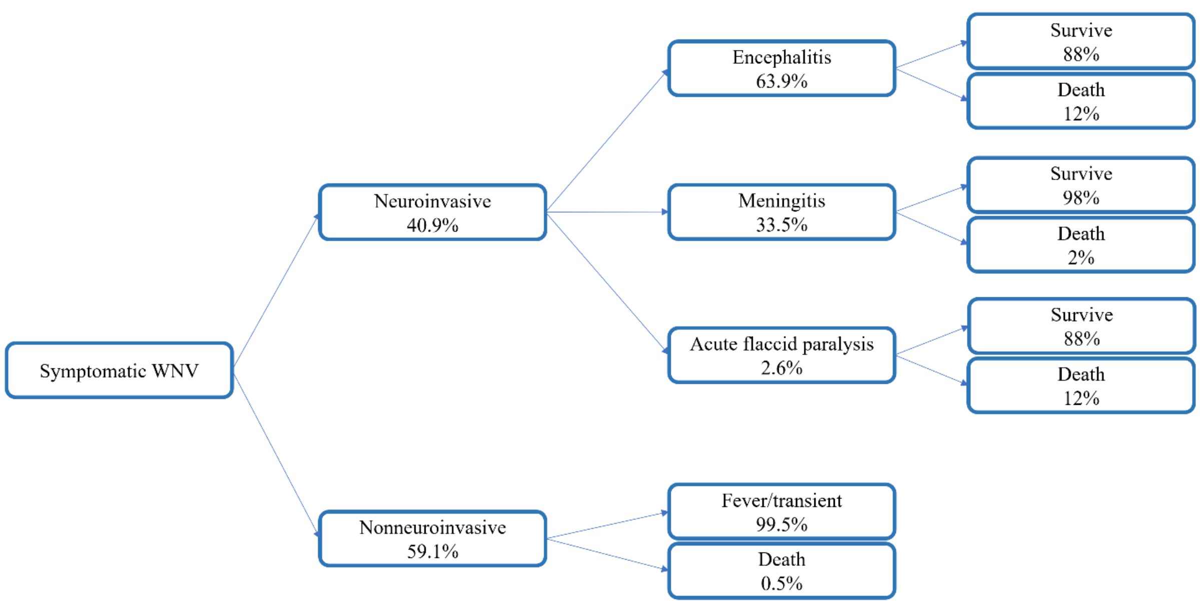

Figure 2-3. WNV decision tree model showing the range and percentages of outcomes.

EEE Decision Tree

Figure 2-4 shows the decision tree model for EEE, which is adapted from Silverman et al. (2013). There are very few cohort studies showing the breakdown of outcomes for EEE-infected individuals. ERG found that there are four different outcomes: full recovery, mild to moderate neurological symptoms, severe neurological symptoms, and mortality (Silverman et al., 2013). ERG assigned outcomes to infections based on the proportion of each outcome in its decision tree model. It should be noted that EEE has long term outcomes, so the symptoms listed above often last for years after infection (Silverman et al., 2013).

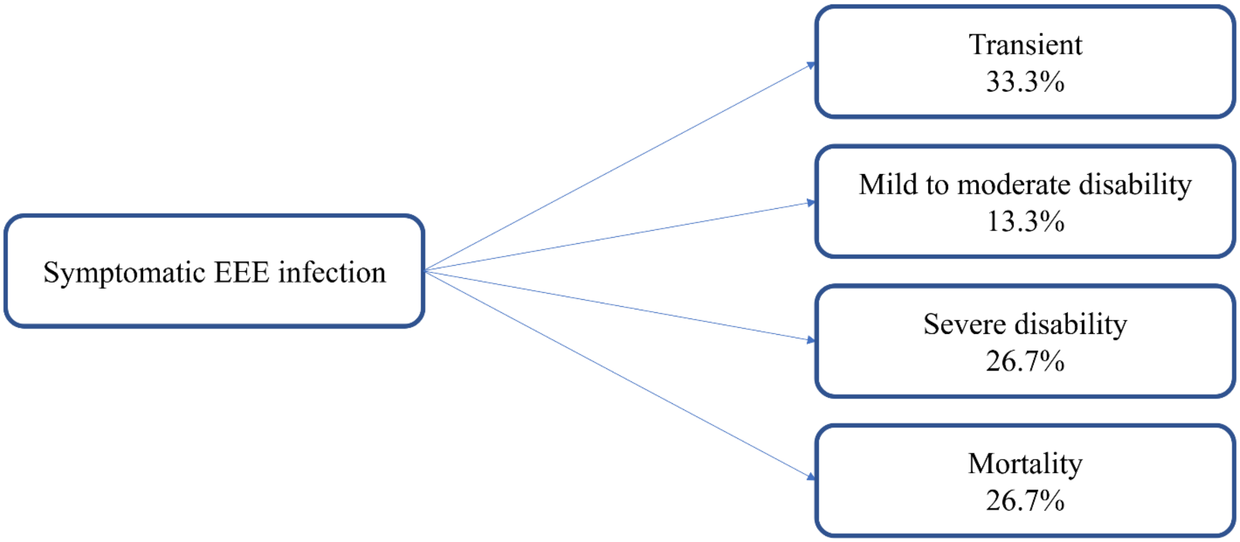

Figure 2-4. EEE decision tree model showing the range and percentages of outcomes.

Estimating the Cost of Infections

Using the modeled outcome of each infection, ERG applied a cost model to estimate the dollar value of each disease. To do this, ERG gathered cost data for the outcomes of WNV and EEE infections from the literature (outlined in Figures 2-3 and 2-4). For WNV, ERG referenced (Staples et al., 2014), which found the distribution type and values for each acute infection type. For EEE, ERG found data from normal distributions (Villari et al., 1995). ERG translated the estimated cost for each infection type to 2021 U.S. dollars using the Consumer Price Index for Urban Consumers. Using the parameters for each distribution type and disease outcome, ERG randomly chose a value from these distributions to represent the cost for each infection.[28] In the case of mortality, ERG used the 2020 Value of a Statistical Life (VSL) and adjusted it to 2021 dollars based on the ratio of 2021 income to 2020 income using the Bureau of Economic Analysis personal income,[29] according to the method the U.S. Department of Health and Human Services guidance describes (U.S. Department of Health and Human Services, 2016). The VSL is a standard metric for valuing life in economic and public health studies[30] (Colmer, 2020; U.S.

[28] Choosing random values from a distribution is an integral component of Monte-Carlo models. Using this approach allows for a wide variety of outcomes to be accounted for in our results. Using just the average would restrict results and not allow us to evaluate the full range of potential outcomes.

[29] https://apps.bea.gov/iTable/iTable.cfm?reqid=19&step=2#reqid=19&step=3&isuri=1&1921=survey&1903=58

[30] According to Colmer (2020) "The VSL represents aggregate demand for wide-spread, but individually very small, reductions in mortality risk, i.e. how much individuals are willing to pay for a very small reduction in the probability of death" To further explain Colmer states "If, on average, each individual is willing to pay $100 per year to reduce

Department of Health and Human Services, 2016). Table 2-3 shows cost data for WNV by infection outcome, and Table 2-4 shows cost data for EEE by infection outcome.

Table 2-3. Costs of WNV Infections by Outcome

Outcome	Distribution Type	Mean Cost (2021 US$)	Cost Standard Deviation (2021 US$)	Source
Encephalitis (neuroinvasive)	Gamma	$33,664	$61,063	Staples et al. (2014)
Meningitis (neuroinvasive)	Weibull	$8,673	$4,111	Staples et al. (2014)
Acute flaccid paralysis (AFP) (neuroinvasive)	Pearson V	$87,443	$99,836	Staples et al. (2014)
Fever/transient (nonneuroinvasive)	Inverse Gaussian	$8,665	$7,827	Staples et al. (2014)
Mortality	Point estimate	$12,771,671	NA	U.S. Department of Health and Human Services (2016)

NA = not applicable

Table 2-4. Costs of EEE Infections by Outcome

Outcome	Distribution Type	Mean Cost (2021 US$)	Cost Standard Deviation (2021 US$)	Source
Transient	Point estimate	$64,922	NA	Villari et al. (1995)
Mild to moderate disability	Uniform	$1,633,906	$956,080	Villari et al. (1995)
Severe disability	Uniform	$1,633,906	$956,080	Villari et al. (1995)
Mortality	Point estimate	$12,771,671	NA	U.S. Department of Health and Human Services (2016)

NA = not applicable

2.1.1.4 Results

WNV

Table 2-5 shows the estimated number of WNV cases in Massachusetts over the course of a year under various control scenarios. If current levels of mosquito control are continued, ERG's model estimates there would be 12 cases of WNV with zero deaths in a typical year, and the estimated healthcare and mortality costs for those cases range from $22,099 to more than $25.8 million. The range in each scenario is large because the cost is highly dependent on whether or not deaths are assumed to occur; given the magnitude of the Value of a Statistical Life, mortality drives the cost estimate in every scenario.

If the entire state eliminated larval and adult mosquito control programs, the ERG model predicts that cases would increase to approximately 40 per year (95 percent CI: 7 to 134) with up to seven deaths. Implementing all larval, adult, and aerial mosquito control throughout the state

the probability of dying by 0.00001, then collectively the group would be willing-to-pay $10m per year to prevent the loss of one 'statistical life'."

each year results in eight estimated annual cases (95 percent CI: 2 to 21) with zero deaths (95 percent CI: 0 to 2).

Table 2-5. Estimated WNV Outcomes from Different Mosquito Control Levels

Control	Cases	Deaths	Costs
Business-as-usual	12 (3–28)	0 (0–2)	$194,232 ($22,099–$25,890,766)
No mosquito control	40 (7–134)	2 (0–7)	$13,476,290 ($64,709–$78,848,062)
Tier 1	22 (4–63)	1 (0–4)	$12,888,278 ($34,686–$51,509,733)
Tier 2	11 (2–27)	0 (0–2)	$157,852 ($14,408–$25,823,942)
Tier 3	8 (2–21)	0 (0–2)	$107,365 ($11,636–$25,683,101)

Cases, deaths, and costs are reported in median with 95 percent CI in parentheses.

Figure 2-5 shows the mean annual outcomes of WNV infections. Fifty-nine percent of infections are transient cases with mild symptoms, but 41.0 percent of cases result in neuroinvasive disease. An estimated 80 percent of neuroinvasive infections require hospitalization (Lindsey et al., 2010).

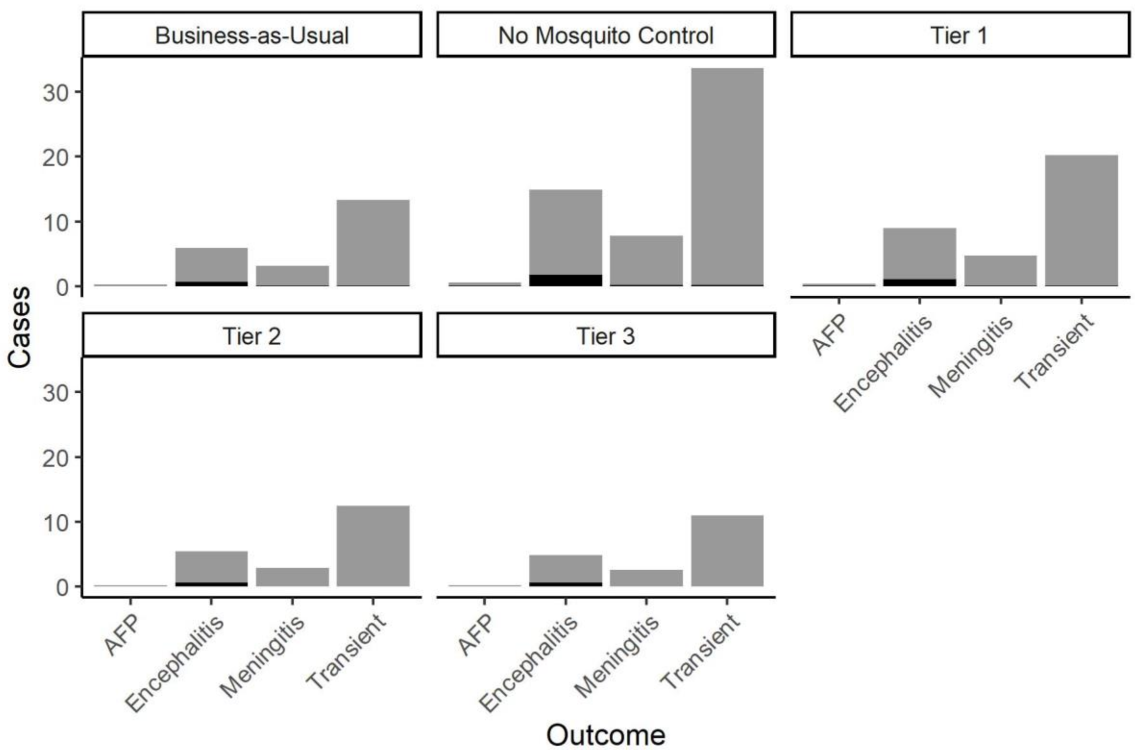

Figure 2-5. Mean annual WNV outcomes by mosquito control level.

Figure 2-5 shows the number of outcomes during a year of simulated infections by mosquito control tier. The gray bars represent the number of infections, and the black bars represent the number of deaths for each infection outcome.

ERG also looked at the breakdown of infections by county. Figure 2-6 shows the mean number of cases per county by level of mosquito control. Based on the business-as-usual scenario, Middlesex County has the largest number of modeled cases on average, 5.5 infections each year. Next is Suffolk County, with 2.3 infections. Both of these counties contain highly urban areas, the habitat for WNV vector mosquitoes. However, for the no mosquito control scenario, the model estimates that Suffolk County would see a rise in cases, from 2.3 to 13.5, and Middlesex County would see an additional 11 cases, increasing from 5.5 to 16.7. Suffolk and Middlesex counties would see similar increases in cases because they have similar mosquito control practices. Around 80 percent of Middlesex County municipalities are in two separate MCDs, while the entirety of Suffolk County is covered by two MCDs (Suffolk and Northeast). All four MCDs use Tier 2 control methods (except in a single year where one of the Middlesex MCDs employed Tier 1 control methods). Since both of these counties use Tier 2 control methods, they would see similar increases in cases.

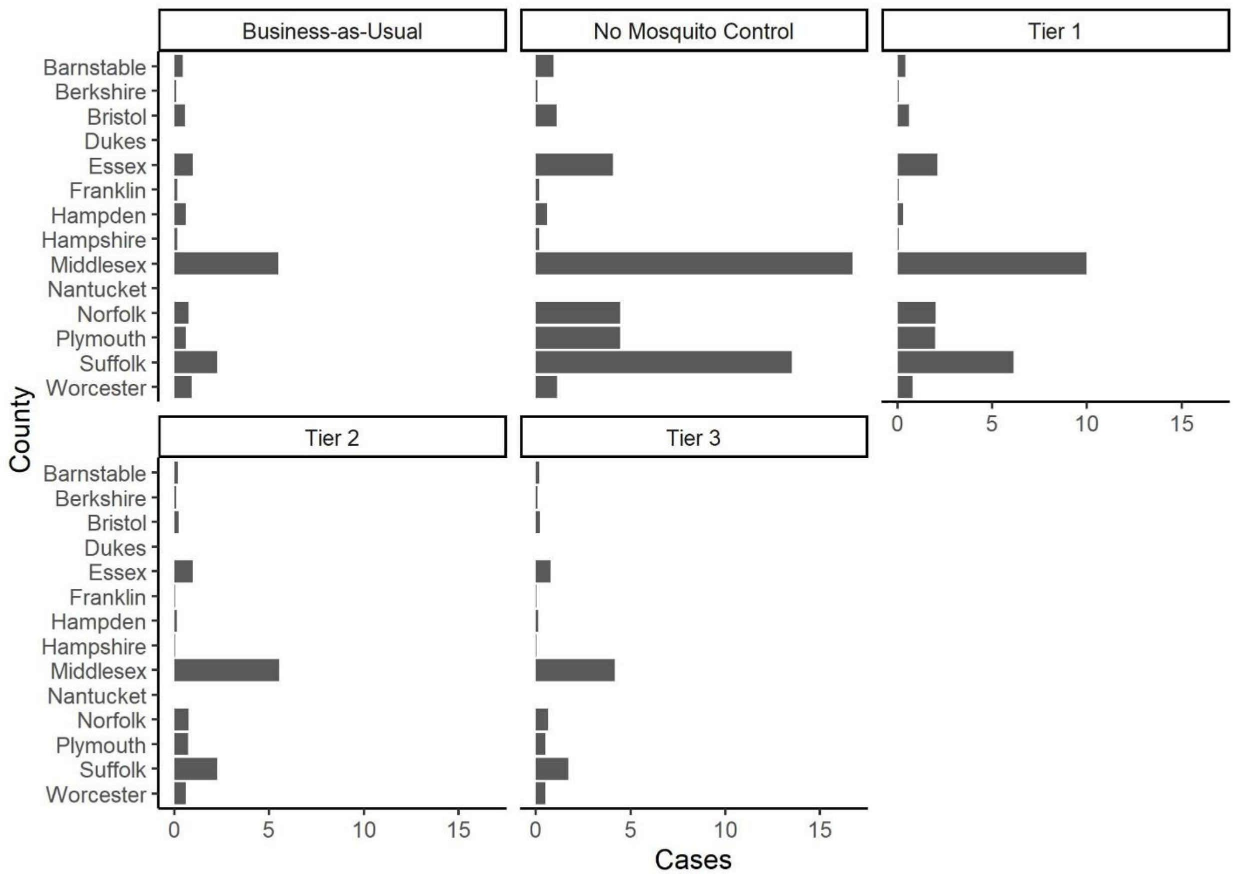

Figure 2-6. Average WNV cases per county by mosquito control level.

