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Integrated Pest Management for Mosquito Control in Massachusetts

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Integrated Pest Management for Mosquito Control in Massachusetts

A Major Qualifying Project submitted to the Faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science.

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April 7th, 2013
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Abstract

Eastern equine encephalitis (EEE) is a rare but fatal viral disease transmitted by mosquitos. West Nile Virus (WNV), also transmitted by mosquitos, is more common and symptoms of severe cases include coma, muscle weakness, vision loss and paralysis. There are currently no treatments for EEE and WNV. Pesticides are one of the most common management practices used to control mosquito populations and limit human risk of EEE and WNV. However, pesticides have the potential to harm nontarget organisms, humans, and the environment. This project researched EEE, WNV, pesticides, regulations, integrated pest management, Mosquito Control Projects, and mosquito management options in Massachusetts. Results were used to develop a decision tree to help decision makers choose which mosquito control options are best suited for their county.
Executive Summary

Mosquitos are capable of carrying fatal diseases such as malaria and yellow fever. In the northeastern part of the United States, mosquitos have been known to transmit eastern equine encephalitis (EEE) and West Nile Virus (WNV). EEE has a 33% mortality rate to those infected. From 2004 to 2006, there were 4 to 5 cases of EEE every year in Massachusetts. In 2012, there were 7 cases of EEE in Massachusetts. WNV has a lower mortality rate of 5%, but is more prevalent than EEE. In 2012, there were 26 cases of WNV in Massachusetts. Most cases of EEE and WNV occur in late summer and early fall.

The most common form of mosquito control is using chemical pesticides which are designed to destroy, slow down, or alter the life cycle of pests. The most common pesticides used in Massachusetts are synthetic pyrethroids for adult mosquito control and methoprene, *Bacillus thuringiensis israelensis* (BTI), and *Bacillus sphaericus* for larval mosquito control. Pesticides come with a risk to non-target organisms, humans, and the environment. One way to reduce pesticide use is by utilizing an Integrated Pest Management (IPM) plan which combines several mosquito control practices. In Massachusetts, mosquito control is administered through Mosquito Control Projects (MCPs) located primarily in the eastern half of the state, where most cases of EEE and WNV occur.

The goal of this project was to help decision makers choose which mosquito management options are best suited for their towns and county. The major objectives included:

- Researching mosquitos, EEE, WNV, and pesticides;
- Researching the current mosquito control structure in Massachusetts;
- Collecting data from Massachusetts Mosquito Control Annual Operations Report (MMCAOR); and
- Evaluating mosquito management options based on cost and efficacy.

For the first objective, research was conducted on the mosquito life cycle, benefits and risks of pesticides, number of cases of EEE and WNV in Massachusetts, and regulations associated with pesticides. In Massachusetts, there were 23 cases of EEE since 2003 and 98 cases of WNV since 2001. Plymouth County has the highest number of cases of EEE with 11 in 2003. Middlesex County has the highest number of cases of WNV with 40 cases since 2001.

For the second objective, interviews with David Henley, superintendent of East Middlesex Mosquito Control Project, and Ellen Bidlack, entomologist of Plymouth County Mosquito Control Project, were conducted in December of 2012 to gain a better understanding about how mosquitos are managed in towns and counties. MCPs were found to be funded in two different ways – state and town funding. State funding allowed the MCP to decide which services are needed for a town or county, while town funding allowed individual decisions by towns. Different species of mosquitos were prevalent in different MCPS, which determined which mosquito management option should be used. East Middlesex (EM) MCP had to control *Culex* genera mosquitos who reside in the canopies of trees which lead to EM using mostly larvicides. Plymouth County (PC) MCP had *Coquillettidia perturbans* which, in their larval stage, reside in the roots of cattails making larvicides inefficient. As such, PC used *Gambusia affinis* fish to eat the *Cq. perturbans* (Bidlack, 2012; Henley 2012).

For the third objective, the Massachusetts Mosquito Control Annual Operations Reports (MMCAORs) were researched to see what pesticides and IPM services were used by each MCP. In addition, budgets were obtained from each MCP. MCPs provide up to seven IPM services to the towns. They are larval mosquito control, adult mosquito control, source reduction, ditch maintenance, open marsh water management, adult mosquito surveillance, and education. With
the exception of EM, Berkshire County (BC), and Suffolk County (SC) MCP, each MCP had a budget of around 1.5 million USD since 2007. EM had a budget of around 0.6 million USD while BC and SC each had budgets of around 0.2 million USD since 2007 (MA OEEA, 2007-2012).

For the fourth objective, many mosquito management options were researched to help decision makers choose which options would work best for them. The mosquito management options researched were *Bacillus thuringiensis israelensis* (BTI), *Bacillus sphaericus*, *Gambusia affinis*, mosquito magnets, truck spraying, and aerial spraying. BTI was a relatively cheap biological pesticide at around $1 per pound while *B. sphaericus* was more expensive at $9.62 per pound (NOW, 2012). However, studies suggested that the toxins produced by BTI is persistent and therefore have the potential to harm beneficial species in a water body (Manty, 2000). *Gambusia affinis* is a fish that eats mosquito larva and costs $0.50 to 1.50 per fish. Stocking rates for *G. affinis* ranged from several hundred to 2,500 depending on the size of the water body (MD DOA, 2013; NJ MCA, 1996). *G. affinis* is unable to survive in the winter in Massachusetts and, due to the aggressive nature of *G. affinis*, are not recommended to be used in water bodies with other fish in them (USGS, 2013).

A decision tree was developed as a classification tree. The endpoints included seven mosquito management options to help decision makers choose their combination of options. These options were mosquito magnets, *Gambusia affinis*, BTI, *Bacillus sphaericus*, truck spraying, aerial spraying, and source reduction. The endpoints were organized by attributes which were chosen based on research and interviews. The attributes were presence of EEE and WNV, control of mosquitos for nuisance reduction, type of funding, type of mosquito, target mosquito life cycle, cost effectiveness (adult only), and risk (larva only).
Eastern equine encephalitis (EEE) is a rare but fatal disease and West Nile Virus (WNV), also transmitted by mosquitoes, is more common and symptoms of severe cases include coma, muscle weakness, vision loss and paralysis. Both viruses can be transmitted to humans via infected mosquitoes. To reduce risk of EEE and WNV, Mosquito Control Projects (MCPs) service towns and counties by controlling the mosquito populations through use of pesticides and other management practices. Pesticides have a risk of harming human health, nontarget organisms, and the environment. Thus, the use of Integrated Pest Management (IPM) is highly encouraged. IPM is an approach to pest control which relies on a combination of cultural, mechanical, biological, and chemical practices to reduce damage done by pests while being economical and minimizing hazards to people and the environment. The purpose of this Major Qualifying Project was to design a decision tree to help town and county officials choose a mosquito management option for their region in Massachusetts.

The project addressed the cost of the mosquito management options. Some mosquito management options, such as aerial spraying, are not feasible for MCPs with low budgets. By researching the costs of mosquito management options, a better understanding of which options are realistic for towns and counties. Some of the options used to control mosquitoes are more effective than others or more costly to produce therefore they are higher in price. Therefore, the type of mosquito management plan an MCP chooses depends greatly on costs.

The project addressed the risk of the mosquito management options. One of the objectives of this project was to design an Integrated Pest Management Plan to minimize the use of pesticides. Pesticides have the potential to harm humans, nontarget organisms, and the environment. Therefore, designing a mosquito management plan with the least amount of risk to the environment and non-target organisms was a major part of the design.

The last design component for this project was the effectiveness of the mosquito management option. The effectiveness of mosquito management options were obtained through research and interviews. Interviews with the MCPs were used to determine the effectiveness of truck and aerial spraying. Research was used to determine the efficacy of the larval mosquito control options *Bacillus thuringiensis israelensis*, and *Bacillus sphaericus*. 
Introduction

Mosquitos are an increasingly growing problem in the United States. Mosquitos carry diseases such as eastern equine encephalitis and West Nile Virus. These viruses are fatal to humans, so the control of these mosquitos is important to human health. One of the most effective ways of controlling mosquito populations is through the use of pesticides. A pesticide is any substance used to destroy, slow down, or alter the life cycle of any pest (NSW EPA, 2013).

While the benefit of using pesticides to control mosquito populations is great, they come with a risk to non-target organisms, and have the potential to contaminate the environment. In the early twentieth century, malaria claimed more than 50 million lives, which largely included children. In 1939, Paul Müller discovered the effects of dichlorodiphenyltrichloroethane (DDT) on insects, consequently increasing success in controlling insect-borne diseases such as typhus, and yellow fever. The success in controlling these diseases leads to a Nobel Prize in Medicine by 1948 for Paul Müller. By the 1980’s, nearly 5 billion pounds of DDT has been applied in both indoors and outdoors worldwide. However, the use of DDT led to many problems. Insects developed a resistance to the insecticide, the persistence of DDT led to traces being found in Antarctica, and DDT bioaccumulated in food chains and human body fat. As of 1972, DDT has been banned in the United States but it is still being used in other countries (Wargo, 1998).

Integrated Pest Management (IPM) is an approach to controlling pests such as mosquitos which utilizes a combination of practices to minimize damage done by pests. IPM does not eliminate the use of pesticides. Instead, the goal of IPM is to minimize the amount of pesticide needed to control pests which lowers the amount of potentially harmful chemicals in the environment (EPA, 2013; Texas A&M University, 2013). This paper will introduce the types of IPM practices that have been used in the Massachusetts, and analyze the benefits and risks of such practices.

Threat of Eastern Equine Encephalitis and West Nile Virus

Eastern equine encephalitis virus (EEEV) is a rare disease in humans which is transmitted by the bite of an infected mosquito and is found east of the Mississippi River. People infected with EEEV may experience little to no symptoms. However, severe cases of EEEV may lead to encephalitis, or EEE, which causes inflammation of the brain and spinal cord (CDC, 2012a; Nandular, 2012).

EEEV is maintained naturally in a cycle between Culiseta melanura mosquitos and birds living near freshwater marshes and swamps. Culiseta melanura mosquitos do not pose a risk to humans for EEE because they feed exclusively on birds. However, the Aedes, Coquillettidia, and Culex mosquitos do pose risks to humans because they feed on both birds and humans. When one of the three mosquito genera feed on a bird with EEEV, then the mosquito becomes infected with EEEV. If the mosquito bites a human, then the human may become infected with EEEV and may develop EEE within 2 weeks (CDC, 2012g; CDC, 2012h).

EEEV infections can progress into one of two categories – systemic and encephalitic (EEE). Systemic infections are characterized by chills, fever, discomfort, pain at the joints, and pain at the muscles and lasts for 1 to 2 weeks. Encephalitic infections follows after systemic infections and symptoms include fever, headache, irritability, restlessness, drowsiness, anorexia, vomiting, diarrhea, convulsions, and coma (CDC, 2012g).
From 1955 to 1967, 256 cases of EEE were reported to the Centers for Disease Control and Prevention (CDC) with an average of 6 cases in the United States reported annually. New Jersey, Massachusetts, Georgia, and New York had the most cases of EEE with 70, 37, 28, and 20 from 1964 to 2010, respectively. The mortality rate for those infected with EEE is 33% and survivors may have mild or significant brain damage (CDC, 2012g; CDC, 2012b; Nandular, 2012).

Figure 1 shows the confirmed or probable human cases of EEE in Massachusetts by year since 1964. Since 1964, hospitals in Massachusetts have reported 45 cases of confirmed or probable cases EEE to the CDC. Approximately half the cases of EEE (23 out of 45) occurred since 2003 (CDC, 2011).

