Integrated Vector
Management Program

APPENDIX

E

ALTERNATIVES ANALYSIS REPORT

MARIN/SONOMA
MOSQUITO & VECTOR CONTROL DISTRICT

Protecting Public Health Since 1915

Document Information

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Introduction

This report documents the analysis of alternatives for the control of mosquitoes and/or other vectors within the District's immediate Service Area, and when necessary in adjacent counties to assist in those areas as well. The Service Area and the adjacent counties are called the Program Area for purposes of environmental impact analysis under the California Environmental Quality Act (CEQA). This report is provided as Appendix E, Alternatives Analysis Report, to the District's Programmatic Environmental Impact Report (PEIR). It presents a list of potential alternatives or "tools" and screening criteria to produce recommended components of the Proposed Program. These components represent a reasonable range of alternatives to be discussed in the environmental consequences/impacts sections of the PEIR on the entirety of the District's Program.

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1 Program Background

The Marin/Sonoma Mosquito & Vector Control District (District) has evaluated a range of control methods for mosquitoes and other vectors of human disease and discomfort in its Service Area, comprised of Marin and Sonoma counties. The District will continue to develop the most effective strategy and methods or "tools" to achieve Program objectives in order to protect human and animal health.

1.1 Program Location

The District's Program Area is located in the following counties of the state of California: Marin and Sonoma. The areas proposed for control activities cover an area of approximately 2,100 square miles. These activities would be focused in the areas with the greatest problems based on vector surveillance, vector surveillance associated with service requests from the public, and surveillance and testing for presence of the disease pathogens.

1.2 Program History

The original part of the District was established in 1915 to provide mosquito and/or vector control services to the residents and businesses of Marin County. In 1976, the District annexed the central area of Sonoma County, becoming the Marin/Sonoma Mosquito Abatement District. The Town of Sonoma and surrounding areas were annexed into the District in 1982, and in 2004, voters approved the annexation of all remaining unincorporated areas of Marin and Sonoma counties, thus making vector control services available to all residents of the two counties.

The District's Program is an ongoing series of related actions for control of mosquitoes and other vectors of human disease and discomfort. The District's activities involve the identification of vector problems; responsive actions to control existing populations of vectors, preventing new sources of vectors from developing, and managing habitat to minimize vector production; the education of landowners and others on measures to minimize vector production or interaction with vectors; and the provision and administration of funding and institutional support necessary to accomplish the District's objectives.

The District has, for at least the past two decades, taken an integrated systems approach to mosquito and vector control, utilizing a suite of tools that consist of public education and outreach surveillance, vegetation management, and physical, biological, and chemical controls. These Program "tools" or components are described in the subsequent subsection as "Program alternatives" for the California Environmental Quality Act (CEQA) process (except for public education, which is exempt from CEQA). Program implementation is weighted heavily towards public education, vegetation management and physical and biological control, in part, to reduce the potential for environmental impacts. To realize effective and environmentally sound vector management, vector control must be based on several factors:

> Public Education, outreach, and interaction

> Carefully monitoring or surveying vector abundance and/or potential contact with people

> Establishing treatment guidelines

> Selecting appropriate tools from a wide range of control methods

This ongoing Program consists of a dynamic combination of surveillance, treatment guidelines, and use of multiple control activities in a coordinated program with public education that is generally known as Integrated Pest Management (IPM) or Integrated Vector Management (IVM).

While these Program components or tools together encompass the District's IVM Program (IVMP), it is important to acknowledge that the specific tools utilized by District staff vary from day to day and from site

to site in response to the vector species that are active, their population size or density, their age structure, location, time of year, local climate and weather, potential for vector-borne disease, proximity to human populations, including:

> proximity to sensitive receptors,

> access by District staff to vector habitat,

> abundance of natural predators,

> availability and cost of control methods,

> history of effectiveness of previous control efforts at the site,

> potential for development of resistance in vector populations,

> landowner policies or concerns,

> proximity to special-status species, and

> applicability of Endangered Species Recovery Plans, Habitat Conservation Plans, Natural Community Conservation Plans, and local community concerns, among other variables.

Therefore, the specific actions taken in response to current or potential vector activity at a specific place and time depend on factors of vector and pathogen biology, physical and biotic environment, human settlement patterns, local standards, available control methods, and institutional and legal constraints. While some consistent vector sources are exposed to repeated control activity, many areas with minor vector activity are not routinely treated, and most of the land within the District's Service Area has never been directly treated for vectors.

2   Potential Tools

Potential tools for use in the Program are described below and include measures used for other similar control programs in California. This chapter presents a brief description of each tool. The evaluation of each as to whether it is applicable to or an effective component of a mosquito and/or vector control program is presented briefly here, but explained further in Section 3.

2.1   Integrated Pest Management

2.1.1   Description

Integrated pest management (IPM) is a decision making process that involves the use of one or more tools to prevent pest numbers from reaching damaging levels. Important components of a successful IPM program are: selecting a proactive approach; identifying the pest; understanding pest biology, behavior, and population dynamics; monitoring pest numbers; establishing treatment guidelines or threshold levels to trigger actions that will prevent damage or loss; selecting the appropriate tool to prevent pest numbers from reaching harmful levels; implementing management tools in a timely manner; following-up with evaluation on effectiveness and any unintended impacts of management actions taken; and recognizing that often some damage due to pest presence may occur and is acceptable.

2.1.2   Examples of Tool Use

Integrated Pest Management is used in nearly all crop systems and by all vector control agencies in California as Integrated Vector Management (IVM), a specialized form of IPM.

2.1.3   Applicable to District IVMP

The District's current IVMP uses the key concepts of IPM. Where IPM controls pest numbers and believes that some crop damage is acceptable, the District has instances in which the threat to public health from vectors of human and animal disease requires additional measures that go beyond traditional IPM to be taken.

2.2   Vector Surveillance

2.2.1   Description

Vector surveillance, which is an integral part of the District's responsibility to protect public health and welfare, involves monitoring vector populations and habitat, their disease pathogens, and human/vector interactions. Vector surveillance provides the District with valuable information on what vector species are present or likely to occur, when they occur, where they occur, their population sizes, and if they are carrying pathogens or otherwise affecting humans. Vector surveillance is critical to an IVM program because the information it provides is evaluated against treatment guidelines to decide when and where to institute vector control measures. Information gained is used to help form action plans that can also assist in reducing the risk of pathogen transmission and disease occurrence. Equally important is the use of vector surveillance in evaluating the efficacy, cost effectiveness, and environmental impacts of specific vector control actions.

2.2.2   Examples of Tool Use

Examples include field counting/sampling and trapping, arbovirus surveillance, field inspection of known or suspected habitats, and public service requests.

2.2.3 <u>**Applicable to District IVMP**</u>

Already used under current Program.

2.3 Physical Control

2.3.1 <u>Description</u>

Physical control is managing vector habitat to reduce and possibly eliminate vector production and dispersal through "source reduction'" measures that are comprised of nonchemical or nonbiological techniques. In many cases, physical control activities involve restoration and enhancement of natural ecological functioning. For mosquitoes, these activities include, but are not limited to, water management and maintenance of channels, tide gates, levees, and other water control facilities to improve water circulation.

2.3.2 <u>Examples of Tool Use</u>

The District routinely undertakes source reduction projects in cooperation with other agencies. An example is water circulation improvement work performed with the California Department of Fish and Wildlife at the Petaluma Marsh. Another example is a project planned and carried out in conjunction with U.S. Fish and Wildlife Service that improved tidal circulation in Lower Tolay Creek in Sonoma County. Both projects significantly reduced the potential for mosquito production in the respective areas.

2.3.3 <u>Applicable to District IVMP</u>

Already used under current Program.

2.4 Vegetation Management

2.4.1 <u>Description</u>

The species composition and density of vegetation are basic elements of the habitat value of any area for mosquitoes and other vectors, for predators of these vectors, and for protected flora and fauna. District staff routinely undertakes vegetation management activities as a tool to reduce the habitat value of sites for mosquitoes and other vectors or to aid production or dispersal of vector predators, as well as to allow access by District staff to vector habitat for surveillance and other control activities. Direct vegetation management by District staff generally consists of activities to reduce the mosquito habitat value of sites by improving water circulation or access by fish and other predators, or to allow access by District staff to standing water for inspections and treatment. For vegetation management, the District uses hand tools or other mechanical means (i.e., heavy equipment) for vegetation removal or thinning and sometimes applies herbicides (chemical pesticides with specific toxicity to plants) to improve surveillance or reduce vector habitats. Vegetation removal or thinning primarily occurs within or adjacent to aquatic habitats to assist with the control of mosquitoes and in terrestrial habitats to help with the control of other vectors.

2.4.2 <u>Examples of Tool Use</u>

Trimming of vegetation to allow access to water sources such as creeks, low areas, seasonal wetlands, ponds and floodplains. Mowing of access paths in dense stands of cattails to facilitate access for mosquito surveillance and larvicide treatment.

2.4.3 <u>Applicable to District IVMP</u>

Already used under current Program.

2.5 Biological Control Pathogens (Viruses)

2.5.1 Description

Mosquito pathogens are highly host-specific and usually infect mosquito larvae when they are ingested. Upon entering the host, these pathogens multiply rapidly, destroying internal organs and consuming nutrients. The pathogen can be spread to other mosquito larvae in some cases when larval tissue disintegrates and the pathogens are released into the water to be ingested by uninfected larvae.

2.5.2 Examples of Tool Use

Examples of viruses that can infect mosquitoes are mosquito iridoviruses, densonucleosis viruses, nuclear polyhedrosis viruses, cytoplasmic polyhedrosis viruses, and entomopoxviruses.

2.5.3 Applicable to District IVMP

These viruses are not commercially available for mosquito control at present. Becnel and White (2007) provide a thorough summary of the current understanding and last 20 years of research concerning mosquito pathogenic viruses. Their review indicates there are still numerous issues to be addressed before mosquito viral pathogens can be used as an effective mosquito control strategy.

2.6 Biological Control Pathogens (Bacteria)

2.6.1 Description

Mosquito pathogens are highly host-specific and usually infect mosquito larvae when they are ingested. Upon entering the host, these pathogens multiply rapidly, destroying internal organs and consuming nutrients. The pathogen can be spread to other mosquito larvae in some cases when larval tissue disintegrates and the pathogens are released into the water to be ingested by uninfected larvae. . Environmental factors such as salinity, low temperatures, high larval densities, life stage (age) of the mosquito, and dense vegetative cover that interferes with application at the mosquito-breeding site can limit the effectiveness and presence of certain bacterial pathogens of mosquitoes. For example, *Bacillus sphaericus* (Bs) works best in highly polluted waters but not very well in brackish or saline environments. The species of mosquito may also play a role in effectiveness (e.g. several species of *Aedes* mosquitoes, including salt marsh *Aedes*, are not very susceptible to the larvicide Bs (Baumann et al., 1991; Davidson, 1989; Mittal, 2003).

2.6.2 Examples of Tool Use

The only live bacteria commercially available and pathogenic to mosquitoes is *Bacillus sphaericus* (Bs). This material is currently available as a granule (VectoLex FG), water dispersible granule (VectoLex WDG), and water-soluble packet (VectoLex WSP) for the treatment of immature mosquitoes. There are no other commercially available bacterial pathogens for the management of other vector populations (e.g. Yellowjackets, rodents, and ticks).

Examples of bacteria pathogenic to mosquitoes are *Bacillus sphaericus* (Bs), the several strains of *Bacillus thuringiensis israelensis* (Bti), and *Saacharopolyspora spinosa*. Two bacteria, Bs and Bti, produce proteins that are toxic to most mosquito larvae, while *Saccharopolyspora spinosa* produces compounds known as spinosysns, which effectively control all larval mosquitoes. Bs can reproduce in natural settings for some time following release. Bti materials applied by the District do not contain live organisms, but only spores made up of specific protein molecules.

2.6.3   <u>Applicable to District IVMP</u>

Bti and Bs are already used under current Program. *Saccharopolyspora spinosa* is under consideration and may be used in the future.

Bacillus sphaericus is a commonly occurring spore-forming bacterium found throughout the world in soil and aquatic environments. Certain strains of this bacterium produce a protein endotoxin, which is pathogenic to immature mosquitoes. This endotoxin destroys the insect's gut in a way similar to the protein crystals of *Bacillus thuringiensis* var. *israelensis* (Bti). That is, the toxin is only active against feeding mosquito larval stages and it must be partially digested before it becomes activated.

B. sphaericus adversely affects larval mosquitoes but, in contrast to Bti, is virtually nontoxic to Black Flies (Simuliidae). *Culex* species are the most sensitive to *Bacillus sphaericus*, followed by *Anopheles* and some *Aedes* species. In California, *Culex* spp. and *Anopheles* spp. may be effectively controlled. Several species of *Aedes* have shown little or no susceptibility, and salt marsh *Aedes* are not susceptible. *B. sphaericus* differs from Bti in being able to control mosquito larvae in highly organic aquatic environments, including sewage waste lagoons, animal waste ponds, and septic ditches. Also, in contrast to Bti, field evaluations of commercial *B. sphaericus* products (VectoLex) have shown environmental persistence for 2-4 weeks, and the ability to recycle (grow and reproduce). This persistence varies with a number of environmental parameters, and is low in saline or highly organic environments.

B. sphaericus has been extensively tested and has had no adverse effects on mammals or other nontarget organisms (Ali and Nayar, 1986; Aly and Mulla, 1987; Aly et al., 1985; Holck and Meek, 1987; Karch et al., 1990; Key and Scott, 1992; Lacey and Merritt, 2003; Merritt et a.l, 2005; Miura et al., 1981; Mulla et al., 1984; Rodcharoen et al., 1991; Shadduck et al., 1980; Siegel and Shadduck, 1990; Tietze et al., 1993; Walton and Mulla, 1991; Yousten et al., 1991). No mortalities, pathogenicity or treatment-related evidence of toxicological effects were observed in rats administered oral, intravenous or intratracheal doses of technical *B. sphaericus*. The acute oral and dermal LD_{50} values are greater than 5,000 mg/kg and 2,000 mg/kg respectively. Oral exposure of *B. sphaericus* is practically nontoxic to mallard ducks. No mortalities or signs of toxicity occurred following a 9,000 mg/kg oral treatment. Birds fed diets containing 20 percent w/w of the technical material experienced no apparent pathogenic or toxic effects during a 30-day treatment period. Mallards given an intraperitoneal injection of *B. sphaericus* demonstrated toxicological effects including hypoactivity, tremors, ataxia and emaciation. The LD_{50} value was greater than 1.5 mg/kg.

Acute aquatic fresh water organism toxicity tests were conducted on bluegill sunfish, rainbow trout and daphnids. The 96-hour LC_{50} and NOEC (No Observable Effect Concentration) value for bluegill sunfish and rainbow trout was greater than 15.5 mg/liter; the 48-hour EC_{50} and NOEC value for daphnids was greater than 15.5 mg/liter. Acute aquatic saltwater organism toxicity tests were conducted on sheepshead minnows, shrimp and oysters. The 96-hour LC_{50} value for both sheepshead minnows and shrimp was 71 mg/liter, while the NOEC value was 22 mg/liter for sheepshead minnows and 50 mg/liter for shrimp. The 96-hour EC_{50} value for oysters was 42 mg/liter with a NOEC of 15 mg/liter. The LC_{50} and NOEC value for immature mayflies was 15.5 mg/liter. Honeybees exposed to 10^{-4} to 10^{-8} spores /ml for up to 28 days demonstrated no significant decrease in survival when compared to controls. Additional studies on various microorganisms and invertebrates, specifically cladocerans, copepods, ostracods, mayflies, chironomid midges, water beetles, backswimmers, water boatmen, giant water bugs, and crawfish, have shown no adverse effects or negative impacts. Furthermore, Ali (1991) states that although *B. sphaericus* is known to be highly toxic to mosquito larvae, *B. sphaericus* does not offer any potential for midge control. Acute toxicity of *B. sphaericus* to nontarget plants was also evaluated in green algae. The 120-hour EC_{50} and NOEC values exceeded 212 mg/liter.

Lacey (2007) reviews the prior 20 years of research concerning *B. sphaericus* toxins, their modes of action and factors affecting activity, resistance, safety, and the role of this entomopathogen in integrated mosquito management programs. He concludes that in many situations this bacterial biological control

agent of mosquitoes is an effective alternative to many other broad spectrum mosquito larvicides as it has numerous environmental benefits including safety to nontarget organisms, reduction of pesticide residues, no effect on the activity of other mosquito predators and pathogens, and little or no overall environmental impact. The compatibility of this insecticide with other biological control agents also allows for a more sustainable integrated management approach and it is the cumulative effect of the aforementioned advantages that help to offset the significant increases in costs associated with the use of this insecticide. The one concern is resistance, especially since the *B. sphaericus* toxin apparently binds to a single receptor on the microvilli of the larval midgut. Resistance has been reported in a number of regions throughout the world (Adak et al., 1995; Chevillon et al., 2001; Mulla et al., 2003; Nielsen-LeRoux et al., 2002; Oliveira et al., 2003, 2004; Rao et al., 1995; Silva-Filha et al., 1995; Su and Mulla, 2004; Wirth et al., 2000). Therefore, this material must be used with care and routinely rotated with the use of other available insecticides (e.g. Bti) and management strategies to minimize the risk of resistance (Regis and Nielsen-LeRoux, 2000; Zahiri et al., 2002).

2.7   Biological Control Parasites

2.7.1   <u>Description</u>

The life cycles of mosquito parasites are biologically more complex than those of mosquito pathogens and involve intermediate hosts, organisms other than mosquitoes. Mosquito parasites are ingested by the feeding larva or actively penetrate the larval cuticle to gain access to the host interior. Once inside the host, parasites consume the internal organs and food reserves until the parasite's developmental process is complete. The host is killed when the parasite reaches maturity and leaves the host (*Romanomermis culicivorax*) or reproduces (*Lagenidium giganteum*). Once free of the host, the parasite can remain dormant in the environment until it can begin its developmental cycle in another host.

2.7.2   <u>Examples of Tool Use</u>

Examples of mosquito parasites are the fungi *Coelomomyces spp.*, *Lagenidium giganteum, Culicinomyces clavosporus*, and *Metarhizium anisopliae*; the protozoa *Nosema algerae, Hazardia milleh, Vavraia culicis, Helicosporidium* spp*., Amblyospora californica, Lambornella clarki*, and *Tetrahymena* spp.; and the nematode *Romanomermis culicivorax*.

> **Lagenidium giganteum:** *Lagenidium giganteum*, an oomycete fungus, was briefly available under the trade name Laginex. Production, storage (long shelf life), registration, and costs were some of the issues limiting the use of this parasite for mosquito control. Other factors included the environmental limitations of temperature (less than 16 or more than 32°C), moderate salinity levels (less than 10 ppt) and moderate organic content of the water (Kerwin, 2007, Merriam and Axtel, 1982). Scholte et al. (2004) reviews the different entomopathogenic fungi that have been studied for mosquito control purposes and states there are nine key features of an ideal fungus for mosquito control. These are:

  – kills adult and larval stages,

  – requires no more than a few applications per season,

  – is easily dispersed by adult female mosquitoes to uninfected breeding sites,

  – shows residual activity and persistence in mosquito populations after introduction,

  – kills only mosquitoes,

  – is effective over a wide range of salinity, temperature, humidity, and water quality conditions,

  – is easily and cost-effectively mass produced,

  – has a long shelf-life and can be easily stored, and

  – is not harmful to humans or other nontarget organisms.

Scholte concludes by stating that "none of the mosquito-pathogenic fungi presently known exhibit all of these characteristics, but they all exhibit at least some."

> **Other Fungi:** Other fungi, including the recently reclassified microsporidia, continue to be found and studied for their potential as biological control agents. Andreadis (2007) and Scholte et al. (2004) provide thorough updated reviews of the entomopathogenic fungi of mosquitoes. Elucidation of their complex life histories and effectiveness as biological control agents of mosquitoes (e.g. *Coelomomyces* spp., *Culicinomyces* spp. and certain microsporidia) are discussed. As mentioned above there are still some technical issues to be solved before these biological control agents could be commercially produced and available for use.