EEE

Table 2-6 shows the results of ERG's model for EEE infections, deaths, and healthcare costs. Based on the model, the business-as-usual scenario results in four EEE infections on average during a normal outbreak year. However, the number of estimated cases ranges from one to nine across the state of Massachusetts over one year. Of the four estimated cases, there is one estimated death (95 percent CI: 0 to 4). Altogether, the healthcare and mortality costs of the business-as-usual scenario would total $16.1 million (95 percent CI: $64,922 to $53.9 million) in 2021 U.S. dollars. The estimated cost of EEE in a given year is much greater than that of WNV given the worse outcomes associated with infection.

Table 2-6. Infections, Deaths, and Healthcare Costs of EEE Infections by Mosquito Control Level

Control	Cases	Deaths	Costs (2021 US$)
Business-as-usual	4 (1–9)	1 (0–4)	$16,140,721 ($64,922–$53,923,164)
No mosquito control	15 (1–48)	4 (0–14)	$61,966,720 ($64,922–$213,451,451)
Tier 1	9 (0–24)	2 (0–8)	$33,603,256 ($0–$113,013,673)
Tier 2	4 (0–12)	1 (0–4)	$15,206,854 ($0–$60,561,657)
Tier 3	3 (0–7)	1 (0–3)	$12,901,515 ($0–$42,171,000)

Figure 2-7 shows infections by county. Infections vary by county, largely occurring in counties in the eastern half of the state, which contain known habitat for EEE-carrying mosquitoes. According to ERG's model, several counties would not experience cases under any level of control: Barnstable, Berkshire, Dukes, Hampshire, Nantucket, and Suffolk counties. Plymouth County would have the majority of cases in a scenario with limited mosquito control. This is an artifact of the model since there have been no cases in these counties over the past twelve years. It is possible that mosquito populations will shift or expand to these counties in the future but measuring this change was outside the scope of this project.

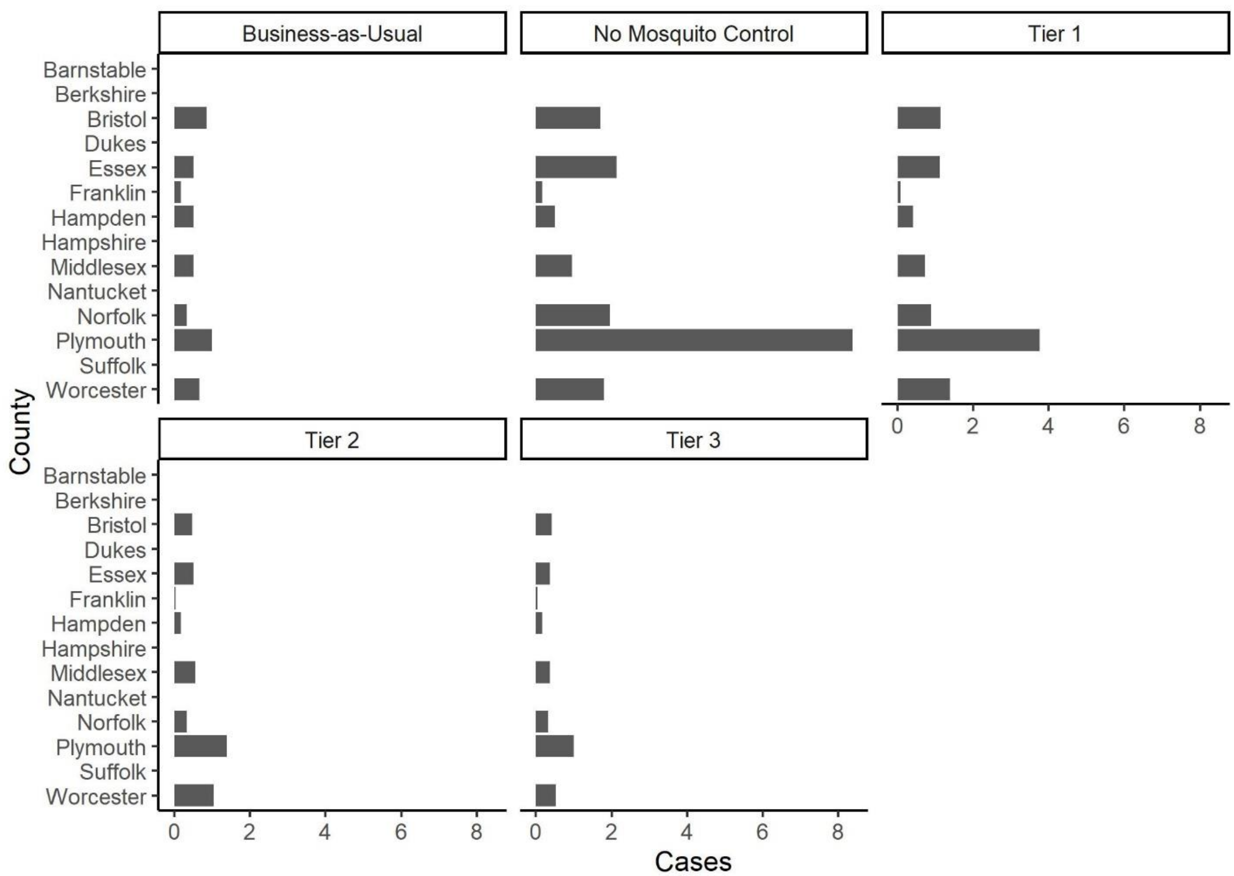

Figure 2-7. Mean EEE cases per county by mosquito control level.

EEE cases have a high case fatality rate. However, many of the individuals that survive also have permanent damage (Silverman et al., 2013). Figure 2-8 shows the number of cases by outcome for each level of mosquito control. Death is a high proportion of these cases, 26.6 percent, but severe disability also accounts for a large proportion of cases, 33.3 percent. These cases can also incur large healthcare costs throughout their lives that are not measured here (Villari et al., 1995).

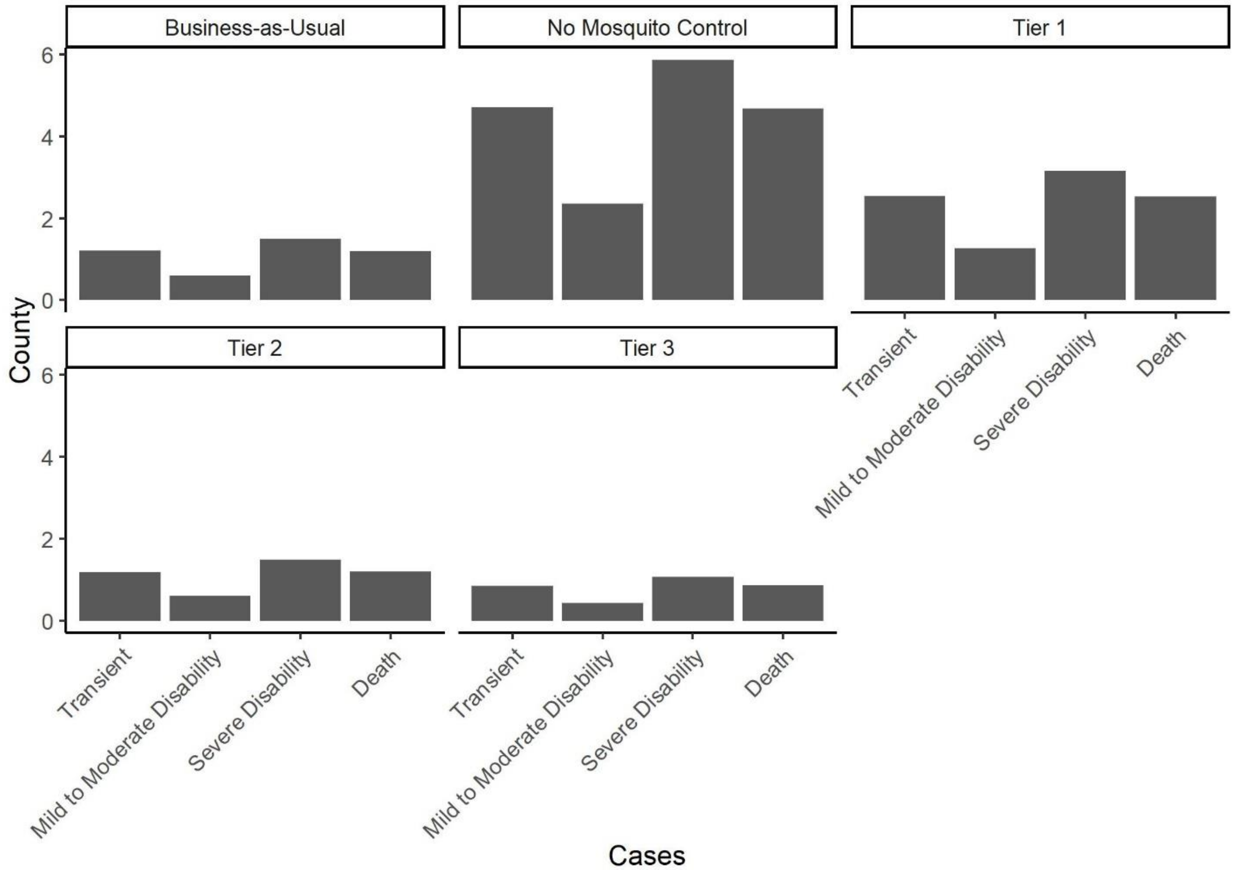

Figure 2-8. Mean EEE case outcomes by mosquito control level.

2.1.1.5 Discussion

In the models for both EEE and WNV, the available data indicate that increasing levels of mosquito control result in decreasing numbers of cases, as would be expected. According to the ERG model, if all chemical mosquito control methods were stopped, there would be more than double the number of WNV cases and a 275 percent increase in EEE cases.

Additionally, the model shows diminishing returns with increasing controls when moving from no control to Tier 3 control. As presented in Figure 2-9, Tier 2 control would cause cases to decrease by approximately 70-73 percent, versus the scenario of no control for both WNV and EEE. However, adding aerial spraying (Tier 3) would only reduce cases by an additional 7 percent, to 80 percent, for both WNV and EEE.

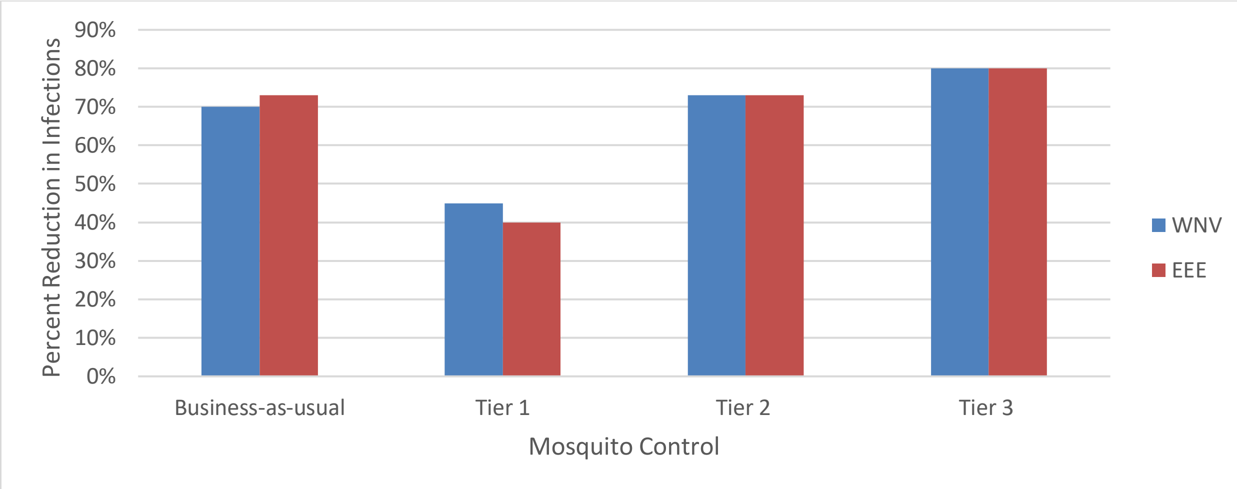

Figure 2-9. Percent Reduction in Infections from the No Mosquito Control Scenario

In evaluating the results of this analysis, several limitations and assumptions must be considered. Table 2-7 outlines limitations and assumptions for each data source used.

Table 2-7. Model Limitations

Data Source	Limitations, Assumptions, and Considerations
Number of infections	The finest level at which cases can be reported is at the county level, by year. However, mosquito control programs can have impacts on much smaller scales, such as at the town level (Tedesco et al., 2010). ERG's model does not capture the finer impacts of mosquito control practices. This model uses historical data over the past 12 years and therefore does not account for long-term trends. Since ERG used historical data, the model is restricted to the largest number of cases over the past 12 years and cannot predict a higher number for the business-as-usual scenario for any county. Additionally, the risk of vector-borne diseases depends on a multitude of factors (e.g., human behavior, climate), and ERG's model only evaluates the impact of mosquito control practices on the risk of vector-borne diseases.
Mosquito control/infection reduction efficacy	ERG's model assumes that a reduction in mosquito populations equals a reduction in infections. While select publications have shown a reduction in cases due to mosquito control practices (Carney et al., 2008), this has not been shown to be a direct result of a decrease in mosquito populations. Additionally, the data used for the efficacy of larviciding and adulticiding are not specific to Massachusetts but are for products the Commonwealth often uses.
Infection outcome proportions	There are very few studies assessing the proportions of outcomes for EEE infections. ERG used a study that only evaluated the outcomes of 15 children (Silverman et al., 2013). A more substantial database of EEE outcomes would improve the model.
Infection costs	ERG evaluated the outpatient costs of cases, but this is only one dimension of costs. Infections, especially EEE, can have long-term impacts on individuals and society, such as long-term disability and lost wages.

This analysis focuses on the number of infections in each county under different mosquito control practices. Future analyses should build on this and incorporate the costs of mosquito control, as well as the amount of pesticides used. These could take the form of benefit-cost or cost-effectiveness analyses. Using different control measures throughout the state while increasing practices in areas with high infections could save money and reduce infections and exposure to pesticides; an analysis of such measures and practices could provide valuable guidance moving forward.

2.1.2 Impact of Mosquito Control on Public Health

Table 2-8 presents the active ingredients in the pesticides used by MCDs and the SRB for mosquito control in the past five years. Quantifying risk from mosquito control activities requires a statewide exposure assessment and chemical-by-chemical dose-response evaluations for noted hazards. This was not feasible given the scope and resources allocated. Therefore, refer to Report 4: Chemical Composition and Toxicity of Pesticides Used in Ground and Aerial Spraying in Massachusetts for a comprehensive evaluation of the human health toxicity of these compounds.