![Figure 1: Confirmed or Probable Human Cases of EEE in Massachusetts by Year, 1964 to 2012.](source: CDC, 2011; USGS, 2012a)

Figure 2 shows the number of confirmed or probable human cases of EEE in Massachusetts by county since 2003. Plymouth County has the highest number of reported cases of EEE with 11 cases since 2003. Essex and Bristol County have the second highest with 3 reported cases each. Some counties, particularly those in the west and far southeast have no reported cases of EEE since 2003 (USGS, 2012a). Detailed data by year and county are provided in Appendix A.
Figure 2: Number of Confirmed or Probable Human Cases of EEE in Massachusetts by County, 2003 to 2012.
(source: USGS, 2012a)

Figure 3 shows the EEE incident rate per 100,000 person-year in Massachusetts by county since 2003 using 2010 Census data for population. Plymouth County has the highest incidence rate with 0.22 cases per 100,000 person-year, followed by Franklin County with 0.14 cases per 100,000 person-year (USCB, 2012; USGS, 2012a). Population data and incidence rate calculations are shown in Appendix A.

Figure 3: EEE Incidence Rate per 100,000 person-year in Massachusetts by County, 2003 to 2012.
(source: USCB, 2012; USGS, 2012a)
The West Nile Virus (WNV) originated in the West Nile district in Uganda in 1937. From 1975 to 1993, no major epidemics of WNV were documented. However, in the following years, outbreaks of WNV occurred in North Africa, Europe, North America, and the Middle East. In 2000, Israeli had more than 400 cases with 35 deaths. WNV first appeared in the United States in 1999 in New York – hospitalizing 59 people and causing 7 deaths (Campbell et al., 2002). In 2012, WNV spread through all of the United States, resulting in 5,054 reported cases of WNV (CDC, 2012j).

Similar to EEE, WNV is maintained naturally between mosquitos and birds by Culex mosquitos. Culex genera mosquitos are known for biting both birds and humans, forming a bridge for disease transmission (Campbell et al., 2002).

Most West Nile infections are symptomless. Approximately 4 out of 5 people infected by WNV will show no adverse effects. Approximately 1 out of 5 infected people will experience symptoms such as fever, headache, body aches, nausea, vomiting, and sometimes swollen lymph nodes (5% of cases), or a skin rash (22% of cases). These symptoms last from a few days to several weeks. Severe symptoms of WNV occur once in every 150 people, and symptoms include disorientation, coma, tremors, convulsions, muscle weakness, vision loss, numbness, and paralysis. Symptoms from severe cases of WNV can last several weeks and the neurological effects can be permanent (Campbell et al., 2002; CDC, 2012j).

WNV was first documented in Massachusetts in 2001. There have been a total of 98 cases of WNV in the Massachusetts with an approximately 5% mortality rate in the country in only the severe cases of WNV (CDC, 2012c; CDC, 2012d; CDC, 2012e; USGS, 2012b). Figure 4 shows the number of confirmed and probable cases of WNV in Massachusetts from 2001 to 2012. Due of the nature of WNV to most humans, less than 1% of which will experience symptoms resulting in hospitalization, the reported number of cases only reflects severe cases of WNV and is not accurate in how prevalent the virus actually is (CDC, 2012j).

![Figure 4: Confirmed or Probable Human Cases of WNV in Massachusetts by Year, 2001 to 2012.](source: CDC, 2012f; USGS, 2012g)
Figure 5 shows the number of confirmed or probable human cases of WNV in Massachusetts by county since 2001. Middlesex County has the highest number of reported cases of WNV with 40 cases since 2001. Suffolk and Worcester County have the second highest with 19 and 13 reported cases respectively (USGS, 2012b). Population data and incidence rate calculations are shown in Appendix A.

Figure 5: Number of Confirmed or Probable Human Cases of WNV in Massachusetts by County, 2001-2012.
(source: USGS, 2012b)

Figure 6 shows the WNV incident rate per 100,000 person-year in Massachusetts by county since 2003 using 2010 Census data for population. Middlesex and Suffolk County has the highest incidence rate with 0.22 cases per 100,000 person-years, followed by Worcester County with 0.14 cases per 100,000-person-years (USCB, 2012; USGS, 2012b). Population data and incidence rate calculations are shown in Appendix A.

Figure 6: WNV Incidence Rate per 100,000 person-year in Massachusetts by County, 2001 to 2012.
(source: USCB, 2012; USGS, 2012b)
Mosquitos and Mosquito Life Cycle

In the state of Massachusetts, there are 51 different species of mosquito, each with its own specific preferences and traits. Only a handful of these mosquitoes are known to carry EEE or WNV. For the purposes of this study, only the mosquitos capable of carrying EEE and WNV are discussed (EMMCP, 2012).

Figure 7 shows a picture of the mosquito *Ochlerotatus canadensis*. This species is common only in the late spring and early summer months in Massachusetts and is a fierce biter of mammals and humans. It breeds in woodland pools, swamp borders and grassy hummock areas (EMMCP, 2012).

![Figure 7: Picture of an Ochlerotatus canadensis mosquito. (source: EMMCP, 2012)](image)

Figure 8 shows a picture of an *Aedes vexans*. This mosquito is very common in the summer and is capable of breeding multiple generations in one season. This combined with its breeding in temporary pools and wetlands means that in a very rainy season, this mosquito population can boom (EMMCP, 2012).

![Figure 8: Picture of an Aedes vexans mosquito. (source: EMMCP, 2012)](image)
Figure 9 shows a picture of a *Culex pipiens* mosquito. *Culex pipiens* as well as *Culex restuans* are the most known for their transmission of insect-borne diseases. These types of mosquitoes are common year-round and typically bite birds. However, they will bite humans under the right circumstances. They are considered shy and will only bite humans if they are motionless. It is common to be bitten by this mosquito while sleeping (EMMCP, 2012).

![Figure 9: Picture of a *Culex pipiens* mosquito.](source: EMMCP, 2012)

Figure 10 shows a picture of a *Coquillettidia perturbans* mosquito. This mosquito is common from mid-June to mid-August and is an indiscriminate biter of mammals, humans, and birds. This larva is particularly difficult to kill because the larva attach to the roots of cattails and other aquatic plant life. This makes typical larvicides and pesticides ineffective (EMMCP, 2012).
The life cycle of a mosquito occurs in four stages. The first stage is the egg stage. Depending upon the breed of mosquito, the eggs can be laid in an egg raft or as individual eggs. An egg raft is a collection of approximately 150 eggs floating on the surface of the water as one unit. After 48 hours of development inside the eggs, the infant mosquitoes hatch and begin their larval stage. Depending upon the breed, this stage can last from two to four weeks. This stage is where most of the development occurs. Mosquitoes can molt their skin four times during this period. Once they have reached peak development in this stage, they create a cocoon and enter the pupa stage. This stage lasts approximately another 48 hours depending on the breed. The wings emerge from the pupa and develop as well as the proboscis.

Once the pupa is ready to become an adult mosquito, the pupa rises to the surface of the water, and emerges from the shell and the water at the same time. The newly emerged mosquito rests on the water surface for twelve hours to allow its wings to dry and for all of its parts to harden. Due to the immobility and fragility of the mosquito during this final developmental stage, they are vulnerable to attack from various fish and bird species. Once the mosquito has lifted off from the water surface, it is now considered an adult mosquito and begins looking for nutrients to supply its eggs (EPA, 2013).

Benefits of Pesticides

One of the most common methods to control mosquito populations is by the use of chemicals, or pesticides, to kill the mosquito in the larva or adult form. There are several different classes of pesticides. Some of these classes include organophosphates, carbamates, organochlorines, and pyrethroids. Each class of pesticide share similarities in chemical composition, and mode of action (Reigart and Roberts, 1999).

Organophosphate

Organophosphate (OP) pesticides are the most commonly used pesticides in the United States accounting for 35% of total pesticide use in 2007 (Grube et al., 2011). Over 40 types of organophosphate chemicals are registered all of which run the risk of acute toxicity to insects.
and mammals (Reigart and Roberts, 1999). The three most common organophosphate pesticides are acephate, chlorpyrifos, and malathion (Grube et al., 2011).

Organophosphate pesticides are cholinesterase inhibitors. OPs block the acetylcholinesterase enzyme (AChE) from hydrolyzing acetylcholine (ACh) in the muscle by non-reversible phosphorylation. OPs will bind to the positively charged active site of an AChE, preventing the enzyme from hydrolyzing ACh into acetic acid and choline. ACh is a chemical that is used as a neurotransmitter in the nervous system. The loss of AChE allows for ACh to build up, causing the nervous system to continually send signals to muscles, leading to muscle twitching, contraction, and eventually death (Brown, 2006; Costa, 2006; Reigart and Roberts, 1999).

Figure 11 shows the AChE hydrolyzing ACh into acetic acid and choline without the presence of an organophosphate pesticide. The double bonded oxygen in ACh goes into the positively charged site of the AChE while the nitrogen atom goes into the negatively charged site (Soreq and Seidman, 2001).

Figure 12 shows acephate, an organophosphate, binding to an AChE. Note that the double bonded phosphorus-oxygen is binding to the positively charged site, similar to the double bonded carbon-oxygen in ACh.

Figure 11: Acetylcholinesterase Hydrolyzing Acteylcholine into Acetic Acid and Choline. 
(source: Soreq and Seidman, 2001)

Figure 12: Acephate Inhibiting an Acetylcholinesterase Enzyme. 
(source: Soreq and Seidman, 2001)
Figure 13 shows the general chemical composition of an organophosphate pesticide. The R is usually either ethyl or methyl. The “Leaving Group” is used to identify the organophosphate and give the organophosphate unique characteristics in toxicity. The double bonded sulfur may also be oxygen. The oxygen in the phosphorus-oxygen bond may also be sulfur.

![Chemical Composition of an Organophosphate Pesticide](image)

**Figure 13: General Chemical Composition of an Organophosphate Pesticide.**
(Reigart and Roberts, 1999)

Figure 14 shows the chemical composition of the three most commonly used organophosphate pesticides in the United States; acephate, chlorpyrifos, and malathion (Grube et al., 2011). All three chemicals share similarities in having a phosphorus atom that is double bonded to an oxygen or sulfur atom.

![Chemical Composition of Acephate, Chlorpyrifos, and Malathion](image)

**Figure 14: Chemical Composition of Acephate (left), Chlorpyrifos (middle), and Malathion (right).**
(source: EPA, 2012d)

**N-Methyl Carbamate**

Carbamate pesticides, like organophosphates, are cholinesterase inhibitors. As such, the symptoms experienced from cholinesterase inhibition by carbamate poisoning are the same as OP poisoning. However, carbamate pesticides block AChE from hydrolyzing ACh in the muscle by carbamylation. Unlike the phosphorylation of AChE, which is a non-reversible reaction, carbamylation is a reversible reaction. Thus, human recovery from carbamate poisoning is faster than with organophosphate poisoning due to the AChE being able to break apart from the carbamate chemical (Reigart and Roberts, 1999).

Figure 15 shows the chemical composition of carbaryl, a carbamate, and acephate, an organophosphate. The chemical compositions of carbaryl and acephate make it possible to bind to AChE due to the double bonded oxygen – similar to the double bonded oxygen in acetylcholine. The double bonded oxygen allows the chemicals to bind to the enzyme acetylcholinesterase through carbamylation and phosphorylation.
Figure 15: Chemical Composition of Carbaryl (left) and Acephate (right).
(source: EPA, 2012d)

**Organochlorine**

Organochlorine (OC) pesticides are chlorinated hydrocarbons that are known for their effectiveness in controlling mosquito and pest populations, but many have been banned in developed countries – most notably dichloro-diphenyl-trichloro-ethane (DDT), aldrin, dieldrin, heptachlor, mirex, chlordecone, and chlordane – for their long half-lives, and toxicity (Reigart and Roberts, 1999).