> *Lambornella clarkii***:** *Lambornella clarki*, has been studied as a biological control agent of container breeding mosquitoes, especially the Western Treehole Mosquito, a natural host of this endoparasitic ciliate (Washburn and Anderson, 1986, 1990a, 1990b; Washburn et al., 1988). This parasite has cysts, which are resistant to desiccation and, therefore, allow this ciliate to persist to the next year. Production and storage methods investigations, and early field trials have been conducted to determine the efficacy of this ciliate for biological control (Anderson et al., 1986a, 1986b, 1989; Anderson and Washburn 1989a, 1989b, 1990). Although the data demonstrates that L. clarki appears to be a promising biological control agent, it is at this time not commercially available for use.

> **Nematodes:** Mermithid nematodes, especially *Romanomermis* spp. and *Reesimermis* spp., have received a fair amount of study for use as biological control agents of mosquitoes, with *Romanomermis culicivorax* having been commercially produced as Skeeter Doom for a short time many years ago. Although this nematode showed much promise there were still the following limitations restricting its widespread use: low salinity levels, organically rich waters with low oxygen levels, predation by other aquatic organisms, the potential for the development of host resistance, and the costs associated with mass in-vivo production (Legner, 1995; Peterson, 1978; Peterson and Willis, 1970; Platzer, 2007; Platzer, 1981).

2.7.3   Applicable to District IVMP

These parasites are not generally available commercially for mosquito control at present. The District does not currently use mosquito parasites in its mosquito control program.

2.8   Biological Control Predators

2.8.1   Description

Mosquito predators are represented by highly complex organisms, such as insects, fish, birds, and bats that consume larval or adult mosquitoes as prey. Predators are opportunistic in their feeding habits and typically forage on a variety of prey types, which allows them to build and maintain populations at levels sufficient to control mosquitoes, even when mosquitoes are scarce.

The ability of predators to control mosquitoes is related to four factors: 1) whether mosquitoes are preferred prey, 2) whether the hunting strategy of the predator maximizes contact with mosquitoes, 3) whether the predator consumes large numbers of mosquitoes, and 4) whether the predator is present in sufficient numbers to control mosquitoes. Predator effectiveness is enhanced when proper conditions are present.

The District recognizes the value of maintaining and promoting as many native predatory species as possible in mosquito breeding habitats, as this helps to reduce the use of pesticides as well as human-vector interactions and associated health issues.

2.8.2 Examples of Tool Use

Predators as discussed in this section are, therefore, loosely grouped into five general categories: invertebrates, amphibians, fish, bats and birds.

Only mosquitofish are commercially available to use at present. The District supports the presence of the other predatory species when this proves practical. The District's practice of rearing and stocking of mosquitofish in mosquito habitat reflects the most commonly used biological control agent for mosquitoes in the world. The fish are stocked only in water features such as ponds, closed ornamental ponds or horse troughs and care is taken to ensure that they cannot gain access to waters of the state or waters of the U.S.

2.8.2.1 Invertebrates

These are the most numerous and commonly encountered predators of mosquitoes within any mosquito breeding habitat. Their members include but are not limited to: coelenterates; platyhelminths (flatworms); cyclopoid copepods; insects of many orders, especially *Odonata* (Dragonflies and Damselflies), *Ephemeroptera* (Mayflies), *Hemiptera* (the True Bugs), *Coleoptera* (Beetles); and spiders. A resurgence of research and evaluation on the various invertebrate predators of immature mosquitoes began in the late 1960s and has continued to this day (Ali and Mulla, 1983; Bay, 1969, 1967; Collins and Washino, 1978; Ellis and Borden, 1970; Garcia and Schlinger, 1970; Garcia et al., 1974; Hazelrigg, 1974; Hokama and Washino, 1966; Lee, 1967; Legner and Medved, 1970, 1974; Miura et al., 1978; Qureshi and Bay, 1969; Rayah, 1975; Robert et al., 1967; Sjogren and Legner, 1974; Stewart and Miura, 1978; Veneski and Washino, 1970; Washino, 1969a, 1969b; Yu and Legner, 1975; Yu et al., 1974; Zalom et al., 1978). Factors, such as, effectiveness, culture techniques and release, as well as potential environmental limitations of salinity, temperature, pH, presence/lack of vegetation, substrates, seasonality of flooding and drying of habitats, persistence, and prey selectivity have been examined for a number of mosquito predators.

Quiroz-Martinez and Rodriguez-Castro (2007) provide a nice summary of the use of aquatic insects as predators of immature mosquitoes. Their discussion includes a review of the factors significant to the success of biological control programs for mosquitoes, especially with respect to the predator-prey relationship. These factors are:

> prey preference of the predator,

> species diversity within the mosquito habitat,

> aquatic ecosystem stability,

> density of the larval mosquito population,

> where the predator typically spends most of its time within the water column;

> number of predators needed for release and optimal efficacy,

> recovery of the immature mosquito population,

> predator-prey synchronization,

> refugia for both the predator and especially the prey,

> coevolution of the antipredation responses of the prey and the attack processes of the predator, and

> community participation in both the planning and operational efforts to help the community understand the roles various biocontrol organisms play in controlling mosquitoes.

Mogi (2007) elaborates further on some of the challenges associated with the use of invertebrate predators. First, is the issue of mass production, storage and release, especially since most predators are cannibalistic and also require live organisms as a food source. Second, many are opportunistic in their predatory habits and consume a wide variety of prey other than mosquitoes. This can be helpful as it

allows predators to survive when mosquito populations are low or altogether absent. Conversely, it can be a disadvantage because predators may not effectively reduce mosquitoes due to the availability of alternative prey; some of which include populations of other beneficial mosquito predators. Third, is the presence of other indigenous predators and the complexity of the relationships and differences in vulnerabilities that exist not only between predator-prey but also amongst the different predator populations within a given ecosystem. Anti-predator behaviors, chemical cues and other types of interference are not fully understood; and more research is required to better understand what factors contribute to predator effectiveness.

Marten and Reid (2007) provide a good review of the research concerning cyclopoid copepod biology, mass production, storage, field application, and environmental and health impacts. It is important to note that copepods cannot be utilized in all habitats and therefore must be matched to the appropriate mosquito breeding site to be effective. Equally important, cyclopoid copepods effectively reduce *Aedes* mosquitoes, but are less effective at reducing *Anopheles* spp. and *Culex* spp. mosquito populations. Depending on the species of copepod being utilized, other factors that can affect their use include desiccation, temperature, the presence of heavy metals, and chlorine.

Legner (1995) includes a review of the research and current knowledge concerning the use of platyhelminth (flatworms) for the biological control of mosquitoes. The advantages of their use include ease of mass production, tolerance to environmental contaminants, their ability to reproduce quickly following introduction, excellent predatory behavior in shallow water habitats with emergent vegetation, and their ability to overwinter. Conversely, the disadvantages include the requirement that mass culture be continuous and requires the need for highly trained technical staff, and that the persistence of flatworms in the field depends on the presence of adequate alternative food resources when immature mosquito populations are low.

2.8.2.2 Amphibians

Amphibians are known predators of a number of aquatic organisms including mosquitoes. Diet studies of newts, salamanders, frogs and toads indicate that they are opportunistic generalist predators preying upon various arthropods such as cladocerans, ostracods, insects, spiders and small crayfish, as well as snails, slugs, oligochaete worms, planaria, and the occasional small vertebrate such as fish or other immature amphibians (Anderson, 1968; Avery, 1968, Blum et al., 1997; Brophy, 1980; Bruggers, 1973; Clarke, 1974; Dodson and Dodson, 1971; Freda, 1983; Frost, 1935; Fulk and Whitaker, 1969; Hayes and Tennant, 1985; Hamilton, 1940; Korschgen and Moyle, 1955; Taylor et al., 1988). Although arthropods make up a significant portion of most amphibian diets, mosquitoes appear to be insignificant as a prey item.

Specific studies and data addressing the role and/or use of amphibians as a viable and effective tool for the control of mosquitoes is limited. Howard (1901) reports on the preliminary work of a Mr. Albert Koebele who recounted the use of salamanders that were imported from California to Hawaii. Although not a formal published study, this is one of the earliest records of attempting to use amphibians to help manage mosquito populations. Barber and King (1927) recounts observations and subsequent experiments with the tadpoles of Hammond's Spadefoot Toad (*Scaphiopus hammondii*) in New Mexico that were found to consume crustaceans and mosquito larvae. He concluded that although the tadpoles consumed mosquito larvae the short active season of the toad, the restriction of its habitat to temporary pools, and its lower larval consumption efficiency compared to larvivorous fishes limited its usefulness. Matheson and Hinman (1929) examined the gut contents of 59 Vermilion Spotted Newts and noted that 47 of them contained an average of eight or more mosquito larvae per newt. Other prey items consumed included cladocerans, ostracods, copepods, phyllopods and an occasional aquatic insect. Feeding studies in the lab utilizing battery jars indicated these newts were efficient predators of mosquito larvae and that when provided alternative prey preferred mosquito larvae. Matheson and Hinman were also careful to point out that in their gut content studies they did not carefully assess the full extent of the other prey items found. Spielman and Sullivan (1974) worked with tadpoles of the Giant Tree Frog *Hyla*

septentrionalis on Grand Bahama Island and suggested that the presence of frogs seemed to limit the abundance of the Southern Little House Mosquito, *Culex pipiens quinquefasciatus,* in certain manmade container habitats. Their lab studies utilizing enamel pans indicated that the tadpoles would consume mosquito larvae, especially the earlier instars, although the tadpoles did not actively pursue the larvae nor did the pans accurately reflect natural environmental conditions (e.g. other predator prey relationships that might occur as well as the presence of significant numbers of alternative prey items for the tadpoles). In large artificial containers such as 55-gallon drums and cisterns, they found tadpoles effectively controlled *Culex pipiens quinquefasciatus*. Therefore, they concluded from their lab studies, field observations of mosquito habitats with and without tadpoles, and the fact that immature mosquitoes were usually absent or in very low numbers when tadpoles were present that *Hyla septentrionalis* immatures "denied certain breeding sites to *Culex pipiens quinquefasciatus*." Freed (1980) examined prey selection, activity, and size with the Green Tree Frog *Hyla cinerea* in the lab and found that this frog consistently selected houseflies over four different mosquito species. Prey size was found to be insignificant as a determining factor for selection. Difficulty of prey capture and prey activity were significant with prey item activity being a factor in determining prey selection. Ritchie (1982) also worked with *Hyla cinerea* noting that tadpoles consumed *Culex nigripalpus* mosquito larvae and suggested that *H. cinerea* could play a significant role in the natural control of some mosquitoes in Florida. Blum, Basedow and Becker (1997) performed a 3-year field study of the Rhine Valley in Germany, examining the stomach contents of 2,163 anurans and found an average of 7.7 prey items per stomach with 0.16 percent consisting of mosquitoes. They concluded from their observations that the impact of anurans on mosquitoes would be negligible and furthermore that biological mosquito control with Bti would not negatively impact the diet of anurans. Brodman et al. (2003) worked with Blue Spotted and Tiger Salamanders in both natural wetlands and artificially created mesocosms to assess their effects on aquatic invertebrate and larval mosquito densities. They found the data from the mesocosms was consistent with what they observed in the field and that overall densities of mosquito larvae in mesocosms with salamanders was 91 to 94 percent lower than those without salamanders. Therefore, the larvae of pond breeding salamanders have the potential to control mosquitoes that utilize temporary wetlands. Lab studies by Willems et al. (2005) with four species of common Australian frogs found that although the tadpoles consumed some mosquito larvae, they did not consume substantial numbers and therefore were not effective predators of mosquito larvae. They suggested that alternate food preferences and the lack of active prey searching limited their effectiveness as biological control agents. Brodman and Dorton (2006) examined the gut contents of 42 field-collected tiger salamanders in Indiana and found that 93 percent of all prey items observed were cladocerans and ostracods and were present in 36 percent of the stomachs dissected. Mosquitoes were found in 26 percent of the stomachs examined and comprised 1.67 percent of all prey items collected and identified from the 42 stomachs. In lab experiments, they found Tiger Salamander larvae could consume an average of 144 mosquito larvae per day and postulated by extension that a population of 8,000 salamander larvae could consume over 1,000,000 mosquitoes per day. Although possible, this did not take into account a number of factors such as presence, abundance, availability, and seasonality of alternative prey, nor the fact that wetlands and the interactions of the organisms that reside within them are quite complex and do not readily lend themselves to such broad generalizations. Their suggestion that Tiger Salamander larvae could naturally reduce immature mosquito populations in wetlands seems possible, although the stomach content analysis would indicate mosquito larvae are a small portion of their overall diet. DuRant and Hopkins (2008) performed feeding experiments with Red-Spotted Newts, Mole Salamanders and the mosquitofish *Gambusia holbrooki*. Both the newt and the salamander readily consumed more than 300 mosquito larvae per day suggesting that these amphibians could have an impact on larval mosquito populations. The study also recognized that only a single prey item, mosquito larvae, was utilized and therefore did not account for the influence of invertebrate community composition in a natural setting on overall larval mosquito consumption rates of salamanders and newts.

A review article by Rhagavendra et al. (2008) summarizes the current knowledge concerning the use of frogs for the biological control of mosquitoes. Their review notes the limited number of studies available

and numerous information gaps. They also point out the need for ecological investigations that help clarify the interactions, connections and predator-prey relationships between frogs, mosquitoes and other wetland organisms to better determine and understand the possible role of frogs as biological control agents of mosquitoes. These same concerns can also be said for salamanders, newts and toads whose broad diets include, albeit on a limited scale, mosquitoes.

Some additional areas of concern when considering the use of amphibians as a biological control agent include but are not limited to:

> their inability to be utilized in all types mosquito breeding habitats (e.g. saline tidal marshes, wastewater ponds, sewage lagoons, winery waste ponds, septic tanks, storm drains, etc.);

> what the ecosystem effects would be of introducing or mass releasing amphibians into new or nonnatural areas;

> the ability to rear and quickly introduce large numbers of amphibians to various locations throughout the county; and

> potential concerns by some members of the public about the sudden appearance of "large numbers" of frogs or salamanders in their yards that could also get into their homes, and/or the "noise" created by large numbers of frogs in their yards at night.

Although amphibians feed on a wide variety of prey items, including mosquitoes, the current knowledge and understanding indicates they have a minimal effect on mosquito populations. The District does however emphasize the recognition and importance of amphibians within any mosquito-breeding habitat with its staff and also makes every effort to promote the continued presence and well-being of amphibians while engaging in vector management activities.

2.8.2.3   *Fish*

The recommendation that certain species of fish were useful biological control agents of mosquitoes dates back to the earliest control work with mosquitoes (Felt, 1904; Hildebrand, 1921; Howard, 1901; Howard et al., 1912; Hardenburg, 1922; Hubbs, 1919; Kennedy, 1916; Rockefeller Foundation, 1924; Scofield, 1915; Smith, 1904; Stead, 1907). There are a number of fish that have been studied as potential immature mosquito predators. Walton (2007), Legner (1995), and Downs (1991) discuss the use and limitations of mosquitofish (*Gambusia* spp.) as well as other fish species that have received considerable attention as potential biological control agents of immature mosquitoes. Examples of other fishes studied include but are not limited to: the Three-Spine Stickleback (*Gasterosteus aculeatus*), Common Guppy (*Poecilia reticulata*), Pupfish (*Cyprinodon* spp.), Goldfish (*Crassius auratus*), Tilapia (*Tilapia zilli*), Green Sunfish (*Lepomis cyanellus*), and Inland Silversides (*Menidia beryllina*). These and other species have been examined and in many instances found to be of limited use, not as effective as mosquitofish, or as in the cases of some fish taxa they tend to out compete the native fauna and/or are nonnatives whose use is restricted or not allowed.

Only the mosquitofish (*Gambusia affinis* and *Gambusia holbrooki*) are commercially available for use at present, with *G. affinis* being the species typically utilized in the Western United States. Both species are very similar in behavior, biology and habits and therefore the term mosquitofish as used here will apply to both. It has been presumed that both species are present within California (Dill and Cordone, 1997) and may even exist within the Program area. Therefore, this review will encompass literature and data for both species.

A thorough review of *Gambusia affinis* and *G. holbrooki* biology, emphasizing information concerning physiology, growth, development, reproduction, courtship, mating, foraging behavior, diet, dispersal and movement patterns, physical and chemical tolerances, and ecosystem and interspecific interactions is provided by Johnson (2008), Pyke (2008, 2005) and Swanson et al. (1996). Mosquitofish in general are quite tolerant of a wide range of environmental conditions. This feature when combined with their surface

feeding habits, ability to reproduce quickly, ease of transport, and sustainability in small volumes of water makes them ideally suited as a biological control agent of immature mosquitoes when utilized in carefully selected, isolated aquatic habitats (e.g. neglected residential swimming pools, ornamental ponds, water gardens, large fountains, animal troughs, etc.).

Mosquitofish, despite their name, cannot survive solely on a diet of mosquito larvae (Reddy and Pandian, 1972). Laboratory and field studies have shown that mosquitofish are opportunistic omnivores that consume a wide variety of prey items, including algae, zooplankton, copepods, cladocerans, and immature stages of many insects, including but not limited to midges, water beetles, water boatmen, damselflies and mayflies (Ahmed et al., 1970; Barnickol, 1941; Bence, 1988; Erguden, 2013; Farley, 1980; Garcia-Berthou, 1999; Gkenas et al., 2012; Hess and Tarzwell, 1942; Hildebrand, 1921; Lawler et al., 1999; Mansfield and Mcardle, 1998; Miura et al., 1979; Pen and Potter, 1991; Reed and Hoy, 1970; Rice, 1941; Walters and Legner, 1980; Walton and Mulla, 1991; Washino and Hokama, 1967). The research of Hess and Tarzwell (1942) concluded that mosquitofish were true opportunistic feeders, so that the simple availability of prey was the key criterion in prey selection by mosquitofish. As such, the selection of food items by mosquitofish apparently shifts away from specific prey as its abundance drops.

Within their generally wide diet, mosquitofish do have some clear feeding preferences, including food at the water surface, prey size ranging from large zooplankton to very small fish or invertebrates, and prey that does not have highly effective escape behaviors (Swanson et al., 1996). While their feeding preferences, ability to rapidly reproduce and colonize a habitat, and ease of transport make these fish useful for mosquito control purposes, their use has also generated questions concerning their potential, impacts to native fauna and sensitive ecological systems. This has resulted in an extensive body of research attempting to address these questions.

Views vary widely with respect to the benefits and adverse environmental impacts of mosquitofish as a biological control agent for mosquito control programs. Rupp (1996) examined 59 years of literature that contained statements pointing out the concerns of ichthyologists and some researchers about the ineffectiveness as a predator as well as the nontarget impacts to native biota of mosquitofish. Indeed, there can be circumstances when the generalist predatory nature of mosquitofish would make this biocontrol agent either ineffective or inappropriate to use. As with any tool utilized for the management of mosquitoes, proper use and placement is everything. Indiscriminate placement without regard for recognizing the sensitive nature of habitats, the diversity and density of potential prey items present at the site, the use of too few or too many fish for the size of the area, an understanding of the historical and present mosquito population dynamics, the potential for unintended relocation from the placement site, the seasonality of flooding and drying, density of vegetation, water quality, and behavior and habitat use of the species of mosquito being managed are but a few of the factors that can render mosquitofish ineffective and even a potential problem for sensitive native organisms.

Rowe et al. (2008) performed an exhaustive review of the biology, behavior and impacts of a number of invasive fishes in Australia, including the mosquitofish. Their report to the Australian government summarized the results of more than 40 studies that had been conducted through part of 2007 concerning the impacts of *Gambusia holbrooki* to native Australian amphibians and fishes. Their review also included some of the studies conducted in the United States and New Zealand concerning zooplankton and other invertebrates as well as aquatic vertebrates. This report classified the impact studies into four types:

> correlative, using field studies on distribution and relative abundance to provide evidence that a native species may have been impacted where an introduced species now occurs;

> impact assessments based on field studies which utilize information of biology and ecology to predict the feasibility of species interactions, or tank studies which examine the likelihood of certain interactions under controlled laboratory conditions;

> impact assessments in the field that demonstrate the existence of impact mechanisms in the wild; and

> species manipulations (removal of the invasive) in the field to determine if native species recover.

They are careful to point out the shortcomings of each study type on their own and that it is the combination of all four, which is necessary to better understand what types and range of ecosystem impacts truly are associated with the introduction of a nonnative organism. Their conclusions concerning mosquitofish are as follows:

> irrefutable proof of the impact of *Gambusia* is lacking although there are a number of studies that provide some evidence of impacts on native fishes and amphibians;

> that evidence from these studies indicate that this fish can create ecological issues through a reduction in native species diversity in some areas and not in others; and

> the ecological impact of *Gambusia* is affected by other environmental factors (e.g. temporal, spatial, weather, human induced) which vary in intensity from location to location.