Table 2-8. Active Ingredients Used for Mosquito Control by MCDs or the SRB in the Past Five Years

Active Ingredient	Chemical Abstracts Service Registry Number	Role in Mosquito Control
Bacillus thuringiensis israelensis (*Bti*)	68038-71-1	Larvicide
Bacillus sphaericus ABTS 1743	143447-72-7	Larvicide
Bacillus sphaericus AM614	143447-72-7	Larvicide
Spinosad	131929-60-7; 131929-63-0	Larvicide
Methoprene	40596-69-8; 65733-16-6	Larvicide
Mineral oil	8012-95-1; 8042-47-5	Larvicide
d-phenothrin	26002-80-2	Adulticide
Etofenprox	80844-07-1	Adulticide
Deltamethrin	52918-63-5	Adulticide
Fluvalinate	69409-94-5	Adulticide
Prallethrin	23031-36-9	Adulticide
Permethrin	52645-53-1	Adulticide
Piperonyl butoxide (PBO)	51-03-6	Synergist

The larvicides used by MCDs have minimal human health toxicity concerns. The bacterial larvicides, mineral oil, and methoprene are all rated in the lowest tier of concern for acute toxicity, and EPA does not categorize any of them as carcinogenic (EPA, 1998, 2007, 2019, 2021). Spinosad is categorized as minimally acutely toxic and not carcinogenic, but it did cause some toxicity in toxicological evaluations in rodents and dogs, with impacts at multiple target organs (e.g., epidiymides, thymus, thyroid, larynx) (USEPA, 2016g). However, the doses where effects may occur are at least 100 times higher than the levels of expected exposure if these larvicides are applied appropriately (USEPA, 2016g).

The adulticides used by MCDs and the SRB for mosquito control are all in the pyrethroid class. High-dose, acute exposures to this class of chemicals can result in skin, eye, and respiratory system irritation and possible neurologic dysfunction (ATSDR, 2018). The neurologic effects observed with pyrethroid exposure are one of the key characteristics of these compounds. These effects can present as aggressive behavior, tremors, and/or seizures, depending on the compound of exposure. Deltamethrin, fluvalinate, and permethrin all elicit standard pyrethroid responses. However, d-phenothrin and etofenprox are unique in their toxicity profiles. D-phenothrin does not elicit the same neurologic response even at high-dose exposure (e.g., greater than 2,000 mg/kg/day) (USEPA, 2016b). Etofenprox, although grouped as a pyrethroid, has a structural difference from the other pyrethroid compounds (i.e., an ether moiety instead of an ester moiety) and targets several organs (liver, thyroid, kidney, and the blood system). These effects have been observed in toxicological studies at doses above 180 mg/kg/day (USEPA, 2017b).

One active ingredient used by MCDs and the SRB, permethrin, has been categorized as "suggestive of carcinogenic potential" (USEPA, 2020c). Only three to seven gallons of this product have been reported as used by any MCD in the past five years. EPA categorizes all other pyrethroids as not likely to be carcinogenic. Other toxic effects observed include impacts to nasal turbinates with inhalation exposure (for d-phenothrin, the effect is observed a 0.219 mg/L in rats; for PBO, the effect is observed at 0.15 mg/L in rats) and enzymatic or histopathologic changes to the liver with dietary exposure (for d-phenothrin, the effect is observed at 26.8 mg/kg/day in rats; for PBO, effects are observed at doses greater than 50 mg/kg/day in rats) (USEPA, 2006).

In addition to reviewing EPA's information on these ingredients, ERG reviewed (Saillenfait et al., 2015)'s comprehensive literature review on pyrethroids and human health impacts. The authors state that the evidence of various health effects from low-level chronic exposure to pyrethroids is "limited and controversial" (Saillenfait et al., 2015). The epidemiological studies reviewed observed potential associations between pyrethroid exposure and sperm quality, sperm DNA, reproductive hormones, pregnancy outcomes, and neurobehavioral outcomes (e.g., attention-deficit/hyperactivity disorder) after in utero exposure.[31] However, the authors also note that these findings are inconclusive, and that further research is needed to determine the potential risks associated with long-term, low-level exposure to pyrethroids.

2.2 Commercial Impacts of Mosquitoes, Mosquito-Borne Diseases, and Chemical Mosquito Control

Nuisance levels of biting mosquitoes and outbreaks of mosquito-borne illness impact Massachusetts in different ways. Vector mosquitoes infect individuals; this may result in human infections and potentially death and have associated healthcare costs, as Section 2.1.1.3 discusses. All biting mosquitoes, even non-vector mosquitoes, incur individual costs for bug spray and other pest control methods, but they could impact the state in other ways—such as reduced enjoyment of outdoor activities, closure of recreational areas, and determent of tourists—causing economic impacts. Considering the controls used to minimize mosquito prevalence, spraying could theoretically impact recreation or tourism, such as if activities are postponed or cancelled due to spraying activities. However, ERG was unable to locate any data

[31] Summaries of all studies evaluated by Sallienfait et al. (2015) are included in Table 1 (male hormonal and reproductive effects) and Table 2 (health effects of pyrethroids during pregnancy) of the article.

to indicate such impacts of chemical mosquito control. Therefore, this section focuses only on the impacts of mosquitoes on commerce.

2.2.1 Impact of Mosquitoes on Commerce (Recreation and Tourism)

Although ERG had aimed to quantify the impact of mosquitoes and mosquito-borne diseases on commerce (i.e., recreation and tourism) in the Commonwealth, data were not available for such an exercise. Therefore, this section summarizes the available evidence for recreation and tourism impacts, with as much quantification from the original sources as possible.

2.2.1.1 Recreation

The presence of nuisance mosquitoes in Massachusetts negatively impacts the enjoyment of outdoor activities. ERG did not find any studies conducted in Massachusetts, but studies from nearby states in the mid-Atlantic and Midwest show that individuals have a stated value of enjoying more mosquito-free time outdoors. However, these studies take place in different geographic locations, where people may have different perspectives than those in Massachusetts.

Halasa et al. (2014) analyzes residents' experiences with mosquitoes and the importance of outdoor relaxation in Monmouth and Mercer counties in New Jersey. They found that 59.5 percent of individuals surveyed stated that mosquitoes prevented them from enjoying outdoor activities to some extent (measured as either "a little bit," "somewhat," or "very much," compared to "none at all") (Halasa et al., 2014). Additionally, individuals rated the importance of being able to relax in their backyards without mosquitoes, just below importance of being able to walk around their neighborhoods without fear of crime(Halasa et al., 2014). They also stated that an additional hour of work-free and mosquito-free time relaxing outside per summer week was worth more than $10 (Halasa et al., 2014).

Another study conducted in Madison, Wisconsin surveyed homeowners on their stated preferences for WNV-transmitting and nuisance mosquito control measures. The authors asked residents about their willingness to pay (WTP) under current and increased WNV risk scenarios. Current risk is stated as one infection in every 250,000 residents, high risk is defined as 10 in every 250,000, and highest risk is defined as 100 in every 250,000 (Dickinson & Paskewitz, 2012). Residents were not willing to pay for a control program that only targeted WNV vector mosquitoes under the current risk scenario (WTP: -$21) but were willing to pay for control programs that target nuisance mosquitoes (WTP: $147) (Dickinson & Paskewitz, 2012). This changed as the risk of WNV increased; residents were more likely to allocate more money for targeting only WNV vector mosquitoes under the highest level of risk (WTP: $158), but they still were willing to pay for control programs targeting nuisance mosquitoes under that same level of risk (WTP: $108) (Dickinson & Paskewitz, 2012).

While nuisance mosquitoes may keep individuals in their homes more than they would be in the absence of mosquitoes, disease vectors could have a more defined impact on recreation. As part of the phased response to elevated risk of EEE or WNV, the 2021 Arbovirus Surveillance and Response Plan recommends that towns and schools reschedule outdoor recreation events to avoid the hours between dusk and dawn, when mosquito vectors are most likely to be active (Bharel & Cranston, 2021b). Examples of this recommendation being implemented include the city of Haverhill closing all school facilities and canceling all after-school activities after 7 p.m. in 2019 (LaBella, 2019), as well as parts of Massachusetts banning outdoor organized activities during peak mosquito hours in 2012 (Times Staff, 2012). This may also result in economic losses for some communities due to concession stands being closed, which may fund sports teams or other school initiatives.

2.2.1.2 Tourism

Massachusetts' tourism industry brings more than 30 million visitors to the state every year (Visit Massachusetts, 2020). These visitors spend nearly $25 billion and support more than 155,000 jobs. Disease outbreaks are a risk to the tourism industry. One author found that more than 52 percent of travelers either "very likely" or "for sure" would stay home if the risk of an infectious disease were more widespread (greater than 0.5 percent, compared to less than 0.5 percent), compared to 47 percent opting to stay home if wildfires occurred more often or 46 percent if temperatures were uncomfortably hot (León et al., 2020). While the risk of WNV or EEE infection in Massachusetts was not as high as in the study (the study considered moderate risk to be a 0.5 to 2 percent chance and severe risk to be a chance of more than 4 percent), even a small percentage reduction in tourism could impact Massachusetts' economy. One study found that locations that had high Zika transmission rates were less likely to be considered in the travel plans of expecting parents (Gallivan et al., 2019). Experiences from the Zika outbreak have suggested that mosquito-borne disease outbreaks have the potential to impact a region's tourism. However, ERG found no publications that quantified or estimated the impact of EEE outbreaks on Massachusetts' tourism industry; thus, it is unclear if any impacts have occurred.

2.3 Agricultural, Livestock and Domesticated Animals Impacts of Mosquitoes and Mosquito-Borne Diseases

In addition to infecting humans, mosquitoes can also infect animals, which can result in illness or death. These infections may adversely affect agriculture if they occur in livestock or other domesticated animals, such as horses. Section 2.3.1 presents an overview of the impact mosquitoes may have on agriculture, mainly livestock or other domestic animals.

Mosquito control methods may also impact agriculture, especially through impacts on ecosystem services such as pollination. In recent decades, declining populations of pollinators have been attributed to factors including pests (e.g., the Varroa mite), pathogens, management stressors, environmental stressors, and pesticides (USEPA). ERG explored this issue by providing a baseline estimate of the value of agriculture in Massachusetts and the proportion of that value that Massachusetts pollinators support. ERG also evaluated available data on pollinator exposure to the pesticides used in aerial spraying and available toxicity data on the active ingredients used by MCDs and the SRB to control mosquitoes and their impacts on pollinators. The available data did not allow for quantification of effects; therefore Section 2.3.2 provides a qualitative discussion.

2.3.1 Mosquito Impacts on Agriculture, Livestock and Domesticated Animals

In addition to humans, many animals can also be infected with WNV and EEE, including cows, horses, and birds. ERG used data from the past 15 years to map the impacts of EEE and WNV on livestock and domesticated animals in Massachusetts. The 2020 Arbovirus Surveillance and Response Plan presents the number of confirmed animal infections between 2004 and 2019 (Bharel & Cranston, 2020b), which DPH confirmed. Table 2-9 reproduces this information. The numbers of infections are likely vast underestimates because animals are less likely to be tested for these infections; animals are tested when they have severe neurological disease that is suspected to be caused by EEE or WNV (Bharel & Cranston, 2020b).

DPH surveils horses even in years with low disease risk because EEE and WNV are known to cause serious illness and death in horses, but DPH does not surveil any other animal regularly (Bharel & Cranston, 2020b). Hence, Figure 2-10 and Figure 2-11 show the temporal trends in horse EEE and WNV cases. Horse EEE cases are more pronounced than horse WNV cases and generally track well with human cases. Spikes in horse EEE cases have accompanied spikes in human EEE cases, such as in 2006, 2012, and 2019.

Table 2-9. Confirmed Animal Infections of WNV and EEE Between 2004 and 2019 in Massachusetts

Species	EEE Infections	WNV Infections
Alpaca	4	1
Cow	1	0
Deer	1	0
Emu	2	0
Goat	1	0
Horse	44	9
Llama	1	0
Turkey	1	0

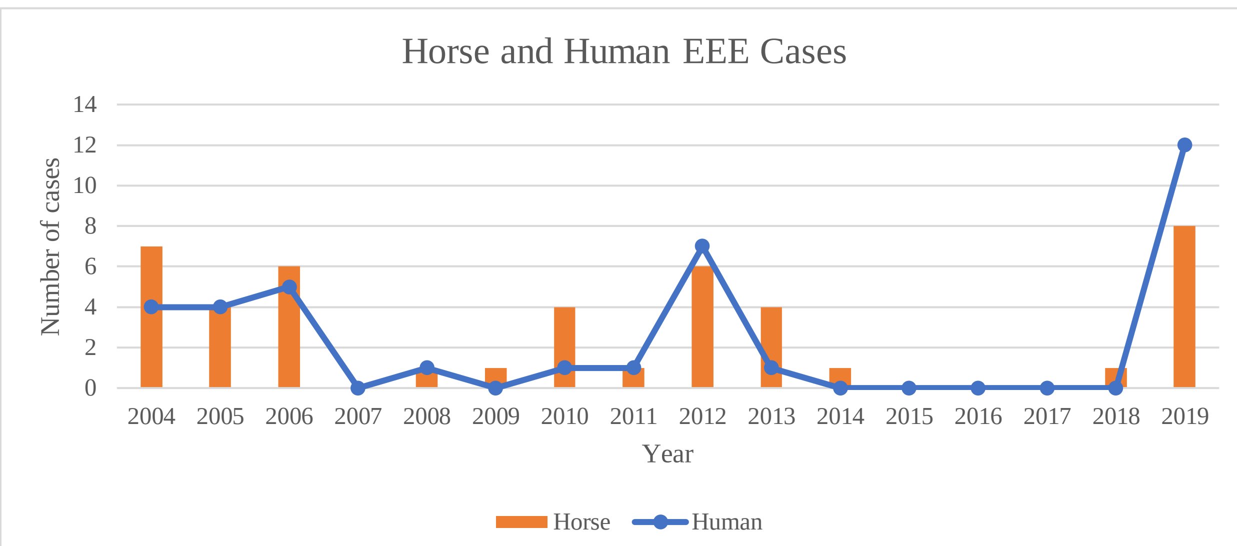

Figure 2-10. Horse and human EEE infections.

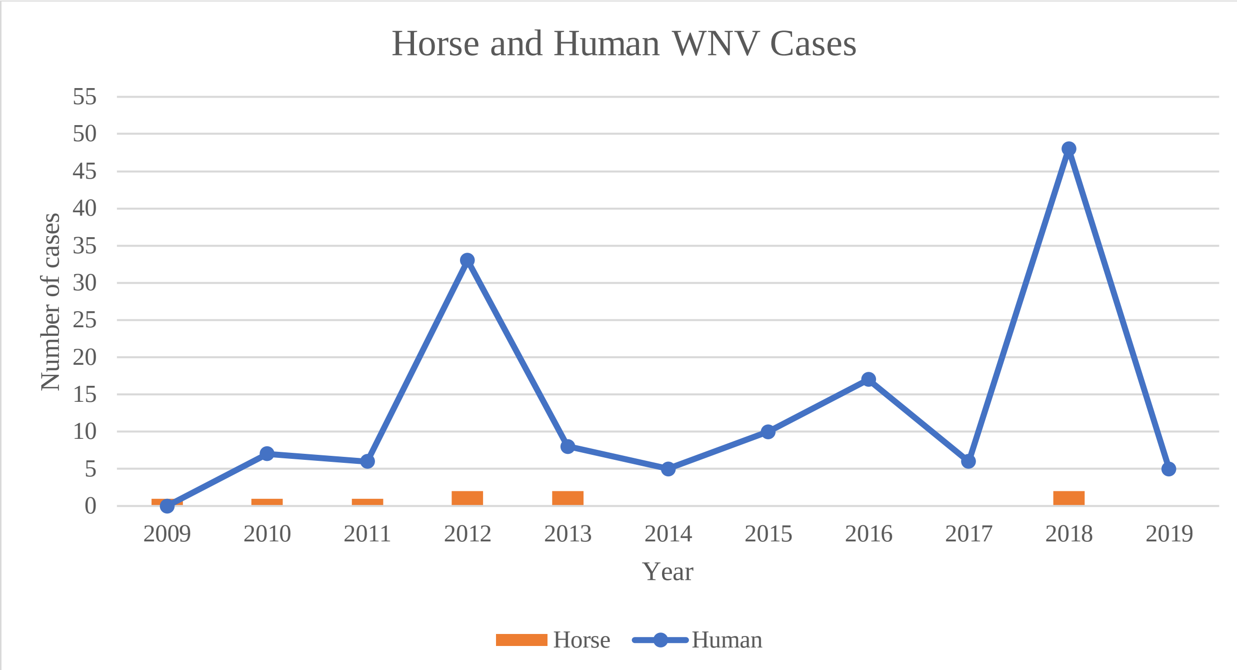

Figure 2-11. Horse and human WNV infections.

DPH surveilled bird populations until 2009. When WNV originally emerged in the United States, testing dead birds for WNV was a productive way of learning how the virus spreads and where it is located. However, DPH discontinued avian surveillance in 2009 after it was clear that testing mosquitoes was more informative to help reduce human infections (Bharel & Cranston, 2021b). EEE can infect birds, but it does not usually kill them, making testing birds for EEE impractical (Bharel & Cranston, 2021b). However, birds that are not native to the United States, such as emus, are vulnerable to EEE (Bharel & Cranston, 2021b).