One of the most well-known OC pesticides is DDT. The insecticidal properties of DDT were discovered by Mueller in 1939. The discovery of DDT as a pesticide was key in controlling the prevalence of malaria, yellow fever, typhus, lice, and many other mosquito-borne diseases. DDT was extremely useful because of its broad spectrum targeting of insects, and persistence in the environment. The long persistence was useful in minimizing the frequency of application which saves costs. DDT was banned from use in the United States in 1972 for its environmental effects. DDT is fat soluble, which allows it to accumulate in the fat of animals. The half-life of DDT is very long. In soil, DDT can last between 2 to 15 years. In water, DDT can last for 150 years (NPIC, 2000).

The mode of action for OCs is by inhibiting the gamma-aminobutyric acid (GABA) receptor in the nervous system. The purpose of a GABA receptor is to stop nerve impulses by closing chloride channels, unlike AChE where its purpose is to start nerve impulses. When an OC binds to a GABA receptor, the GABA receptor is unable to close the chloride channels, resulting in overstimulation of the nervous system and similar symptoms to carbamate and organophosphate poisoning (Brown, 2006).

**Pyrethroids**

Pyrethroids are synthetic versions of pyrethrin, a naturally occurring chemical found in chrysanthemum flowers. Both pyrethroids and pyrethrins break down faster in sunlight as opposed to breaking down chemically or microbially. However, pyrethroids are more stable, or degrade slower, than pyrethrin. This quality makes pyrethroids more suitable in agricultural use than pyrethrin. In addition, pyrethroids are typically combined with another active ingredient, such as piperonyl butoxide, to retard their degradation. Retardation allows the chemical to persist longer in the environment, thus requiring less frequent and smaller doses to kill the pests (Reigart and Roberts, 1999; Woodard and Melendez, 2008).
The mode of action for pyrethroids is by altering the sodium channels inside nerves. The sodium channels are responsible for changing the sodium and potassium permeability of the nerve membrane which dictates excitability in the insect. When under the effects of pyrethroid poisoning, the sodium channels are kept open, increasing the permeability of the nerve membrane. The altering of the sodium channel causes the insect to go into a hyperexcitable state, and experience tremors followed by death (Brown, 2006; Narahasi, 1971; Sonderlund et al., 2002).

**Risks of Pesticides**

The use of pesticides has a great benefit in controlling the mosquito population, thus limiting human health risks to EEE and WNV. However, pesticides have risks in contaminating the environment, and killing non-target organisms.

*Environmental Fate*

Pesticides have the potential to contaminate groundwater, surface water, soil, and air, and be metabolized or stored in non-target organisms. Knowing where the pesticide ends up in the environment, known as environmental fate, is key in understanding the risks a pesticide has on ecological habitats. Several characteristics of pesticides are used to help determine their environmental fate. These characteristics water solubility, adsorption, and half-life (Ministry of Agriculture, 2012).

Photolysis, hydrolysis, oxidation, reduction, microbial activity, and metabolism all contribute to a measurement known as half-life. The half-life is defined as the time needed for half of the mass of a pesticide to degrade in the environment (NPIC, 2012). Longer half-lives pose a greater risk to the environment because pesticides will be more likely to contaminate the soil, air, and surface and ground water by lasting longer in the environment.

Unfortunately, it is not safe to assume that once the pesticide has degraded, that it is safe in the environment or for non-target organisms. Sometimes, the degrade of the pesticide has a longer half-life and is more toxic than the pesticide itself. For example, acephate has a half-life of less than 2 days in soil, but the degrade methamidophos has a half-life of less than 10 days in soil (Christiansen et al., 2011). According to the EPA (2012c), methamidophos is also one of the most acutely toxic organophosphate pesticides.

The water solubility of a pesticide is important in determining how much of a pesticide can dissolve in a water body – whether it be a surface water or groundwater. Low water solubility indicates that the pesticide is more likely to be in soil, and have less of an impact on aquatic organisms. Conversely, high water solubility indicates that the pesticide is more likely to be dissolved in water.

Adsorption is the capability of a chemical to bind to solids. In terms of environmental fate, adsorption is how strongly the pesticide binds to soil. A high adsorption coefficient indicates that the pesticide will bind strongly to soils.

The relationship between half-life, water solubility, and adsorption helps predict the environmental fate of a pesticide. For example, a pesticide with a long half-life (>1 week), high water solubility, and low adsorption is likely to contaminate groundwater. However, with a short half-life (<1 week) or high adsorption coefficient, the pesticide is not likely to contaminate groundwater (Ministry of Agriculture, 2012).

Table 1 shows the water solubility, adsorption, and half-life of three common organophosphates and three common pyrethroids. Acephate has high water solubility at 790 g/L,
low adsorption at 2, and low persistence at less than 2 days. Acephate may contaminate groundwater, but due to its low half-life, it is not likely to do so (Christiansen et al., 2011; EPA, 2001). Permethrin, phenothrin, and resmethrin are similar by having low water solubility, and high adsorption. Based on these two characteristics, it is expected for permethrin, phenothrin, and resmethrin to not contaminate groundwater. The persistence for the three pyrethroids varies greatly when in soil, water and air. Phenothrin and resmethrin degrade quickly in air, taking roughly 1 hour. Permethrin is not expected to degrade in air. The persistence in soil and water for the three pyrethroids varies based on the chemical. The half-life of permethrin in water is about a day while resmethrin is over 89 days. In the case of phenothrin, when exposed to light in water, the half-life is about a week while the half-life is 173 day in anaerobic degradation (Jackson et al., 2008; Jackson et al., 2011; Toynton et al., 2009).

Table 1: Characteristics of Three Common Organophosphates and Three Common Pyrethroids. (data compiled from Christiansen et al., 2009; Christiansen et al., 2011; Gervais et al., 2009; Jackson et al., 2008; Jackson et al., 2011; Toynton et al., 2009).

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Water Solubility (mg/L at 25 °C)</th>
<th>Adsorption</th>
<th>Half-Life (in soil) (days)</th>
<th>Half-Life (in water) (days)</th>
<th>Half-Life (in air)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acephate</td>
<td>790,000</td>
<td>2 to 2.7</td>
<td>&lt; 2</td>
<td>n/a</td>
<td>50 d</td>
</tr>
<tr>
<td>Chlorpyrifos</td>
<td>1.4</td>
<td>360 to 31,000</td>
<td>7 to 120</td>
<td>3.5 to 20</td>
<td>4.2 hr</td>
</tr>
<tr>
<td>Malathion</td>
<td>145</td>
<td>93 to 1,800</td>
<td>1 to 17</td>
<td>1.65 (pH 8.16)</td>
<td>n/a</td>
</tr>
<tr>
<td>Pyrethroid</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permethrin</td>
<td>0.0055</td>
<td>100,000</td>
<td>11.6 to 113</td>
<td>1</td>
<td>n/a</td>
</tr>
<tr>
<td>Phenothrin</td>
<td>0.0097</td>
<td>125,000 to 141,000</td>
<td>1-2 (dry)</td>
<td>6.5 (in light)</td>
<td>38.4 min to 1.2 hr</td>
</tr>
<tr>
<td>Resmethrin</td>
<td>0.0379</td>
<td>100,000</td>
<td>30</td>
<td>&gt; 89</td>
<td>20 to 90 min</td>
</tr>
</tbody>
</table>

Toxicity

The toxicity of a chemical is determined through three routes of exposure: dermal absorption, inhalation, and oral. Toxicity is measured in LD₅₀ for dermal absorption and oral, and LC₅₀ for inhalation. LD₅₀ and LC₅₀ are the median lethal dose and concentration, respectively, which are expected to kill 50% of the population. LD₅₀ is measured in mg pesticide per kg body weight. LC₅₀ is measured in mg pesticide per liter of air or in ppm. These numbers are used to quantify how toxic a chemical is, and compare toxicity between chemicals (Stenerson, 2004).

Experiments are typically done with rats for inhalation and oral studies, and rabbits for dermal absorption. These species are used to estimate acute toxicity of chemicals to humans with a safety factor of 10,000 or 1,000 (Stenerson, 2004).

Table 2 is the common toxicity classification of substances. Based on the oral LD₅₀ of a chemical, its toxicity can be classified as extremely, very, moderately, weakly toxic, practically nontoxic, or nontoxic.
Table 2: Toxicity Classification of Substances.
(source: Stenerson, 2004)

<table>
<thead>
<tr>
<th>Toxicity Class</th>
<th>LD$_{50}$ (mg/kg)</th>
<th>Examples, LD$_{50}$ (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Extremely toxic</strong></td>
<td>&lt;1.0</td>
<td>Botulinum toxin, 0.00001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aldicarb, 1.0</td>
</tr>
<tr>
<td><strong>Very toxic</strong></td>
<td>1 - 50</td>
<td>Parathion, 10</td>
</tr>
<tr>
<td><strong>Moderately toxic</strong></td>
<td>50 - 500</td>
<td>DDT, 113 - 118</td>
</tr>
<tr>
<td><strong>Weakly toxic</strong></td>
<td>500 - 5,000</td>
<td>NaCl, 4,000</td>
</tr>
<tr>
<td><strong>Practically nontoxic</strong></td>
<td>5,000 - 15,000</td>
<td>Glyphosate, 5,600 Ethanol, 10,000</td>
</tr>
<tr>
<td><strong>Nontoxic</strong></td>
<td>&gt;15,000</td>
<td>Water</td>
</tr>
</tbody>
</table>

For comparison, Table 3 shows the acute toxicity categories for pesticide products from the Code of Federal Regulations excluding eye and skin irritation. Unlike Table 2, the Code of Federal Regulations categorizes pesticides into four categories as opposed to six. In addition, the Code of Federal Regulations distinguishes toxicity based on the routes of exposure - oral, dermal, and inhalation. Category I according to the Code of Federal Regulations encompasses extremely toxic and very toxic pesticides, category II are moderately toxic, category III is weakly toxic, and category IV is practically nontoxic and nontoxic.

Table 3: Acute Toxicity Categories for Pesticide Products.
(source: EPA, 2006a)

<table>
<thead>
<tr>
<th>Hazard Indicators</th>
<th>Oral LD$_{50}$ (mg/kg)</th>
<th>Dermal LD$_{50}$ (mg/kg)</th>
<th>Inhalation LC$_{50}$ (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>&lt; 50</td>
<td>&lt; 200</td>
<td>&lt; 0.2</td>
</tr>
<tr>
<td>II</td>
<td>&gt; 50 - 500</td>
<td>&gt; 200 - 2,000</td>
<td>&gt; 0.2 - 2</td>
</tr>
<tr>
<td>III</td>
<td>&gt; 500 - 5,000</td>
<td>&gt; 2,000 - 20,000</td>
<td>&gt; 2 - 20</td>
</tr>
<tr>
<td>IV</td>
<td>&gt; 5,000</td>
<td>&gt; 20,000</td>
<td>&gt; 20</td>
</tr>
</tbody>
</table>

Table 4 shows the acute mammalian toxicity of three common organophosphate and pyrethroid pesticides. The dermal and inhalation toxicities, according to the Code of Federal Regulations, all fall under Category III. The oral toxicity of these pesticides is mostly Category III with the exception of chlorpyrifos, permethrin, and phenothrin which are Category II, IV, and IV respectively.
Table 4: Acute Mammalian Oral, Dermal, and Inhalation Toxicity of Three Common Organophosphates and Three Common Pyrethroids.