The complexity of interactions between organisms within an ecosystem, and for that matter the dynamics of any given ecosystem, presents many challenges when attempting to assess and understand the many biotic and abiotic inter- and intra-relationships that exist; and Rowe and coworkers plainly state this concern while reviewing the body of literature on the impacts of introduced fishes in Australia. Pyke (2008) also reviewed mosquitofish biology, ecology and the impacts of these fish and included in his discussion concerns about trophic level effects as well as the management issues of mosquito control and wildlife management.

A study not mentioned by Rowe but of interest is that of Goodsell and Kats (1999). They performed as a part of their research a gut content analysis of 36 stream collected *G. affinis* and found Pacific Treefrog tadpoles in 65 percent of the stomachs. This is unusual as there appear to be no other gut content studies that have been reported with mosquitofish that co-existed with amphibians. Their laboratory and field experiments also showed that mosquitofish preyed upon tree frog tadpoles even when high densities of mosquito larvae were given as alternate prey.

Mosquitofish impact studies on frogs and fish since Rowe et al. (2008), as well as all research on other organisms also neatly fits into their categorization system of correlative, two types of impact assessment and, invasive species manipulations or removal. Most of the research continues to be either correlative or impact assessments that demonstrate the likelihood of certain interactions under controlled laboratory conditions. The remaining discussion will review research on frogs and fish since Rowe and coworkers report and then review the research both before and after Rowe for other amphibians and wetland organisms.

The interactions between mosquitofish and frogs has begun to receive more attention with the increased awareness that most research had been focused on mosquitofish interactions with native fishes. Gregoire and Gunzberger (2008) utilized tanks in the lab to assess the effects of three species of predatory fish, including *Gambusia holbrooki*, on the survival and behavior of the Southern Leopard Frog and the Gopher Frog. Their observations noted that mosquitofish did injure the frog tadpoles and that this increased tadpole hiding behavior. They suggested that the introduction of predatory fish could negatively affect frog populations especially in normally fish-free wetlands. It should be noted that this study did not provide alternative prey and therefore focused strictly on the interactions between the fish and frog tadpoles contained within 10-gallon aquaria. Karraker et al. (2011 **[Ref list has 2010])** worked with four species of frogs and one toad from the lowland wetlands of southern China and noted that the four species of frog tadpoles were susceptible to predation. They also suggested that the other frog species present within the Chinese lowland wetlands may be subject to predation and therefore further investigation and potential conservation measures should be taken. It is of interest to note that predation testing in this study occurred in small containers, and no form of refugia was provided for the tadpoles. Stanback (2008 **[Ref list has 2010])** observed the interaction of hatchling tadpoles of the Upland Chorus frog, *Pseudacris feriarum*, and

mosquitofish in 100-gallon cattle tanks. Those tanks with fish had no tadpoles remaining while the tadpole only tanks had approximately 10 percent of the introduced tadpoles still present. He suggested that *Gambusia* were highly effective predators of hatchling tadpoles, even on frogs that have co-evolved with this fish. This particular study does have some issues though. First, there was a high density of fish placed into the tanks. Second, there was no assessment concerning the presence or abundance of alternative prey. Third, as Stanback pointed out, the potential for tadpole cannibalism was not taken into account.

The study by Shulse et al. (2013) is different from most prior research in that they examined mosquitofish and the development of community structure over a 4-year period in constructed experimental wetlands. They found that the introduction of mosquitofish reduced the abundance of two species of Grey Treefrogs (*Hyla versicolor* and *H. chrysoscelis*), the Boreal Chorus Frog (*Pseudacris maculata*), and aquatic invertebrates. They also noted that mosquitofish had no significant effect on the Green Frog, *Lithobates clamitans.* When mosquitofish were removed, invertebrate abundance increased; and they suggested that mosquitofish removal may have also been a contributing factor in Chorus Frog recolonization of the experimental wetlands with low invertebrate predator abundance. From their observations, they suggested that mosquitofish were detrimental to wetland communities and recommended against their future use.

Reynolds (2009) performed a gut content, field correlative and lab controlled species interactive study and essentially found there was minimal impact when assessing the effect of *Gambusia holbrooki* on six species of amphibians in Southwestern Australia. His study noted that the gut contents of 48 fish collected from five wetland sites where frogs occurred showed no evidence of frog eggs or tadpoles. Furthermore, in laboratory feeding trials, *Gambusia* that had not fed for four days did not consume the eggs of any of the frog species worked with in the lab but did consume alternate invertebrate prey at the end of the egg palatability trials. Unfortunately, trials with tadpole hatchlings for all but one species and the older tadpoles of one frog species did result in a mosquitofish feeding response. Reynolds also surveyed 25 wetland sites and found *Gambusia* at 20 of the sites, frogs at all 25 sites, and that the combination of all frog species co-existed with fish at more than eight of the sites. Most importantly, he noted that frog species richness did not differ between sites with and without mosquitofish. He concluded that "in contrast to the situation in eastern Australia, populations of anuran species in southwestern Australia do not appear to be strongly affected by this small invasive fish." It was further suggested that other factors such as frog egg deposition site, breeding time of the frogs, availability and abundance of alternative prey, condition of the wetland, and temporal variation in fish abundance and size may influence the impact of mosquitofish on frogs. Bottom line, the interactions of mosquitofish and amphibians is a complex issue and requires careful consideration and analysis in light of the many studies completed to this point in time.

Two additional studies of note are those of O'Meara and Darcovich (2008) and Alvarez et al. (2004), both of which report changes in frog populations following the removal of nonnative fish. Alvarez et al. (2004) surveyed 90 managed stock ponds within the Kellogg Creek Watershed (Contra Costa County, CA) and noted seven ponds with exotic fish, four of which also had mosquitofish, and that these ponds had little use as well as almost no reproduction by Red-Legged Frogs. Two of the ponds in particular only had large populations of mosquitofish. When the fish were removed, frog use and reproduction improved. O'Meara and Darcovich (2008) report the increase of Green and Golden Bell frogs following the rotational drainage and subsequent removal of mosquitofish from ponds in a wetland park that had 22 habitat ponds constructed for the frog. Over a period of three years, a different set of ponds, or about one third of the 22 ponds, were drained and allowed to remain dry for a period of four weeks. Ponds were then refilled and monitored. Although fish and frogs did coexist, frog numbers, especially tadpoles and juveniles, improved with the reduced presence of mosquitofish. Additionally, sightings of adult frogs were significantly improved and had reached their highest levels on record since construction of the wetland in 2000 in 2004–2005 and again in 2005–2006. It should be noted that fish did reinvade many of the ponds within a few months of draining, and data concerning tadpole numbers post fish recolonization is not

clearly presented. There is also a lack of data concerning the presence and abundance of other potential predators of these frogs with the exception of a passing reference to a predatory eel.

The more recent impact studies concerning native fish are varied both in scope and design although there is one that attempted to assess the removal of mosquitofish in the field to determine if native species would recover. Laha and Mattingly (2007) observed the interaction between *Gambusia affinis* and the Barrens Topminnow, *Fundulus julisia* in small glass tanks in the lab. They noted that for short-term exposures, juvenile topminnows were quite vulnerable to aggression and predation, which they attributed to mosquitofish. A 60-day interaction study with the adults of both species yielded no negative effects with the exception of fin injury to top minnows that were syntopic with mosquitofish. From their observations, they suggested that the impacts of mosquitofish on Barrens Topminnows was primarily through predation and injury to the early life stages. Laha and Mattingly also pointed out the limitations of their experimental design, specifically that not all dimensions of the natural environment could be adequately represented. Keller and Brown (2008) examined the behavioral interactions that occurred between allopatric and sympatric populations of wild caught *Gambusia holbrooki* and the native Australian Ornate Rainbow fish, *Rhadinocentrus ornatus* in laboratory maintained aquaria and from their observations suggested that mosquitofish presence and aggression was responsible for the behavioral and microhabitat shifts that occurred with the Rainbow fish. They noted that Rainbow fish individuals from allopatric populations were more susceptible to fin nipping and being chased than their sympatric counterparts, that sympatric Rainbow fish had shifted their microhabitat preferences (thus allowing them to coexist with mosquitofish) and also exhibited a greater level of aggression during all stages of mosquitofish exposure. MacDonald et al. (2012) performed a quantitative survey of 93 wetlands in Southeastern Australia in an effort to develop a model of the influence of *Gambusia holbrooki* on native fish species diversity, abundance and physical condition. From their findings, they asserted that *Gambusia holbrooki* exerted a strong effect on the likelihood of wetlands being occupied by most other species of fishes and that their level and direction of influence on the presence, abundance and/or physical condition of different fish taxa seemed dependent on both biotic and abiotic factors. It was also observed that three species of native fishes, Australian Smelt, Flat-Headed Gudgeon and Carp-Gudgeon, co-existed with mosquitofish in wetlands without aquatic vegetation and both species of Gudgeon juveniles showed no strong evidence of fin damage. Therefore, they proposed that some generalist life history strategies may insulate certain native fish species allowing them to successfully coexist with mosquitofish. Tonkin et al. (2013 **[Ref list has 2014]**) performed a field based study, utilizing 13 wetland sites, to assess the effects of mosquitofish removal on wetland fishes. Like MacDonald et al. (2012), a predictive modeling approach was used and overall it was found that there was no response by three species of fish, the Carp Gudgeon, Australian Smelt and the Common Carp, to removal of mosquitofish. It was suggested that the limited duration of the study and number of sites, and possibly even the species used, may have played a role in not being able to detect an impact of *Gambusia* on the rate of population change for any of the three species of fish being observed. However, the authors did conclude that their data supported the earlier findings of MacDonald et al. (2012) that suggested the direction and level of impact of mosquitofish on wetland fish species was quite fluid and dependent on biotic and abiotic influences. It was also suggested that those organisms with more flexible life-history strategies are more able to coexist with mosquitofish than those, which have more an overlap in time, diet and habitat.

Other studies with mosquitofish suggest they may impact some species of native salamanders and newts, aquatic invertebrate populations and planktonic communities. Gamradt and Kats (1996) surveyed 10 streams in the Santa Monica Mountains of southern California in 1994 and 1995 and compared those data to surveys conducted by other workers between 1981 and 1986. All streams contained newts in the 1980s surveys. The 1994/95 surveys found three streams no longer had newts but did have mosquitofish and/or crayfish. Furthermore, the remaining seven streams that had newts did not have the introduced predators mosquitofish or crayfish. Their subsequent lab studies utilizing small tubs found that mosquitofish would consume larval newts but not the eggs. This correlation study though has a significant limitation. There is no way of really knowing that mosquitofish were responsible for newt disappearance in

the three streams. Many other possible factors, biotic and abiotic could be responsible for newt absence (e.g. human influence on water flows, unknown released contaminants, disease, etc.). Leyse and Lawler (2000, 1998) investigated the relationship between mosquitofish and the California Tiger salamander, *Ambystoma californiense,* in six 3.05 m – by - 6.1 m – by - 0.6 m outdoor experimental ponds. The results of their 1998 experiment showed that mosquitofish presence did not affect either larval growth, weight, size or the number reaching metamorphosis. Their trials with aquaria in the lab indicated young salamander larvae often successfully swam away from mosquitofish when attacked, although a few were consumed. Their second set of pond experiments yielded different results and they reported delayed metamorphosis, tail injuries, decreased weights, and significant reductions in salamander survival. It should be noted that the significant difference between the two experiments was the initial number of fish stocked in the ponds between the two trials. The first trial utilized 12 fish per pond (placed in February) while the second stocked 300 fish per pond. Mosquitofish populations drop to a very low level during the winter months as most adult females and nearly all adult males die during this time period (Swanson et al., 1996). Therefore, when activity begins in the spring there are very few adults remaining and these adults serve as the population that will begin reproduction, which occurs in late spring. Large numbers of fish are typically not observed until well into summer. The higher initial February stocking rate was well beyond what would normally be seen for winter survival and therefore altered the temporal and spatial separation that would otherwise have occurred between salamanders and mosquitofish populations. Segev et al. (2008 **[Ref list has 2009]**) while observing fire salamander (*Salmandra infraimmaculata*) and *Gambusia affinis* populations in three natural pools noted that salamander larvae exhibited damage consistent with mosquitofish biting activity when populations of the mosquitofish were high. They also found the tail:body ratios of the salamander larvae were significantly higher (longest tails) when mosquitofish were absent. When comparing observations for the years 1999 and 2003, which were pre- and post-introduction of mosquitofish for two of the pools, they also found larval salamander densities had significantly decreased. Their mesocosm experiments using 180-liter containers in the lab demonstrated results similar to what they observed in the natural pools, which is *Gambusia* impacted larval salamander survival and size, and fish attacks resulted in damaged appendages.

Invertebrate and planktonic interactions with mosquitofish vary although again it has been suggested from the data and observations that potential impacts may occur. Leyse et al. (2004) tested the effects of mosquitofish on the fairy shrimp, *Linderiella occidentalis* in experimental ponds and found fairy shrimp survival and invertebrate biomass was significantly reduced in ponds with mosquitofish. Their feeding trial studies with lab aquaria also demonstrated that mosquitofish generally preferred fairy shrimp to alternative prey. From their data, they suggested that mosquitofish introductions into naturally fishless wetlands could impact species diversity. Mosquitofish interactions with insects indicate that reductions can occur (Bence, 1982; Farley and Younce, 1977) and may be influenced by the seasonal nature of mosquitofish population density, fish size (which affects prey selection), instar of the insect, and stocking rate (Bence, 1982; Miura et al., 1984; Walton and Mulla, 1991). Planktonic studies have also shown declines in abundance as well as shifts in population structure (Bence, 1988; Bence and Murdoch, 1982; Hurlbert and Mulla, 1981; Margaritoria et al., 2001; Singh, 2013). Of particular interest is the study by Singh (2013) who also found higher pH, dissolved oxygen, and turbidity in ponds following introduction of mosquitofish. Singh concluded that mosquitofish demonstrated a top-down effect on zooplanktonic and phytoplantonic community structure and abundance and therefore could be one of the factors affecting the productivity in Lake Nainital, which had received mosquitofish as part of a mosquito control program in the 1990s.

2.8.2.4   *Bats*

The concept of bats as effective predators of mosquitoes has been espoused for the better part of 100 years (Campbell, 1925; Felt, 1904: Grinnell, 1918; Howard, 1901; Howard et al., 1912). The biggest surge in this theory came about with the assertions of Dr. Charles Campbell who had been publicly sharing his work with bats and the construction of bat houses near wetlands for many years prior to the release of his 1925 publication titled "Bats, Mosquitoes and Dollars." His work received wide acclaim and

became highly popularized with the general public. Unfortunately, the concerns of scientists with contradictory data from consulted experts, or who were themselves knowledgeable about such matters, went unnoticed (Goldman, 1926; Howard, 1920; Nelson, 1926; Storer, 1926). The link between bats, the construction of bat houses near wetlands, and numbers of mosquitoes affecting people had not been made as there was no definitive data presented from the examination of fecal pellets or gut contents. Ross (1967) provides a summary of the work examining Dr. Campbell's claims.

Fifteen species of insectivorous bats within the families *Molossidae* and *Vespertilionidae* are known to occur within the San Francisco Bay region (see: www.sfbaywildlife.info/species/mammals). The Molossid Bats are: the Brazilian (Mexican) Free-Tailed Bat (*Tadarida brasiliensis*) and the Western Mastiff Bat (*Eumops perotis*). The Vespertilionid Bats are: the Pallid Bat (*Antrozous pallidus*), the Big Brown Bat (*Eptisicus fuscus*), the Silver-Haired Bat (*Lasionycteris noctivagans*), the Western Red Bat (*Lasiurus blossevillii*), the Hoary Bat (*Lasiurus cinereus*), the California Myotis (*Myotis californicus*), the Long-Eared Myotis (*Myotis evotis*), the Little Brown Myotis (*Myotis lucifugus*), the Fringed Myotis (*Myotis thysanodes*), the Long-Eared Myotis (*Myotis volans*), the Yuma Myotis (*Myotis yumanensis*), Townsend's Big-Eared Bat (*Plecotus townsendii*), and the Western Pipistrelle (*Pipistrellus hesperus*). Published research shows that some of these bats do indeed feed on mosquitoes, although the assertion that mosquitoes are a significant or primary part of their diet, which, therefore, makes them effective predators, and by extension good biological control agents of mosquitoes does not always hold true.

Published dietary studies examining gut contents or the guano of bats within San Francisco Bay appears limited. There are a number of observations and studies though from other parts of California and throughout the United States that suggest flies, especially mosquitoes, constitutes a small portion of the diet for most of these bats (Black, 1974; Borell, 1942; Brigham and Saunders, 1990; Buchler, 1976; Easterla and Whitaker, 1972; Feldhamer et al., 2009; Freeman, 1979; Hamilton, 1933; Hatt, 1923; Kunz et al., 1995; Orr, 1954; Perlik et al., 2012; Ross, 1967; Ross, 1961; Whitaker and Barnard, 2005; Whitaker, 1972; Whitaker and Lawhead, 1992; Whitaker et al., 1981a,b; and Whitaker et al., 1996). Midges, belonging to the family Chironomidae have been found in both gut content and fecal pellet analysis to be a significant part of the diet of *Myotis lucifigus* and *Myotis californicus* in western Oregon (Whitaker, 2004; Whitaker et al, 1977). Additional studies by Anthony and Kunz (1977) and Belwood and Fenton (1976) also show aquatic insects, especially midges are important to the diet of *Myotis lucifugus*.

Although gut content and fecal analysis help to confirm and clarify the diets of these bats, care should still be taken when working with and interpreting these data. The different regions where these studies and observations occurred, the insect fauna available as prey items at these locations, and time of year the studies were conducted are but a few of the factors that can account for the variability in diet and behavior of these species of bats. Existing data would indicate that overall, bats may consume some mosquitoes but without further research it is hard to claim bats are an effective biological control agent of mosquitoes. However, the District does make every effort to provide information to interested individuals and organizations about bat conservation.

2.8.2.5 Birds

Insectivorous birds are another of the many potential predators of mosquitoes within bay area wetlands. The San Francisco Bay region supports a number of species of insect eating birds: however, there do not appear to be any that feed exclusively on mosquitoes. Some of these species (e.g. Purple Martins, Swallows) have received considerable promotion as being effective predators of mosquitoes that could, with the erection of nesting boxes and achievement of sufficient population levels, significantly reduce the need for other forms of mosquito control, especially chemical sprays (BirdNote 2014; Blickle 2005 **[Ref list has 2011]**; Make Your Own Bird Food 2014; Rural Survival 2014; Wade, 1966). Unfortunately, feeding observations and gut content analysis studies of these opportunistic insectivores do not support the anecdotal claims for Purple Martins and Swallows being effective biological control agents of

mosquitoes (Beal, 1918; Farley, 1901; Grant, 1945; Jackson and Weber, 1975; Johnston, 1967; Mengelkoch et al., 2004; Orlowski and Karg, 2011; Riggs, 1947; Walsh, 1978).

Kale (1968) reviews Purple Martins and their effectiveness as a biological control agent of mosquitoes. He discusses (as mentioned above) that gut content analysis studies indicated mosquitoes were an insignificant part of their diet. It is further pointed out that these birds typically fly from 100 to 200 feet above the ground, although they can and do fly anywhere from a few inches to an altitude of almost 500 feet. Since mosquitoes tend to remain closer to the ground (below tree canopy) and are usually active during hours that Purple Martins typically are not, this significantly limits mosquitoes as being a viable prey item for these birds. Kale goes on to review literature where attributions and unsubstantiated claims concerning Purple Martins and mosquitoes have been made. Of special interest are the claims made by Wade (1966) wherein Purple Martins could conservatively consume 2,000 mosquitoes per day and when mosquitoes are plentiful up to 10,000-12,000 per day. Kale points out not only is this misleading, it is without any basis in fact. Grossman (1990) reiterates Kale's point and also references another article by Hill (1990 [Ref list has 1989]), which discusses a number of Purple Martin myths including their effectiveness as a mosquito predator.