Horse populations in Massachusetts are at risk from EEE and WNV. The threat of these diseases creates economic costs for horse owners, as seen in an economic impact analysis of the effects of a WNV outbreak on the North Dakota equine industry in 2002. The overall cost to the state of North Dakota from vaccinations, treatment, and mortality was nearly $2 million 2002 U.S. dollars (Ndiva Mongoh et al., 2008).

2.3.2 Mosquito Control Impacts on Agriculture, Including Pollinators and Apiaries

Pollinators are essential for many agricultural products, and the impact of pesticides on pollinators has emerged as an important issue surrounding mosquito control in Massachusetts. Massachusetts is home to a diverse set of pollinators, including an estimated 380 species of bees and 120 species of butterflies in the wild, as well as four managed bee species used in crop pollination (Massachusetts Department of Agricultural Resources, 2017). Other animals, such as birds, moths, beetles, and wasps, also perform pollination services, though bees are generally considered the most abundant and efficient pollinators (Lavengood). In recent decades, the declining health of honey bees has been attributed to a variety of factors such as pesticides, pests, poor nutrition, and bee management practices (USEPA). Several pesticides used in Massachusetts for mosquito control can be toxic to bees (see Report 4: Chemical Composition and Toxicity of Pesticides Used in Ground and Aerial Spraying in Massachusetts). Even when pesticide applications do not directly kill bees, pesticides can affect bees' metabolism, reproductive success, motor function, behavior, and cognition (Chmiel et al., 2020). Although measures can be taken to reduce the potential for exposure, (e.g., spraying at night when honey bees are inside their hives), not all measures are equally effective or protective of all pollinators (see Report 6: Best Practices to Maximize Impact of Pesticide Use on Mosquito Populations and Minimize Non-target Impacts of Mosquito Pesticides).

This section describes the model ERG developed to estimate the monetary value of agriculture in Massachusetts. In addition, it describes available data on pesticide exposure for pollinators in Massachusetts and the toxicity of products to which pollinators may be exposed. This analysis focuses on available data for pesticide exposure in Massachusetts honey bees, as data for pesticide exposure in other Massachusetts pollinators are not as readily available. Although pollinators have other roles in maintaining ecosystems, the data needed to quantify these impacts are less tangible and were not readily available.

2.3.2.1 Methods

ERG began this analysis by interviewing a pollinator expert on approaches to quantifying the impacts of pesticides on agriculture and pollinators and conducting a literature review. From this, ERG determined it was feasible to quantify Massachusetts pollinators' contribution to agriculture. This is because data were readily available on the price of crops, the acreage of crops, and the dependance of these crops on pollinators. Although some data from the field on the exposure of honey bees to pesticides used by MCDs and the SRB were available, these data, along with available data on the toxicity of these pesticides, did not allow for the quantification of the impacts of mosquito control on agriculture. Therefore, ERG developed a baseline quantitative understanding of the importance of pollinators to Massachusetts agriculture and qualitatively describes the literature related to the relationship between the pesticides used by MCDs and the SRB and bee toxicity.

To determine pollinators' contribution to agriculture, ERG used Equation 2-3, which was adapted from Morse and Calderone (2000).

Equation 2-3. Pollination value formula.

$$Pollinator\ contribution = A \times Y \times P \times D$$

A is the acreage of crops, Y is the yield per acre, P is the price per unit yield, and D is the dependence on pollination. The product $A \times Y \times P$ represents the value of crops. D ranges from 0 to 1, where 1 represents a complete dependence on pollination and 0 represents no dependence on pollination. The pollinator contribution can further be multiplied by the fraction of pollination attributable to honey bees to obtain the honey bee-specific contribution to agriculture. Pollinator contribution estimates were drawn from the literature (Morse & Calderone, 2000), while the value of pollinated crops was calculated using data from the 2017 U.S. Department of Agriculture Census of Agriculture.

ERG selected 12 crops in Massachusetts for the analysis based on data availability. The analysis includes key crops such as cranberries—of which Massachusetts is the United States' second-largest producer (UMass Cranberry Station)—and apples. The calculation was done for all of Massachusetts, as well as by county, since the level of pesticide application varies significantly by county. ERG then qualitatively examined available evidence for the impacts of mosquito control on pollinators in Massachusetts.

2.3.2.2 Results

Table 2-10 shows the total acreage of 12 crops in Massachusetts, the calculated value of the crops, the annual value of crops attributable to pollinators, and the annual value of crops attributable to honey bees. Table 2-11 shows the same values aggregated by crop and presented by county. All values are presented in 2021 U.S. dollars and were adjusted using a gross domestic product price deflator.[32]

Table 2-10. Pollination Value by Crop and Pollinator Type

Crop	Total Crop Acreage in Massachusetts[a] (Acres)	Total Value of Crop[b] (2021$)	Annual Value Attributable to Pollinators[c] (2021$)	Annual Value Attributable to Honey Bees[c] (2021$)
Apples	3,715	22,843,895	22,843,895	20,559,506
Blueberries	906	7,654,161	7,654,161	6,888,744
Cantaloupes	59	417,881	334,305	300,874
Cranberries	13,306	69,268,458	69,268,458	62,341,611
Cucumbers	245	2,650,229	2,385,206	2,146,685
Onions (dry)	134	953,400	953,400	858,060
Peaches	458	4,268,173	2,560,904	2,048,724
Pears	92	453,166	317,216	285,494
Pumpkins	1,728	7,139,391	6,425,452	642,545
Squash (summer)	302	2,555,438	2,299,894	229,989
Squash (winter)	990	4,610,857	4,149,771	414,977
Strawberries	314	5,960,933	1,192,187	119,218
Watermelons	62	435,137	304,596	274,136
Total[d]	**22,311**	**129,211,118**	**120,689,444**	**97,110,564**

[a] USDA National Agricultural Statistics Service (2017).
[b] Hird and Deane (2020).
[c] Morse and Calderone (2000).
[d] Slight differences between the totals in Table and Table are due to rounding.

Table 2-11. Crop Acreage and Value by County and Pollinator Type

County	Total Crop Acreage in County[a] (Acres)	Total Value of Crop[b] (2021$)	Annual Value Attributable to Pollinators[c] (2021$)	Annual Value Attributable to Honey Bees[c] (2021$)
Barnstable	973	5,305,563	5,106,897	4,441,869
Berkshire	289	1,681,762	1,627,206	1,087,256
Bristol	1,657	9,344,756	8,732,747	6,514,954
Dukes	7	55,616	54,138	48,724
Essex	581	4,586,081	3,354,193	1,951,971
Franklin	1,416	9,952,911	8,958,902	6,927,578
Hampden	671	4,333,972	3,822,830	2,691,174

[32] https://apps.bea.gov/iTable/iTable.cfm?reqid=19&step=3&isuri=1&nipa_table_list=13

County	Total Crop Acreage in County[a] (Acres)	Total Value of Crop[b] (2021$)	Annual Value Attributable to Pollinators[c] (2021$)	Annual Value Attributable to Honey Bees[c] (2021$)
Hampshire	1,279	8,126,565	6,687,086	3,031,169
Middlesex	833	5,328,803	4,421,875	2,780,227
Nantucket	16	190,021	77,998	7,800
Norfolk	201	1,378,249	1,075,553	580,747
Plymouth	11,938	62,766,872	62,115,726	54,787,308
Worcester	2,450	16,159,948	14,654,294	12,259,788
Total[d]	**22,311**	**129,211,119**	**120,689,444**	**97,110,567**

[a] USDA National Agricultural Statistics Service (2017).
[b] Hird and Deane (2020).
[c] Morse and Calderone (2000).
[d] Slight differences between the totals in Table and Table are due to rounding.

As Table 2-11 shows, four of these crops wholly depend and eight almost entirely depend (*D* >0.5) on pollination. Of the 129 million dollars contributed to Massachusetts' agricultural economy through the pollination of these 14 crops, 97 million dollars can be attributed to honey bees alone. Plymouth County comprises more than half of the entire state's honey bee-dependent agricultural contributions.

To understand the potential impact of chemical-based spraying on honey bee health, the Massachusetts Department of Agricultural Resource's (MDAR's) Apiary Program conducts honey bee monitoring before and after statewide aerial applications. This was done in both 2019 and 2020. Monitoring was conducted in towns that received aerial spraying, as well as towns located outside the application area. These available apiary reports post-aerial application focused on acute impacts of aerial sprays and found that overall, the aerial spraying did not appear to significantly harm the health of monitored honey bee colonies throughout the duration of monitoring (about two weeks, including pre-spray monitoring and post-spray monitoring). This conclusion is based on a combination of visual observations (by both the MDAR Apiary Program team and the beekeepers whose colonies were monitored) and sampling results for the pesticides used in the aerial application (Skrym & Wijnja, 2019, 2020). Additionally, all detectable pesticide concentrations were below the level that would cause lethal effects in adult honey bees (as determined by the 50 percent lethal dose [LD_{50}] values).

The *2018 Massachusetts Hobbyist Health Survey Report*, a collaboration between MDAR and the University of Massachusetts Honey Bee Extension Program, states that 58 out of 266 tested pesticide compounds were detected in samples from 40 hobbyist apiaries (Whitehead & Adler, 2018). Table 2-12 shows the detected insecticides. A few compounds commonly detected in this study are known to have been used in Massachusetts mosquito control, such as PBO, a synergist used in Massachusetts' aerial applications, and etofenprox, an adulticide used in non-aerial applications (see the Report 4: Chemical Composition and Toxicity of Pesticides Used in Ground and Aerial Spraying in Massachusetts). While PBO has very low toxicity for honey bees (Whitehead & Adler, 2018), etofenprox is highly toxic to bees exposed to direct treatment on blooming crops or weeds (USEPA, 2013). Though these compounds have been used by MCDs and the SRB in mosquito control, the presence of detected insecticides in samples cannot be definitively attributed to mosquito control as these compounds may have been used in other applications.

Table 2-12. Insecticides Found in Massachusetts Bees

Compound	Contact LD_{50} (µg/Bee)	Oral LD_{50} (µg/Bee)	Pollen		Wax	
			Level of Detection (ng/g)	Percent Samples Positive	Level of Detection (ng/g)	Percent Samples Positive
Acetamiprid	7.9	14	0.05	6.3	0.04	7.5
Bifenazate	7.8	141	0.19	2.5	0.14	1.3
Carbaryl	0.232	0.15	0.09	26.6	0.07	3.8
Chlorantraniliprole	0.706	0.0274	1.17	15.2	0.88	8.8
Chlorpyrifos	0.01	0.051	0.47	2.5	0.35	0
Clothianidin	0.039	0.004	0.23	6.3	0.18	0
Dinotefuran	0.047	0.022	0.7	1.3	0.53	0
Etofenprox	**0.015**	**0.024**	**0.12**	**1.3**	**0.09**	**1.3**
Fipronil	0.006	0.001	0.23	8.9	0.18	16.3
Fipronil sulfone	0.006	0.001	0.47	16.5	0.35	16.3
Flubendiamide	200	200	0.7	1.3	0.53	0
Hexythiazox	200	NA	0.47	0	0.35	1.3
Imidacloprid	0.044	0.004	0.23	22.8	0.18	16.3
Methiocarb-sulfoxide	0.29	0.47	0.05	1.3	0.04	0
Methonyl	0.16	0.24	0.23	2.5	0.18	0
Methoxyfenozide	100	100	0.19	1.3	0.14	1.3
PBO (synergist)	**11**	**NA**	**0.05**	**34.2**	**0.04**	**81.3**
Spinosyn A	**0.003**	**0.057**	**0.23**	**5.1**	**0.18**	**1.3**
Tebufenpyrad	6.8	1.8	0.19	0	0.14	10
Thiamethoxam	0.024	0.005	0.19	3.8	0.14	1.3

Bolded text indicates compounds that have been reported as used for mosquito control by MCDs.

2.3.2.3 Discussion

ERG's analysis of the value of agriculture in Massachusetts certainly underestimates the entire value that pollinators bring to Massachusetts. For instance, ERG was unable to quantify the total value of honey and non-agricultural flowering plants due to a lack of data. The agricultural industry in Massachusetts produces an annual market value of more than $475 million in goods ranging from dairy products to berries (Massachusetts Department of Agricultural Resources), and more than 45 percent of Massachusetts' agricultural commodities depend on pollination services. Pollination can enhance both the yield and quality of crops, while reductions in pollination services have been linked to reductions in agricultural production (Aizen et al., 2009; Novais et al., 2016; Pimentel, 2005).

It is difficult to link the results of these and other studies to the potential economic impacts of mosquito control on Massachusetts' agricultural industry. There were few samples of dead bees during the 2020 MDAR honey bee health post-spray monitoring, ranging from one to 20 dead bees per apiary (Skrym & Wijnja, 2019, 2020). For context, the estimated populations of hives during monitoring events in 2019 ranged from 40,000 to 65,000 individual bees, and each apiary has multiple hives. Between 0 and 100 dead bees per day is considered natural mortality for a colony (Tew, 1998). Exact counts are unavailable for 2019, a year in which spraying was more widespread, due to inconsistencies in the monitoring process (Skrym & Wijnja, 2019, 2020). Furthermore, even though there were no observable health issues, sublethal effects cannot be ruled out, as detectable concentrations were observed at sites within the aerial spray zones (Chmiel et al., 2020). The widespread presence of Varroa mites, along with many other viruses, chemicals, and parasites in collected samples reveals the complex landscape in which mosquito control takes place (Skrym & Wijnja, 2019, 2020; Whitehead & Adler, 2018). In the *2018 Massachusetts Hobbyist Health Survey Report,* many of the other detected compounds may not have been explicitly used for mosquito control (e.g., those falling into the categories of miticides or fungicides), but there is always the potential for synergistic (non-additive) interactions between chemicals that could exacerbate the impacts of pesticides used for mosquito control. In many cases, disentangling the direct effects of mosquito control from other potential threats to pollinators is extremely complicated. Migratory beekeeping is an additional factor to consider; according to conversations with ERG's pollinator consultant, many bees are brought into Massachusetts to pollinate specific crops only when the crops are in season, so not all honey bees that pollinate Massachusetts crops will be exposed to sprays if the sprays do not occur when the bees are in Massachusetts.

Studies from other locations also tell a complicated story. In Louisiana, a 2018 study found no significant differences in honey bee mortality, colony health, or detoxification enzyme activities between sites sprayed with a truck-based ultra-low-volume mosquito adulticide and sites without the spraying treatment. The authors suggest that proper application of these insecticides results in little or no exposure for domestic honey bees (Pokhrel et al., 2018b). ERG found no published evidence of mosquito control pesticides impacting honey bee populations in Massachusetts, but the lack of evidence does not mean that adverse effects have not occurred or will not occur in the future. A potential for harm exists, given that the active ingredients in some pesticides used for mosquito control by MCDs and the SRB are toxic to honey bees. Specifically, both Spinosad (a larvicide) and pyrethroids are categorized by the EPA as highly toxic to bees, meaning the dose of these products which results in death of 50 percent of a population (LD_{50}) is less than 2 µg active ingredient/bee. Given this potential and the significant benefits that honey bees deliver via pollination to the Massachusetts agriculture industry, surveillance of apiaries is important to ensure that pesticide applications are not adversely impacting pollinators.

2.4 Ecosystem Health Impacts of Mosquitoes and Mosquito Control

The Task Force requested information on the impact of mosquitoes and mosquito control on ecosystem health. In communications with DPH, staff members mentioned that there is public concern that reducing mosquito populations in Massachusetts using mosquito control measures will have negative impacts on other species, particularly bats that prey on mosquitoes. Therefore, ERG qualitatively addresses this issue in Section 2.4.1.

Another major concern in the Commonwealth related to the mosquito control program is the impact of chemical control on ecosystem health. Quantifying the impact of the mosquito control program on ecosystem health was not possible at the time given the extensive data needs (i.e., exposure values, fate and transport evaluations, dose-response analyses) and analytical resources needed to prepare a full ecological risk assessment. Therefore, Section 2.4.2 summarizes toxicity impacts on ecosystem health. Refer to Report 4: Chemical Composition and Toxicity of Pesticides Used in Ground and Aerial Spraying in Massachusetts for more detailed information on the toxicity of the pesticides used in the mosquito control program to ecological health.