<table>
<thead>
<tr>
<th></th>
<th>Oral LD$_{50}$ (mg/kg)</th>
<th>Dermal LD$_{50}$ (mg/kg)</th>
<th>Inhalation LC$_{50}$ (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OP</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acephate</td>
<td>1,494</td>
<td>&gt; 2,000</td>
<td>12.1</td>
</tr>
<tr>
<td>Chlorpyrifos</td>
<td>199</td>
<td>&gt; 2,000</td>
<td>5.4</td>
</tr>
<tr>
<td>Malathion</td>
<td>4,810</td>
<td>&gt; 2,000</td>
<td>7.9</td>
</tr>
<tr>
<td><strong>Pyrethroid</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permethrin</td>
<td>&gt; 5,000</td>
<td>&gt; 5,000</td>
<td>2.1</td>
</tr>
<tr>
<td>Phenothrin</td>
<td>&gt; 5,000</td>
<td>&gt; 2,000</td>
<td>2.3</td>
</tr>
<tr>
<td>Resmethrin</td>
<td>2,600</td>
<td>&gt; 2,000</td>
<td>2.6</td>
</tr>
</tbody>
</table>

**Regulations**

The Environmental Protection Agency (EPA) has multiple laws and regulations to control the use of pesticides in the United States. These laws and regulations determine the allowable residual levels found in foods and drinking water, as well as the allowable contamination level of surface water bodies in the environment. There are two main federal statutes that authorize the EPA to closely monitor the pesticides industry. They are the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) of 1947 and the Federal Food, Drug, and Cosmetic Act (FFDCA) of 1938. The Food Quality Protection Act (FQPA) of 1996, the Clean Water Act of 1948, and the Safe Drinking Water Act of 1974 are also very influential in the monitoring of pesticides in the United States. Under these acts the EPA can prohibit the use of a pesticide if there is enough evidence that suggests the pesticide is an environmental or health risk. The EPA works closely with the Food and Drug Administration (FDA) and the United States Department of Agriculture (USDA) to ensure safe levels of pesticide residues in foods through monitoring and testing (CropLife America, 2012; EPA, 2012).

**Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)**

FIFRA allows federal control of all the sales, distributions, and uses of pesticides in the United States. This act ensures the proper registration of all pesticides through the USDA and the EPA. Proper registration assures appropriate labeling and guarantees that the product will not cause careless harm to the environment. FIFRA monitors the use of pesticides by making sure the product’s use is consistent with that of the labeling. FIFRA was first amended in 1972 through the Federal Environmental Pesticide Control Act (FEPCA). FQPA was a crucial amendment to this act, changing the law to focus on the protection of human health and the environment rather than pesticide efficiency. These amendments authorized the EPA to strengthen their registration process, and to help acknowledge banned and unregistered pesticides as health risks. FIFRA does not have full authority over state, tribal, or local law; therefore state, tribal, and local governments can have their own laws to regulate the use of pesticides (EPA, 2012a).
Federal Food, Drug, and Cosmetics Act (FFDCA)

FFDCA allows the establishment of maximum pesticide residue level in foods. With this act, the EPA is allowed to seize the production or use of a pesticide if the residue level found in the food is above the tolerance level. The EPA defines a product as safe under the “reasonable certainty that no harm will result from aggregate exposure to the pesticide residue” (EPA, 2012g). To ensure safety, the EPA considers the toxicity of a pesticide product, its ability to break down naturally in the environment, exposure levels in foods, and special risks to infants and children. If a pesticide is found to have no health risks under any circumstances, the EPA may grant an exemption to a maximum residue level. This act was amended in 1954 and then again in 1958 through the Delaney Clause. The clause specifies that all processed foods must be free of any pesticide that is considered to be a carcinogen. A carcinogen can be classified as a substance that is capable of causing cancer (EPA, 2012g).

Food Quality Protection Act (FQPA)

The FQPA, signed on August 3, 1996 by President Bill Clinton, amended FFDCA and FIFRA to set maximum pesticide residue levels on all raw or processed foods. It also amended these acts to focus on all health risks instead of only focusing on carcinogens. FQPA takes the risks of infants and children to a much higher standard. If a pesticide is found to not meet the requirements of the act the pesticide must be removed from use completely. Some of the efforts this act works to establish are as follows:

- mandating a single, health-based standard for all pesticides in all foods;
- providing special protections for infants and children;
- expediting approval of safer pesticides;
- creating incentives for the development and maintenance of effective crop protection tools for American farmers; and
- requiring periodic re-evaluation of pesticide registrations and tolerances to ensure that the scientific data supporting pesticide registrations will remain up to date in the future.

Figure 16 is a chart that shows the decision making process that the Environmental Protection Agency goes through to regulate the use of pesticides in the United States. It includes input from FIFRA and FQPA as noted above (EPA, 2012i).
Clean Water Act (CWA)

The CWA sets regulations for discharges of pollutants into all United States waters and regulates the quality standards for all United States surface waters. The CWA was originally called the Federal Water Pollution Control Act. The name change came in 1972 when the act was amended to reorganize and expand on the water standards it upholds. Through the CWA, the EPA has set wastewater standards and wastewater discharge standards for industries. This act also sets water quality standards for all contaminants in surface water bodies in the United States. The CWA also makes it illegal to discharge pollutants into water bodies unless the discharge source has a permit. The permit program is controlled through the National Pollutant Discharge Elimination System (NPDES). The CWA requires all industrial, municipal, and other facilities to obtain a permit through NPDES if they discharge into any surface waters. The discharge of pollutants without a permit was made illegal to protect aquatic life and to ensure human health. High doses of pesticides in water bodies can pollute the water and the environment, making CWA pertinent to the application of pesticides (EPA, 2012f).

Safe Drinking Water Act (SDWA)

The SDWA protects the quality of drinking water and its sources in the United States. Any source that is even potentially a drinking water source is protected through this act. Unlike the CWA, the SDWA protects groundwater as well as surface waters. The 1996 amendments to the SDWA allow the EPA to develop standards to protect tap water sources through a risk and cost assessment approach. This act also sets standards to protect underground drinking water sources from underground injections of fluids. This act also sets maximum contaminant levels
(MCL) in drinking water. Many pesticides are made up of organic chemicals that have a set MCL.

Laws and Regulations in Massachusetts

Massachusetts regulates pesticides under the Massachusetts Pesticide Control Act (MPCA). This law was introduced in 1978. This law was enacted in order to modify Massachusetts laws on pesticides to ensure compliance with the federal requirements of registration and certification of pesticides. The MPCA was created using the guidelines of the FIFRA along with input from the other federal laws stated above. This law gives the Massachusetts Department of Agricultural Resources (MDAR) control of pesticide regulations. The Pest Management branch of the MDAR carries out the managerial actions and responsibilities of the MPCA. The MPCA also created the Massachusetts Pesticide Board, which is a thirteen member committee in the MDAR focused on the control of pesticides in Massachusetts. The Board has representatives from the MDAR, the Department of Environmental Protection, the Division of Food and Drugs, the Department of Fish and Game, the Department of Conservation and Recreation, the Department of Public Health, farmers in Massachusetts, commercial pesticide applicators, the environmental community, the medical community, and Massachusetts citizens. The Board is responsible for advising the commissioner of the MDAR in the application and administration of the MPCA. The full list of regulations and elements of the MPCA can be found in full detail in the Code of Massachusetts Regulations under Chapter 333 (Corte-Real, 2012).

Integrated Pest Management

Integrated Pest Management (IPM) is an approach to pest control which relies on a combination of cultural, mechanical, biological, and chemical practices to damage done by pests while being economical and minimizing hazards to people and the environment (EPA, 2013; Texas A&M University, 2013). IPM, according to the Massachusetts Mosquito Control Annual Operations Report from 2007 to 2011 (MA OEEA, 2007-2013), is defined 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.” In short, IPM is the use of multiple practices for pest control to minimize the use of chemical pesticides so that the risk to harming both people and the environment are minimized.

The inherent risks to the use of pesticides, such as harm to nontarget organisms and contamination of the environment, can be mitigated by using non-chemical or less chemically intensive pest control methods in lieu of pesticides.
Methodology

The objective of this project was to create a decision tree by which county and town officials can make decisions on the best mosquito management options. To meet this objective, the following methods were used:

1. Research the Mosquito Control Projects (MCPs) in Massachusetts and their current methods of mosquito management.
2. Research Integrated Pest Management (IPM) and alternative practices to spraying for adult mosquitos.
3. Create a decision tree that can be used by county or town officials to evaluate the best practices for their county or town.

Details on each of these methods are provided below.

Mosquito Control Project Research

MCPs in Massachusetts are organized by county; thus there are nine MCPs in Massachusetts. Unstructured in-person interviews were conducted with employees from two of the MCPs to learn more about the MCPs, how they operate, and Integrated Pest Management methods used. The first interview was conducted with David Henley, Superintendent from East Middlesex (EM) Mosquito Control Project (MCP), and the second interview was conducted with Ellen Bidlack, Entomologist for Plymouth County (PC) MCP. EM was chosen because they have the highest WNV infection rate in the state and PC has the highest EEE infection rate in the state. Both interviews were completed in December 2012. A list of interview questions and topics can be found in Appendix B.

At the conclusion of the interviews, Massachusetts Mosquito Control Annual Operations Reports (MMCAORs) were obtained. The reports were accessed from the Massachusetts State Reclamation and Mosquito Control Board webpage (MA OEEA, 2013). Data gathered included budgets for each of the MCPs and information on use of Integrated Pest Management methods. Data regarding which pesticides were used, the quantity of pesticides applied, and the costs of these pesticides were analyzed for all nine MCPs in the state. Disease rates were also analyzed for all of the counties to determine which counties have the highest rates of WNV and EEE. The budgets of each MCP were then compared to the number of cases of EEE and WNV in the state.

The next section of research focused on the IPM methods of each MCP. Data were collected from the MMCAORs on IPMs which IPM methods each MCP uses, how often each IPM is used in each MCP, and how each IPM is applied. Current larviciding and adulticiding methods were researched concurrently to compare IPM methods with larviciding and adulticiding.

Mosquito Management Research

Research was conducted on chemical and non-chemical mosquito management options (MMOs). The main objective was to collect data for a decision tree to help choose the best option for a particular region. Therefore, costs of IPM options, risks of IPM options, regulations on IPM options, and effectiveness of IPM options were needed to develop the decision tree. The research was primarily driven through internet searches, websites, journals, and publications on the internet. Search engines such as Google Scholar, Google, and Bing were used to search for keywords related to IPM. The keywords searched included mosquito borne diseases such as EEE.
and WNV, chemicals in pesticides such as pyrethroids and organochlorine, pesticide regulations, pesticide risks and toxicity, and IPM practices. IPM topics included mosquito magnets, *Gambusia affinis*, *Bacillus thuringiensis israelensis* (BTI), *Bacillus sphaericus*, truck spraying, and aerial spraying. A list of keywords used to search can be found in Appendix C. Most searches included reports and websites published by the U.S. Environmental Protection Agency and Commonwealth of Massachusetts.

**Decision Tree**

The decision tree was intended to help county or town officials choose which mosquito management options would best fit their Integrated Pest Management (IPM) plan in Massachusetts. The tree was made as a classification tree which deals with the prediction of a discrete category (Shalizi, 2009). The decision tree was designed in a top-down fashion and was drawn using a GTK+ based diagram creation program Dia v0.97.2.

Attributes in the decision tree were chosen based on research, and interviews. Endpoints, or leaf nodes of the decision tree, were the mosquito management options that were researched. These endpoints were mosquito magnets, *Gambusia affinis*, BTI, *Bacillus sphaericus*, truck spraying, aerial spraying, and source reduction.
Results

The objective of this project was to create a decision tree to help decide the best mosquito management options for a specific county or town. Data were collected from MCPs in Massachusetts; research on IPM, MCP budgets, and truck and aerial spraying was conducted. The results were used to develop a decision tree focusing on mosquito management options.

Mosquito Control Project

Research and Interviews

Interviews were conducted with Ellen Bidlack of the Plymouth County Mosquito Control Project and David Henley of the East Middlesex Mosquito Control Project. The interviews were conducted to obtain quantitative and qualitative information about how two different MCPs in Massachusetts control mosquito populations. Topics discussed ranged from funding to control methods for larvicides.