Wiggins (2005) provides a conservation assessment that includes a thorough and detailed review of the exiting literature concerning Purple Martins. The reader is referred to this document for additional information on biology, ecology, information gaps and recommended management practices. Though more specific for the great plains and the rocky mountain region there is still a great deal of useful information on this bird species.

Studies on foraging ecology, and prey size and selection of swallows indicates a preference for smaller prey items, especially small flies (McCarty and Winkler, 1999; McCarty and Winkler 1991; Quinney and Ankney, 1985; Turner, 1982 [Ref list has 2013]). This would suggest that mosquitoes, when available, would be opportunistically utilized as a food source. Unfortunately, some species of mosquitoes are active during periods when swallows are inactive. In other instances there are species of mosquitoes whose seasonal abundance does not fully coincide with that of swallows. Lastly, there are some species of mosquitoes that breed within habitats and areas that preclude swallows from being able to readily access and consume them.

The consideration and use of insectivorous birds also has legal constraints. At the federal level there is the protection of migratory game and insectivorous birds under Title 16, Chapter 7. Sections 701 and 702, the Migratory Bird Treaty Act or MBTA, clearly state that it is unlawful to take, possess, import, export, transport, purchase, barter, or offer for purchase, barter or sale, any migratory bird, their eggs, parts, and nests except with a valid permit. There are limited exceptions but local governmental mosquito and vector control agencies are not included. Title 50, Section 10.13 contains the list of migratory birds protected under the MBTA. It should also be noted that some of the species on this list also appear on the list of endangered and threatened species under Title 50, Section 17.11, the Endangered Species Act (ESA). At the State level similar restrictions apply, although permits can be obtained for specific scientific studies and research pursuant to any endangered and threatened species limitations or sensitive habitat concerns. Therefore, if birds were to be an effective biological control agent of mosquitoes, and they were also available and could be utilized, the additional limitations to be addressed include 1) managing the bird population to minimize unintended impacts to other native fauna; 2) making sure there was sufficient habitat and resources for optimal survival of the released birds; 3) making certain the birds are disease free at the time of release and do not unintentionally introduce pathogens into native bird populations; and 4) the release does not significantly increase the potential population of reservoir organisms for vector-borne pathogens.

Kale (1968) points out an additional significant factor concerning the potential of insectivorous birds serving as an effective biological control agent, specifically that even when insects are abundant birds remove a very small proportion. He references the works of Lack (1967) as well as Andrewartha and Birch

(1961 **[missing from ref list]**) noting that the timing of the abundance of insects tends not to coincide with the timing of maximum bird population presence. Therefore, the numbers of birds needed are insufficient to effectively control high pest insect densities. From a historical perspective, the anecdotal accounts of mosquito abundance contained within the diaries of early settlers and explorers (Gray, 1951) would seem to bear this out as the wetlands at the time were pristine and contained abundant populations of birds, bats and mosquitoes.

The potential for the spread of mosquito-borne pathogens, especially West Nile virus, is a concern that needs more research, especially as it relates to birds and mosquito control. Both the Centers for Disease Control (CDC) and the U.S. Geological Survey (USGS) maintain lists of those birds that have tested positive for the presence of West Nile virus. McLean (2006) discusses the impact of West Nile Virus on the North American bird fauna noting that more than 200 different species of birds have tested positive. Although not all birds readily succumb to infection or make for good reservoir hosts there is still much being learned about West Nile virus and its impacts to birds as well as the amplification of this virus in different bird populations. Wheeler et al., (2009) reviews California bird surveillance data from 2004 to 2007 and notes that bird susceptibility varies widely. Oesterle et al. (2009) experimentally infected Cliff Swallows with West Nile virus and suggested that cliff swallows are a competent reservoir host and could therefore play a role in the early season amplification and maintenance of West Nile virus. Since this virus is still relatively new to the North American continent, caution should be exercised, as there is still a lot that is unknown about the relationships of this virus and North American birds.

Therefore, intentionally breeding and mass releasing birds to help manage mosquito populations is not viable at this point in time and could have adverse effects on the ecosystem, including the epidemiology of West Nile virus. The lack of hard data to support the claims of being effective mosquito predators, the potential for mosquito-borne disease issues, and regulatory constraints are but a few of the factors limiting the use of insectivorous birds as a biological control tool. However, the District does make every effort to support and encourage their health and wellbeing of potential mosquito predators. This includes providing information about bird biology, ecology and conservation.

Examples of Tool Use: Examples of mosquito predators include representatives from a wide variety of taxa: coelenterates, *Hydra* spp.; platyhelminths, *Dugesia dorotocephala, Mesostoma lingua, and Planaria* spp.; insects, *Anisoptera, Zygoptera, Belostomidae, Geridae, Notonectidae, Veliidae, Dytiscidae, and Hydrophilidae*; arachnids, *Pardosa* spp.; mosquitofish, *Gambusia affinis, Gasterosteus aculeatus*; bats; and birds, *anseriformes, apodiformes, charadriiformes, and passeriformes*.

2.8.3   Applicable to District IVMP

The overall objective of using predators is to reduce the potential need for or frequency of pesticide applications. This minimizes the risk of potential environmental impacts associated with pesticides and minimizes the potential for development of mosquito resistance to pesticides.

Predation on mosquitoes is a natural process that will occur without human intervention. However, the level of mosquito control by natural predators can be increased by the conservation of predators in the environment and by augmentation of the predator population through stocking and habitat enhancement.

References to some of the predators of mosquitoes can be found dating back more than 100 years and help form the basis for much of the research that has occurred since (Beutenmuller 1890; Cattel 1903; Felt 1904; Howard 1901, 1910; Mitchell 1907; Smith 1904; Weeks 1890).

From the review of the above research, it is clear that mosquitofish do have the potential to impact the environments within which they are placed. Yet, it is also important to remember that care should be taken when working with and evaluating the data from the myriad of studies that have been conducted with mosquitofish. While these studies suggest that mosquitofish can reduce populations of amphibians, fish and invertebrates, there are some significant factors to be considered when working with the data. First, the results of many of these studies are laboratory based and utilize artificial environments that are limited in

their ability to emulate natural fully functioning wetland habitats and/or they offer the fish limited prey selection. Second, some studies created outdoor simulated wetland mesocosms; yet even these sites were limited as they did not in many cases have the diversity of microhabitats, vegetation and full range of complex biotic interactions that one might find in well-established natural wetland systems. Third, many studies lacked populations of potential predators of mosquitofish that can be found in natural habitats thus allowing the populations of mosquitofish to exceed levels that would otherwise be found. Fourth, some studies use stocking rates well above those utilized by mosquito control agencies or had stocked ponds with numbers of fish that were much higher than what would occur in the wild for that time of year. Walton (2007) cogently points out that "predation on mosquitofish, environmental complexity and environmental factors may ameliorate the strong effects observed in simple laboratory and mesocosm systems."

Although there is little doubt that mosquitofish are a useful biological control agent of immature mosquitoes, their use and application does have limitations both in terms of effectiveness and in limiting the risk of potential unwanted impacts. The District supports and encourages the presence of the other biological control predators of mosquitoes when practical. Yet, the only readily available biological control agent for use, other than the bacterium *Bacillus sphaericus*, is the mosquitofish. The rearing and stocking of mosquitofish in mosquito breeding habitats is also the most commonly used biological control agent for mosquitoes in the world. Nonetheless, the District's use of mosquitofish is limited and carefully monitored and includes rechecking planted sites to verify presence and abundance. Mosquitofish are typically used as a long-term control measure and therefore are not planted in habitats prone to drying. Fish are placed in closed man-made water features such as ponds, ornamental ponds, water gardens, horse troughs, rain water barrels, and large fountains and care is taken to verify that this biological control agent cannot gain access to unintended habitats, especially creeks and sensitive wetlands. Citizens are also advised of State regulations prohibiting the introduction of nonnative species (e.g. mosquitofish) into waters of the State and the U.S. Operationally, the use of mosquitofish is also limited by factors such as highly polluted water (e.g. dairy lagoons, winery waste ponds, septic ponds), presence or proximity of sensitive species and habitats, and whether or not the mosquito breeding site is a seasonal water source or a permanent impoundment.

Therefore, the District, as mentioned above, limits the use of mosquitofish to those sites with reduced potential for impacts to native species and sensitive habitats to occur. Mosquitofish are stocked only in compliance with federal and state endangered species regulations, so as to avoid the potential to harass and impact threatened and endangered fish, amphibians, insects and other wildlife. District staff is highly-trained, are certified by the California Department of Health Services, and are required to complete frequent continuing education sessions sponsored by the State, the District, or the Mosquito and Vector Control Association of California. Lastly, District staff routinely coordinates and consults with other responsible agencies, including the California Department of Health Services, the California Department of Fish and Wildlife, the U.S. Fish and Wildlife Service, BCDC, the California State Lands Commission, the San Francisco Regional Water Quality Control Board, USACE. to ensure that biological control activities with mosquitofish do not result in significant impacts or substantial adverse effects to biological resources.

2.9 Biological Control Plants

2.9.1 Description

Insectivorous plants have been mentioned as possible biological control agents of mosquitoes for almost 100 years (Howard et al., 1912). One genus of particular interest has been the Bladderworts (*Utricularia* spp.), an aquatic plant which has been studied sporadically for more than 80 years. Other members include, but are not limited to, other species such as Pitcher Plants (*Sarracenia* spp.), the Sundews (*Drosera* spp.) and the Venus Fly Trap (*Dionaea muscipula*). The District is not aware of any native carnivorous plants within the Program area, although there are citizens cultivating carnivorous plants, especially *Sarracenia* spp.

In Matheson's (1930 **[Ref list has 1931]**) review of aquatic plants and mosquito control, he summarizes both previous and current work with *Utricularia* spp. and concludes that these plants deserve further consideration as possible biological control agents of mosquitoes. He also points out that food items were varied, consisting of small crustaceans, protozoa and even some small insects, including immature mosquitoes. Angerilli and Bierne (1974) observed the influence of certain freshwater plants, including *Utricularia minor*, and noted significant but inconsistent levels of mosquito larval predation. Unfortunately, this study had placed these plants in tanks that utilized tap water, which also did not have significant populations of alternative prey items. Baumgartner (1987) studied Bladderworts and their effectiveness as a predator of late fourth instar *Culex pipiens* larvae in the lab and determined that these carnivorous plants do capture mosquito larvae but are inefficient as a biological control agent of mosquitoes. The research of Gordon and Pacheco (2007) examined prey composition of two species of Utricularia in Venezuela and found prey items consisted of rotifers, cladocerans, copepods, rhizopods, annelids, insects and various phytoplankton. It should be noted that algae made up more than 60 percent of prey items while animal forms were the remainder (insects comprising an insignificant amount of the animal taxa consumed). Ogwal-Okeng et al. (2011) worked with *Utricularia reflexa* and another species of carnivorous plant to test their larvicidal activity on Anopheles mosquitoes and concluded that *Utricularia reflexa* significantly reduced mosquito populations and was therefore a potential biological control agent for control of mosquitoes and malaria in Uganda. Again, it should be pointed out that the small tanks used in this study did not accurately reflect natural environmental conditions (e.g. the presence of significant numbers of alternative prey items).

The terrestrial *Sarracenia* spp. seem to be even less effective as predators of mosquitoes. Cresswell (1991) examined the insect prey of 214 pitchers of the Pitcher Plant (*Sarracenia puprurea*) for a period of 55 days. A total of 504 prey items were extracted (503 belonging to 49 families of insects) and only four of these were mosquitoes. Wray and Brimley (1943) collected the prey and inquilines of *Sarracenia flava*, *S, purpurea* and *S. rubra* from five localities in North Carolina, two of the sites being well populated by Pitcher Plants and a quarter acre in size or larger. With the exception of the larval forms of *Wyeomyia smithii*, a species of mosquito whose larvae develop in the water of the Pitcher Plant, four adult mosquitoes were found as prey items. The popular idea that large numbers of pitcher plants prevent human interactions with mosquitoes seems dubious and has yet to be proven beyond what one finds anecdotally.

Drosera spp. also have a wide range of invertebrate prey, although prey composition and capturing efficiency varies depending on the species of *Drosera* involved (Baltensperger 2004; Thum 1986). Other than anecdotal information there appears to be a paucity of scientific research examining the efficiency of Sundew plants as a biological control agent of mosquitoes.

2.9.2 Examples of Tool Use

The District does not employ the use of carnivorous plants.

2.9.3 Applicable to District IVMP

There are vendors of carnivorous plants (nurseries, private dealers, and clubs) where citizens can acquire and also receive information on the cultivation of these plants. The District does not utilize carnivorous plants as a part of its IVMP.

Carnivorous plants, whether terrestrial or aquatic, utilize a wide range of invertebrate prey and are not specific predators of mosquitoes. What little data exists indicates that carnivorous plants, especially terrestrial species, are inefficient for the control of mosquitoes. Therefore, the District does not utilize carnivorous plants as a part of its IVMP.

2.10   Synthetic Insecticides

2.10.1   Description

These manufactured compounds are similar to insecticides derived from plants. In particular, a pyrethroid is an organic compound similar to the natural pyrethrins produced by the flowers of selected chrysanthemums.

2.10.2   Examples of Tool Use

Permethrin, resmethrin, and etofenprox. Etofenprox is applied via ULV equipment to control adult mosquito populations in areas such as oak woodlands and sewage treatment plant facilities.

2.10.3   Applicable to District IVMP

The District currently uses etofenprox and to a limited extent, resmethrin as mosquito adulticides. The method of application is limited to ultra-low volume fogging via truck-mounted, ATV=mounted, or by hand foggers. Deltamethrin as a dust is used to control yellowjackets. Deltamethrin is introduced to ground nesting Yellowjacket nests via hand equipment to eliminate the nests. Wasp-Freeze (d-trans Allethrin and Phenothrin) is used in limited spot applications to control wasps and hornets.

2.11   Botanical Insecticides

2.11.1   Description

Botanical insecticides are derived from natural plants in contrast to the synthetic versions described above. Pyrethrins are botanical insecticides derived from natural plants like chrysanthemum cinerariaelfolium and *C. coccineum*. The essential oils of many plants are used as botanical insecticides.

2.11.1.1   Botanical Insecticides

Botanical insecticides (e.g., pyrethrin) are derived from natural plants in contrast to the synthetic versions described in Section 2.10. Pyrethrin (pyrethrum) is one of the most commonly produced and used natural insecticides and is sometimes used by the District as a part of its IVMP. Pyrethrin is a natural insecticide extracted from certain varieties of the flower *Chrysanthemum cinerariaefolium* and consists of six active ingredients collectively known as pyrethrins (USEPA 2006; Gunasekara 2005; Worthing and Hance 1991). This insecticide provides effective control of adult mosquitoes and other insect pests at very low dosage and has little residual activity (persistence) due to its sensitivity to sunlight. The chrysanthemum flowers used to produce pyrethrins are grown commercially in parts of Africa, Asia, and Australia.

Pyrethrins and pyrethroids exhibit rapid knockdown and kill of adult mosquitoes, characteristics that are considered a major benefit of their use. The mode of action of these compounds relates to their ability to affect sodium channel function in the insects' neural membranes. Their toxicity in insects is markedly increased by the addition of synergists (primarily piperonyl butoxide) which inhibit detoxification of the pyrethrins in insects. No evidence suggests that these synergists increase toxicity in mammals.

Pyrethrins are not cholinesterase inhibitors, are noncorrosive, and will not damage painted surfaces. They are less irritating than other mosquito adulticides and have a less offensive odor. In comparison to other adulticides, pyrethrins may be effectively applied at much lower rates of active ingredient per acre.

The District recognizes that pyrethrins can impact other organisms, especially insects, and therefore takes great care when using this insecticide to minimize effects to nontarget organisms. At mosquito control label application rates, aerial applications with pyrethrins showed no impact on large-bodied arthropods but did have some impact on small-bodied organisms (Boyce et al. 2007). Jensen et al. (1999) found that ULV applications over three seasonal wetlands on Sutter National Wildlife Refuge resulted in no detectable reduction in the abundance or biomass of aquatic macroinvertebrates. However, they did

find a temporary decrease in flying insect abundance in both treated and control wetlands that recovered within 48 hours. Davis et al. (2007) performed an ecological risk assessment of pyrethrins, permethrin, resmethrin, phenothrin, and two organophosphates to warm- and cold-water vertebrates and aquatic invertebrates that may be in a watershed where mosquito spray applications occur, as well as those mammals and birds that would be in the spray zone. They found that the risk quotient for pyrethrin was low, suggesting that the risk to nontarget receptors was most likely small.

The District sometimes uses pyrethrin to manage adult mosquitoes and yellowjackets. The use of pyrethrin is also a least preferred method for controlling mosquitoes, while pyrethrin dust is the primary method for eliminating yellowjacket nests found in the ground. Operationally, the District is very careful when using pyrethrins, as they are not selective for mosquitoes. Therefore, use near beehives is restricted. Additionally, wind restrictions also apply to minimize unwanted drift when making ULV fogging applications.

2.11.2 Examples of Tool Use

Pyrethrins are applied with ULV equipment in areas such as oak woodlands, wetlands, tidal marshes, and around homes.

2.11.3 Applicable to District IVMP

The District currently uses Pyrocide synergized with Piperonyl Butoxide (PBO) as a mosquito adulticide. The method of application is limited to ultra-low volume fogging via a truck-mounted, ATV-mounted, or boat-mounted applicator, or by hand foggers.

2.12 Insect Growth Regulators

2.12.1 Description

Insect Growth Regulators target juvenile harmful insect populations while causing less detrimental effects to beneficial insects. They do not kill adult mosquitoes; and unlike classic insecticides, IGRs do not affect an insect's nervous system. Juvenile hormone must be absent for the mosquito's pupal stage to molt to the adult form, so methoprene treated larvae are unable to successfully become adult insects.

Insect Growth Regulators (IGRs) target immature insect populations, they do not kill adult mosquitoes. IGRs do not affect the insect's nervous system. IGRs can be target specific, depending on the formulation used and the concentration that is applied to the target population of insects being managed. Therefore, adhering to label requirements and when used in the manner for which they are designed, IGRs affect the juvenile stages of the target organisms while causing little or no effects to the nontargets present (e.g., methoprene and mosquitoes). Unlike many traditional insecticides, IGRs do not affect an insect's nervous system, nor do they kill adult mosquitoes. Rather, IGRs prevent the ability of the immature stages to complete their final molt from the pupal stage to adult (prevent adult emergence).

The IGR currently used, and that has been used by the District for more than 2 decades, is s-methoprene. S-Methoprene (known simply as methoprene or as its trade names, Altosid and MetaLarv) is a synthetic analogue (mimic) of a naturally occurring insect hormone called Juvenile Hormone (JH). JH is found during the mosquito's aquatic life stages and in other insects, but is most prevalent during the early instars. As mosquito larvae mature, the level of JH steadily declines until the 4th instar molt, when levels are very low. This period when all the physical features of the adult begin to develop is considered sensitive. Methoprene in the aquatic habitat can be absorbed on contact and the immature mosquito's hormone system then becomes unbalanced. When happening during the sensitive period, the imbalance interferes with 4th instar larval development. One effect is to prevent adults from emerging. Since pupae do not eat, they eventually deplete body stores of essential nutrients and then starve to death. Based on its mode of action, methoprene is considered an IGR. This material has no effect on mosquito pupae and must be contacted by larvae to be effective.

Methoprene is a material with very high specificity in its mode of action. Exhaustive reviews of the published literature on this material demonstrate that methoprene has little or no adverse environmental impact when used at label rates for mosquito control (Anderson et al. 1996; Butler et al. 2010; Glare and O'Callaghan 1999; Hanowski et al. 1997a,b; Henrick 2007; Kenyon and Kennedy 2001; Lawler et al. 2000; Mian and Mulla 1982; Office of the Minnesota Legislative Auditor 1999; Rexrode et al. 2008; Russell et al. 2009; Stark 2005). However, it has been suggested that potential direct and indirect effects may exist for some nontarget organisms subjected to repeated short-term or continuous long-term exposures of methoprene.