2.4.1 Impact of Mosquitoes on Ecosystem Health

ERG conducted a literature search for studies on the diets of bat species native to New England. Several New England bat species are insectivores and prey on mosquitoes. The big brown bat and the little brown bat are the two most abundant species of bats in Massachusetts (Mass Audubon). In a recent study on New England bat diets, the researchers analyzed the diets of 195 big brown bats (*Eptesicus fuscus*) and found their diets to be 81 percent Coleoptera (beetles), one percent Diptera (which mainly consists of flies but also includes mosquitoes), four percent Lepidoptera (butterflies and moths), and 14 percent “other.” The diet of the little brown bat (*Myotis lucifugus*) was composed of 22 percent Coleoptera, 16 percent Diptera, three percent Lepidoptera, and 31 percent “other” (Moosman et al., 2012). While changes in climate aspects, such as monthly precipitation, changed the amounts of coleopterans and lepidopterans in the bats’ diets, there was no significant change in the proportion of dipterans consumed. When more species were available, the big brown bats adapted their diets to consume more lepidopterans and dipterans (Moosman et al., 2012). This study shows that the diets of insectivorous bats are flexible and may change based on the available insects. Additionally, insectivorous bats are not so reliant on a particular species or insect that they would be in danger if it were no longer available.

Another study focused on the diet of eastern small-footed bats (*Myotis leibii*). This bat’s diet consisted of 46.2 percent Lepidoptera and 18.6 percent Diptera. Within Diptera, only 0.4 percent was made up of Culicidae (the family name of mosquitoes) (Moosman et al., 2007). Another study of insectivorous bats in New England found that, of five insectivorous bats, Diptera never made up more than 18 percent of their diets, and Culicidae never made up more than one percent (Thomas et al., 2012). These results show that mosquitoes constitute a relatively small proportion of the diets of the bats most commonly found in Massachusetts. Thus, available evidence does not indicate that mosquito control has a major effect on bats via the impact on mosquito populations.

ERG conducted literature searches for fish diets in New England but could not find anything to support the idea that a large portion of aquatic fish diets were composed of mosquitoes. In a study from Texas, many terrestrial insects were found among the diets of largemouth bass, but none were identified as mosquitoes (Harrel, 1997). ERG also searched for striped bass diets and found only aquatic species among them (Harding & Mann, 2003; Walter & Austin, 2003). Report 6: Best Practices to Maximize Impact of Pesticide Use on Mosquito Populations and Minimize Non-target Impacts of Mosquito Pesticides further discusses the impact of mosquito control on aquatic ecosystems via pesticide application.

2.4.2 Impact of Mosquito Control on Ecosystem Health

Regarding the impact of mosquito control on ecosystem health, a full quantitative ecological risk assessment of the processes used to control mosquitoes in Massachusetts was not feasible. Therefore, see Report 4: Chemical Composition and Toxicity of Pesticides Used in Ground and Aerial Spraying in Massachusetts for a comprehensive review of the ecologic toxicity information on the active ingredients in pesticides. For completeness, this section summarizes that information.

Based on EPA's analyses, there is a range of acute ecotoxicity concerns across ecological categories and active ingredients in the pesticides of interest. In most instances, ecological toxicity is the risk driver for these pesticides. Table 2-13 summarizes the toxicity categorizations from EPA.

It is clear from Table 2-13 that pyrethroids are highly toxic to most categories of the ecological environment. According to EPA, their impact on aquatic systems is their risk driver. As a result, EPA is currently revising application protocols in an attempt to reduce exposure as much as possible to minimize the impact of these compounds on aquatic systems (USEPA, 2020d).

The majority of the compounds used as active ingredients have half-lives in the environment of fewer than five days. The one exception is the active ingredients that make up spinosad (spinosyn A and spinosyn D), which have half-lives ranging from 77 to 142 days. Additionally, all the active ingredients have biotransformation half-lives of fewer than five days in fish. It is difficult to gain an understanding of the persistence of *Bti* and *B. sphaericus* in the environment, given that they occur naturally and can grow under certain environmental conditions (USEPA, 1998). EPA data indicate that *Bti* is easily degraded by sunlight and has a half-life of approximately one to four days when it is on foliage (USEPA, 1998). However, *Bti* may persist in soil for several months (USEPA, 1998).

Beyond the acute toxicity classification EPA provides, additional studies and considerations are pertinent when considering the ecological toxicity of these compounds. One is the indirect impacts of compounds. For example, although *Bti* and *B. sphaericus* are not directly toxic to birds, they could indirectly affect avian species. This was demonstrated by Poulin, Lefebvre, and Paz (2010), who assessed the impact of *Bti*-treated sites on the diets of house martins. They found that house martin prey at *Bti*-treated sites was much smaller (flying ants at treated sites versus spiders and dragonflies at untreated sites) and the reproductive success of the birds was also lower at treated sites, with decreased clutch size and fledgling survival. Further, there is some evidence that it may be necessary to evaluate the toxicity of active ingredients for different life stages of non-target insects and aquatic invertebrates to obtain a full understanding of their toxicity profiles. Kästel et al. (2017) demonstrate this; they observed increased toxicity in first instar larvae of Chironomidae (midges) compared to fourth instar larvae.

Additionally, if environmental conditions result in the breakdown of chemicals, it would be useful for toxicity evaluations to also evaluate these breakdown products. A study from La Clair, Bantle, and Dumont (1998) demonstrates this. They found s-methoprene itself was not toxic to amphibians, but low-level exposure (1 µg/L) to several of s-methoprene's breakdown products results in deformities in juvenile amphibians.

A 2010 study was commissioned by MDAR to evaluate the impacts of aerial spraying for mosquito control on non-target species in the Hockomock Swamp, a wetland in southeastern Massachusetts. The results of the study suggested that small bodied arthropods were negatively impacted by the spray event; the impacts of the spray event on other species were confounded by other factors (Mello et al., 2010).

Table 2-13. Summary of Acute Toxicity Classifications for Active Ingredients Used by MCDs and the SRB in Mosquito Control

Active Ingredient	Freshwater Fish	Freshwater Invertebrates	Estuarine/Marine Fish	Estuarine/Marine Invertebrates	Birds	Non-target Insects
Bti	Practically nontoxic to slightly toxic	Moderately toxic	Practically nontoxic	Practically nontoxic	Practically nontoxic	Practically nontoxic
Bs[a]	Practically nontoxic	Practically nontoxic	Practically nontoxic	Practically nontoxic	Practically nontoxic	Practically nontoxic
Spinosad	Moderately toxic	Slightly toxic	Moderately toxic	Highly toxic	Low toxicity with acute exposure, more sensitive with chronic exposure[b]	Highly toxic
Methoprene	Moderately to highly toxic[b]	Highly toxic	Data not presented	Very highly toxic	Practically nontoxic	Data not presented
Mineral oil	Practically nontoxic	Highly toxic	Not toxic	Moderately toxic	Practically nontoxic	Practically nontoxic
Pyrethroids[c]	Very highly toxic	Very highly toxic	Very highly toxic	Very highly toxic	Generally not expected[b]	Highly toxic

EPA's classification scheme for acute toxicity dictates the categorization of the compounds (USEPA, 2018b).

Avian acute oral LD_{50}s (mg/kg-body weight: very highly toxic: <10; highly toxic: 10–50; moderately toxic: 51–500; slightly toxic: 501–2,000; practically nontoxic: >2,000.

Avian dietary LD_{50}s (mg/kg-diet): very highly toxic: <50; highly toxic: 50–500; moderately toxic: 501–1,000; slightly toxic: 1,000–5,000; practically nontoxic: >5,000

Aquatic fish lethal concentration 50 (mg/L): very highly toxic: <0.1; highly toxic: 0.1–1; moderately toxic: >1–10; slightly toxic: >10–100; practically nontoxic: >2,000

Aquatic invertebrates.

Non-target insects lethal concentration 50 acute concentration (µg/bee): highly toxic: <2; moderately toxic: 2–11; practically nontoxic: >11

[a] Given the similar biochemical profile to AM614's, EPA assumed AM614 is likely also nontoxic in the environment.

[b] EPA's rationale documentation did not classify the impacts following the standard categorization. The range exists due to different LD_{50} values for different fish species (USEPA, 2019).

[c] The categorizations in this table are based on the pyrethroid category, not individual pyrethroid compounds. This is because, in the most recent evaluation of data for registration of 19 pyrethroids, EPA focused on nine specific compounds (bifenthrin, cyfluthrins, cyhalothrins, cypermethrins, deltamethrin, esfenvalerate, fenpropathrin, permethrin, and the pyrethrins) and provide rationale that all 19 pyrethroids did not need to go through full risk evaluations.

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Report 9: Climate Change Impacts to Mosquito Populations and Mosquito-Borne Diseases

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1. EXECUTIVE SUMMARY

As mosquito life cycles are tied to the water-cycle and seasonal temperature change, mosquito-borne diseases are intrinsically impacted by changes in weather and climate (Ogden & Public Health Risk Science Division, 2017). Researchers have evaluated the impact of changing climate, including precipitation, temperature, on mosquito prevalence and arbovirus risk. Climate-arborvirus modeling focused on changes in temperature is most advanced and clearly attributes temperature change to changes in mosquito population and arborvirus occurrence. Research on precipitation, shows complex nonlinear relationships between mosquito species and precipitation due to the influence of water infrastructure, management practices, and other climate factors. Other climate-related factors that may affect mosquito populations and arbovirus risk and require additional study include changes in bird migration patterns and sea level rise.

The ERG team conducted a literature review of best available science on climate-arborvirus modeling to identify these key climatic factors attributed to changes in arbovirus/mosquito habitat. Our review of the latest modeling in Massachusetts region identified a growing risk of West Nile Virus (WNV) in the northeast over time as well as increased risk of diseases from *Aedes albopictus* and *Aedes aegypti* mosquitoes. The team could not identify any studies attributing change in eastern equine encephalitis (EEE) risk to climate change. These findings point to the importance of the Commonwealth's ongoing investment in: a) surveillance to detect emerging diseases; b) on-the-ground management that is responsive to the demands of an intensifying water cycle (e.g., ensuring treatments do not wash away in storms and responding to flooded culverts); and c) public outreach and education to ensure the public is aware of the best available strategies to keep safe as mosquitoes species and their biting patterns shift.

2. REPORT OVERVIEW

This report responds to the following requested area of research from the scope outlined by the Task Force: "Address best available science on how climate change is anticipated to impact mosquito populations and mosquito-borne diseases into the future."

To address this scope, ERG conducted a literature review of approximately 45 peer-reviewed journal articles and authoritative government publications on climate change and mosquito-borne disease and interviewed four experts on their concerns regarding climate change and emerging arborvirus and strengths/weaknesses of arborvirus-climate models. Through this review of best available science, our team identified climatic variables linked to changes in arbovirus/mosquito habitat and presented model outputs attributing climate change factors to changes in mosquito populations and arborvirus. We also identified some of the challenges in climate-arborvirus modeling, identifying specific climate factors in need of further study. This report focuses on arbovirus risk related to EEE and WNV as well as broader discussion of emerging tropical viruses from *Aedes aegypti* and *Aedes albopictus* mosquitoes given projections of their expanding range.

Most climate models reviewed presented results of one or more future climate change scenarios. For example, the models considered what temperature are projected to be in 2100 with major cuts to global greenhouse gas emissions versus limited emissions reductions. As noted below, our review focused on the latter (known as "Representative Concentration Pathway 8.5" in the language used by the Intergovernmental Panel on Climate Change [IPCC] language or "high emissions scenario" for short)—this is the scenario adopted by Massachusetts Executive Office of Energy and Environmental Affairs for its upcoming state Climate Vulnerability Assessment (IPCC, 2014).

3. CLIMATE FACTORS THAT AFFECT MOSQUITO POPULATIONS IN MASSACHUSETTS

Given that the mosquito life cycles are tied to the water-cycle and seasonal temperature change, mosquito-borne diseases are intrinsically sensitive to changes in weather and climate (Ogden & Public Health Risk Science Division, 2017). Geographic and seasonal patterns of mosquitoes and mosquito-borne disease may be impacted by both direct and indirect weather and climate factors. Direct factors include high and low temperature impacts on mosquito mortality; temperature impact on the duration of the incubation period for pathogens in mosquito vectors; and rainfall pattern impacts on available larval habitat. Indirect factors include: climate impact on habitat available to support both specific mosquito species and the animals that provide them blood meals (Ogden & Public Health Risk Science Division, 2017).[33]

This section reviews how Massachusetts' climate is changing, drawing connections to how these changes may impact mosquito populations.

3.1 <u>Warmer winters, later frosts</u>

Temperature changes, particularly warmer winters and later frosts, are known to impact mosquito populations. This is because hard frosts, typically defined as temperatures falling below 28ºF, can kill adult mosquitoes. Studies that examine links between climate change and mosquito-borne disease have therefore focused on how increases in late and mild winters might affect mosquito populations and disease (Massachusetts DPH, 2021). Similarly, laboratory, modeling, and surveillance efforts have also focused on the possibility of mosquitoes suited to tropical environments becoming established in Massachusetts should winters continue to become milder. This is discussed further in Section 8.

The Northeast Climate Adaptation Science Center at the University of Massachusetts, Amherst has reported that average, maximum, and minimum temperatures in Massachusetts are likely to increase significantly over the century, with winter temperatures expected to increase fastest. By mid-century (2040-2069), the average winter temperature of 26.6°F[34] is projected to increase by 2.9 to 7.4°F (up to a 28 percent increase). By end of century (2080-2099), the average winter temperature is projected to increase by 4.1 to 10.6°F (up to a 40 percent increase), over the 26.6°F average baseline (MA Emergency Management & EEA, 2018; MassEEA & DER, 2018).

[33] Ogden & Public Health Risk Science Division, 2017 describes how vector-borne diseases generally are affected by direct and indirect climate and weather factors.

[34] Based on the 1971-2000 observed temperature average.

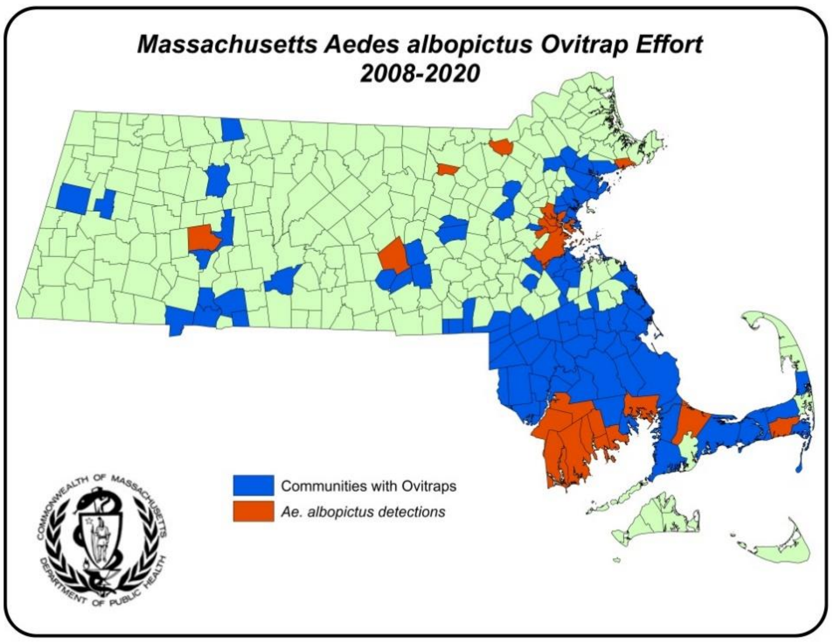
The climate projections (using a high emission scenario) also show that the frost-free season is getting longer across New England by at least 19 days by the year 2055, and up to one to two months by the end of the century. These projections are coupled with an observed trend across New England of a later first frost in the fall (UMass Amherst, 2017; USGCRP, 2018)

3.2 Warmer temperatures year-round

Temperature is an important component of habitat suitability and disease transmission dynamics. Studies on *Culex* mosquito species show that temperature increases accelerate mosquito biological processes and transmission, by speeding up biting rates and viral replication rates within the mosquito (allowing blood-fed mosquito to pass on the virus faster). This suggests an increased risk of human infection in areas where *Culex*-diseases like West Nile Virus are present (Beard, 2016; Wimberly et al., 2014). Higher temperatures also decrease the time needed for a mosquito to complete its life cycle (i.e., go from larva to adult). For multivoltine species which go through more than one generation per season, this could mean higher peak populations, or extended seasons for those species (Sutherst, 2004). However, it should also be noted that additional studies investigate the interplay of temperatures and precipitation patterns, finding that extreme high temperatures and decreased precipitation can lead to a decline in mosquito populations (Morin & Comrie, 2013).