Figure 17 shows the nine Mosquito Control Projects (MCPs) in Massachusetts and which towns each MCP provides services for. The nine MCPs are Berkshire County, Bristol County, Cape Cod, Central Massachusetts, East Middlesex, Norfolk County, Northeast Massachusetts, Plymouth County, and Suffolk County. The MCPs are located primarily in the eastern half of Massachusetts which is where EEE and WNV are most prevalent. Not all towns receive services from MCPs. It was not discovered as to why only certain towns and counties receive services from MCPs and others do not.

Figure 17: Mosquito Control Projects and Districts in Massachusetts.
(source: MA OEEA, 2013)
MCPs get their funding one of two ways. The MCP can either propose a budget to the state and the funding comes from the state, or the funding can come from the towns via voluntary appropriations. Plymouth County (PC) MCP is an example of a project that receives funding from the state. They propose a budget to the state depending on what the MCP estimates they will need to conduct operations, which the state will either accept or lower. East Middlesex (EM) MCP receives funding from towns via voluntary appropriations. In other words, towns decide what services and how much of those services they want for their area as opposed to state funding where MCPs decide what services are needed and the MCP proposes this to the state. Thus, the advantage of town funding is that towns have more control over mosquito control decisions (Henley, 2012). The advantage of state funding is that the budgets are typically greater then town funding. For example, in 2012, PC had a budget of $1,469,658 while EM had a budget of $641,987 (MA OEEA, 2012). PC services 28 towns while EM serves 25. PC serves only three more towns than EM, but receives more than twice the funding.

Both MCPs interviewed treat catch basins, which are defined as any areas that collect water. Catch basins provide a mosquito-breeding environment. Urban areas have more artificial catch basins than rural areas. Examples of artificial catch basins are blocked storm drains or bird baths. EM has roughly 65,000 catch basins to treat while PC has less than 10,000. Treating all the catch basins in EM is made difficult by the number of catch basins and limited funding.

Larviciding is also handled differently in each MCP. EM largely uses BTI and *Bacillus sphaericus*. PC uses BTI but will also buy *Gambusia affinis* fish from suppliers for certain types of swamps and wetlands. This is due to the difference in mosquito types in the MCPs. Even though both MCPs use truck-mounted spraying to control adult mosquito populations; it is far more effective in PC than it is in EM according to the MCPs. The primary mosquito in the East Middlesex region is the *Culex pipiens*, which lives high in the trees and is often out of range from the ground sprayers. In addition, EM has 3 truck-mounted sprayers, compared to 15 truck mounted sprayers with nearly double the staff in PC (Bidlack, 2012; Henley, 2012). This allows PC to sufficiently cover areas with a highly dense population of mosquitoes better than EM. The type of mosquito that resides in PC also contributes to the ability of that county to treat the area with truck-mounted spraying. The primary mosquito living in Plymouth County is the *Coquillettidia perturbans*. Because the mosquito breeds in the roots of cattails, BTI larviciding will not kill this mosquito. *G. affinis* was introduced to these swamp areas to eat the cattails and *Cq. perturbans*. Currently, East Middlesex does not have a solution for this type of mosquito other than truck-mounted spraying (Henley, 2012).

Mosquito Control Project Budgets

Figure 18 shows the budgets from every MCP in Massachusetts from 2007 to 2012, compiled from the Massachusetts Mosquito Control Annual Operations Reports (MMCAORs). With the exception of Berkshire, East Middlesex, and Suffolk, the MCPs each have a budget of around 1.5 million USD per year. From 2007 to 2012, most MCPs have relatively stable budgets (e.g. East Middlesex, Norfolk, and Suffolk). Bristol County experienced the steepest decrease in budget from 2009 to 2011, with 1.71 million USD in 2009 and 1.14 million USD in 2011, a 0.57 million USD decline (MA OEEA, 2007-2012). Details on the MCP budgets are shown in Appendix D.
Figure 18: Budgets from 2007 to 2012 from all Mosquito Control Projects in Massachusetts (source: MA OEEA, 2007-2012)

Figure 19 shows the number of reported and probable cases of EEE and WNV from 2007 to 2012. The number of cases of EEE in Massachusetts remained steady at 0 or 1 cases per year, with the exception of 2012 where there were 7 cases. For WNV, the number of cases varied between 0 to 7 cases per year from 2007 to 2011; however, in 2012, there were 26 cases of WNV (CDC, 2011; CDC, 2012f; USGS, 2012a; USGS, 2012b). According to David Henley, Superintendent of East Middlesex MCP (2012), the high rates of EEE and WNV in 2012 were due to the abnormally warm winter of 2011 which prevented catch basins from freezing, and led to earlier mosquito breeding times. There does not seem to be relationship between MCP budget and number of cases of EEE and WNV.
Figure 19: Number of Confirmed and Probable Cases of EEE and WNV in Massachusetts from 2007 to 2012.
(data compiled from CDC, 2011; CDC, 2012f; USGS, 2012a; USGS, 2012b)

The percent change in budgeting for each MCP from 2007 to 2012 is shown in Table 5. The table does not account for inflation. Berkshire County experienced the highest percent change in budgeting with 51%. Five out of nine MCPs have a percent change ranging from 0 to 23% while three out of nine MCPs have a percent change in budgeting that is negative (MA OEEA, 2007-2012). Data and calculations are shown in Appendix D.

Table 5: Percent Change in Budgeting for each Mosquito Control Project in Massachusetts from Fiscal Year 2007 to 2012.
(source: MA OEEA, 2007-2012)

<table>
<thead>
<tr>
<th>MCP</th>
<th>Budget (USD, in millions)</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berkshire</td>
<td>0.15</td>
<td>0.22</td>
</tr>
<tr>
<td>Bristol</td>
<td>1.48</td>
<td>1.20</td>
</tr>
<tr>
<td>Cape Cod</td>
<td>1.41</td>
<td>1.66</td>
</tr>
<tr>
<td>Central</td>
<td>1.47</td>
<td>1.80</td>
</tr>
<tr>
<td>East Middlesex</td>
<td>0.57</td>
<td>0.64</td>
</tr>
<tr>
<td>Norfolk</td>
<td>1.27</td>
<td>1.48</td>
</tr>
<tr>
<td>Northeast</td>
<td>1.46</td>
<td>1.51</td>
</tr>
<tr>
<td>Plymouth</td>
<td>1.61</td>
<td>1.47</td>
</tr>
<tr>
<td>Suffolk</td>
<td>0.23</td>
<td>0.23</td>
</tr>
</tbody>
</table>

Integrated Pest Management Services

The Massachusetts Mosquito Control Annual Operations Reports (MMCAOR) lists 7 IPM services the MCPs provide along with an “Other” category for services outside of the eight. These 7 services are larval mosquito control, adult mosquito control, source reduction, ditch maintenance, open marsh water management, adult mosquito surveillance, and education (MA OEEA, 2007-2012).
The goal of the larval and adult mosquito control services is to reduce the risk of EEE and WNV and to lower nuisance levels by suppressing larval mosquito populations by the use of pesticides. MCPs begin their larval mosquito control in spring (March through April), and their adult mosquito control in summer (May through June). Both mosquito control services end in the fall (September through October). Pesticides for larval mosquito control are typically ground applied and include BTI, *B. sphaericus*, and methoprene. Table 6 shows all the larvicides used in 2012 by all MCPs in Massachusetts and their main ingredient. The typical dosage for larvicides is about one 7 or 10 gram packet per basin or 50 square feet. The minimum criterion for a basin to be eligible for larvicide application is at least one larva per ten dips (MA OEEA, 2007-2012). A larva dip performed using cup attached to a 10 foot pole, which the operator dips into a water body and the number of larva in the cup is counted (O’Malley, 1995). For MCPs, the minimum requirement for a catch basin to have treatment is 1 larva per ten dips (Henley, 2012).

Table 6: List of All Reported Larvicides used by Mosquito Control Projects in 2012.

<table>
<thead>
<tr>
<th>Active Ingredient</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>B. sphaericus</em></td>
<td>Spheratax SPH WSP</td>
</tr>
<tr>
<td></td>
<td>VectoLex WSP</td>
</tr>
<tr>
<td><em>B. sphaericus</em> &amp; BTI</td>
<td>FourStar 45 Day Briquets</td>
</tr>
<tr>
<td></td>
<td>FourStar 90 Day Briquets</td>
</tr>
<tr>
<td></td>
<td>VectoMax G</td>
</tr>
<tr>
<td></td>
<td>VectoMax WSP</td>
</tr>
<tr>
<td>BTI</td>
<td>Aquabac G</td>
</tr>
<tr>
<td></td>
<td>AquabacXT</td>
</tr>
<tr>
<td></td>
<td>BTI Briquets</td>
</tr>
<tr>
<td></td>
<td>Teknar HP-D</td>
</tr>
<tr>
<td></td>
<td>VectoBac 12AS</td>
</tr>
<tr>
<td></td>
<td>VectoBac G</td>
</tr>
<tr>
<td></td>
<td>VectoBac CG</td>
</tr>
<tr>
<td>Methoprene</td>
<td>Altosid XR Briquet</td>
</tr>
<tr>
<td></td>
<td>Altosid Pellets WSP</td>
</tr>
<tr>
<td></td>
<td>Altosid Pellets</td>
</tr>
<tr>
<td>Oil</td>
<td>BVA2</td>
</tr>
<tr>
<td></td>
<td>Cocobear</td>
</tr>
<tr>
<td>Other</td>
<td>Agnique MMF(^1)</td>
</tr>
<tr>
<td></td>
<td>Agnique MMF G PAK 35(^1)</td>
</tr>
</tbody>
</table>

\(^1\)Ethoxylated Alcohol
\(^2\)poly(oxy-1,2-ethanediyl,.alpha.-((C16-20 branched and linear alkyl)).omega.-hydroxyl
The three most common adulticides used in 2012 by MCPs are, in alphabetical order, Anvil 10+10, DUET, and Suspend SC. All three of these adulticides are synthetic pyrethroids (Anvil 10+10 MSDS, 2009; DUET MSDS, 2008; Suspend SC MSDS, 2007). Table 7 shows a list of all the MCPs and which adulticides they reported using in 2012 for the three most common adulticides reported in the MMCAOR. Adulticides are typically ground applied at ultra-low volumes of 0.62 or less fluid ounces per acre. The range of frequency for pesticide application to suppress adult mosquito population is once every 1-3 weeks and never shorter than 24 hours apart. EM reported spraying residential areas anywhere from 1 to 4 times a month in 2012 (Henley, 2013). Interestingly, Cape Cod MCP is the only MCP that does not have an adult mosquito control service (MA OEEA, 2012; Sakolsky, 2013).

Table 7: Pesticides Used in 2012 for Adult Mosquito Control by Mosquito Control Project. (MA OEEA, 2012)

<table>
<thead>
<tr>
<th>MCP</th>
<th>Anvil 10+10</th>
<th>DUET</th>
<th>Suspend SC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berkshire</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Bristol</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cape Cod</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>East Middlesex</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Norfolk</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Northeast</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Plymouth</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suffolk</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

All MCPs provide the following IPM services to their towns and cities: source reduction, ditch maintenance, adult mosquito surveillance, and education. The source reduction service is designed to reduce the number of potential breeding sites for mosquitoes. Source reduction is done by removing tires and turning containers upside down. Source reduction is typically conducted year round for MCPs. The ditch maintenance program is designed to restore the proper flow of water by clearing silt, vegetation and debris (Lawson, 2013). The time frame where ditch maintenance is used is typically fall through spring. Some MCPs, such as Northeast Massachusetts MCP, perform ditch maintenance year round (MA OEEA, 2012; Mehaffey et al., 2013).