Most invertebrate field studies have shown minimal effects to nontarget organisms. Pinkney et al. (2000) investigated the repeated application of Altosid Liquid Larvicide to experimental ponds (rate of 3 ounces per acre or 0.16 ounce AI/acre) and found only isolated instances of reductions of aquatic nontargets. Overall, their analysis of the data indicated no significant differences between the Altosid and control ponds. Invertebrate populations in tidal salt marsh habitats treated with Bti, methoprene, or a combination of Bti and methoprene either were not affected or showed nominal effects with affected nontargets recovering quickly following exposure to methoprene (Lawler et al. 2000, Russell et al. 2009). Hershey et al. (1995) examined the effects of methoprene and Bti on nontarget insects in subdivided temporary woodland ponds and found no evidence of negative effects of larvicide treatments on density or biomass of any invertebrate group or in the richness of benthic fauna. Two studies, however, have suggested that repeated exposure and/or increased duration of exposure may increase the likelihood of nontarget indirect effects (e.g., reduced food resources). Hershey et al. (1998) performed a 3-year study evaluating insect populations in Wright County, Minnesota, wetlands that were treated 6 times from April through July of each year (1991–1993) with Bti and methoprene granules, and had a use pattern of methoprene that subjected wetland organisms to a continuous exposure during each year's test period. Methoprene had minimal effects on nontarget insect groups after the first year of treatment. Reductions in species richness, especially nematocerous flies in the families Tipulidae, Ceratopogonidae, and Chironomidae, were observed during the second and third year. Niemi et al. (1999) completed an integrated 6-year study that assessed the potential ecological impacts of Bti and methoprene use on zooplankton, insects, and breeding birds in Wright County, Minnesota wetlands. Their analysis included the data collected by Hershey et al. (1998), since the same wetlands and Hershey's work was a part of Niemi et al.'s original before and after study design. Changes in insect species richness reported by Niemi et al. was, therefore, simply additional analysis and discussion of the data already reported by Hershey. No negative effects were found to breeding birds or zooplankton as a result of exposure to methoprene, even though reductions in benthic insects were observed. Niemi et al. (1999) also noted that wetlands are ecologically complex and that other factors that may affect species distribution and abundance were not accounted for. Therefore, the lack of close coupling observed among birds, insects, and zooplankton suggests wetlands are highly complex ecological systems requiring additional study to better understand the many abiotic and biotic relationships that make up a wetland system.

Overall, methoprene is an effective tool for the management of immature mosquitoes when taking into account use patterns, material specificity (the large number of organisms that are unaffected at mosquito control rates), application methods, its rapid degradation in the environment, and the volume of published data indicating little or no adverse effects when used at mosquito control label rates. Additional hazard analysis of methoprene is provided in the Ecological & Human Health Assessment Report (see Section 4.3.4) prepared for the PEIR.

2.12.2   Examples of Tool Use

Methoprene liquid, pellets, granules, and briquettes used for control of mosquitoes in freshwater and tidal marshes, seasonal wetlands, ponds, fountains, water gardens, all types of man-made containers, septic tanks, wastewater ponds, winery waste ponds, etc. Methoprene formulations are useful in places that have limited access or where source reduction and routine maintenance are impractical.

2.12.3 <u>Applicable to District IVMP</u>

The District uses S-methoprene products in liquid, pellet, granular, and briquette formulations. Methoprene is a component of the District's IVM program and allows for control of late instar larvae, prevents adult mosquito emergence, provides control for up to several weeks, can be utilized in foul water sources, and can be rotated with the bacterial products.

2.13 Mineral Oils

2.13.1 <u>Description</u>

These products use oil formulations to control mosquito larvae and pupae. Unlike the Bti and Bs bacterial formulations, these oils are effective against pupae and late-stage larvae. The mode of action is via blocking air respiration and altering the surface tension of the water, which also makes them somewhat effective against adult mosquitoes that land on the water to rest or lay eggs. The active ingredient is mineral oil, although CoCoBear Oil, a newer product made by Clarke, is comprised of 10 percent mineral oil, with the remaining oil content being derived from food-grade coconut and vegetable oils.

The District currently uses two surfactants with mineral oil available for mosquito control purposes. BVA-2 and CoCo Bear, are fairly new, function in a similar manner to older products, and contain 97 and 10 percent mineral oil, respectively. Therefore, since an extremely limited body of literature is available concerning BVA-2 or CoCo Bear, literature for Flit MLO and Golden Bear products will be referenced.

Four studies by Tietze et al. (1991, 1992, 1993, 1994) tested three species of fish (inland silversides, mosquitofish, and sheepshead minnows) and a range of microorganisms and concluded that GB-1111 oil was not toxic to the tested organisms at label application rates. Mulla and Darwazeh (1981) experimented with GB-1111 in small experimental ponds and found that benthic invertebrates were unaffected while populations of surface-breathing insects were temporarily reduced following application of this larvicide. Miles et al. (2002) completed a significant independent study of nontarget effects of GB-1111, with US Fish and Wildlife Service's financial assistance, on the tidal marshes of Newark, California, and observed the following effects: (1) surface-breathing insect populations were reduced at the time of treatment; (2) this effect did not persist beyond a few days (= no residual pesticide effects); (3) those potentially affected invertebrates with high mobility left the site, while some of those that could not leave died (especially water boatmen [*Corixidae*]); and (4) overall populations of invertebrate species were not affected, apparently because of recolonization from neighboring untreated sites. They also examined the potential effects on mallard ducklings and noted that the ducklings showed no significant effects of weight loss due to depletion of invertebrate prey. It was observed, however, that some initial oiling and consequent matting of feathers occurred, but that survival, mass and weight gain, and overall condition remained good. Miles et al. (2001) also examined in a lab setting the effects of GB-1111 on hatching success of red-winged blackbird and bobwhite quail eggs and observed reduced hatching success when the eggs were treated with 3 and 10 times the maximum field application (label) rates. It is important to note though that at maximum label rates no significant effects to avian embryos were observed. Subsequent studies by Albers et al. (2003) and Hoffman et al. (2004) yielded similar results when eggs of mallard ducks, red-winged blackbird, and bobwhite quail were exposed to GB-1111 at 3 and 10 times maximum label rates. Both studies also concluded that the potential hazard to embryos was minimal until maximum label rates were exceeded. An earlier study by Albers and Heinz (1983) examined the hatchability of mallard duck eggs and duckling behavior following different levels of exposure to FLIT MLO. At 3 times the maximum label rate, egg hatchability was significantly reduced and changes in behavior, specifically reduced avoidance response, were observed. They concluded that application within label rates did not appear to pose a risk to the embryos of breeding birds.

2.13.2   Examples of Tool Use

BVA 2 Oil, and CoCoBear Oil are used as needed, in aquatic habitats and anthropogenic sources to control mosquitoes and particularly those in the later stages of development including pupae and in foul water habitats.

2.13.3   Applicable To District IVMP

These products are part of the District's existing mosquito control program.

2.14   Mass Trapping

2.14.1   Description

Large numbers of traps, baited with a strong lure (e.g. carbon dioxide, octenol, lactic acid, heat, certain wavelengths of light and sound, and food items such as sugars and proteins) are placed in an effort to catch sufficient target pests to reduce the population to healthful levels. Depending on the species and density of the vector population being managed, traps may be distributed over a large area. Lures for mosquitoes include but are not limited to carbon dioxide, light, heat, and octenol. Yellowjacket traps utilize heptyl butyrate, sugars (e.g. fruits) and/or proteins (meats). An insecticide, rodenticide, food, or a sticky insert may also be used in the trap. Traps utilizing a toxicant or electric grids are covered below in Section 2.15 Attract and Kill.

2.14.1.1   Mass Trapping Mosquitoes

The use of depletion or mass trapping as a possible alternative and/or supplement to the use of pesticides has received considerable attention (Adams, 1996; Consumer Reports, 2003; Day and Sjogren, 1994; Henderson et al., 2006; Hougaard and Dickson, 1999; Kline, 2007, 2006, 2002; Kline and Lemire, 1998; Ogawa, 1988; Quarles, 2003, Smith et al., 2010; Weidhaas and Haile, 1978). This technique utilizes specialized traps, which may also contain attractants to enhance their effectiveness, for collecting large numbers of vector or pest organisms. Recent advances in trap design and advances in understanding the biochemical cues and other factors which attract different vectors to their potential hosts has begun to illustrate the possibilities as well as the limitations of mass trapping as a potential management tool.

For example, Revay et al. (2013) tested the efficiency of seven commercially available mosquito host protection devices including three spatial repellent based products, one type of citronella candle and three traps with CO_2 and/or ultraviolet light attractants. Their data indicated that the ThermaCELL Patio Lantern repelled the most mosquitoes at distances of 10 feet or more from the host when compared to controls. Mosquito traps with attractants on the other hand either increased or had no effect on mosquito biting activity at distances of 10 feet or less from the host when compared with unprotected controls. They also found that the placement of four of any one type of trap, one at each corner of a 4050 and 8192 m^2 area, yielded the best protection with the Blue Rhino Trap being the most efficient, demonstrating a 40.1 percent and 18.1 percent reduction in biting activity respectively.

Henderson (2006) tested the effectiveness of the Mosquito Magnet Pro, which releases a combination of CO_2, heat and moisture, to reduce mosquito abundance in both a rural and urban setting. Although six different species and nearly 2,000,000 mosquitoes were collected over a total of 94 trap nights, it was found that continuous operation of these traps did not significantly reduce mosquito activity for either setting. Hougaard and Dickson (1999) tested both the ABC Pro and the Mosquito Magnet traps for their efficacy in managing adult Western Treehole Mosquito (*Aedes sierrensis*) populations and found the Mosquito Magnet had trapped more treehole mosquitoes while the ABC Pro trap had collected more Little House Mosquitoes (*Culex pipiens*). They concluded from their data that the Mosquito Magnet was an effective tool in "helping control" Western Treehole Mosquitoes in Salt Lake City, Utah. They also pointed out that neither trap eliminated all of the mosquitoes but they did help, especially with the homeowners who felt that some form

of effort was being made to address a challenging mosquito problem where the effectiveness of traditional control methods was limited. Kline (2006) noted the results of two unpublished mass trapping experiments conducted in Florida between 2002 and 2004 using Mosquito Magnet Pro traps. The first was on three small islands associated with the Lower Suwannee Wildlife Refuge where enormous populations of the salt marsh mosquito, *Ochlerotatus taeniorhynchus* would make visitation impossible from May through October. One 23-acre island was selected and a minimum of 21 traps were utilized continuously from June to October of 2003 and 2004. Overall there was a significant reduction in adult biting activity such that no repellent was required while on the island. The second study was a collaborative effort with the United States Department of Agriculture (USDA) and involved a residential area in Gainesville. Two separate neighborhoods were surrounded by twelve Mosquito Magnet Pro traps that also used octenol as an additional attractant. Initial analysis of the data indicated a moderate level of control with a 50 percent reduction in mosquito levels in treated versus untreated residential neighborhoods. Smith et al. (2010) utilized 12 Mosquito Magnet-X traps at a coastal Florida State park and found that the traps did not significantly reduce mosquito numbers compared to the control sites. They further noted that during the latter part of the study mosquito numbers had reached such severe levels that park management requested spraying because of the number of complaints received from users of the park's facilities. They concluded that additional traps, a smaller treatment area, lower mosquito population levels or some combination of all three would be necessary in order to achieve non-pesticide control using mass trapping.

Kline (2007, 2006) also provides an overview of the recent advancements in mass trapping technology and its potential as a mosquito management tool. He notes a number of important concerns significant to the effectiveness of mass trapping as a mosquito management strategy. These are: 1) a thorough understanding of the target mosquitoes' behavior, biology and ecology; 2) which attractants work best since an attractant for one species of mosquito can be ineffective for another; 3) reproductive or biotic capacity; 4) spatial distribution, as this affects placement of the traps; 5) dispersal capacity, as a high dispersal rate, especially with species that travel long distances, poses challenges with managing localized populations and increases the risk of reinvasion from other sites; 6) density of the mosquito population since this can influence the number of traps required; 7) design of the trap and attractant delivery system since no one trap works best for the collection of all species of mosquitoes; and 8) the willingness of the local citizenry to tolerate a lower level of mosquito control in some circumstances and situations. Other factors such as wind, temperature, humidity, density of vegetative cover, species of mosquitoes present, and time of year, also play a part in the effectiveness of these types of traps.

Other potential methods of mass trapping include the use of sound and ovitraps. Walker (1996) and Mankin (2012) both provide a review of the application of sound as a tool for managing insects. Unfortunately, the bulk of the research deals with insects other than mosquitoes. There are however a few studies, most of which seem to be interested in collecting male mosquitoes to learn more about male mosquito ecology and mating competiveness, or to test responses of different species of males to sounds. Ikeshoji et al. (1985) reported that when a black cloth was attached to the base of a tripod and sound traps suspended at different heights above the tripod, that the mean male age and the insemination rate of females resting near the sampling site decreased compared to controls. It was suggested that removal of sound sensitive males by this approach had the potential to be more efficient than other possible male manipulation mosquito control techniques although long term and larger scale trapping experiments were needed. Ogawa (1988) working with *Mansonia* spp. mosquitoes in Malaysia reported that mass trapping of males by an attracting sound was promising. It should be noted though that dry ice and the odor of guinea pigs was also used with the sound traps as this enhanced the attraction of mosquitoes near the traps, most of which were *Mansonia uniformis.* Stone et al. (2013) examined the factors affecting the responsiveness of male *Aedes aegypti* and *Aedes polynesiensis* mosquitoes to sounds and the use of sound traps in the field to better understand male ecology and mating competiveness. It was found that age and mating status influenced the overall responsiveness to sound, while size did not. Traps modified with a device to produce a tone of 465 Hz collected 76.2 percent and 49.7 percent of male *Aedes aegypti* in lab cages and greenhouse enclosures respectively. Traps

modified to emit a tone of 440 Hz collected up to 50.8 percent of male *Aedes polynesiensis* in lab enclosures. In field settings, captures of *Ae. polynesiensis* was higher than *Ae. aegypti*, although the numbers of male *Ae. aegypti* captured was low in all field settings. Lastly, when sound emitting traps were placed 16.5 meters from male mating swarms there was no significant difference in the male capture rate between experimental and control traps. Mass trapping of mosquitoes with sound for vector control purposes would at this point in time appear to be ineffective.

Ovitraps help assess egg laying female activity and are widely used as a part of mosquito surveillance and monitoring. These types of traps are specifically designed to attract and sample gravid female mosquitoes, either directly or by means of the eggs that are deposited within the trap. The design varies depending on the species of mosquito being sampled. For example, *Culex* spp. mosquitoes are sampled with larger gravid traps such as the Reiter Gravid Trap. This device has a large dishpan-like plastic tub base, filled with hay infused water or some other water with an attractant, and a small fan with a collection net or chamber placed above to suck in egg laying mosquitoes that are attracted to the water. On the other hand, sampling for certain species of *Aedes* mosquitoes is best accomplished with small dark colored cups or black painted jars containing water and an egg laying surface such as a hardboard paddle or coarse paper strip or paper ring near the water surface. These small style ovitraps are used for sampling *Aedes* spp. eggs and do not collect the egg laying adults. Irrespective of the type of ovitrap used, this tool is not effective at capturing large numbers of mosquitoes and also has other limitations. First, these traps either collect female mosquitoes that have already taken at least one blood meal or the eggs of blood fed mosquitoes. This is counter to a vector control agency's purpose and the public desire of minimizing human vector interactions. Second, the water in the larger traps tends to have a rather strong, unpleasant odor. Having large numbers of these traps about would result in complaints concerning the "unusual" smells in one's yard or neighborhood. Third, these traps tend to be effective at trapping the adults or collecting the eggs of certain species of mosquitoes, especially those that breed in specific types of container water (e.g. Little House, Banded Foul Water, Fish Pond and some species of *Aedes* mosquitoes such as Western Treehole, Asian Tiger and Yellow Fever). Therefore, although useful for assessing female mosquito egg laying activity, these traps do not appear to be a viable means for significantly reducing mosquito populations.

2.14.1.2 *Mass Trapping Yellowjackets*

Mass trapping of yellowjackets has received considerable attention for almost 50 years (Davis et al., 1973, 1969, 1968, 1967; Ennik, 1973; Landolt et al., 1999; MacDonald et al. 1973; McGovern et al., 1970; Reierson and Wagner, 1978, 1975; Rogers, 1972; Rogers and Lauret, 1968). This technique utilizes small plastic traps that have an attractant, usually heptyl butyrate and/or a protein or sugar food source, to attract and trap foraging yellowjackets. Although useful, the effectiveness of these types of traps varies with the density of the wasp population, location and placement of the traps, timing of use for a given situation, frequency of maintenance, and numbers of traps placed. Braband (2007) performed studies examining the placement of 20 traps, twenty feet apart, around the periphery of an area that measured 100 feet by 100 feet. Near the center they placed three more traps in a triangle, twenty feet apart, to test whether perimeter trapping would reduce yellowjacket numbers in the center of the plot. Although initial results demonstrated little difference in wasps collected between the center and peripheral traps, later work with more plots indicated that peripheral trapping did reduce but not eliminate the presence of yellowjackets in the center area of the test plots. Peripheral trapping of school playgrounds unfortunately was inconclusive and concern was expressed that the risk of being stung at playgrounds may not have been reduced, especially since the traps were designed to attract yellowjackets. MacDonald (1973) evaluated yellowjacket abatement and the merits of toxic baiting, attractant trapping and the potential for biological control. He noted that attractant trapping as an abatement technique was ineffective, especially since the chemical attractants were useful for a limited number of species and only under certain conditions. Although this technology has improved since MacDonald's review, especially with the increased understanding of chemical and food source attractants, and the biology and ecology of the

different species of yellowjackets, it still has limitations. Reierson et al. (2008) reported that the strategic placement of a ring of traps at a picnic food pavilion reduced foraging yellowjacket numbers but that longer term control of one year was achieved only with the use of toxic baits. Cox (2006) reviewed the use of protein and sweet or carbohydrate baits, as well as the timing of the use of these baits, for more effective trapping. She noted the success of a baiting program at Waterfront Park baseball stadium that utilized several hundred traps to reduce yellowjacket numbers to a tolerable level for park attendees. Still attractant trapping as a primary means of managing yellowjackets has issues including timing of trap use, safety and convenience of deployment, consistent routine maintenance, and minimizing contamination.

Effective IPM of yellowjackets involves the interrelated use of a number of techniques including but not limited to, good sanitation, toxic baits, location and destruction of the nests, and attractant trapping. It is the combination of these techniques, especially good sanitation and location and destruction of the nests, that provides the best long-term population management of yellowjackets. Attractant trapping as a primary means of managing yellowjackets has issues including timing of trap use, safety and convenience of deployment, appropriate bait and/or attractant, consistent routine maintenance, and minimizing contamination.

2.14.2   Examples of Tool Use

The District does not employ mass trapping as an abatement measure for the reduction of vector populations.

2.14.3   Applicable to IVMP

There are operational difficulties in placing out and retrieving large numbers of traps for most vectors, the least of which are the volume of traps required, numbers of staff, amount of staff time, access, and travel necessary for this tool to be effective. Mass trapping of mosquitoes has proven to be both costly and in most instances ineffective. Mass trapping of yellowjackets has also has a limited effect on the abatement of yellowjackets, with the traps sometimes becoming an attractive nuisance. When dealing with rodents, the District primarily performs site inspections and provides information on rodent control and exclusion. Therefore, the District does not utilize this methodology as a tool for the abatement of vector populations. Instead, trapping is used to help assess vector and vector-borne pathogen presence and abundance and guide the application of other methodologies such as source reduction, sanitation, biological control, public education, and when necessary the use of pesticides.

2.15   Attract and Kill

2.15.1   Description

The attract and kill tool involves the use of a lure to draw the target vector to a location where the vector organism dies after either feeding on or crawling over the pesticide lure mixture, crawling over or touching an electric grid, or being physically killed by some other mechanical means. There are many different kinds of attract and kill devices such as mechanical snap traps, bug zappers, sticky card traps, and various types of bait stations. Some are specific for the type of vector organism being worked with (e.g. yellowjacket bait stations) while others may be more general in nature (e.g. bug zappers). Their placement and use vary and care must be taken when working with this methodology in order to optimize the intended result.

2.15.1.1   Bug Zapper/Electrocuters

Electric insect management devices or "bug zappers" have a long and varied history with the first publication of an electric fly control device appearing in a 1911 edition of Popular Mechanics Magazine. Later more efficient versions of electric insect control devices to help homeowners and farmers appeared in the same magazine in 1931 and 1934. The first patent was issued in 1934, although it would be a few years before the bug zapper would be readily available on the commercial market.