Aedes albopictus (Asian tiger mosquito) and *Ae. aegypti*, which can transmit tropical diseases such as Zika and Dengue fever are generally found in humid tropical or sub-tropical climates, though have started to inhabit temperate zones in urban areas. *Ae. albopictus* has become established in temperate regions by undergoing diapause (a period of suspended development) to survive cold winters (Ryan et al., 2019). For example, Massachusetts Department of Health (DPH) and partners use ovitraps to monitor for the presence of *Aedes albopictus* across the Commonwealth and have identified small populations focused in the southeast (see Figure 3-1). Transient populations have been identified as far west as Worcester County (MassDPH, 2020). Under a warmer climate, the Commonwealth may be more hospitable to this invasive mosquito species in the future (Massachusetts DPH, 2021).

Figure 3-1. *Aedes albopictus* Monitoring Detection (2008-2020) source: MassDPH, 2020.



Climate projections for Massachusetts derived from research out of the Northeast Climate Adaptation Science Center indicate that by midcentury (2040-2069), average annual temperature will increase from 47.6°F (the baseline average temperature from 1971-2000) to between 50.4 to 53.8°F. Average annual temperature will increase to 51.4 to 58.4°F by the end of this century (2080-2099) (MA Emergency Management & EEA, 2018; MassEEA & DER, 2018).

3.3 Intensifying water cycle

Studies and observations indicate that annual changes in mosquito populations are impacted by year-to-year changes in precipitation rates and frequency as rain and snow melt can create aquatic breeding sites for mosquitoes. However, research to date shows complex nonlinear relationships between mosquito species and precipitation due to the influence of water infrastructure, management practices, and other climate factors. For example, in urban areas, extreme precipitation events may cause *Culex* larvae to be washed out of underground breeding areas (leading to a drop in population). In rural areas or areas experiencing dry conditions, precipitation events can provide the moisture needed for *Culex* species to breed (Beard, 2016; Wimberly et al., 2014). Mosquito outbreaks can occur during droughts when species such as *Cx. pipiens* and birds are attracted to concentrated organic matter in shrinking water bodies (Paz, 2019), increasing levels of WNV.

Total annual precipitation is projected to increase over the coming decades. Total annual precipitation in Massachusetts in expected to increase 1 to 6 inches by mid-century (2040-2069) and 1.2 to 7.3 inches by the end of this century (2080-2099) above the 1971-2001 baseline of 47 inches annually (MA Emergency Management & EEA, 2018; MassEEA & DER, 2018). Increases are expected to be focused on the winter and spring season, with a decrease in precipitation during summer and fall. The number of days the state receives more than 1 inch of rain is projected to increase as are the number of days of continuous drought (MassEEA & DER, 2018). Such an increase in extremes creates mosquito management challenges. For example, the increased number of rain storms is likely to increase the need to postpone or cancel truck-based spraying—with enough frequency, such interruptions could impact mosquito populations (MDAR & Berry, 2021).

3.4 Additional Climate Factors

The literature that ERG reviewed overwhelmingly pointed to temperature as the key climate-related factor affecting mosquito populations. The literature also points to precipitation as a factor affecting mosquito populations, however, research shows mosquito populations and precipitation as exhibiting complex, sometimes nonlinear relationships. Accordingly, these factors were reviewed in greater detail (see Sections 3.1, 3.2, and 3.3). The literature has far less information on other climate-related factors that may affect mosquito populations, and these other climate-related factors are briefly discussed here:

Sea level rise. The link between sea level rise and mosquitoes has not been extensively studied, but may be an important area of research in the future. As seas rise and dunes or other barriers are toppled by storms, some of Massachusetts' currently fresh, coastal water bodies, may become brackish. Anecdotally, the Cape Cod Mosquito Control Project reported a mosquito outbreak in the Wellfleet this summer (July 2021) after a breached dune caused saltwater inundation in Duck Harbor which created a breeding area (Gavin, 2021). In other parts of the world, increases in brackish habitat from storms has led to an increase in habitat for salinity-tolerant vector mosquitoes, or led freshwater mosquitoes to adapt to tolerate a brackish environment (Ramasamy & Surendran, 2011). While the ERG team did not find studies on this topic specifically in Massachusetts, it is worthy of further research.

Bird migration. Through their annual migration, birds allow for long-range movement of viruses, such as West Nile and EEE. While bird migrations are driven by climate factors, the impacts of climate-driven changes in migration on disease transmission to mosquitoes and humans is a current research gap (Beard, 2016). ERG's literature review through 2021 did not locate research attributing changes in arborvirus occurrence to changing climate-driven bird migration patterns.

4. Challenges in Linking Past Change in Arbovirus to Climate Change and Predicting Future Changes

While there are many models and studies evaluating links between climate change, mosquito populations, and arborvirus, there are significant hurdles in decoupling risk of arborvirus due to climate change from other factors. Some of the challenges of attributing arbovirus risk to climate change include:

- **Limited temporal coverage in vector-borne disease incidence data**. Available data on pathogens and human disease incidence rarely cover enough time to represent large climatic shifts. (Metcalf et al., 2017). For example, West Nile Virus surveillance began in Massachusetts in 1999, with a surveillance and response plan developed in 2001. The state's EEE surveillance activities started in the 1950s (Massachusetts DPH, 2021).
- **Challenge of addressing confounding factors in climate-arborvirus modeling.** Mosquito control practices, land use planning, extent of public health education, and restrictions placed on outdoor activity can all impact mosquito populations and arborvirus risk to humans. It is challenging to integrate all of these factors into modeling.
- **Vectors and pathogens may evolve, creating uncertainty.** Recent research by Couper et al., 2020 investigates the rate of mosquito adaptation to rising temperatures (Couper et al., 2020). Much of the current climate-arborvirus modeling assumes that thermal niches for mosquito species will remain the same over time. If mosquito and vector thermal niches adapt under a changing climate, this additional factor much be included in modeling.
- **Limitations of climate projections**. The resolution and uncertainty of downscaled global climate models varies by climate variable. In the northeast, like most of the U.S., precipitation projections have greater uncertainty compared to other climate variables. Uncertainty in these climate projections propagates through disease-climate models.

5. BEST PRACTICES FOR ATTRIBUTING ARBORVIRUS RISK TO CLIMATE CHANGE

Several steps can increase confidence in the models that explore the interplay between climate and mosquito population/arbovirus risk, regardless of the specific methods used to study climate change and arborvirus. These steps may be helpful to keep in mind while reviewing new research in this area of research. They are as follows:

- Build effects of additional factors beyond climate variability into models (e.g., human behavior and demographics).
- Explore uncertainty in the models and a range of future climate projections.
- Validate models with data independent of those used to calibrate models and continue to validate models over time with observed data on climate change (Ogden & Public Health Risk Science Division, 2017) (Metcalf et al., 2017).
- Ensure that research and models establish causal mechanisms between climate variable and disease cases (not simply correlations and statistical associations) (Metcalf et al., 2017).

6. IMPACT OF CLIMATE CHANGE ON EEE

The ERG team could not identify any studies attributing change in EEE risk to climate change. The lack of studies on this topic was verified by a review paper on EEE which identified over 700 papers published on EEE between 1933 and 2019 and categorized them into topic areas (e.g., epidemiology, economics). The review paper specifically notes that no predictive models on climate change impacts on EEE were identified during the literature search (Corrin et al., 2021).

ERG's review of two dozen papers on EEE range and vector-borne disease response to climate change found that there has been very limited exploration of the EEE-climate change relationship. That said, we identified three papers and government reports that suggest that EEE cases may increase with climate change (Bureau of Environmental Health, 2014; Corrin et al., 2021). For example, in their paper, Armstrong and Andreadis raise concerns about this connection, noting:

> "…we should not lose sight of already-established vector-borne diseases that occur in temperate zones and may more readily exploit regional climate changes. We are now seeing recurrent EEE cases each year and their expansion into northern New England for the first time, a phenomenon that requires further scrutiny." (Armstrong & Andreadis, 2013)

Similarly, this potential link between increased EEE incidence and climate change is raised by a group of doctors and researchers in a letter in the New England Journal of Medicine calling for attention to EEE, noting that "effects of climate and weather, such as changes in heat and rainfall and their impact on variables associated with viruses, vectors, and vertebrates, are cause for additional concern, since they may affect the life cycles and geographic distribution of arthropod vectors and viral transmission patterns" (Morens et al., 2019). These papers are not based on a quantitative analysis establishing a link between EEE and climate change and point to an area for future research.

7. IMPACT OF CLIMATE CHANGE ON WEST NILE VIRUS

ERG's literature review of over two dozen papers on West Nile Virus identified more research to date attributing projected change in WNV incidence to climate change. The team identified research in the following topic areas:

- Thermal biology of WNV and temperature at which WNV mosquito transmission peaks (which has implications for a changing climate) (Mordecai, 2019; Shocket et al., 2020).
- Investigations of the potential for mosquitoes that transmit WNV (as well as dengue, chikungunya, Zika, and malaria) to adapt to climate change, specifically rising temperatures (Couper et al., 2020).
- Models projecting future WNV incidence based on climate change projections (Belova et al., 2017; Brown et al., 2015; Harrigan, 2014; Morin & Comrie, 2013; USGCRP, 2018; Wimberly et al., 2014)

In addition, the team identified several papers summarizing observed correlations between climate impacts and epidemiology of WNV (Paz, 2019; Wimberly et al., 2014).

Many of these papers on WNV and climate change look at the issue from a global or continental scale, making it challenging to narrow results applicable to Massachusetts or the Northeastern U.S. As such, below, we have focused on research with results that can be interpreted at the Northeast regional-scale.

The U.S. Fourth National Climate Assessment reports that there will be an additional 490 cases of neuroinvasive WNV cases per year across the Northeast by 2090 under the higher emissions scenario (USGCRP, 2018). This finding is based on a methodology developed by Belova et. al. in their 2017 paper which generated county-level estimates of the annual number of West Nile neuroinvasive disease (WNND) cases based on historical incidence, population size, and annual average temperature (together known as a Health Impact Function). The function was adjusted to project the impact of future temperature change on WNND (Belova et al., 2017). Shortcomings of the approach include lack of accounting for precipitation change and potential changes in human behavior (government mosquito control and personal protection measures) (EPA, 2018).

A 2014 study modeled WNV response to a changing climate (focused on temperature and precipitation change) across North America, finding that WNV risk will increase in parts of Massachusetts and decline in other parts of the state by 2050 (Harrigan, 2014). As shown in Figure 7-1 results are presented across all of North America, making it challenging to home in on specific results for Massachusetts. However, the mix of red (for increasing WNV risk) and blue (for declining risk) are visible with Massachusetts on the map. Researchers produced these findings by using data on WNV infections in vectors and hosts (from 2003– 2011) and species distribution models to model WNV incidence under current climate conditions. Suitable climate for WNV was modeled for future climate scenarios.

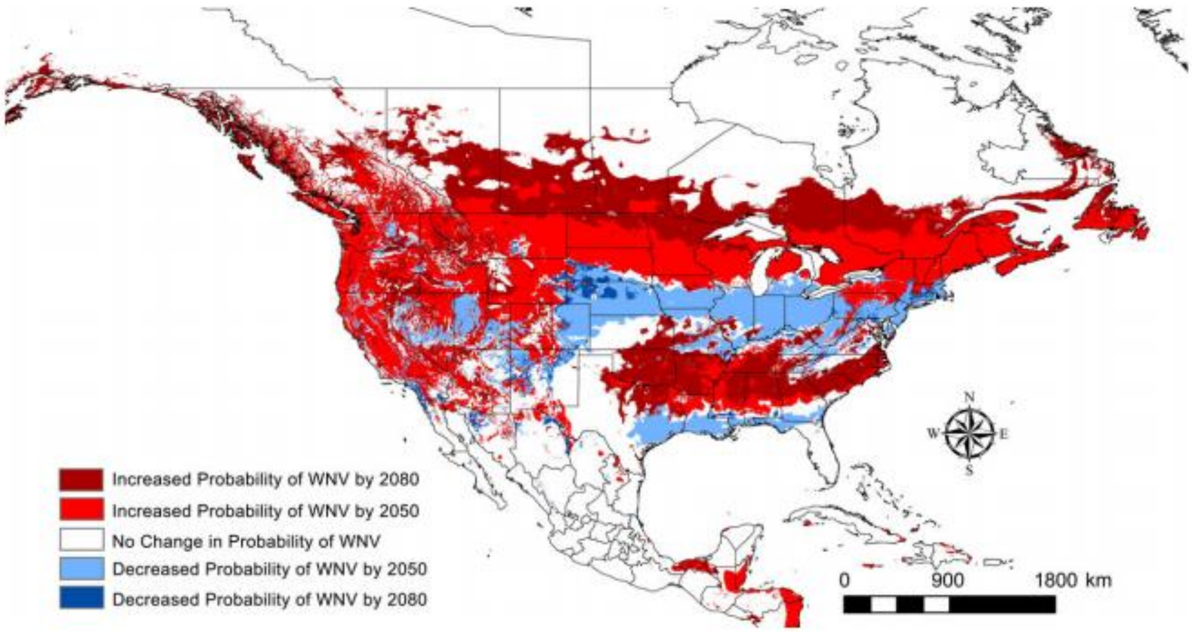


Figure 7-1. Probability of presence of WNV in vectors projected across North America, for the year 2050 and 2080 (Harrigan, 2014).

Given that neither Belova or Harrigan's studies focused on the northeastern U.S. and this field is rapidly evolving (e.g., improved down-scaled climate models emerging), there is a need for additional research to better understand WNV risk in Massachusetts under a changing climate.

8. IMPACT OF CLIMATE CHANGE ON OTHER MOSQUITO-BORNE DISEASES

Public health officials and researchers alike are concerned that temperate climates, such as New England will become increasingly hospitable to tropical and subtropical mosquito species, specifically *Aedes albopictus* (already established in small numbers in Massachusetts) and *Aedes aegypti* (identified in New York state) which are involved in transmission of dengue, chikungunya, Zika, and yellow fever. Ogden's 2017 paper pointed out that while we can predict that climate change will increase the probability of tropical/subtropical vector-borne disease establishing in temperate countries, it is challenging to specifically attribute a change in risk to climate change. The paper states, "A range of climate-independent plausible explanations include increased travel and globalization of trade increasing introduction probabilities, adaptation of vectors and virus to temperate climates, and the occurrence of unexpected suitable niches for exotic vectors" (Ogden & Public Health Risk Science Division, 2017).

Over the past few years, researchers have focused on this topic of modeling changes in distribution of tropical arborvirus into currently temperate zones given climate change. ERG reviewed eight recent papers on this topic. Findings are challenging to down-scale specifically to Massachusetts as models are often run on a global or continental scale. Below we have shared study results where findings can be identified for North America and New England.

Ryan et. al. 2020 applied an "empirically parameterized model of viral transmission by the vectors *Aedes aegypti* and *Aedes albopictus*, as a function of temperature" to predict range shift and transmission risks under figure climate conditions. The model parameters link the basic reproduction number for *Aedes*-borne viruses based on physiological response curves for lifespan, transmission probability and other traits, determined through experiments (Ryan et al., 2019). The model outputs identified increase in population at risk due to temperature suitability for *Aedes* aegypti and *Aedes* albopictus virus transmission. Results for North America (for a high emissions scenario) are displayed in Figure 8-1.

	Current Population at Risk	Additional People at Risk in 2050	Additional People at Risk in 2080
***Aedes aegypti* virus transmission**	281.9 million	55.0 million	62.8 million
***Aedes albopictus* virus transmission**	311.6 million	32.1 million	34.7 million

Figure 8-1. Changing population at risk due to temperature suitability for *Aedes aegypti* and *Aedes albopictus* virus transmission (Ryan et al., 2019).

Figure 8-2, extracted from Ryan et al. (2021) visualizes the geographic distribution of risk across North America (and the globe), showing the northward expansion of temperature suitability in North America for both species over time. The figure indicates that the New England region will have at least one to two months of increased temperature suitability for both species in 2050. Downscaled results, specific to Massachusetts, will be helpful in the future.