Adult mosquito surveillance is used to monitor numbers of human-biting mosquitoes, to assess the presence and level of EEE and WNV, to determine where EEE and WNV are present, and to determine the efficacy of larval and adult mosquito control services. Monitoring of mosquitos, EEE and WNV is conducted between June and October when human cases of EEE and WNV are most likely to occur. Preliminary monitoring for the number of human-biting mosquitoes and level of EEE and WNV is done with a combination of gravid traps, resting boxes, Centers for Disease Control light traps, American Biophysics Corporation light traps, and New Jersey light traps with and without carbon dioxide. It is up to the MCP to decide which light traps should be used and where they are located. Table 8 shows the reported average number of catch basins submitted per week in the summer of 2012 for adult mosquito surveillance. For areas that have been treated with pesticides, monitoring is done with larva dippers. Dippers are
used in catch basins throughout the larval and adult mosquito control services (MA OEEA, 2012).

Table 8: Reported Average Number of Catch Basins Submitted Weekly for Adult Mosquito Surveillance in 2012 by Mosquito Control Projects. (MA OEEA, 2012)

<table>
<thead>
<tr>
<th>MCP</th>
<th>Average Catch basins Submitted Weekly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berkshire</td>
<td>10</td>
</tr>
<tr>
<td>Bristol</td>
<td>25</td>
</tr>
<tr>
<td>Cape Cod</td>
<td>15</td>
</tr>
<tr>
<td>Central</td>
<td>50 to 75</td>
</tr>
<tr>
<td>East Middlesex</td>
<td>22.5</td>
</tr>
<tr>
<td>Norfolk</td>
<td>30+</td>
</tr>
<tr>
<td>Northeast</td>
<td>70</td>
</tr>
<tr>
<td>Plymouth</td>
<td>60</td>
</tr>
<tr>
<td>Suffolk</td>
<td>12.5</td>
</tr>
</tbody>
</table>

Only four MCPs have an open marsh water management program (OMWM). MCPs only have OMWM programs if the towns and cities they cover have salt marshes (Henley, 2013). The MCPs that have an OMWM are Bristol County, Norfolk County, Northeast, and PC. The goal of the OMWM is to create greater access to mosquito-eating fish such as *Gambusia affinis* to hinder mosquito larval development and reduce the need for pesticides (MA OEEA, 2012).

The education, outreach and public relations programs vary from MCP to MCP and year to year. In general, MCPs participate in radio and television interviews, and attend meetings with city councils and boards of health to discuss mosquito related issues. All MCPs also have a website they maintain to provide general information about mosquitoes, spray schedules, safety information, procedures, and towns covered (MA OEEA, 2012). A list of mosquito control services and which MCPs provide those services are shown in Appendix D.

**Mosquito Management Options**

The different types of mosquito management options have different advantages and disadvantages. Some mosquito management options, such as truck and aerial spraying, involve the use of pesticides. Other mosquito management options, such as mosquito magnets are only effective for personal small scale use. As well, some mosquito management options are not allowed in certain areas. Detailed results of the mosquito management options researched are provided below.

*Mosquito Magnets*

Mosquito magnets are a mosquito management option that use mosquito attractants to trap mosquitoes. Mosquito magnets have increased in efficiency in the past few years. Specific example of a mosquito magnet would be a propane-powered mosquito trap. These traps use counter flow technology along with catalytic combustion to produce mosquito attractants. These attractants include carbon dioxide, water vapor, and heat. Some of these traps have a thermoelectric generator used to convert heat into electricity used to power the mosquito trap. Another type of mosquito magnet being used is the counter flow geometry (CFG) mosquito trap.
These magnets use odor technology to simulate human smells to attract mosquitoes. CFG traps have shown higher efficiencies than Portable Propane (PP) mosquito traps. Some other types of mosquito magnets include light traps and sound traps (Kline, 2002).

The propane powered mosquito magnets available on the market today offer about an acre of coverage during usage. This is a good amount of space for an independent home owner but it may not be the best MMO on a scale the size of Massachusetts (Woodstream Corporation, 2013).

Figure 20 shows six different types of mosquito magnets that have been used to control pests. The Professional (PRO) trap in Figure 20A is powered by a 6-V, 10 ampere-hour rechargeable gel-cell battery. The CFG trap uses two fans to provide counterflow at the trap entrance. The CFG trap, shown in Figure 20B, is powered by a 12-V DC battery. The fans create a plume of CO₂ enriched air that comes from a compressed gas cylinder. The counterflow technology causes any mosquito in the vicinity to be sucked into the trap if they have a flight speed of 3.5 m/s or less. Figure 20C shows the Propane-1 mosquito magnet trap that is very similar to the CFG trap. The Propane-1 produces CO₂, heat, and water vapor used to attract mosquitoes. The attractants are produced though external catalytic combustion of propane and the excess heat is used to produce electricity to power the two fans. The Portable-CO₂ (PC) trap, shown in figure 20D, uses counterflow technology to attract mosquitoes as well. It combines the same techniques used in the CFG trap and the propane-powered traps. Figure 20E shows a Portable Propane (PP) trap. This trap is similar to the PC trap however it uses a catalytic combustion unit to convert propane to CO₂, water vapor, and heat. The trap also has a thermoelectric generator, which uses heat to produce electricity, which allows this type of trap to be run unattended for twenty days on a standard barbecue grill propane tank. This type of trap has the advantage of being able to be placed in an area of high mosquito density rather than placed next to a convenient power supply. The Mosquito Magnet Beta-1 (MMB-1) trap uses a more efficient catalytic converter along with a redesigned durable housing unit replacing the old metal style housing units. This trap was briefly released on the market in 1999 under the name the Counterflow 2000™ as shown in Figure 20F (Kline, 2002).
Some other traps not shown in Figure 20 include the Mosquito Magnet Beta-2 (MMB-2), the Mosquito Magnet (MM), and the Nicosia Device. The MMB-2 trap was a modified version of the MMB-1. The MMB-2 utilizes an outflow tube to entrain octenol in the attractant plume rather than having an octenol packet near the trap entrance like in the MMB-1. The MM trap is a commercially available version of the MMB-1 trap. The power generator was modified for easy
field service and higher reliability. The Nicosia Device is an experimental mosquito trap that utilizes pulsed liquid technology to produce an acoustic signal. The trap can attract mosquitos without the use of CO₂; however for maximum efficiency the combination of CO₂ and acoustic signals is highly recommended. Once captured, the trap uses an electrocution grid to kill the mosquitos. It has been shown that mosquito powered traps can capture over 70% of host seeking mosquitos released into a confined space such as a testing cage. These types of propane traps cost from $300 to $1000 (Woodstream Corporation, 2013).

Neither Plymouth County Mosquito Control Project nor East Middlesex Mosquito Control Project use mosquito magnets. This is because of the small scale of mosquito control offered by mosquito magnets. Mosquito magnets are meant as a personal mosquito management option, not for a county-wide Mosquito Control Project.

**Gambusia affinis**

*Gambusia affinis*, more commonly known as the Western Mosquitofish, is another mosquito management option. Some MCPs have intentionally introduced this species to non-native areas in an attempt to control mosquito populations. The fish help to control the larva and the adult forms of mosquitos by feeding on both of them (Masterson, 2013).

*G. affinis* is not the most effective form of pest management. The fish cannot survive in colder climates therefore they are not a good option for Massachusetts. The fish population would have to be restocked every spring for seasonal control. The species sells for about $0.50 to $1.50 per fish; however, the stocking rate is anywhere from 1,000 to 2,500 fish per acre (MD DOA, 2013; NJ Mosquito Control Association, 1996).

Although they are nonindigenous to Massachusetts, they have been introduced to Massachusetts waters in the past to try to help manage the mosquito populations. The PC currently uses *G. affinis* as a mosquito management option. They were introduced in many states across the United States as a safe and inexpensive way to combat malaria when the widespread malaria outbreak hit during and after World War II. Today they are used to control mosquito larva in place of insecticides. The introduction of *G. affinis* in some northern areas is limited due to its aggressive predatory behavior which can lead to the decline in native fish species, and a decline in the invertebrate predators. This decline in native mosquito eating fish species could cause an increase the number of mosquitos (USGS, 2013).

**Bacillus thuringiensis israelensis (BTI)**

When *Bacillus thuringiensis israelensis* (BTI) forms spores, the bacterium produces proteins that kill mosquito larva. The only way for the mosquito larva to be affected by the protein compounds is through ingestion. The proteins act as stomach poison in the larva and damages gut cells. BTI is a mosquito management option because the bacterium is highly selective. It is only lethal to mosquitos and the larva of some mosquito related flies. However, it is not effective in killing pupae, considering pupae do not feed. The most common form of BTI for pest control on the market is the Mosquito Dunk. The Mosquito Dunk is a doughnut-shaped float that can last up to 30 days in water (University of California, 2013).

BTI acts as an insecticide used on growing agricultural crops, harvested agricultural crops in storage, bodies of water, ornamentals, and around the home. The environmental effects of BTI use as an insecticide are still unknown. To date there are no known negative health effects associated with the use of BTI as an insecticide. However, BTI may produce toxins that may be harmful to non-target species. Therefore, the EPA is requiring “further testing of the bacterium
as an insecticide” (EPA, 1998). The EPA constructed a final toxin report for BTI and its persistence and ecological effects. The final report was made with the results of testing from 1997-2000. The report was then extended through May 2002. The findings in the report conclude that the use of BTI as pesticide shows no adverse health effects in any type of bacteria, fungi, plants, animals, vegetables, or any other non-target organisms. The report does warn however that BTI toxin could persist and accumulate in the environment, posing a hazard to non-target organisms (Manty, 2000). The target pests for BTI include lepidoptera, coleopteran, and dipteran insects. BTI can be applied through spraying, overhead irrigation systems, aerial application, or hand-held equipment (EPA, 1998). BTI can be purchased at less than $1 per pound therefore it is a rather inexpensive option.

Both the PC and the EM use BTI as a mosquito management option. Both MCPs concur that the use of BTI as a mosquito management option is quite effective. The use of BTI as a mosquito management option is not 100% effective; however, neither is the use of pesticides.

*Bacillus sphaericus*

*Bacillus sphaericus* is a very similar to BTI. The bacterium attacks mosquito larva through ingestion just like BTI. *B. sphaericus* can be found naturally in the environment in soil substrate. It is produced commercially through fermentation. It also has an extended residual activity in aquatic environments. One negative of *B. sphaericus* is that it is highly sensitive to light. High intensity light exposure can cause problems in the effectiveness of the bacterium. It is applied directly to water bodies to kill larva. *B. sphaericus* was registered as an active ingredient in 1991. As of 1999, there were two EPA registered pesticide products containing *B. sphaericus*. The cost of *B. sphaericus* is relatively high due to the cost of the production of the medium (EPA, 1999). *B. sphaericus* can be sold for retail at about $9.62 per pound (Natural Organic Warehouse, 2013).

Some of the use sites for *B. sphaericus* include water bodies such as swamps, rivers, lakes, and ponds. These are all areas where mosquitoes live and lay their eggs. Molecules that contain *B. sphaericus* are mixed with water and other substances and then sprayed into the target environment. There are several techniques used for spraying including aerial spraying and ground spraying. The sprayed pesticide containing *B. sphaericus* can remain active in the environment for up to four weeks after being sprayed. The half-life of the bacterium varies depending on dosage of spraying, environmental conditions, and species of mosquito (EPA, 1999).

Based on laboratory testing, no harmful effects are expected through the use of *B. sphaericus* as a pesticide as long as the pesticide is applied according to the label directions. However, non-fatal risks including skin and eye irritation may occur during spraying. Extensive laboratory testing also shows no harmful effects are expected through the application of *B. sphaericus* as a pesticide to non-target organisms (EPA, 1999).