A bug zapper is a device that attracts and kills flying insects with an electric current. These devices typically consist of a protective cage of plastic or grounded metal bars that contain inside an electrified metal grid with an internal fluorescent light source for emitting violet and ultraviolet light. The protective outer cage prevents people and animals (excluding insects) from touching the high voltage grid. The light attracts insects to the metal grid and when they land on the grid they are electrocuted.

Unfortunately these traps are not effective at killing biting mosquitoes and instead kill large numbers of harmless and beneficial insects (Frick an Tallamy, 1996; Lewis, 1996; Nasci et al., 1983; Science Daily, 1997; Surgeoner and Helson, 1977). Frick and Tallamy (1996) assessed the insects that were killed in electric insect traps from six sites in Newark, Delaware. They noted that of the 13,789 total insects electrocuted, 18 or 0.13 percent were female mosquitoes. Additionally, 1868 (13.5 percent) predatory and parasitic insects, and 6670 (48.4 percent) aquatic insects were killed. Their data suggested, albeit circumstantially, that the bug zapper was not an effective means for significantly reducing mosquitoes in one's yard. Nasci et al. (1983) tested the ability of these types of devices to reduce mosquito biting activity in six adjacent backyards in South Bend, Indiana. They observed that only 3.3 percent of the 3212 insects killed on an average night were female mosquitoes. They also noted that humans were more attractive to mosquitoes than the bug zappers. Surgeoner and Helson (1977) evaluated the effectiveness of electric grid light traps in backyards in southern Ontario and concluded that they did not prove effective in reducing mosquito biting activity. When the release of carbon dioxide was added to the tops of the trap, their effectiveness significantly increased. Still they noted that these traps destroyed large numbers of other types of insects and that mosquitoes constituted a small portion of the total number of insects killed.

Another issue generally overlooked by the general user of these traps is the potential for release of airborne insect particles and microbial contaminants. A number of studies examined the potential for this issue and noted that indeed there was a release of such contaminants when insects, especially certain kinds of flies and moths, were disintegrated in electrocuting insect traps (Ananth et al., 1992; Broce, 1993; Pickens, 1989; Tesch and Goodman, 1995; Urban and Broce, 2000). Pickens (1989) further noted that trap design, placement height of the traps, and potential air movement or wind velocity were important factors in determining the distance of scatter of dismembered parts of electrocuted flies. Under normal circumstances and with proper trap placement, he suggested that a distance of two meters between wall mounted traps and work areas would provide sufficient space to prevent potential contamination. This unfortunately may not be the case for traps used in ones backyard, especially those hanging from porch, patio or deck areas. Again trap design, placement, potential air currents and numbers of insects being zapped at any one time will be the determining factors concerning risks for potential contamination of food and drink items.

2.15.1.2 *Attractive Toxic Sugar Baits (Mosquitoes)*

Attractive toxic sugar baits (ATSBs) are a technology garnering considerable attention as a potential tool for the management of adult mosquito populations (Beier et al. 2012; Khallaayoune et al. 2013; Muller et al. 2008, 2010a,b,c; Muller and Schlein 2008; Naranjo et al. 2013; Qualls et al. 2014, 2012; Revay et al. 2014; Xue et al. 2006, 2008, 2011). This strategy takes advantage of the fact that adult mosquitoes feed on plant sugars, which are an important source of energy influencing adult mosquito longevity, reproductive capacity, host seeking, and the potential to transmit disease (Andersson 1990; Andersson and Jaenson 1987; Magnarelli 1979, 1983; Nayar and Pierce. 1980; Nayar and Sauerman 1971; 1975; Yuval 1992). Both genders of mosquitoes feed on plant sugars, with some species exhibiting preferences for certain types of nectars or sugars (Grimstad and DeFoliart 1974: Muller et al. 2010a, 2011; Schlein and Muller 2008). Potential sugar sources can include, but are not limited to, flowers, sap, juices of decaying fruits, and honeydew.

ATSBs typically are solutions that consist of a sugar bait base, which contains a toxicant such as boric acid, dinotefuran, Saccharopolyspora spinosa, fipronil, eugenol, garlic oil, or some other microencapsulated insecticide or plant essential oil/extract. Adult mosquitoes are attracted to the ATSB, which may either be

contained within a bait station with an accessible surface allowing mosquitoes to feed on the bait, or is applied as a liquid spray to the foliage of plants and man-made nonporous surfaces (e.g., painted or stained wood, metal, and plastic). Mosquitoes are then killed following ingestion of the ATSB.

Current research results indicate this approach has promise although with some concerns and limitations. First, a limited amount of data exists concerning impacts to nontarget organisms (Khallaayoune et al. 2013; Qualls et al. 2014; Revay et al. 2014). Although the potential impacts to nontarget organisms appear low, more research needs to be done to confirm these results with different formulations, application methods, and in different settings. Second, ATSBs require that a sufficient number of bait stations be placed within the area of mosquito activity (Xue et al. 2008) or that a certain amount of the surface area within a treatment site be covered with the ATSB solution to maximize effectiveness. Sprayed ATSBs must also be applied in a way that uniformly wets, and depending on the formulation, saturates the surfaces of treated foliage and nonporous surfaces. Third, although low, a risk exists that some surfaces may discolor when sprayed with certain liquid ATSB formulations (Universal Pest Solutions Terminix AllClear label 2013). Therefore, care must be taken to minimize potential discoloration of treated surfaces. Fourth, hand watering or automatic irrigation within sites that have been sprayed with an ATSB must be avoided for at least 24 hours, otherwise the material may be washed off and rendered ineffective.

2.15.1.3 *Yellowjacket Bait Stations*

The toxic baiting of yellowjackets has received considerable attention with a wide variety of potential toxic baits, numbers of bait stations per unit area, bait station designs, bait texture, and wasp foraging habits and behavior having been evaluated (Chang 1988; Ennik, 1973; Grant et al. 1968; Grothaus et al. 1973; Keh et al. 1968; Parrish and Roberts 1983; Reed and MacDonald 1986; Reierson and Wagner 1975; Reierson et al. 2008; Rogers 1972; Ross et al. 1984; Ruddock and Rohe 1968; Spurr 1996, 1995; Wagner and Reierson 1969). Although a useful management strategy, there are potential issues that must be addressed for this tool to be effective. These include but are not limited to: placement of the bait station, type of bait used, texture of the bait used, type of toxicant used, amount of toxicant used, timely bait station maintenance, time of year, and weather conditions.

Many changes have occurred concerning the availability of effective microencapsulated pesticides that can be used in bait stations for the management of yellowjackets. The goal of using toxic baits is to have the foraging yellowjackets take the toxic bait back to the nest where the young and other members of the nest can feed on the bait. As more workers bring back the bait, more members of the nest will die, ultimately resulting in the extermination of the nest. This process can take a few days to two weeks, depending on nest size, weather conditions, and any potential bait shyness issues that might occur. Unfortunately, many of the earlier microencapsulated toxicants (e.g. Knox-Out 2FM and Rabon) are no longer available, with the remaining toxicants being either significantly less effective or having other issues such as repellent properties resulting in bait shyness.

Ultimately, the District has found that the limited availability of effective toxicants for use with baiting has currently made this particular tool of little value as part of its IVMP for yellowjackets. The best strategy for managing yellowjackets involves excellent sanitation practices combined with location and destruction of the nests. Good sanitation practices includes but is not limited to: limiting access to food items by tightly covering waste receptacles; keeping waste receptacles clean; feeding pets indoors or in screened enclosures; not leaving left over pet food in bowls out of doors; properly disposing of containers that contained sweet foods, sweet drinks, and meats; proper disposal of household organic wastes; and minimizing spillage of certain food items such as meats and sugary drinks. When nests are located, contacting the District or a pest control professional is recommended as they have the proper tools and materials to safely and effectively control yellowjacket wasps and, if needed, remove the nest.

2.15.1.4 *Rodent Bait Stations and Snap Traps*

The effective management of rodent populations, specifically rats and mice, poses many challenges as these organisms are quite adaptable to a wide range of habitats and conditions. Although there are a variety of management strategies, one of the more common techniques is the use of attract and kill technology which employs poison baits or snap traps. This strategy, while useful for helping to manage rodent populations, also has potential issues which can reduce its effectiveness. For baiting these are: bait shyness, resistance, ingestion of sufficient amounts of the toxic bait to be effective, risk of non-target secondary poisoning, location and proper disposal of poisoned rodents, the potential for poisoned rodents to die in wall voids where they are inaccessible resulting in unwanted odors, proper placement of the bait stations, and timely maintenance of bait stations. For snap traps the issues are: proper placement of the traps, use of an effective attractant, adequate number of snap traps, and timely maintenance of traps including removal and disposal of deceased rodents. Since the District utilizes trapping for rodents (e.g. snap traps for rats) on a very limited basis for surveillance only, this form of attract and kill technology will not be discussed any further.

There are a number of different toxic baits that can be utilized for the management of rodent populations. These poisons can be generally grouped as single dose (second generation) or multiple dose (first generation) poisons. Examples of single dose toxicants include: the metal phosphides (e.g. zinc phosphide), the hypercalcemics (calciferol, cholecalciferol and ergocalcifrol), and the anticoagulants (brodifacoum, bromadiolone and difethialone). Examples of multiple dose rodenticides include the anticoagulants chlorophacinone, diphacinone and warfarin.

There are two inherent risks associated with the use of these materials, namely direct access to the poison baits by non-target organisms and indirect exposure via consumption of the poisoned rodent. Direct access is managed by the use of rodent bait stations that are designed to restrict access to the poison baits. These devices are tamperproof and set up to allow mice and rats access to the bait while preventing pets, birds, larger animals, children and unauthorized persons from accessing or being directly exposed to the baits contained within. The second risk, unintended consumption of poisoned rodents or secondary poisoning, requires intensive surveillance for and removal of dead rodents to minimize the risk of indirect exposure of non-target organisms.

The potential for secondary poisoning has received a considerable amount of attention, especially by wildlife managers and organizations that are dealing with unwanted rodent and introduced small mammal populations (Alterio, 2013; Bartos et al., 2012; Eason and Spurr, 2013; Kaukeinen, 1982). Additionally, confirmation of secondary poisoning, especially with anticoagulant rodenticides, has also occurred (Albert et al., 2010; Berny et al., 1997; Berny and Gaillet, 2008; Fournier-Chambrillon et al., 2004; Gillies and Pierce, 1999; Hosea, 2000; Lambert, 2007; Shore et al., 1999; Stone et al., 2003, 1999). The best way to minimize unwanted rats and mice is to remove potential food and water sources, eliminate harborage, and thoroughly seal all points of potential entry. Brown (1969) clearly points out the short term effectiveness poisons have for managing rat populations and the value and long term effects of good sanitation practices. Specifically, a Norway rat population of a city block was subjected to repeated applications of poisons for five years. With each application of toxicants the population markedly declined only to rebound until the next application of poisons. For the next three years only good sanitation practices were employed resulting in population levels that went down and stayed down. Therefore, continual good sanitary practices are an effective means for managing rodent populations in and around businesses and homes.

2.15.2 <u>Examples of Tool Use</u>

At this time there are no effective toxicants for yellowjacket baiting although the District reserves the right to utilize yellowjacket bait stations should an effective and environmentally compatible toxicant become available for use.

2.15.3 <u>Applicable to District IVMP</u>

Due to the limited effectiveness of insect electrocution traps, and their propensity for destroying large numbers of nontarget insects, the District does not use these devices as a part of its IVMP. The District also does not recommend the use of bug zappers to its constituents as a method for dealing with the presence of biting mosquitoes.

ATSBs for the management of adult mosquitoes show promise but are limited in their availability. The District is aware of one commercially available product, Terminix AllClear, which contains an essential oil of garlic. This product is new to the market, registered and released for use in California as of July 2014. The District still needs to operationally test this material, as well as other potential ATSBs, to determine those circumstances where their use may be effective while also having little or no nontarget species impacts. Therefore, although currently not used, the District reserves the right to use ATSBs in the future as a part of its IVMP (which may require additional CEQA analysis). The District has found the limited availability of effective toxicants for use with yellowjacket baiting has currently made the methodology of attract and kill of little value as part of its IVMP. The best strategy for managing yellowjackets involves excellent sanitation practices combined with location and destruction of the nests. Good sanitation practices include, but are not limited to, limiting access to food items by tightly covering waste receptacles; keeping waste receptacles clean; feeding pets indoors or in screened enclosures; not leaving left-over pet food in bowls out of doors; properly disposing of containers that contained sweet foods, sweet drinks, and meats; properly disposing of household organic wastes; and minimizing spillage of certain food items such as meats and sugary drinks. When nests are located, contacting the District or a pest control professional is recommended as they have the proper tools and materials to safely and effectively destroy, and if needed, remove the nest. The use of this strategy for the management of yellowjackets has been inconsistent in its effectiveness, especially with the limited availability of effective bait toxicants. The use of snap traps can help with the management of rodent populations. The District primarily relies on public education and site inspections to help citizens with their rodent issues. Rodent bait stations and rodenticides are currently not employed in the District's IVMP. Limited trapping is done for surveillance rather than rodent control.

2.16 Inundative Releases

Inundative releases are large scale, periodic releases of parasites or predators to quickly control pest populations.

2.16.1 <u>Description</u>

Inundative releases are large-scale, periodic releases of parasites or predators to quickly reduce vector populations. This technique also includes the release of large numbers of genetically modified vectors that have been irradiated, chemosterilized, or have had a gene altered. Inundative releases of predators and parasites can be used in situations where the existing levels of natural enemies are unable to sufficiently reduce vector populations to healthful levels. The use of genetically modified vectors can be for population suppression or to reduce the ability of a vector to harbor and transmit disease. The release of irradiated or chemosterilzed males is similar to the release of predators and parasites in that the goal is vector population reduction. Releases of vector natural enemies or sterile males is not self-sustaining and must be periodically repeated to provide effective long-term control. The use of gene-altered vectors does not have to be regularly repeated as the goal is to introduce a gene into the vector population that is self-sustaining. This introduced gene changes the vector population to a less harmful form and/or reduces or eliminates the vector population entirely. Since potential and known predators and parasites of vectors have been discussed above in Sections 2.5 through 2.9, they will not be addressed further here. Instead, this section will focus on the use of genetically modified vectors. The following discussion is a brief summation of some of the literature concerning genetically modified vectors and their future potential as part of an integrated vector management program:

2.16.2   Examples of Tool Use

2.16.2.1   *Genetically Modified Mosquitoes*

The use of sterilized or genetically altered mosquitoes for the management of mosquitoes and/or mosquito-borne disease has received and continues to receive considerable attention (Alphey et al. 2002, 2010, 2011; Bellini et al. 2013a,b; Benedict and Robinson 2003; Cha et al. 2006; Corby-Harris et al. 2010; Dame 1985; Dame et al. 1974, 2009; Gould et al. 2006; Harris et al. 2011; Ito et al. 2002; Knols et al. 2007; Laven 1967; Lavery et al. 2008; Lofgren et al. 1974; Lowe et al. 1974 **[missing from ref list]**; Macer 2005**[missing from ref list]**; Morlan et al. 1962; Patterson et al. 1968, 1970, 1975, 1977; Reisen et al. 1982; Scott et al. 2002; Toure et al. 2004; Toure and Knols 2006; Weidhaas 1972; Weidhaas et al. 1962, 1974; Wise de Valdez et al. 2011). This interest has spanned more than 50 years and has intensified with advancements in technology; increased understanding of mosquito population biology, ecology and behavior; pesticide resistance; and malaria drug resistance. Areas of interest include, but are not limited to, male fitness or mating competitiveness, ecology and behavior of genetically modified mosquitoes, field performance, sterilization methods and materials, release methods, site assessment and selection, cultural issues and public concerns, ethical and legal issues concerning the use of genetically modified organisms, biosafety and risk assessment of using them, sustainability of introduced desired traits into a mosquito population, and effectiveness of reducing vector-borne pathogen transmission and occurrence of disease.

Success with the use of this approach has been inconsistent. Benedict and Robinson (2003) summarize the results of sterile and incompatible male releases (also known as sterile insect technique [SIT]) and note that regardless of mosquito species three significant factors have contributed to the observed field failures. The significant factors are production below desired levels, loss of male fitness, and immigration of mosquitoes into the release areas. Mosquito population levels and geographic distribution of the population to be treated may also contribute to the success of sterile male releases for the suppression of mosquito populations. For example, when working with isolated populations (e.g., populations within an isolated geographic area) and moderate population levels, SIT has been effective (Patterson et al. 1970; Weidhaas et al. 1974).

Whether or not SIT can work and be sustainable over a very large geographic area, as well as in circumstances with multiple species of mosquitoes, is not clear at this time. The release of sterile mosquitoes is a complex process involving initial colonization of the relevant species, mass rearing of competitive males for release, packing, transport, and release at the optimum place and time (Dame 1985). Having a good understanding of target population size, which helps determine the release period, number of releases, and ratio of sterile males to indigenous males released, is also important for successful use of this technique. Reduction of male competitiveness by radiation, immigration of fertilized females from outside release zones, and inability of laboratory-bred males to perform in the wild are some of the factors observed to affect SIT efficacy in some field tests (Dame et al. 2009). Even with significant advances in technology and understanding of mosquito population ecology, much is still to be learned about the application and effectiveness of SIT as a potential tool for integrated mosquito management.

Mosquitoes that have had their genetic makeup altered to reduce their ability to harbor and transmit vector-borne diseases such as malaria and dengue have also shown promise. This approach requires the use of a genetically engineered system to give the mosquitoes the desired trait as well as a system, known as "gene drive," to successfully spread the desirable gene into the wild mosquito population. Gene drive is important as it ensures that the desirable gene is passed on to more than half of the mosquito population, continues to spread, and will ultimately replace the undesirable trait (i.e., the ability to harbor and ultimately transmit a pathogen such as malaria). Gene replacement is different from more traditional SIT forms, which are self-limiting and usually emphasize population suppression rather than replacement, the release of large numbers of sterile or incompatible male individuals, and require repeated releases.

One of the more prominent issues associated with genetically modified mosquitoes is public perception. The release of genetically altered organisms into the environment, safety to humans, what they will do, what they may become, potential unforeseen effects, and the actual effectiveness to suppress mosquito populations and/or transmission of mosquito-borne pathogens are all important questions being posed. A number of articles have been published discussing the moral, ethical, social, and legal issues concerning the use of genetically modified organisms for public health purposes (Alphey et al. 2010; Knols et al. 2007; Lavery et al. 2008; Macer 2005, 2007; Ostera and Gosten 2011; Toure and Knols 2006; Toure et al. 2004). Public concern about genetically modified organisms, some of which has been propagated by media sensationalism of "new or mutant organisms," is growing

Ecological and population biology issues create serious challenges to the application of genetically modified mosquitoes for disease control (Scott et al. 2002). Biosafety and concerns involving genetically modified mosquitoes are also significant issues (Ostera and Gosten 2011). Whether a self-limiting (e.g., population suppression or "no bite") or a longer-term self-sustaining approach (e.g., introduction of a desired gene) is used, the success of both bite and no-bite strategies for genetically modified mosquitoes depends on the ability of the altered mosquitoes to spread through the wild population. Although a number of recent developments have occurred, none of the genetically modified mosquito methods has been adequately field-tested and consistently demonstrated as operationally effective. The circumstances by which this technology may be used with local mosquito populations are also unclear and will require significant study to determine if and where this technology can be effectively used. Therefore, the District does not at this time use genetically modified mosquitoes as part of its IVMP.

2.16.2.2 Genetically Modified Yellowjackets

The District is not aware of any research concerning the use of genetically modified yellowjackets for managing population levels. Sterile male technique does not make sense as male yellowjackets do not forage and only leave the nest once to mate with a new queen, which has also recently left the nest. Males die shortly after mating with the new queens, which then overwinter and start new colonies in the spring. Attempting to introduce a gene to suppress yellowjacket population levels also seems unlikely. Therefore, since genetically modified yellowjackets are not available for use, this technique is not a part of the District's IVMP for yellowjackets.

2.16.2.3 Genetically Modified Rodents

A limited body of information is available concerning the use of sterile male rodents for managing rodent populations. Glass (1974) reported on work performed in Oklahoma that found male Norway rats born with an unusual color pattern to be sterile. Observations were initiated to assess the effects of producing and releasing sterile males into a wild population. Although some issues with the experimental design and controls occurred, the data did suggest that within certain situations the eradication of Norway rats may be possible with the use of sterile male rats. Issues such as release rates, feralizing of released males, and monitoring the progress of control were areas in need of additional research. Landreth et al. (1976) studied the influence of sterile males on the reproductive capacity of Norway rats. They observed significant offspring reduction by wild female Norway rats. Outdoor and indoor pen experiments with release ratios of 3:1, 1:1, and 1:3 of sterile males to wild males yielded reductions of 82 and 91, 47 and 66, and 83 and 70 percent, respectively. They concluded that the use of sterile males had potential as a tool for the management of wild rodent populations.