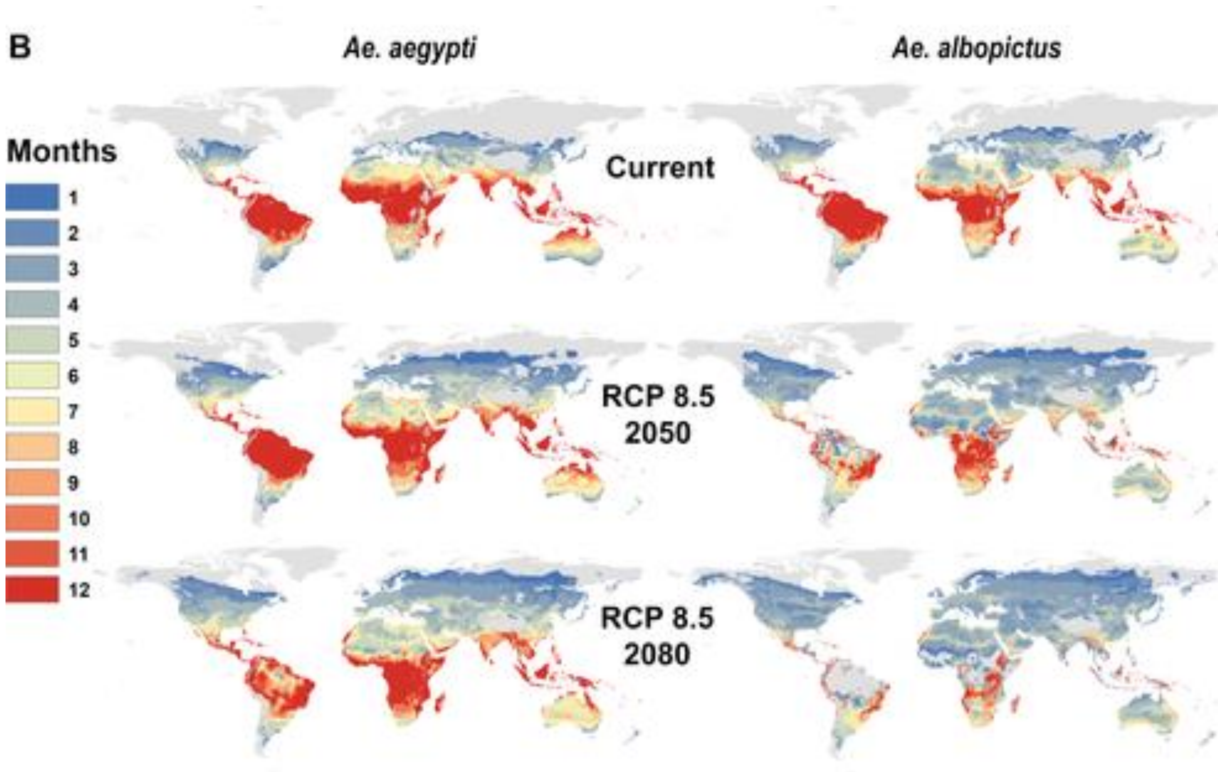


Figure 8-2. Mapping future temperature suitability for transmission scenarios for *Aedes aegypti* and *Ae. albopictus*. (Ryan et al., 2019).

Another recent paper approached this topic by developing ecological niche models for *Aedes aegypti* and *Ae. albopictus* across the U.S. and Canada and applied current and simulated climate and land use data. This work found that under a high emissions scenario, the suitable niche for both mosquito species will gradually expand (throughout the 2100 study period) across the northern and northeastern U.S. and southern Canada and increase the population at risk to *Aedes*-borne diseases (Khan et al., 2020). Results were not available specifically for Massachusetts. Additional work is needed to down-scale these studies to Massachusetts and integrate local land use information and other local drivers.

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Errata and Addenda for

Mosquito Control Task Force Report (September 2021)

Change	Location(s)
"*An Act to Mitigate Arbovirus in the Commonwealth*" should cite: An Act to Mitigate Arbovirus in the Commonwealth, § Chapter 120 (2020). https://malegislature.gov/Laws/SessionLaws/Acts/2020/Chapter120	Report 3: 3.1.2, page 91
MCDs reporting use of CocoBear oil should read "Norfolk, Northeast"	Report 4: Table 4-7: CocoBear oil row (pg. 128)
Change "not likely to be carcinogenic" to "possibly carcinogenic to humans"	Report 4: Table 5-2: PBO data row. (pg. 134)
Text in right-most arrow should read "Public education re: personal protection"	Report 5: Figure 3-1. IPM activities and their effect on mosquito life stages. (pg. 183)
Text in right-most arrow should read "Public education re: personal protection"	Report 5: Figure 4-1. Education and public engagement and their effect on mosquito life stages. (pg. 194)
Currently, [t]here are no testing standards to ensure comparability to testing carried out by DPH and DPH does not utilize test results other than those produced by its own laboratory.	Report 6: Table 3-1. Comparison of Best Practices to Maximize Impact of Pesticide Use on Mosquito Populations to Current Practices in Massachusetts: Current Surveillance Practices in Massachusetts (pg. 238)
For aerial spraying, Massachusetts regulations prohibit spraying directly over surface water supplies. ~~All MCDs use SRB mapping to inform spray routes and avoid protected areas.~~	Report 6: 4.2.1.4 Drinking Water (pg. 248)

Summary of

Mosquito Control for the 21st Century Task Force Comments

Comments have been lightly edited for spelling, grammar, clarity. Comments are organized by the most relevant section of the report, with overarching or general comments first. Comments are listed in the order they were received.

Includes comments received from task force members by September 17, 2021.

Table of Contents

General Comments:

Russ Hopping

Overall, the report could do a better job at distinguishing between nuisance control versus control for human health.

Heidi Ricci

[footnote 1: Note: The report abbreviates the task force as MCTF, but the full title is important, as the legislature specifically formed the task force to bring this antiquated program into the Twenty-First Century. Therefore I use the acronym MC21CTF.]

The report includes a compilation of available information about mosquito control programs and practices in Massachusetts, and identifies significant gaps in that need to be addressed. These include gaps in record keeping and analysis, discrepancies between best available industry standards and science vs. actual practice, and lack of information about the impacts of mosquito control practices on human health and the environment. It confirms that significant reforms are needed to bring the program into the 21st Century. It also confirms that the program is fragmented and inconsistent. The focus for reform should be on protecting human health and the environment, based on science and with systems established to monitor efficacy and cost-effectiveness. The rights individuals and communities to avoid undesired exposures to toxic chemicals must also be respected.

The report concluded that there is no quantifiable data available on the effectiveness of mosquito control as currently practiced (p.184), as well as significant gaps in science and an inability of the consultant to conduct a quantifiable analysis of the impacts of mosquito control pesticides on human health (p.138) or on the environment and ecological health (p.301). Despite this, Section 8 of the report attempts to create a model of potential mosquito-borne disease impacts that would be associated with curtailing or discontinuing current practices. This model lacks scientific rigor and is based on fundamentally flawed assumptions. It should not be given any weight in considering recommendations for the future of the program.

Title and Introduction: The report is entitled “Mosquito Control Task Force Report,” but it was not produced by the task force. It would more correctly be entitled something like “Consultant Report to the MC21CTF.” The introductory paragraphs at the beginning of the report do not accurately characterize the process by which it was produced. This introduction correctly states that the Act calls for the task for to commission an independent expert study. However, the task force actually had a limited role and the production of the report was coordinated between the consultant and the agencies directly. The MC21CTF provided input to EEA on the scope for the Request for Proposals that was issued through the State’s procurement system, and reviewed the sole bid that was received in relation to the bid criteria. The task force had no opportunity to review and provide feedback on report drafts, although the state agencies did. It is unclear whether this internal agency review also included opportunities for the mosquito districts to review and provide comments on the draft report. In any case, the report is not a product of the MC21CTF, and the task force did not “commission” the study as stated in the introduction.

Ecotoxicology and Human Health Expertise and Assessment: The MC21CTF voted to approve the bid, on the condition that EEA would negotiate with ERG to ensure that the necessary expertise on ecotoxicology and human health effects of pesticides would be included on the consultant team. When the report was presented to the task force on 9/2/21, the task force was informed that those additions to the team had not occurred as originally planned, but that ERG had attempted to cover these subjects through consultation with other, unidentified experts. The lack of this expertise on the consultant team is, unfortunately, reflected in those portions of the report.

Ecotoxicology and Human Health Expertise and Assessment: The MC21CTF voted to approve the bid, on the condition that EEA would negotiate with ERG to ensure that the necessary expertise on ecotoxicology and human health effects of pesticides would be included on the consultant team. When the report was presented to the task force on 9/2/21, the task force was informed that those additions to the team had not occurred as originally planned, but that ERG had attempted to cover these subjects through consultation with other, unidentified experts. The lack of this expertise on the consultant team is, unfortunately, reflected in those portions of the report.

The RFP included:

• *Research, analyze, and report on the quantifiable impact of chemical-based mosquito control aerial and ground-based spraying in Massachusetts.* o *When determining quantifiable impacts, report must account for, but is not limited to: Public health; Human health; Medical; Agricultural land including organic farms, Farm animals; Apiaries; Commerce; Recreation; Tourism; Drinking water sources including groundwater and surface water, and with consideration of established exclusion buffer zones around active public water system reservoirs and/or inlets during aerial spraying events; Ecological health including aquatic ecosystems; Native wildlife species including, but not limited to, birds, invertebrates (e.g. bees, odonates, lepidoptera, beetles, sensitive aquatic invertebrates), fish, and other pollinators and mosquito predators.* [*footnote 2: Request for Proposals: Mosquito Control Task Force Study. The Executive Office of Energy and Environmental Affairs seeks applicants to conduct a study that evaluate the Massachusetts mosquito control process. BD-21-1042-ENV-ENV01-58054. ENV 21 POL 03*]

The report, in Sections 4, acknowledged that there is literature indicating potential human health impacts of mosquito control pesticides that are still under study by the EPA and others. Section 4 also summaries toxicity categorization of mosquito control pesticides, Sections 4 and 8 note that the pyrethroid pesticides in particular are highly toxic to a wide range of organisms. These include pollinators like bees (including hundreds of species of native bees), beetles, flies, and moths, as well as fish and aquatic invertebrates. They are also highly toxic to other beneficial organisms like parasitic wasps and tachnid flies that keep agricultural and forestry pests in check. But there have been few studies on the ecological effects of these pesticides, so little is understood about the impacts, particularly of repeated exposures from routine roadside mosquito spraying operations alone or in combination with other pesticide applications that occur. Table 5-8 in Section 4 indicates no wildlife endocrine or ecotoxicological concerns reported by government agencies for most of the pesticides used in mosquito control. Absence of data does not mean absence of impact. This should be noted in the corrections/errata section of comments on the report.

Government agencies are not the only source of scientific information on these aspects of the scoped review. There is a good deal of evidence of impacts and the need for further studies in several of the references cited in the report, but that information is not well summarized in the report. Further commentary on this is provided in the Comments section below.

There has been a persistent failure by Massachusetts to study the ecological and human health impacts of mosquito control practices, despite many requests over the past several decades by many organizations and individuals.

Comments on Report 1: Arbovirus History in MA (pg. 2–28)

Sam Telford

Page 15, Table 3-1: P=0.00 chi square 45.04 yates correction df 1 between 2004-2011 and 2012-2020

Page 19, Table 3-3: chi square with yates correction 360.3, P=0.00 between sampling periods

Comments on Report 2: Existing Mosquito Control Policy Structure and its Effectiveness, Challenges Experienced (pg. 29–81)

Helen Poynton

Page 59, regarding statement "Constituents often raise concerns about pesticide use in their communities, and some think an MCD's sole activity is pesticide spraying. Respondents expressed frustration about this perception." - The truth is that MCDs spend more of their budgets on larval and adult mosquito control than any other budget item (Figure 3-3, with some MCDs spending more than half their budget on control activities)– so it's not surprising that it is the case.

Russ Hopping

This report clearly identifies the current decision-making process for controlling mosquitoes in Massachusetts is confusing and is not evidenced-based as little data has been presented. Both decision-making and the transparency of this process need to be improved. Furthermore, while interesting, interviews are subjective, and the Commonwealth should seek a more objective process for evaluating the effectiveness of the current decision-making process and use this as a means of monitoring and communicating actual outcomes of mosquito control. I feel strongly the report should highlight this important point.

OMWM (Report 2 and 5). The Report highlights OMWM as an effective strategy to reduce mosquito habitat. While this may be true, I think it is important to point out that OMWM can be highly deleterious to salt marsh. If the specific OMWN design retains standing water within the marsh it can artificially raise and maintain marsh ground water. If the elevation of ground water is at or near the surface it facilitates marsh subsidence by creating water-logged conditions that stress marsh vegetation and unless corrected can result in vegetation die of and mash collapse as plants die and biomass is lost. While the report correctly identifies this practice is seldom used in Massachusetts anymore, it is a practice that should not be used in salt marsh unless carefully designed to avoid raising ground water. Nature-based efforts to restore the salt marsh hydrology, such as ditch remediation should be invested in instead of OMWM. Having both training and funding from the state and federal level that allow the MCDs to assist in these nature-based restoration efforts would go a long way in creating resilient salt marsh with less mosquito breeding habitat in the Commonwealth.

Comments on Report 3: Opt-outs and Exclusions (pg. 82-106)

Russ Hopping

The opt-out option is progressive and allows residents a choice in being exposed to pesticides and managing for pesticide-free habitats.

Heidi Ricci

Opt Outs

Municipalities and landowners should be able to opt-out from pesticide treatments they do not want, while having access to services such as surveillance, education, and ecologically based source control.

The current system for landowner opt outs is cumbersome and should be streamlined, including an easy electronic method for annual renewal.

Opt-outs for organic farms should not be limited to certified organic farms. Mass Audubon's Drumlin Farm employs sustainable farming practices that exceed organic standards, but the farm has not undergone the certification process. Income from crops at Drumlin Farm exceed $450,000 annually and sales to customers including farmers markets, restaurants, and our Community Supported Agriculture members would be jeopardized if the farm were forced to endure pesticide spraying.

Comments on Report 4: Chemical Composition and Toxicity of Pesticides Used in Ground and Aerial Spraying in MA (pg. 107-174)

Helen Poynton

<u>Page 118, Table 4-2.</u> - Arial spraying of 14,104 gallons on 3,009,831 acres results in 1.68 g d-Pehnothrin/ acre (0.74 lbs d-phenthrin/gal = 335.7g). This would result in 41.5 ng/cm2. Comparing this to the LC50 for *Hyalella azteca* (9.4 ng/L) there is potential for toxicity to aquatic organisms to occur.

<u>Page 126, Table 5-9.</u> - Is it possible to get the area or volumes of the water bodies where the insecticide was sprayed?

<u>Page 146, Table 5-9, suggestion for correction</u>: Why was Hyalella azteca not included in this table with much lower LC50 than the value reported for crustaceans? 96-h LC50 for d-phenothrin is 0.0093 ppb (ug/L) or 9.3 ng/L, according to EPA's OPP Pesticide Ecotoxicity Database: https://ecotox.ipmcenters.org/details.cfm?recordID=33378 *[ERG response: ERG has reviewed this source which is a secondary source utilizing EPA's ECOTOX database. ERG did not find this value in the ECOTOX database itself.]*

<u>Page 156, Resistance screening -</u> Half of the MCDs report doing some level of resistance screening as part of their surveillance activities. Can the task force get more details about how the resistance screening is done and what the results are?

Page 170-173, Tables B-3 through B-6 - many of the values for aerial spraying (0.0025 a.i./A) are less than the average amount for d-phenothrin in MA: 0.0037 lb a.i./acres (based on amounts in Table 4-1 and 4-2). Therefore, the amounts sprayed in MA are likely to exceed RQ for fish and invertebrates.

Priscilla Matton

One correction is found on page 128 in Table 4-7 under Coco Bear oil. Central MA MCD has never used Coco Bear oil in their district. *[Note: ERG concurs with this correction and it has been added to the list of errata.]*

Sam Telford

Page 157, note on the quoted statement "*Any reduction in population is expected to be temporary, lasting no more than 2 weeks.*" – This is because of the emergence of new broods that are developing in water at the time the adults are being impacted. "Temporary" is perhaps not the right term. New broods may or may not become risky, that would depend on whether there are viremic animals around when they seek their first bloodmeal.

Page 157, note on the quoted statement "*Mosquito surveillance and weather pattern data are essential in helping to determine need and timing for aerial spray interventions*" – Weather greatly impacts the efficacy of aerial (and ground based) spraying…which is why there is little advance notice of spray operations. The decision for planes to leave is sometimes made a few hours before takeoff. So advance notice to stakeholders can only be made in very general terms, e.g., "we will be spraying sometime this week, depending on weather"

Page 157, note on the statement "The available data show that the total reduction in the number of mosquitoes can range significantly—from 20 to 89 percent—after aerial spraying with pyrethroid compounds. But this reduction is expected to be temporary." – It is not the reduction of the entire mosquito population that is the goal, it is removal of older mosquitoes that have had the chance to take a bloodmeal and thus be infected. Newly emerged mosquitoes have no immediate implications for risk… we don't care if spray kills the new ones because they are not infected and thus pose no risk. Aerial spraying is intended to kill virus-containing mosquitoes (demonstrated to be present by surveillance)… those that pose immediate risk… and only indirectly impact future risk by reducing a new generation of mosquitoes that might become infected. A big gap in demonstrating the efficacy of aerial spraying as an intervention is a way to efficiently assess mosquito age structure.