*Truck & Aerial Spraying*

Spraying is currently the only widespread option used for controlling adult mosquitoes. The two methods for spraying are aerial and truck-mounted spraying. Aerial spraying uses an airborne vehicle, such as an airplane or a helicopter, to disperse adulticides. The advantage of using this method is that every type of mosquito would be affected, including the *Culex* mosquitoes, which primarily reside high in the trees. Helicopter spraying also allows for most of the target areas to be reached. EM is able to spray 95% of the targeted areas that the helicopter
flies over. The price of a single helicopter starts at $100,000 with operating costs of $80,000 per year (MA OEEA, 2007-2012). The operations costs include gas, chemicals, vehicle maintenance, and pay of the vehicle operator. The operations costs are so high because aircraft use jet fuel, not typical gasoline. Also the maintenance and pay of the vehicle operator are higher than a car or truck. The high costs coupled with Massachusetts steep restrictions on aerial spraying makes the use of the method a rare occurrence (Henley, 2012).

The other method of spraying is truck-mounted spraying. This method is less effective due to the limited range of the spraying. It is the most highly used method of spraying because of the cost effectiveness of the method and the general desire by citizens to use this type of mosquito control. A single truck with sprayer can cost $20,000 to $25,000 with an operating cost of $20,000 per year (MA OEEA, 2007-2012). The price of trucks combined with the demand for more truck-mounted spraying makes this method the most common type of spraying from all of the MCPs in Massachusetts.

**Decision Tree**

The decision tree was made to help town or county officials choose which mosquito management options are best for their region. In choosing a mosquito management option, there are several decisions that have to be made in order to determine the most suited option. A decision tree was chosen because it is a visual method for facilitating decision making. A classification tree was chosen because it utilizes categorical attributes to determine an outcome. Regression trees were not used because the results from the research and interviews did not have sufficient quantitative data for the attributes (Seabury, 2013; Ishwaran, 2011; StatSoft, 2002).

Attributes were chosen based on interviews with the East Middlesex (EM) and Plymouth County (PC) Mosquito Control Projects (MCPs), and research on the mosquito management options. The attributes were all used as decision nodes. Even though chance nodes are for when there are attributes that are out of control of the decision maker, they were not used because the attributes could not be quantified in terms of how frequent one branch is to another (Ishwaran, 2011).

The attributes used in the decision tree, from highest priority to lowest, were:

1. Presence of EEE and WNV;
2. Control of Mosquitos for Nuisance Reduction;
3. Type of Funding;
4. Type of Mosquito;
5. Target Mosquito Life Cycle;
6. Cost; and
7. Effectiveness (adult only), and Risk (larva only).

Figure 21 shows the decision tree for mosquito management in Massachusetts.
Figure 21: Decision Tree for Mosquito Management in Massachusetts
The top two attributes, presence of EEE and WNV and control of mosquitoes for nuisance reduction, have binary decisions of yes and no, and were used to see if any mosquito management options are needed. The third attribute, type of funding, was used to distinguish between state funding and town funding. In state funding, the MCPs decide on an integrated pest management plan for the town or county. In town funding, the town or county officials are able to choose which services are desired for their region (Henley, 2012).

The fourth attribute, type of mosquito, is split into three choices: Coquillettidia perturbans, Culex genera mosquitoes, and other. The type of mosquito to be controlled is important for deciding which mosquito management option will be most effective for population control. One of the primary mosquitos treated by PC is Cq. perturbans. These mosquitos, unlike others, have a tendency to reside in the roots of cattails. This makes using larvicides, which cannot reach the roots of cattails, ineffective (Bidlack, 2012). EM has a more urban area than PC. As such, EM deals with Culex genera mosquitoes which usually reside in the canopy of trees. This makes truck spraying ineffective against Culex genera mosquitoes as the sprayers do not reach the canopy of trees (Henley, 2012).

The fifth attribute is the target mosquito life cycle. This attribute has two choices: adult and larva. This attribute was chosen based on research on the mosquito management options which were designed to target a specific mosquito life cycle: adult or larva.

The sixth attribute is cost. There are costs associated with each mosquito management option which is split into high or low cost. It is important to note that costs can only be compared between endpoints under the same target mosquito life cycle attribute. So, the cost of truck and aerial spraying can be compared because they are under the adult branch of the target mosquito life cycle attribute. However, truck and aerial spraying cannot be compared with BTI or B. sphaericus because BTI and B. sphaericus are under the larva branch of the target mosquito life cycle attribute.

In addition to cost, there is a secondary attribute used to compare with cost for adulticides and larvicides. For adulticides, the secondary attribute is effectiveness. Aside from cost, the difference between truck and aerial spraying is how effective each option is. According to David Henley (2012), truck spraying, while having a relatively low capital and operating cost, is not as effective as aerial spraying because truck spraying cannot reach all areas and takes longer to treat a given area. Aerial spraying has a significantly higher capital and operating cost, but is able to cover a given area much more quickly than truck spraying. For larvicides, the secondary attribute is risk. Based on research, the difference between BTI and B. sphaericus, aside from cost, is the persistence of the toxins produced from each larvicide. The toxins produced from BTI have a higher persistence than B. sphaericus which puts beneficial species in water bodies at higher risk (Manty, 2000).

The endpoints of the decision tree are the mosquito management options. The mosquito management options used in the decision tree were mosquito magnets, Gambusia affinis, BTI, Bacillus sphaericus, truck spraying, aerial spraying, and source reduction. Aerial spraying was given an asterisk in the decision tree because, in Massachusetts, aerial spraying is used only in emergencies when the risk for EEE and WNV is high (Henley, 2012).
Conclusions

The Mosquito Control Projects (MCPs) in Massachusetts were researched and Plymouth County (PC) and East Middlesex (EM) were interviewed to determine information, such as budgets and types of mosquito control operations that each MCP uses.

There are nine MCPs in Massachusetts, with the greatest concentration of projects located in the eastern half of the state. This is the area of the state with the greatest number of cases for EEE and WNV. Not all of the towns and counties in Massachusetts receive services from MCPs for reasons unknown. MCPs can receive their funding from voluntary appropriations from the towns they serve, or the MCP can propose a budget to the state, which the state will either approve or lower (Henley, 2012). When the towns voluntarily appropriate money to an MCP, the towns decide the services they want to receive, while state funded MCPs decide which methods would best serve the towns (Bidlack, 2012). Both MCPs also treat catch basins. EM treats approximately 60,000 catch basins while PC only treats 10,000. Finally, larviciding is handled differently by EM and PC. EM uses BTI and B. sphaericus to treat wetlands while PC uses those as well as the G. affinis fish. This is due to difference in mosquito types between counties (Henley, 2012).

The budgets for every MCP in Massachusetts from 2007 to 2012 were compiled from the Massachusetts Mosquito Control Annual Operations Reports. From the nine MCPs in Massachusetts, six of them have a budget of around 1.5 million USD per year, two have budgets of around 0.2 million USD per year, and one has a budget of around 0.6 million USD per year (MA OEEA, 2007-2012). From 2007 to 2012 the annual budgets have remained relatively stable for most of the MCPs. The number of cases of EEE in Massachusetts has remained stable at 0 to 1 cases per year from 2007 to 2011, with the exception of 2012 in which there were 7 recorded cases. The number of cases of WNV per year from 2007 to 2011 remained between 0 and 7, while there were 26 recorded cases in 2012. Six of the nine MCPs had an increase in their annual budget in 2012, while these had a decrease. Thus, there does not seem to be a direct relationship between budgets and the number of EEE and WNV cases (MA OEEA, 2007-2012).

There are 7 IPM services that Massachusetts MCPs provide; they are larval mosquito control, adult mosquito control, source reduction, ditch maintenance, open marsh water management, adult mosquito control surveillance, and education. The larval and adult mosquito control differs in their seasonal control times (MA OEEA, 2007-2012). The two most common larvicides used are B. sphaericus and BTI. The three most common adulticides are Anvil 10+10, DUET, and Suspend SC (Anvil 10+10 MSDS, 2009; DUET MSDS, 2008; Suspend SC MSDS, 2007). Source reduction reduces the number of potential breeding sites for mosquitos, while ditch maintenance restores proper flow to an area by clearing silt, debris, and vegetation (Lawson, 2013). Adult mosquito surveillance monitors the number of human-biting mosquitos to assess the presence of EEE and WNV. Open marsh water management creates greater access for mosquito-eating fish such as G. affinis to hinder larval development (MA OEEA, 2012).

Mosquito magnets use mosquito attractants to trap mosquitos. A common example of a mosquito magnet is a propane-powered mosquito trap that produces mosquito attractants such as carbon dioxide, water vapor, and heat (Woodstream Corporation, 2013). Propane-powered mosquito magnets, cost between $300 to $1000 and offer about an acre of coverage (Woodstream Corporation, 2013). Thus these are a small scale mosquito control option meant for personal use.

Gambusia affinis is a non-native fish that is used to control mosquito populations by feeding on adult and larva mosquitos. The fish cannot survive in cold climates (Masterson,
and there use is limited as the fish has an aggressive predatory nature and will consume native fish species (USGS, 2013).

BTI is a bacterium that produces proteins that kill mosquito larva, when ingested. This management option is highly selective. The most common form of BTI for pest control is the Mosquito Dunk, which floats on water while releasing BTI into the water for mosquito ingestion (University of California, 2013). BTI has no known adverse health effects on non-target organisms or the environment (Manty, 2000). BTI is a rather inexpensive mosquito management option at less than $1 USD per pound. *Bacillus sphaericus* is very similar to BTI except that *B. sphaericus* is light sensitive and more expensive. *B. sphaericus* can be used in swamps, rivers, lakes, and ponds. It can remain in the environment for up to four weeks after being sprayed. Laboratory testing shows non-fatal risks to humans such as skin and eye irritation (EPA, 1999). Spraying is currently the most common and widespread form of mosquito management for adult mosquitos. The two methods used to spray pesticides are aerial and truck spraying. Aerial spraying is much more efficient than truck spraying, affecting every type of mosquito, but equipment starts at $100,000 with operating costs of $80,000 per year (MA OEEA, 2007-2012). Truck spraying is less effective due to the limited range of spraying, however it is the most popular method for spraying due to the cost effectiveness. A single truck with sprayer can cost $20,000 to $25,000 with an operating cost of $20,000 per year (MA OEEA, 2007-2012).

The decision tree was made as a design to help town or county officials choose which mosquito management is best for their region. The attributes used to develop the decision tree were chosen based on research of mosquito management options and interviews with EM and PC. The attributes in order of highest priority to lowest were: presence of EEE and WNV, control of mosquitos for nuisance reduction, type of funding, type of mosquito, target mosquito life cycle, cost, and finally effectiveness for adults and risks for larva. The endpoints of the decision tree are the mosquito management options. The endpoints include mosquito magnets, *G. affinis*, BTI, *B. sphaericus*, truck spraying, aerial spraying, and source reduction.
Recommendations

Based on the above conclusions, a set of recommendations were assembled to guide town, county, or state officials to choose the best mosquito management options for their governing territory.

Due to the limited time and scope of the research, the first recommendation is to investigate Cape Cod Mosquito (CC) Control Project (MCP) because they do not use adult mosquito control. Both EM and PC use adulticiding and larviciding. All of the MCPs in Massachusetts use a combination of adulticiding and larviciding except the CC. CC has had no cases of EEE between 2003 and 2012 and has had one case of WNV between 2001 and 2012. More research needs to be conducted on this MCP to discover the cause for lower EEE and WNV infection rate.

The next recommendation is aimed at state officials. **MCPs should receive proper funding for the type of environment and mosquito that needs to be treated.** Different environments attract different types of mosquitoes. Urban environments attract the *Culex pipiens* mosquito while wooded/wetland type environments with cattails, such as the environments that exist in PC, attract the *Coquillettidia perturbans* mosquito. The treatment for these two mosquitoes is very different. All of the treatment types that exist have different levels of costs associated with them. In order for an MCP to properly treat the type of mosquito that is infecting the area, the MCP needs a proper level of funding. This will be different from county-to-county.