Marsh and Howard (1970, 1973) discuss the prospects of using chemosterilants and genetic control for the management of rodent populations. They note those factors that affect the success of using either of these techniques and suggest that although neither is expected to be a cure-all for rodent problems, both techniques could still be useful. Good chemosterilants possess a degree of specificity, affect both genders (especially the females), produce sterility in a single feeding, and produce permanent sterility. Genetic control, or the selection and enhancement of a desired trait (e.g., a nonlethal gene that results in male sterility) that reduces rodent populations, was less certain. Factors affecting usefulness included

how frequently a selected gene would have to be introduced into a rodent population to overcome dilution, the costs of rearing large numbers of rodents carrying the desired gene for release, and public opinion. Public opinion is very significant, especially if large numbers of genetically modified rodents are needed to bring about a significant decrease in the target population. A "plague" of rodents, even a temporary one, does not sit well with most people, let alone that they are genetically modified and, therefore, might be "super rodents."

Jackson (1972) also discusses the use of chemosterilants as a potential tool for the control of rodents. He notes similar concerns with one exception. He points out that due to the physiology and sexual behavior of domestic rodents, nearly 100 percent of the population would need to be treated to obtain effective control. He also notes the commercial availability of chemosterilants as another limiting factor, which is still an issue today. Therefore, because of the aforementioned issues, limited research data on use and effectiveness, and lack of commercially available genetically modified rodents, this technique is not a part of the District's IVMP.

2.16.2.4   *Genetically Modified Ticks*

Limited research has been done concerning the genetic modification of ticks as a means of managing tick populations and the transmission of tick-borne diseases. A single experiment is known and was performed by Galun et al. in Israel in 1967 **[missing from ref list]**. In this study, they successfully mass reared and irradiated ticks and noted that irradiated males exhibited some reduction, though nominal, of mating competitiveness with normal males. They also determined the optimum effective dose for sterilization and suggested that under certain, restricted circumstances, with more research, this technique had the potential to be a useful management tool.

The idea of using genetically modified ticks as part of an integrated vector management program sounds intriguing. However, potential issues exist. Fully understanding the behavior, biology, and ecology of the various tick species; dependence on hosts for dispersal; the ability to mass rear various tick species; determining what level of radiation or chemosterilization will effectively sterilize but not reduce male mating competiveness; and potential public concern over the possibility of being exposed to large numbers of released biting ticks are but a few of the many unknowns. The likelihood that genetically modified ticks could be a useful tool seems unlikely and, therefore, this strategy is not a part of the District's IVMP for ticks.

2.16.3   Applicable to District IVMP

Inundative releases of genetically modified mosquitoes is still experimental. Genetically modified rodents and ticks have received very little attention from researchers. The District is unaware of any examples of work with genetically modified yellowjackets at this time.

Genetically modified vectors are not commercially available and, therefore, are not used by the District at this time.

2.17   Regulatory Control

2.17.1   Description

Governments use regulatory control measures such as quarantines and hold notices to prevent the human-aided movement of pests and/or items likely to harbor the pest into their jurisdiction or the movement of pests from infested areas into uninfested areas within their jurisdiction.

2.17.2   Examples of Tool Use

This control method is not used in the District's program.

2.17.3 <u>Applicable to District IVMP</u>

Regulatory actions only prevent the human-aided movement of unwanted pests. They do not reduce pest numbers or the ability of the pest to spread on its own.

2.18 Repellents

2.18.1 <u>Description</u>

There are materials that can be applied to humans and animals that will repel pest insects from landing on them and then laying eggs or feeding. Repellents are used to protect individuals from being bitten. They do not kill the pest, nor do they reduce pest numbers. They force the pests into adjacent areas away from the treated areas or individuals.

2.18.2 <u>Examples of Tool Use</u>

As an educational tool, the District makes different types of repellent wipes available at its booth at public events such as fairs, festivals and the District Open House day. District staff use repellent materials and wear repellent-treated clothing as a safety measure during field work.

2.18.3 <u>Applicable to District IVMP</u>

Repellents are not used as a widespread control measure as they will not reduce large numbers of problem insects or mammals and may even enlarge the infested area by driving the pest away from treated sites.

2.19 Other Chemical Control

In addition to the pesticides described previously in Sections 2.6, 2.10, 2.11, 2.12, and 2.13, this section covers the surfactant Agnique MMF.

2.19.1 <u>Description</u>

Various methods using chemicals for mosquito control are commercially available, but the only such tool currently considered by the District is the biodegradable, alcohol ethoxylated (AE) surfactant compounds such as Agnique MMF. AE's are readily biodegradable under aerobic and anaerobic conditions) and are made from renewable plant oils. Agnique MMF can be applied to any mosquito habitat with standing water. Using conventional application methods, an invisible monomolecular film rapidly spreads over the surface of standing water habitats. This film interrupts the critical air/water interface in the mosquito's larval and pupal development cycle causing them to drown.

2.19.2 <u>Examples of Tool Use</u>

Agnique MMF is applied to standing water in an neglected swimming pool to control mosquito populations.

2.19.3 <u>Applicable to District IVMP</u>

The sole tool in this class of surfactants currently in use by the District is the type of product exemplified by Agnique MMF.

3   Screening of Tools

Reasonable alternatives are developed through a review of the feasibility of all identified potential tools. To be feasible, the alternative should be capable of accomplishing project purposes in a successful manner in California within a reasonable period of time. This section explains the process for determining the components of the 2014 Program.

3.1   Program Objectives

The District undertakes mosquito and vector control activities through its Program to control the following vectors of pathogens and/or injury and discomfort in the Program Area: mosquitoes, rats, mice, yellowjackets, ticks, or other stinging/biting insects. Surveillance and testing, but no control, is provided for tick vector species.

The Proposed Program's specific objectives are as follows:

> Reduce the potential for human and animal disease caused by vectors

> Reduce the potential for human and animal discomfort or injury from vectors

> Accomplish effective and environmentally sound vector management by means of:

  – Surveying for vector abundance/human contact

  – Establishing treatment guidelines

  – Appropriately selecting from a wide range of Program tools or components

Most of the relevant vectors are quite mobile and cause the greatest hazard or discomfort at a distance from where they breed. Each potential vector has a unique life cycle, and most of them occupy several types of habitats. To effectively control them, an integrated vector management program (IVMP) must be employed. District policy is to identify those species that are currently vectors, to recommend techniques for their prevention and control, and to anticipate and minimize any new interactions between vectors and humans. Furthermore, the District is committed to using the least environmentally disruptive tools in its IVMP.

3.2   Criteria

The District has a well-defined process for selecting tools to be used in mosquito and/or vector control. The criteria used for determining the viability and ranking of reasonable tools are listed below:

> **Criterion 1.** The District uses tools known to be effective to manage vector species on a widespread level that have developed breeding populations in the State.

> **Criterion 2.** The District does not use experimental or hypothetically effective tools on a broad scale (but does engage in trial applications with newly developed/released products).

> **Criterion 3.** Given equal efficacy and operational constraints, the District will use the least environmentally disruptive tool in its control Program.

3.3   Tool Selection Guidelines

The following guidelines (i.e., additional considerations) are used when applying criteria above to the potential mosquito and/or vector management tools:

> Are there effective control measures for the target pest or closely related species?

> Are these tools available for use in California?

> Are these tools likely to be effective if used in the District's Service Area?

> Are there environmental circumstances that will likely limit the effectiveness or operational aspects of the tools in natural, rural, or urban settings?

> Are there operational constraints that will limit the effectiveness of the tools?

3.4 Evaluation Results

Table 3-1, Screening with Criteria, shows the results of the scoring for each of the 21 tools described in Section 2 for the key criteria. Table 3-2, applies the tool selection guidelines to those tools meeting program criteria. Some alternatives were eliminated from the analysis because they were infeasible or did not meet the overall objectives of the Program, or would not meet the criteria and guidelines for selection. This section concludes with a discussion of how tools remaining (following screening with the criteria and the guidelines) were refined further.

Table 3-1   Screening with Criteria

	Criteria		
	1	**2**	**3**
Alternative Tools	**Method Known to be Effective?**	**Not Experimental or Hypothetical?**	**Least Environmentally Disruptive?**
1. Integrated Pest Management	Y	Y	Y
2. Vector Surveillance	Y	Y	Y
3. Physical Control	Y	Y	Y
4. Vegetation Management	Y	Y	Y
5. Biological Control Pathogens (Viruses)	N	N	N/A
6. Biological Control Pathogens (Bacteria)	Y	Y	Y
7. Biological Control Parasites	N	N	N/A
8. Biological Control Predators	Y	Y	Y
9. Biological Control Plants	N	N	Y
10. Synthetic Insecticides	Y	Y	N
11. Botanical Insecticides	Y	Y	N
12. Insect Growth Regulators	Y	Y	Y
13. Mineral Oils	Y	Y	N
14. Mass Trapping	N	N	N/A
15. Attract and Kill	N	N	N
16. Inundative Releases (Parasites)	N	N	N/A
17. Inundative Releases (Other)	N	N	N/A
18. Regulatory Control	Y and N	Y	Y
19. Repellents	Y and N	Y	Y
20. Other Chemical Control (plant oil surfactant)	Y	Y	Y

Y   = Yes
N   = No
N/A = Not Applicable

ATSBs for the management of adult mosquitoes show promise but are limited in their availability. The district is aware of one new commercially available product, Terminix® AllClear, which contains an essential oil of garlic. The District still needs to operationally test this material, as well as other potential ATSBs, to determine those circumstances where their use may be effective while also having little or no nontarget species impacts.

The District evaluated vector control methods by screening the methods listed in Table 3-1 against the three criteria contained in Section 3.2 above. Tools not passing this screening were eliminated from further analysis, while those passing are further analyzed against the guidelines listed in Section 3.3 and shown in Table 3-2 below.

Table 3-2   Tool Selection and Application Guidelines

Alternative Tools	Guidelines				
	Effective Control Measures?	Tools Available in California?	Tools Effective in District Service Area?	Environmental Circumstances Limiting Effectiveness or Operational Aspects of Tools?	Operational Constraints Limiting Effectiveness of Tools?
1. Integrated Pest Management	Y	Y	Y	N	N
2. Vector Surveillance	Y	Y	Y	N	N
3. Physical Control	Y	Y	Y	Y	Y
4. Vegetation Management	Y	Y	Y	Y	Y
5. Biological Control Pathogens (Bacteria)	Y	Y	Y	Y	Y
6. Biological Control (Other)	Y	Y	Y	Y	N
7. Synthetic Insecticides	Y	Y	Y	N	Y
8. Botanical Insecticides	Y	Y	Y	N	Y
9. Insect Growth Regulators	Y	Y	Y	N	Y
10. Mineral Oils	Y	Y	Y	Y	Y
11. Chemical Control (plant oil surfactant)	Y	Y	Y	Y	Y

Y   = Yes
N   = No
N/A = Not Applicable

3.4.1   Alternatives Considered and Withdrawn from Evaluation

The District determined that of the 20 potential tools from Table 3-1, the following eight methods were not immediately available for use in its IVMP: biological control pathogens (viruses), biological control (parasites), mass trapping, attract and kill, inundative releases (both parasites and other), regulatory control, and repellents.

> *Biological Control pathogens (viruses)* is deemed infeasible as this method is not commercially available in California and there are currently many efficacy related issues.

> *Biological Control (parasites)* is deemed infeasible as this method is not commercially available in California. Research on the use of parasites for mosquito control has also shown several limitations related to efficacy.

> *Mass Trapping* is not considered by the District to be a practical, effective, reliable method of controlling vector populations. Can be very expensive and time consuming (i.e., labor intensive).

> *Attract and Kill* is not considered by the District to be a practical, effective, reliable, method of controlling vector populations. The technology for both mosquitoes and yellowjackets is limited, and effectiveness is either not obtained or is inconsistent. Nontarget insects can be impacted. The District is aware of one commercially available ATSB product, Terminix® AllClear. The District still needs to operationally test this material, as well as other potential ATSBs, to determine those circumstances where their use may be effective while also having little or no nontarget species impacts.

> *Inundative Releases of parasites* is not considered by the District to be a practical or currently feasible method of controlling vector populations. They are not commercially available and remain experimental at this time.

> *Inundative Releases of predators* either sterilized or genetically altered organisms, is not considered by the District to be a practical or a currently feasible method of controlling vector populations. Genetically modified vectors are still experimental. They are also not commercially available at this time.

> *Regulatory Control* is not considered feasible because adoption of regulations is lengthy, time intensive, expensive and uncertain as to the regulatory outcome. This approach is not focused sufficiently on control of existing populations. Moreover, regulatory controls are dependent upon state and federal agencies to initiate and implement, and thus this approach cannot assure that any project objectives would be achieved.

> *Repellants*, although effective for small-scale use by humans and animals, are not part of the overall Program control strategy because they merely displace the problem and do not reduce the mosquito population in an area.

3.4.2   Refinement of Selected Tools

Of the remaining potential tools, the following were determined to be effective for mosquito and/or vector control activity: surveillance, physical control, vegetation management-physical, vegetation management-herbicides, biological control pathogens (bacteria), biological control predators, botanical and synthetic insecticides, insect growth regulators, and mineral oils. Of these tools, further evaluation of the options under each of these methods, including how to deliver the material, was conducted.

3.4.2.1   Vector Surveillance

This tool was found to be an essential component of the District's IVMP.

3.4.2.2   Physical Control

This tool was found to be an essential component of the District's IVMP.

3.4.2.3   Vegetation Management

This tool was found to be an essential component of the District's IVMP.

Physical Controls

These methods of source control include, but are not limited to, vegetation and water management and maintenance activities to reduce habitat values. See Section 3.5.3.1 herein.

Herbicides

This class of products is not generally used by the District .However, in the course of source reduction activities, cooperating public agencies sometimes request that the District assist them by applying herbicides under their permits. Since District staff may apply herbicides under these circumstances, this tool was incorporated into the environmental analysis.

3.4.2.4   Biological Control Pathogens (Bacteria)

> Bacillus thuringiensis israelensis (Bti) This tool is used by the District.

> Bacillus sphaericus (Bs) This tool is used by the District.

> Saccharopolyspora spinosa (Spinosad) This tool is not currently used by the District but is being studied and considered.

3.4.2.5   Synthetic Insecticides

All of the following potential synthetic insecticides were evaluated.

> Permethrin

> Zenivex E20 (Etofenprox)

> Pyrocide (Pyrethrin)

> Deltamethrin

> Resmethrin

3.4.2.6   Natural Insecticides

> Pyrethrin

3.4.2.7   Insect Growth Regulators

> Methoprene in various formulations: liquid, pellets, briquets.

3.4.2.8   Mineral Oils

> BVA 2 Oil

> CoCoBear Oil

3.5   Selected Program Alternatives

The District has selected a systems approach over several years using multiple tools and depending upon conditions at specific locations. The District utilizes an overall IPM approach in order to use procedures that will minimize potential environmental impacts. The District's Program employs IPM/IVM principles by first determining the species, distribution and abundance of mosquitoes/vectors through evaluation of public service requests and field surveys of immature and adult mosquito/vector populations and, then, if the populations exceed predetermined guidelines, using the most efficient, effective, and environmentally sensitive means of control. For all mosquito species, public education is an important control strategy. In some situations, water management or other physical control activities can be instituted to reduce mosquito-breeding sites. The District also uses biological control such as the planting of mosquitofish in some settings: ornamental fish ponds, ponds, water troughs, water gardens, fountains, and neglected swimming pools. When these approaches are not effective, or are otherwise deemed inappropriate, then pesticides are used to treat specific vector-producing or vector-harboring areas.

Three core tenets are essential to the success of a sound IVM program:

> First, a proactive approach is necessary to minimize impacts and maximize successful vector management. Elements such as thorough surveillance and a strong public education program make a major difference in reducing potential human vector interactions.

> Second, long-term environmentally based solutions (e.g., water management, reduction of harborage and food resources, exclusion, and enhancement of predators and parasites) are optimal as they reduce the potential pesticide load in the environment as well as other potential long- and short-term impacts.

> Lastly, utilizing the full array of options and tools (public education, surveillance, physical control, biological control, and when necessary chemical control) in an informed and coordinated approach supports the overall goal of an environmentally sensitive vector management program.

The District's Program consists of the following alternatives, which are general types of coordinated and component activities, as described below. The Proposed Program is a combination of these alternatives with the potential for all of these alternatives to be used in their entirety along with public education as described below.

3.5.1   Surveillance

Vector surveillance, which is an integral part of the District's responsibility to protect public health and welfare, involves monitoring vector populations and habitat, their disease pathogens, and human/vector interactions. Vector surveillance provides the District with valuable information on what vector species are present or likely to occur, when they occur, where they occur, their abundance, and if they are carrying a pathogen(s) or otherwise affecting humans. Vector surveillance is critical to an IVM program because the information it provides is evaluated against treatment guidelines to decide when and where to institute vector control measures. Information gained is used to help form action plans that can also assist in reducing the risk of disease transmission. Equally important is the use of vector surveillance in evaluating the efficacy, cost effectiveness, and environmental impacts of specific vector control actions.

3.5.1.1   Mosquito Surveillance

Mosquitoes in nature are distributed within their environment in a pattern that maximizes their survival to guarantee reproductive success. Immature stages develop in water and later mature to a winged adult that is capable of both long- and short-range dispersal. This duality of their life history presents vector control agencies with unique circumstances that require separate surveillance strategies for the aquatic versus terrestrial life stages.

Surveillance involves monitoring the abundance of mosquito populations, their habitat, mosquito-borne disease pathogens, and the interactions between mosquitoes and people over time and space. The District routinely uses a variety of traps for surveillance of adult mosquitoes, regular field investigation of known mosquito sources for direct sampling for immature stages, public service requests for adult mosquitoes, and low ground pressure all-terrain vehicles (ATVs) to access these sites. The District conducts surveillance by way of a variety of activities that include:

> **Field counting/sampling and use of trapping**, along with the laboratory analysis of mosquitoes, and pathogens to evaluate population densities and potential disease threats such as WNv, WEE, and SLE. Sampling of presence and abundance of mosquito populations tends to occur in areas where the citizenry would have a likelihood of exposure to them or in habitat occurring within the mosquito species flight range to populated areas. Field counts take place both at immature and adult stages of mosquito development or life cycle. Three kinds of traps, host-seeking traps, light traps, and gravid/oviposition traps, are used as described below:

  – Host-seeking traps use dry ice (carbon dioxide) and/or a synthetic lure (e.g. Octenol) to attract female mosquitoes behaviorally cued to seek a host to blood feed. The trap's components include

a container/reservoir for attractant (e.g. dry ice), a battery power source, a low ampere motor/fan combination, and a collection bag for holding captured adults. These types of traps may also include a small light source (e.g. lamp) as an additional attractant for mosquitoes.

–   Light traps (commonly called New Jersey Light traps) use a source of photo-attraction such as an incandescent lamp (25-watt) or fluorescent lamp (7-watt) where they are pulled in by the suction provided by an electric (110 v AC) appliance motor/fan combination. Mosquitoes picked up by the suction are directed downward (via screened cone) inside the trap body to a glass or plastic collection jar containing a 1-inch strip of Vapona, Hot Shot®, or No-Pest® strip (Dichlorvos). The collection jar is enclosed within an expanded metal cage with a hinged trap door that is padlocked.

–   Oviposition traps are used to collect gravid *Culex* spp. mosquitoes and/or to measure their egg-laying activity. This trap uses an infusion, such as 5-day-old hay-infused water contained in a small plastic dish pan that has a 6-volt battery-operated fan directly above to draw the gravid female mosquitoes into the small collection net.