Page 159, note on the statement "Ultimately, pesticides must be used with caution and consideration to the tradeoffs—for example, the need to remove mosquitoes active at nuisance levels versus the ecological risk that may occur as a result of the application" – Aerial spraying is a different game than truck mounted spraying. This section should be careful to make that distinction. It is also not clear whether there is merit in distinguishing between "nuisance" and public health applications. After all, it is very likely that the majority of EEE cases get infected in their own backyards. Backyard mosquitoes are erroneously thought of as nuisance. The main nuisance species in July in most people's yards is C. perturbans… which we think of as the main candidate for EEE vector.

Russ Hopping

While the report does capture readily available data on pesticide toxicity and risk, primarily from the EPA which per the Report has significant gaps in its evaluation of pesticides, the report would be more powerful if it had captured primary literature that could fill in these gaps, specifically where studies were based on similar products and active ingredients used by the State for controlling mosquitoes. The state should seek to supplement the Report finding with primary literature review and where studies are lacking fund and conduct these studies.

Comments on Report 5: Integrated Pest Management and Non-chemical Mosquito Controls (pg. 175-232)

Priscilla Matton

Multiple places in the document but specifically pg 239 Table 3-1 sections on chemical and adult control. Under Current Practices it states that "No information was identified on how MCDs and municipalities not part of MCDs "decide which larvicide/adulticide to use". This is a false statement- all products are reviewed by the MOU between MA Fish and Wildlife and MDAR. All products that are reviewed by this MOU are the products that MCDs are using. We currently don't use products that have not been approved for use in this document. This review by MA Fish and Wildlife was not mentioned in the ERG report.

Sam Telford

Note on section 7.4.4 (Bats), page 220 – There is no evidence that bats have any impact on mosquito populations; they are opportunistic feeders and bats prefer better energy sources such as moths. Promoting bat populations around homes is not a good thing: the majority of rabies exposures in the U.S. are due to bats.

Heidi Ricci

Lack of Efficacy and Noncompliance with IPM Standards

The report confirms that there is no centralized system for tracking the activities of the mosquito districts. Data on mosquito populations, positive disease detections, breeding source locations, and mosquito control services conducted (education, source reduction, larviciding, adulticiding) cannot be correlated to each other or to the locations of the rare occurrences of EEE or WNV is humans or other animals. Therefore it is not possible to determine the efficacy of their operations. The districts claim to employ Integrated Pest Management (IPM), but the lack of a systematic approach indicates it is not a science-based IPM system.

"While all 11 MCDs, along with other state agencies, participate in larval and adult mosquito surveillance efforts, there is a lack of detailed reporting on their specific IPM activities. Expenditures for each component of IPM are presented in Sections 3.1.2.1 and 3.1.2.2. To date, quantitative assessments of IPM's efficacy at reducing mosquito populations in Massachusetts (both nuisance and vector mosquitoes) and the human health risks from vector mosquitoes have not been undertaken (EEA, personal communication, July 2021)." p. 184

See also Table 3-1 on pp. 238-240. Several aspects of IPM standards recommended by the American Mosquito Control Association are not followed.

Practices vary across districts. Cape Cod has a relatively sophisticated and rigorous approach, and works extensively with local officials including conservation commissions on water management in both salt marshes and fresh water settings. Some of these practices can be ecologically beneficial, e.g. helping to reduce the impacts of sea level rise on salt marshes and enhancing fish access to salt marshes and freshwater wetlands. This district rarely uses adulticides and only in conjunction with positive mosquitoes and high risk of disease in specific locations. While we do not endorse all of these practices (e.g. Bti for nuisance control due to literature data on ecological effects), the overall direction the program should be heading is one that is more ecologically based and data driven.

Some of the districts routinely spray adulticides from trucks even when there is no evidence of mosquito-borne disease. This appears to be contrary to the pesticide labels, e.g. this from the Duet label:

This product is highly toxic to bees exposed to direct treatment on blooming crops or weeds. Do not apply to or allow drift onto blooming crops or weeds when bees are foraging in the treatment area, except when applications are made to prevent or control a threat to public and/or animal health determined by a state, tribal or local health or vector control agency on the basis of documented evidence of disease causing agents in vector mosquitoes or the occurrence of mosquito-borne disease in animal or human populations. [Footnote 3: https://www.clarke.com/filebin/productpdf/duet.pdf]

The report also notes this label requirement, and suggests that applicators should be informed when blooming plants are present in their areas. Anyone with a basic understanding of Massachusetts ecosystems knows that blooming plants are widely occurring across the state from early spring through the first hard frosts in the fall. Many plants that commonly grow along roadsides and in yards and meadows produce blooms that attract pollinators. According to Table 5-6, the half-life of pyrethroid pesticides carrying this label warning range from 2.1 to 6.7 days. Therefore, any roadside spraying that is occurring absent any evidence of presence of mosquito-borne disease in the vicinity appears to be a violation of the label.

Ecologically Based Mosquito Management

The sections on stormwater management and on dam removals and culvert upgrades are not complete. Piped stormwater systems with catch basins create prime habitat for the mosquitoes that carry WNV. Rain gardens and bioswales do not create mosquito habitat if properly built and maintained. More cooperative efforts should be put into updating municipal rules for stormwater management to emphasize Low Impact Development techniques that do not create mosquito habitat.

Dam removals and culvert upgrades not only remove ponded stagnant water – they allow fish and eels to get into headwaters. Restoring eel[7] access to headwater wooded swamps could reduce the mosquitoes that amplify EEE [Footnote 7: https://www.youtube.com/watch?v=GpPpBwZ_s8A]. Those mosquitoes breed in “crypts” under tree roots in swamps. Even aerial Bti can’t reach those crypts, but eels can.

Comments on Report 6: Best Practices to Maximize Impact of Pesticide Use on Mosquito Populations and Minimize Non-Target Impacts of Mosquito Pesticides (pg. 233-253)

Sam Telford

Note on section 4.2.1: Spray Notification Location, Precision, and Timing, page 245 – It should be noted that MCPs are limited to the hours between dusk and dawn to apply pesticide to reduce impact on pollinators, which are mainly diurnal. These limitations are not in place for commercial applicators or homeowners who apply on their own. There should be some quantitative comparison in this report of how much pesticide is applied by commercial applicators (e.g., Mosquito Joe) and homeowners for diverse purposed, relative to that applied by MCPs for truck based spraying and that applied by plane for EEE suppression.

Heidi Ricci

The analyses of impacts of pesticides on vulnerable populations, pollinators, and ecological health are incomplete.

Beyond the label requirements, the pyrethroid pesticides are also highly toxic to thousands of native beneficial species Many of native pollinators rest at night on plants in the field (e.g. wild bees, beetles). Moths fly at night and are likely to be directly exposed to spray. Available literature also indicates concerns about potential impacts to vertebrates including fish, birds, and amphibians [Footnote 4: E. Török et al, Unmeasured Side Effects Of Mosquito Control On Biodiversity, European Journal of Ecology, 6.1 (71-76), 2020]

Parasitic wasps and flies that keep agricultural and forest pests[5] in check are highly vulnerable to these pesticides as well but are not addressed in the report. [Footnote 5: https://www.umass.edu/archivenewsoffice/article/parasitic-flies-control-invasive-winter-moths-be-released-may-9-wellesley-umass-amherst]

The analysis of impacts to bats is unscientific. It says impacts on bats are unlikely because mosquitoes are a small part of their food supply – but the pesticides are toxic to many of the other flying insects that bats eat too. There is a lawsuit in Vermont on the risks of mosquito control pesticides to endangered bats [Footnote 6: https://www.burlingtonfreepress.com/story/news/2021/08/17/environmental-groups-sue-vermont-agency-failing-protect-bats/8161620002/]. Similar conclusions on fish and birds are also flawed.

The report cites several studies and literature review summary reports on human health and ecological impacts of mosquito control pesticides, including both larvicides and pesticides. See, for example these:

Mazzacano, C., & Black, S. H. (2013). *Ecologically Sound Mosquito Management in Wetlands: An Overview of Mosquito Control Practices, the Risks, Benefits, and Nontarget Impacts, and Recommendations on Effective Practices that Control Mosquitoes, Reduce Pesticide Use, and Protect Wetlands*. The Xerces Society for Invertebrate Conservation.

Utah Physicians for a Healthy Environment. (2019). *Mosquito Pesticide Spraying*. Retrieved June 22, 2021 from https://www.uphe.org/priority-issues/mosquito-pesticide-spraying/

City of Boulder. (2018). *Review of the Scientific Literature for Impacts of Bacillus thuringiensis sub-species israelensis (Bti) for Mosquito Control*.

The inclusion of these sources and brief summaries of some of the findings are useful. However, we had expected a more rigorous review of this topic in relation to actual practices in Massachusetts. The lack of data on what practices are actually being applied and where, combined with the limited time available to the consultant and lack of ecological expertise on the consultant team resulted in a cursory review that did not fulfill the intention of this portion of the law on the comprehensive study.

Comments on Report 7: Massachusetts Drinking Water Regulations Related to Pesticide Application (pg. 254-269)

Helen Poynton

Page 265, suggestion for additional information that could be added to report to clarify the significance of the levels detected - According to the MassDEP report 2020c, sumithrin was detected in "non-public water system waters" at levels 12-41 ng/L (Table 1 from MassDEP report). Although these values are below aquatic life benchmarks*, but they are above the acute toxicity levels for some aquatic invertebrates (e.g., H. azteca: 9.4 ng/L; mysid shrimp: 25 ng/L). Note that the limit of detection (10 ng/L) is > the LC50 value for H. azteca. *Aquatic benchmarks for sumithrin for invertebrates are Acute: 2.2 ug/L and chronic: 0.47 ug/L – these are not based on the lowest toxicity values in a standard test according to OPP's own database.

Sam Telford

Note on section 4 (Review of Pesticide Monitoring Data), page 266 – There should be some data presented on how much home use pesticide with PBO is applied here in Mass, at the very least a list of products in Home Depot that contain PBO

Note on page 267, statement "Such a system would be a significant undertaking in order to be inclusive all types of pesticides applicators—the SRB, all MCDs, and all 10,000 licensed applicators." – This figure needs to be stated in one of the earlier chapters of this report, in a discussion of sources of pesticides that overlap in their use by MCPs, SRB/DPH aerial sprays, agricultural uses, and homeowners. Public health use of pesticides is what fraction of the total likely pesticide use in Mass?

Comments on Report 8: Impact of Mosquitoes, Mosquitoes as Disease Vectors, And Mosquito Control Measures (pg. 270-309)

Helen Poynton

Page 285 - I have a lot of concern about how this model may be used. I can see MCDs, regulators, and even pesticide manufacturers pointing to this model as justification for spraying; however, I do not think it is robust enough to be used for that purpose.

- Because of a lack of data, ERG was not able to include any IPM measures except for mosquito control measures using insecticides, despite the potential for other non-insecticide programs to be very effective (predators, p. 220; public education campaigns, p. 200, open marsh water management (OMWM), p. 215). The “no control” scenario suggests an increase of 1.5-3 times more disease cases, but if other control measures are put into place instead of insecticide spraying, these numbers may never be realized.
- The effectiveness of spraying was based on the number of mosquitos detected in traps after spraying. However, this is not same as measuring the amount of cases of a disease. It is quite possible that there is not a direct/linear relationship between number of total mosquitos and the number of disease cases.
- “Most respondents [of the ERG survey, chapter 2] indicated that it was difficult to rank the effectiveness of control of disease carrying mosquitoes, citing difficulties with proving the effectiveness of aerial spraying and other control measures and how these activities impact case rates of EEE and WNV” (p. 58) I think this statement highlights some of the limitations on defining the effectiveness of spraying. More research is clearly needed to define how effective spraying is for controlling these diseases.

Page 302 (section 2.4.1) - In the report about mosquito impact to predators, the major missing piece is that the insecticides used for spraying are not specific to mosquitos. For example, if bats primary diet is insects, these insecticides are going to impact populations of many types of insects, and many more of them will be prey items for bats. The same is true of insectivorous fish. The other piece missing is the potential for bioaccumulation and trophic transfer of insecticide residues from insects that were sprayed (and may not have died) and the predators (e.g., bats, fish, spiders).

Page 303 (section 2.4.2) - Biotransformation in fish, some of the biotransformation products of pyrethroid insecticides are endocrine disruptors in fish. “Pyrethroid metabolites have greater endocrine activity than their parent structures...” (Brander et al., 2016, *Environ. Sci. Technol.* 2016, 50, 17, 8977–8992)

Sam Telford

Note on page 275, statement “detectable levels of pesticides used for mosquito control in Massachusetts have been found in honey bees.” – There are many sources of these pesticides (homeowner, agriculture, commercial applicators) besides public health use. This needs to be stated. Why do you think that any detected residues are from state-sponsored mosquito control?

Note on page 275, statement “some chemicals used in mosquito control could have indirect impacts on avian species in Massachusetts.” – Same comment, it is not correct to attribute all pesticide use to state sponsored mosquito control.

Note on page 278, Table 2-1, Ecosystem health: “Mosquitoes are a food source for several bat and fish species in the Commonwealth” – There is no evidence whatever for this. Where is your primary reference? Not a review, actual study.

Note on page 291, section 2.1.2, Impact of Mosquito Control on Public Health: “Table 2-8 presents the active ingredients in the pesticides used by MCDs and the SRB for mosquito control in the past five years…” – The assumption is made that MCP and SRB use is the sole source of pesticide. This is false. This needs discussion in this report.

Note on page 292, statement “Nuisance levels of biting mosquitoes and outbreaks of mosquito-borne illness impact Massachusetts in different ways. Vector mosquitoes infect individuals.” – How do you distinguish a vector from a nuisance? The main nuisance in people’s backyards in July and August is C. perturbans. This mosquito is the best candidate for EEE vector. It is very likely that any generalist mosquito can serve as a vector for EEE. There is no such things as a good mosquito bite.

Note on page 297, statement “ERG began this analysis by interviewing a pollinator expert on approaches to quantifying the impacts of pesticides on agriculture and pollinators and conducting a literature review.” – It should be noted that agriculture itself uses pesticides. How can you distinguish public health use of pesticide from that by agriculture itself?

Page 302, statement “These results show that mosquitoes constitute a relatively small proportion of the diets of the bats most commonly found in Massachusetts. Thus, available evidence does not indicate that mosquito control has a major effect on bats via the impact on mosquito populations.” – This needs to be reflected in text of previous chapters which imply that bats are affected by mosquito control activities. Wouldn’t winter moth caterpillar suppression affect the availability of winter moths (likely preferable to mosquitoes as prey) for bat consumption?

Russ Hopping

Given there is no data on the efficacy of spraying and a reduction in human health risks the model developed by ERG to evaluate potential symptomatic infections under various controls is an imperfect model at best. This is not an evidenced-based model and the science and presumptions behind it need to be thoroughly assessed by knowledgeable third-party scientists for validity before the Report is made fully available with all public comments. Information from such an evaluation would be highly useful for the subcommittees as they conduct their tasks.

Heidi Ricci

Effects of Reducing or Eliminating Mosquito Control

The modeling of projected WNV and EEE cases if mosquito control was discontinued is deeply flawed. Section 8 of the report uses information on the range of percentages of mosquitoes temporarily eliminated by larviciding or adulticiding, then uses that as a proxy for reduction in number of cases of EEE or WNV. There is no basis for this proxy assumption. Reducing mosquitoes by, for example, 50% does not necessarily reduce the number of disease cases by 50%. Other factors such as whether or not people take precautions to prevent exposure to mosquito bites may have more of an effect on outcomes. Since these diseases are extremely rare (0.3 cases per million people per year for EEE, 1.6 for WNV), and mosquito populations are so large and prevalent, even reducing the mosquito population by 50% still means there are millions of mosquitoes present. The Department of Public Health’s Arbovirus Surveillance and Response Plan emphasizes that personal protection measures are the first line of defense, and must always be taken even after aerial or ground spraying has taken place.

Comments on Report 9: Climate Change Impacts to Mosquito Populations and Mosquito-Borne Diseases (pg. 310-324)

No comments from Task Force members were received for this section of the report.