**Expanding the decision tree to include a wider range of mosquito management options is recommended,** taking into account the environmental effects of each mosquito management option. It is difficult to determine which options in the decision tree are more important than others because every Mosquito Control Project has a different set of goals and a different set of tools to achieve those goals. Therefore, the best mosquito management option will be different for each project site.
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Appendices

Appendix A: EEE and WNV Data

The incidence rate in cases per 100,000 person-year is determined by the following equation.

\[
\text{Incidence Rate} = \frac{\text{cases}}{100,000 \text{ person \cdot year}} = \frac{\text{No. of Cases}}{\text{Population}} \times \frac{100,000 \text{ persons}}{\text{No. of Years}}
\]

For example, Plymouth County had 11 cases of EEE from 2003 to 2012 or 10 years. The population of Plymouth County is 472,822 in 2000 according to the 2000 Census Bureau.

\[
\text{Incidence Rate} = \frac{11}{472,822} \times \frac{100,000}{10} = 0.233 \frac{\text{cases}}{100,000 \text{ person \cdot year}}
\]

The rest of the counties were calculated similarly with both 2000 and 2010 Census population data and the differences were shown.

Table A-1: 2010 and 2000 Massachusetts Population by County.
(source: USCB, 2002; USCB, 2012)

<table>
<thead>
<tr>
<th>County</th>
<th>Year 2010</th>
<th>Year 2000</th>
<th>Absolute Change</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barnstable</td>
<td>215,888</td>
<td>222,230</td>
<td>-6,342</td>
<td>-2.85%</td>
</tr>
<tr>
<td>Berkshire</td>
<td>131,219</td>
<td>134,953</td>
<td>-3,734</td>
<td>-2.77%</td>
</tr>
<tr>
<td>Bristol</td>
<td>548,285</td>
<td>534,678</td>
<td>13,607</td>
<td>2.54%</td>
</tr>
<tr>
<td>Essex</td>
<td>743,159</td>
<td>723,419</td>
<td>19,740</td>
<td>2.73%</td>
</tr>
<tr>
<td>Franklin</td>
<td>71,372</td>
<td>71,535</td>
<td>-163</td>
<td>-0.23%</td>
</tr>
<tr>
<td>Hampden</td>
<td>463,490</td>
<td>456,228</td>
<td>7,262</td>
<td>1.59%</td>
</tr>
<tr>
<td>Hampshire</td>
<td>158,080</td>
<td>152,251</td>
<td>5,829</td>
<td>3.83%</td>
</tr>
<tr>
<td>Middlesex</td>
<td>1,503,085</td>
<td>1,465,396</td>
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<tr>
<td>Norfolk</td>
<td>670,850</td>
<td>650,308</td>
<td>20,542</td>
<td>3.16%</td>
</tr>
<tr>
<td>Plymouth</td>
<td>494,919</td>
<td>472,822</td>
<td>22,097</td>
<td>4.67%</td>
</tr>
<tr>
<td>Suffolk</td>
<td>722,023</td>
<td>689,807</td>
<td>32,216</td>
<td>4.67%</td>
</tr>
<tr>
<td>Worcester</td>
<td>798,552</td>
<td>750,963</td>
<td>47,589</td>
<td>6.34%</td>
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</tbody>
</table>
Table A-2: Confirmed and Probable EEE Cases in Massachusetts by County by Year, 2003 to 2012.
(source: USGS, 2012a)

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
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</thead>
<tbody>
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<td></td>
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<td><strong>Total</strong></td>
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Table A-3: Confirmed and Probable WNV Cases in Massachusetts by County by Year, 2001 to 2012.
(source: USGS, 2012b)

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<th>‘10</th>
<th>‘09</th>
<th>‘08</th>
<th>‘07</th>
<th>‘06</th>
<th>‘05</th>
<th>‘04</th>
<th>‘03</th>
<th>‘02</th>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Berkshire</td>
<td>1</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td>1</td>
</tr>
<tr>
<td>Bristol</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Hampden</td>
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<td></td>
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<td></td>
<td>5</td>
</tr>
<tr>
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<td>1</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>3</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Suffolk</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>7</td>
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<td>13</td>
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<tr>
<td><strong>Total</strong></td>
<td>26</td>
<td>6</td>
<td>7</td>
<td>0</td>
<td>1</td>
<td>6</td>
<td>3</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>23</td>
<td>3</td>
<td>98</td>
</tr>
</tbody>
</table>
Table A-4: EEE Incidence Rate in Massachusetts by County, 2003-2012.

<table>
<thead>
<tr>
<th>County</th>
<th>Census Data 2010</th>
<th>Census Data 2000</th>
<th>Delta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bristol</td>
<td>0.06</td>
<td>0.06</td>
<td>0.0014</td>
</tr>
<tr>
<td>Essex</td>
<td>0.04</td>
<td>0.04</td>
<td>0.0011</td>
</tr>
<tr>
<td>Franklin</td>
<td>0.14</td>
<td>0.14</td>
<td>0.0003</td>
</tr>
<tr>
<td>Middlesex</td>
<td>0.01</td>
<td>0.01</td>
<td>0.0003</td>
</tr>
<tr>
<td>Norfolk</td>
<td>0.03</td>
<td>0.03</td>
<td>0.0009</td>
</tr>
<tr>
<td>Plymouth</td>
<td>0.22</td>
<td>0.23</td>
<td>0.0104</td>
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<tr>
<td>Worcester</td>
<td>0.01</td>
<td>0.01</td>
<td>0.0005</td>
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</tbody>
</table>

Table A-5: WNV Incidence Rate in Massachusetts by County, 2001-2012.

<table>
<thead>
<tr>
<th>County</th>
<th>Census Data 2010</th>
<th>Census Data 2000</th>
<th>Delta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barnstable</td>
<td>0.04</td>
<td>0.04</td>
<td>0.0011</td>
</tr>
<tr>
<td>Berkshire</td>
<td>0.06</td>
<td>0.06</td>
<td>0.0018</td>
</tr>
<tr>
<td>Bristol</td>
<td>0.09</td>
<td>0.09</td>
<td>0.0023</td>
</tr>
<tr>
<td>Essex</td>
<td>0.05</td>
<td>0.05</td>
<td>0.0012</td>
</tr>
<tr>
<td>Hampden</td>
<td>0.09</td>
<td>0.09</td>
<td>0.0014</td>
</tr>
<tr>
<td>Middlesex</td>
<td>0.22</td>
<td>0.23</td>
<td>0.0057</td>
</tr>
<tr>
<td>Norfolk</td>
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<td>0.10</td>
<td>0.0031</td>
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<tr>
<td>Plymouth</td>
<td>0.02</td>
<td>0.02</td>
<td>0.0008</td>
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<tr>
<td>Suffolk</td>
<td>0.22</td>
<td>0.23</td>
<td>0.0102</td>
</tr>
<tr>
<td>Worcester</td>
<td>0.14</td>
<td>0.14</td>
<td>0.0086</td>
</tr>
</tbody>
</table>
Appendix B: Interview Questions and Topics

- Does the town/area have problems with mosquitoes?
  - Could you define what a problem would be?
- What is the main method used to treat the town/area for mosquitoes?
- How often do you apply such methods?
  - Specifics, dates, amounts, concentrations, etc.
- Are there any other methods that are used?
  - Are any of your methods integrated pest management?
- Would you be interested in using integrated pest management in your town/area?
- If it meant less spraying, would you be interested in pursuing IPM methods?
- If you were to pursue, what would be perceived difficulties or “roadblocks” in accomplishing this?
- What would be a more pragmatic approach to IPM, household application, or widespread application?

Appendix C: List of Keywords Searched

<table>
<thead>
<tr>
<th>Table C-1: List of Keywords Searched</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern Equine Encephalitis</td>
</tr>
<tr>
<td>Mosquito life cycle</td>
</tr>
<tr>
<td>Organophosphate</td>
</tr>
<tr>
<td>Pyrethroids</td>
</tr>
<tr>
<td>Pesticide Regulations</td>
</tr>
<tr>
<td>Federal Insecticide, Fungicide, and Rodenticide Act</td>
</tr>
<tr>
<td>Food Quality Protection Act</td>
</tr>
<tr>
<td>Integrated Pest Management practices</td>
</tr>
<tr>
<td>Truck and Aerial Spraying</td>
</tr>
<tr>
<td>Mosquito Magnets</td>
</tr>
</tbody>
</table>
Appendix D: Massachusetts Mosquito Control Annual Operations Report Data

For Table 6, percent increase in budget is calculated by the following equation.

\[ P = \frac{B_{12} - B_{07}}{B_{07}} \times 100 \]

Where...
- \( P \) is the percent increase in budget.
- \( B \) denotes the budget while the subscripts denote the year.

For example, Berkshire County Mosquito Control Project had a budget of $145,057 in 2007, and $219,065 in 2012.

\[ P = \frac{219,065 - 145,057}{145,057} \times 100 = 51\% \]

Berkshire County MCP had a budget increase of 51% from 2007 to 2012. Other MCP budget increases were calculated similarly.
Table D-1: Budgets for Berkshire, Bristol, Cape Cod, and Central Mosquito Control Project from Fiscal Year 2007 to 2012. (source: MA OEEA, 2007-2012)

<table>
<thead>
<tr>
<th>Fiscal Year</th>
<th>Berkshire</th>
<th>Bristol</th>
<th>Cape Cod</th>
<th>Central</th>
<th>East Middlesex</th>
<th>Norfolk</th>
<th>Northeast</th>
<th>Plymouth</th>
<th>Suffolk</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>$145,057</td>
<td>$1,481,573</td>
<td>$1,409,016</td>
<td>$1,473,888</td>
<td>$570,957</td>
<td>$1,269,385</td>
<td>$1,460,458</td>
<td>$1,613,630</td>
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<tr>
<td>2008</td>
<td>$154,533</td>
<td>$1,576,558</td>
<td>$1,538,669</td>
<td>$1,679,946</td>
<td>$569,751</td>
<td>$1,467,822</td>
<td>$1,496,525</td>
<td>$1,429,559</td>
<td>$234,638</td>
</tr>
<tr>
<td>2009</td>
<td>$166,512</td>
<td>$1,712,019</td>
<td>$1,609,325</td>
<td>$1,679,946</td>
<td>$648,444</td>
<td>$1,476,966</td>
<td>$1,527,199</td>
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</tr>
<tr>
<td>2010</td>
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<td>$1,606,050</td>
<td>$1,679,946</td>
<td>$631,264</td>
<td>$1,469,305</td>
<td>$1,644,684</td>
<td>$1,409,027</td>
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<tr>
<td>2011</td>
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<td>$658,651</td>
<td>$1,439,277</td>
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<td>$1,526,681</td>
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<td>2012</td>
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<td>$1,200,023</td>
<td>$1,662,428</td>
<td>$1,801,893</td>
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<td>$1,480,282</td>
<td>$1,513,848</td>
<td>$1,469,658</td>
<td>$230,283</td>
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</table>

Table D-2: Integrated Pest Management Services Provided by the Mosquito Control Projects in 2012. (source: MA OEEA, 2007-2012)

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<th>IPM Service</th>
<th>Berkshire</th>
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<th>Central</th>
<th>East Middlesex</th>
<th>Norfolk</th>
<th>Northeast</th>
<th>Plymouth</th>
<th>Suffolk</th>
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<tr>
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Table D-3: List of Reported Larvicides used by Mosquito Control Project in 2012.  
(source: MA OEEA, 2012)

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<th>Central</th>
<th>East Middlesex</th>
<th>Norfolk</th>
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W = Wetlands, B = Catchbasin, C = Containers