Mosquito immatures include eggs, four larval stages, and a transitional pupal stage. Mosquito control agencies routinely target the larval and pupal stages to preclude an emergence of adults. Operational evaluation of the presence and abundance of immature mosquitoes is limited to the larval and pupal stages, although the District may sample eggs for research reasons. Sampling and collection of the immature stages (egg, four larval stages, and a transitional pupal stage) involves the use of a 1-pint dipper (a standardized small plastic pot or cup-like container on the end of a wood or metal handle), which scoops up a small amount of water from the mosquito-breeding site. Operationally, the abundance of the immatures in any identifiable "breeding" source is measured through direct sampling, which provides relative local abundance as the number of immatures per sample and/or area of the source. This method requires access by field personnel to within about 3 feet of larval sites at least every 2 weeks in warm weather. The spatial patchiness of larvae requires access to multiple locations within each source, rather than to single "bell-weather" stations.

>   "Arbovirus"[1] surveillance to determine the likelihood and occurrence of mosquito-borne illness is accomplished by two methods commonly used in California: (1) capturing and testing female vector mosquitoes for the presence of mosquito-borne encephalitis viruses as explained above and (2) periodic testing for the presence of encephalitis virus-specific antibodies in the blood serum of either sentinel chickens, domestic or wild birds. The first method involves the use of host-seeking traps to capture female vector mosquitoes. Captured females are sorted into groups of up to 50 (called pools) and tested via one of two methods. Testing may be carried out in the District's laboratory using a method such as real-time polymerase chain reaction or submitted to UC Davis to test for the presence of mosquito-borne viruses. The District uses method (2) above through the placement of caged chickens as "sentinel birds." Since the viruses of major concern (WNV, WEE, and SLE) are diseases actively transmitted by mosquitoes to both birds and to humans through bites, caged chickens' routine blood samples will reveal whether one or more of the virus-specific antibodies are present. The chickens are placed generally 6 to a caged area (at least 6 by 12 feet or larger), are humanely treated, and are provided ample shelter with nest boxes, water, and feed. Chickens are used as the early detection system for virus transmission, as they are unaffected by the presence of these viruses in their systems. At the end of the mosquito season, the chickens are adopted out. In addition, the District participates in the State's dead bird pickup program as part of its West Nile virus surveillance program. Dead birds are assessed for condition and if they are suitable, collected by the District, and then sent for West Nile virus testing at a State laboratory.

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[1]   Arthropod-borne viruses. The primary reservoir for the pathogens that cause these diseases is wild birds, and humans only become exposed as a consequence of an accidental exposure to the bite of infective mosquito vectors.

> Field inspection of known or suspected habitats where mosquitoes live and breed. Sites where water can collect, be stored, or remain standing for more than approximately 96 hours are potential habitats for mosquito breeding that require continuous inspection and surveillance. Water runoff into catch basins and stormwater detention systems from land uses including, but not limited to, residential communities, parks and recreation areas, and industrial sites, as well as ornamental ponds, neglected swimming pools, seeps/seepages, seasonal wetlands, tidal and diked marshes, freshwater marshes, wastewater ponds, sewer plants, winery waste/agricultural ponds, managed waterfowl ponds, canals, creeks, streams, tree holes, tires, man-made containers, flooded basements/crawl spaces, and other standing waters are likely sources.

> Maintenance of paths and clearings to facilitate sampling and to provide access to vector habitat. It is District policy that staff use preexisting roads, trails, walkways, and open areas to conduct routine and essential surveillance activities if possible and to minimize impact on the environment. Surveillance is conducted on foot or by using ATVs, low-pressure ground vehicles and boats, but off-road access is minimized and used only when necessary.

> Analysis of public service requests and surveys and other methods of data collection.

The District's mosquito surveillance activities are conducted in compliance with accepted federal and state guidelines, in particular the *California Mosquito-borne Virus Surveillance and Response Plan* (CDPH et al. 2013) and *Best Management Practices for Mosquito Control in California* (CDPH and MVCAC 2012).These guidelines recognize that local conditions will necessarily vary and, thus, call for flexibility in selection and specific application of control methods.

3.5.1.2   Tick Surveillance

The District performs surveillance of ticks (e.g. *Ixodes pacificus*) to survey the incidence tick-borne diseases such as, Lyme disease (*Borrelia burgdorferi*), ehrlichia, anaplasma, and rickettsia species by way of the following practices:

> *Collection* of ticks in public contact areas to (a) determine the location of ticks infected with tick-borne diseases such as, *Borrelia burgdorferi* and (b) to determine the seasonal and geographical distribution of the ticks according to species. Ticks are typically collected by "flagging" vegetation along trails. Stiff fabric is dragged for specified distances along the trails to stimulate ticks to attach to the material. Then they are manually removed and placed in vials for transport back to the laboratory for testing.

> *Identification* of ticks brought in by the public, which are usually found biting persons or their domestic animals.

> *Submission* of tick-borne disease test results to the appropriate Public Health Agency (e.g., CDPH). The District also provides tick-borne disease test results and tick abundance data to government agencies and the public. The District on occasion submits tick samples to CDPH for testing.

> *Dissemination* of educational information to the public concerning ticks, Lyme disease, and other tick-borne diseases.

3.5.1.3   Rodent Surveillance

The District responds to public and agency service requests regarding rats and rat populations. The monitoring and control work focuses on domestic rats including Norway rats (*Rattus norvegicus*), roof rats (*Rattus rattus*) and on house mice. Norway rats are known to invade homes and businesses from sources such as sanitary sewers. Property inspections in response to public service requests involve looking for entry ways, rodent burrows, and signs of rodent infestation.

Testing for the presence of hantavirus pulmonary syndrome may be conducted by collecting wild rodents. For hantavirus surveillance, small traps are placed in suspect areas including peridomestic habitats along

the urban fringe or rural areas. The traps are checked the following day to remove any rodents for sampling. Blood samples are submitted for testing.

3.5.1.4   Yellowjacket and Other Wasps

Venomous biting and stinging insect encounters often require the response of District staff. It is important to educate the residents that while these insect bites and stings may potentially induce life-threatening allergic reactions and pain, overall, these insects serve beneficial roles as pollinators and biological control agents.

The District responds to public service requests and provides recommendations and control measures for nonstructural pest populations of yellowjackets. Problems involving bee swarms are referred to the local beekeepers association and/or the County Agricultural Department.

Other Vector Surveillance

Ground squirrels (*Spermophilus beecheyi*) and other sylvatic rodent surveillance for the plague consists of sampling by trapping with blood samples sent to the California Department of Public Health (formerly Health Services) (CDPH), Vector-Borne Disease Section for testing. These animals may also be tested for tularemia. Testing for the presence of plague and murine typhus might be conducted by collecting ground squirrels, opossums, and fleas in addition to wild rodents described in Section 2.3.1.3 above. Small animals will be trapped using live traps baited with food. The traps will be set in late afternoon and will be collected within 24 hours. The animals will be anesthetized and blood, tissue, and flea samples will be obtained. Threatened and endangered species and other legally protected animals that may become trapped will be released immediately and will not be used in these tests.

The two primary reservoir vectors of rabies in California are bats and skunks. Both live in close proximity to humans and their pets because of their ability to adapt to the urban/suburban environment. Residential landscapes provide them with an abundance of food and shelter options that have increased their numbers and the potential for direct contact with the human population. This is true for all wildlife and therefore a potential rabies health threat exists. The District works with home and property owners to discourage wildlife (primarily by providing referrals and information) such as skunks and bats from taking up residence in areas frequented by humans, pets, and livestock on their property. Upon a service request, personnel from the District will survey the property and provide guidance and recommendations on exclusion methods to minimize vector impact on the property.

The District responds to requests from the public to provide information about bed bugs. The Centers for Disease Control and Prevention (CDC) and the United States Environmental Protection Agency (USEPA) have jointly said that bed bugs are a public health nuisance pest. Their biting can cause welts (however, not everyone will react to bed bug bites). Under heavy infestations, asthma or allergy can be problematic for children and senior citizens. The District's bed bug protocol includes the following educational activities:

> Positively identify a specimen brought to the District to confirm that it is a bed bug.

> Educate members of the public on likely bed bug infestation signs (e.g., skin cast, blood stains).

> Provide information on ways to reduce clutter, improve sanitation, make repairs, and use pillow and mattress encasements.

> Advise using passive monitoring devices (e.g., Climb Up or Night Watch bed bug detection devices).

> Advise on hiring a reputable and experienced pest control operator to control the bed bugs.

> Remain neutral on landlord/tenant bed bug disputes.

3.5.2 **Physical Control**

Managing vector habitat to reduce vector production or migration, either directly or through public education is often the most cost-effective and environmentally benign element of an IVM program. This approach to the control of vectors and other pests is often called "physical control" to distinguish it from those vector management activities that directly rely on application of chemical pesticides (chemical control) or the introduction or relocation of living agents (biological control). Other terms that have been used for vector habitat management include "source reduction," which emphasizes the significance of reducing the habitat value of an area for vectors, or "permanent control," to contrast with the temporary effectiveness of pesticide applications.[2] Vector habitat management is important because its use can reduce or virtually eliminate the need for pesticide use in and adjacent to the affected habitat and, in some situations, can virtually eliminate vector production from specific areas for long periods of time, reducing the potential disturbances associated with frequent biological or chemical control activities. The intent is to reduce the abundance of vectors produced or sheltered by an area while protecting or enhancing the habitat values of the area for desirable species. In many cases, physical control activities involve restoration and enhancement of natural ecological functioning, including production and dispersal of special-status species and/or predators of vectors.

3.5.2.1 Mosquitoes

Physical control for mosquitoes consists of the management of mosquito-producing habitat (including freshwater and tidal marshes and lakes, saltwater marshes, temporary standing water for approximately 96 hours or more, and wastewater treatment facilities) especially through water control and maintenance or improvement of channels, tide gates, levees, and other water control facilities. Physical control is usually the most effective mosquito control technique because it provides a long-term solution by reducing or eliminating mosquito developmental sites and ultimately reduces or eliminates the need for chemical applications. The physical control practices may be categorized into three groups: maintenance, new construction, and cultural practices.

Maintenance activities are conducted within tidal, managed tidal, and nontidal marshes, seasonal wetlands, diked, historic bay lands, and in some creeks adjacent to these wetlands. The following activities are classified as maintenance:

1. Removal of sediments from existing water circulation ditches

2. Repair of existing water control structures

3. Removal of debris, weeds, and emergent vegetation in natural channels

4. Clearance or trimming of brush for access to streams or wetland areas

5. Filling of existing, nonfunctional water circulation ditches to achieve required water circulation dynamics and restore ditched wetlands

New construction typically involves the creation of new ditches to enhance tidal flow preventing stagnant water.

Cultural practices include vegetation and water management, placing culverts, bridges or other engineering works, and making other physical changes to the land. These practices reduce mosquito production directly by improving water circulation and indirectly by improving habitat values for predators of larval mosquitoes (fish and invertebrates), or by otherwise reducing a site's habitat value to mosquito larvae.

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[2] This terminology can be misleading if periodic maintenance is needed for physical control devices or structure.

The District performs these physical control activities in accordance with all appropriate environmental regulations (e.g., wetland fill and dredge permits, endangered species review, water quality review, streambed alteration permits, see Section 2.7), and in a manner that generally maintains or improves habitat values for desirable species. Major physical control activities or projects (beyond the scope of the District's 5-year regional wetlands permits with the United States Army Corps of Engineers (USACE), San Francisco Bay Conservation and Development Commission, and Regional Water Quality Control Board) are addressed under this PEIR where known and identified. Minor physical control activities (covered by the regional wetlands permits) are also addressed in this PEIR. They vary substantially from year to year, but typically consist of up to 10,000 linear feet of ditch maintenance. Under the regional permits, the District's work plans are reviewed annually by trustee and other responsible agencies prior to initiation of the planned work. Completed work is inspected by USACE, United States Fish and Wildlife Service (USFWS), California Department of Fish and Wildlife (CDFW, formerly Fish and Game), and other responsible agencies.

The District may request/require landowners and stewards to manage and maintain their properties to minimize the potential for vector production and vector-borne disease or to abate existing production. Maintenance can include: clear debris from drainage channels and waterways; excavate built-up spoil material; remove water from tires and other urban containers; cut, trim, mow, and harvest aquatic and riparian plants (but not including any mature trees, threatened or endangered plant species, or sensitive habitat areas); and install minor trenching and ditching. The District advises landowners and stewards to consult with regulatory agencies regarding the need for agency review and permitting if it appears that natural habitat and nontarget species could be affected.

3.5.2.2   *Other Vectors*

Physical control for other vectors such as rats, mice, raccoons, skunks, and opossums is based on site inspections by the District to determine conditions promoting harborage and signs of infestation. Property owners are provided educational materials on control measures that include removal of food sources (such as pet food, bird/squirrel feeders, and fruit from trees) and blockage of access points into the structure. If the vector is posing a health or safety risk, then removal by trapping is employed by means of referral to a licensed private pest control operator.

Three elements are necessary for a successful rodent management program: sanitation, exclusion, and rodent proofing.

> *Sanitation:* Correcting sanitation deficiencies is basic in rodent control. Eliminating food sources through good sanitation practices will prevent an increase in their populations. Sanitation involves good housekeeping, including proper storage and handling of food materials and pet food. For example, store pet food in metal, rodent-proof containers. For roof rats, thinning dense vegetation will make the habitat less desirable. Algerian or English ivy, star jasmine, and honeysuckle on fences or buildings are very conducive to roof rat infestations and should be thinned or removed if possible.

> *Exclusion:* Sealing cracks and openings in building foundations, and any openings for water pipes, electric wires, sewer pipes, drain spouts, and vents is recommended. No hole larger than 0.25 inch should be left unsealed to exclude both rats and house mice. Doors, windows, and screens should fit tightly. Their edges can be covered with sheet metal if gnawing is a problem. Coarse steel wool, wire screen, and lightweight sheet metal are excellent materials for plugging gaps and holes.

> *Rodent proofing* against roof rats requires more time to find entry points than for Norway rats because of their greater climbing ability. Roof rats often enter buildings at the roofline area so be sure that all access points in the roof are sealed. If roof rats are traveling on overhead utility wires, the District recommends/encourages the property owner to contact a pest control professional or the utility company for information and assistance with measures that can be taken to prevent this access.

While activities designed to reduce vector populations through changes in the physical environment are considered Physical Control, they must be distinguished from activities related to rearing or relocating predators of vectors, which are discussed below as "Biological Control," as well as those tools that impact vector habitat through manipulation of vegetation, which are described below as "Vegetation Management" practices.

3.5.3   Vegetation Management

3.5.3.1   Physical Control

The species composition and density of vegetation are basic elements of the habitat value of any area for mosquitoes and other vectors, for predators of these vectors, and for protected flora and fauna. District staff periodically undertake vegetation management activities, or encourage and provide suggestions to others on how to do so on their property, as a tool to reduce the habitat value of sites for mosquitoes and other vectors or to aid production or dispersal of vector predators, as well as to allow access by District staff to vector habitat for surveillance and other control activities. The District encourages property owners to consult with regulatory agencies and to inquire regarding the need for an agency consult or permit. Direct vegetation management by District staff generally consists of activities to reduce the mosquito habitat value of sites by improving water circulation or access by fish and other predators, or to allow access by District staff to standing water and/or known sources of mosquito production for inspections and treatment if necessary.

For vegetation management, the District uses hand tools or other mechanical means (i.e., heavy equipment) for vegetation removal or thinning and sometimes applies herbicides if requested and provided by other agencies (chemical pesticides with specific toxicity to plants) to improve surveillance or reduce vector habitats. Vegetation removal or thinning primarily occurs in aquatic habitats to assist with the control of mosquitoes and in terrestrial habitats to help with the control of other vectors. To reduce the potential for mosquito breeding associated with water retention and infiltration structures, District staff may systematically clear weeds and other obstructing vegetation in wetlands and retention basins (or request the structures' owners to perform this task). In particular, thinning and removal of cattail overgrowth would be done to provide a maximum surface coverage of 30 percent or less. In some sensitive habitats and/or where sensitive species concerns exist, vegetation removal and maintenance actions would be restricted to those months or times of the year that minimize disturbance/impacts. Vegetation management is also performed to assist other agencies and landowners with the management of invasive/nonnative weeds as it pertains to mosquito source reduction or access to sources of mosquito production (e.g., *Spartina*, *Pepperweed*, *Arundo*, *Tamarix*, and *Ailanthus*). These actions are typically performed under the direction of the concerned agency, which also maintains any required permits.

Tools ranging from shovels and pruners to chain saws and "weed-whackers" up to heavy equipment can all be used at times to clear or trim plant matter that either prevent access to mosquito breeding sites or that prevent good water management practices that would minimize mosquito populations. Generally, however, District "brushing" activities involve the use of hand tools. Trimmed vegetation is either removed and disposed of properly from the site or placed and/or broadcast in such a way as to minimize visual degradation or impacts to the habitat. Trimming is also kept to a minimum to reduce the possibility of the invasion of exotic species of plants and animals. Regulatory agency consultation, coordination with the landowner, and acquisition of necessary permits are completed before any work is undertaken. Follow-up inspections are also conducted to verify that the work undertaken was effective and that the physical manipulation of the vegetation did not result in any unintended overall habitat degradation.

In addition, the use of water management to control vegetation is in some ways an extension of physical control, in that water control structures created as part of a physical control project may be used to directly manipulate hydroperiod (flood frequency, duration, and depth) as a tool for vegetation management. Where potential evapotranspiration rates are high, water management can also become a mechanism for salinity management and, indirectly, vegetation management through another path.

3.5.3.2   *Herbicides*

Herbicides the District may apply in coordination and collaboration with other agencies as a source reduction measure and to achieve habitat enhancement or restoration are listed in Table 2-1 in the PEIR. All herbicides are applied in strict conformance with label requirements.

3.5.4   **Biological Control**

Biological control of mosquitoes and other vectors involves the intentional use of vector pathogens (diseases), parasites, and/or predators to reduce the population size of target vectors. It is one of the principal components of a rational and integrated vector control management program. Biological control is used as a method of protecting the public from mosquitoes and the diseases they transmit without the use of pesticides and potential problem of pesticide resistance; however, the use of pathogens involves chemical treatment with USEPA-registered materials. The different types of biological controls are described in the following paragraphs.

3.5.4.1   *Mosquito Pathogens (Viruses and Bacteria)*

Mosquito pathogens include an assortment of viruses and bacteria. Pathogens are highly host-specific and usually infect mosquito larvae when they are ingested. Upon entering the host, these pathogens multiply rapidly, destroying internal organs and consuming nutrients. The pathogen can be spread to other mosquito larvae in some cases when larval tissue disintegrates and the pathogens are released into the water to be ingested by uninfected larvae. Examples of viruses that can infect mosquitoes are mosquito iridoviruses, densonucleosis viruses, nuclear polyhedrosis viruses, cytoplasmic polyhedrosis viruses, and entomopoxviruses. Examples of bacteria pathogenic to mosquitoes are *Bacillus sphaericus* (Bs), the several strains of *Bacillus thuringiensis israelensis* (Bti), and *Saacharopolyspora spinosa*. Two bacteria, Bs and Bti, produce proteins that are toxic to most mosquito larvae, while *Saacharopolyspora spinosa* produces compounds known as spinosysns, which effectively control all larval mosquitoes. Bs can reproduce in natural settings for some time following release. Bti materials applied by the District do not contain live organisms, but only spores made up of specific protein molecules. All three bacteria are naturally occurring soil organisms that are commercially produced as mosquito larvicides.

3.5.4.2   *Mosquito Predators*

Mosquito predators are represented by highly complex organisms, such as insects, fish, birds, and bats that consume larval or adult mosquitoes as prey. Predators are opportunistic in their feeding habits and typically forage on a variety of prey types, which allows them to build and maintain populations at levels sufficient to provide some level of mosquito control (i.e. depending on predator species), even when mosquitoes are scarce. Examples of mosquito predators include representatives from a wide variety of taxa: coelenterates, *Hydra* spp.; platyhelminths, *Dugesia dorotocephala, Mesostoma lingua, and Planaria* spp.; insects, *Anisoptera, Zygoptera, Belostomidae, Geridae, Notonectidae, Veliidae, Dytiscidae, and Hydrophilidae*; arachnids, *Pardosa* spp.; mosquitofish, *Gambusia affinis*, *Gasterosteus aculeatus*; bats; and birds, *anseriformes, apodiformes, charadriiformes, and passeriformes*. Only mosquitofish are commercially available to use at present, while the District supports the presence of the other species as practical.

The District's rearing and stocking of mosquitofish in mosquito habitat is the most commonly used biological control agent for mosquitoes in the world. These fish are ideal control agents for several reasons. They feed primarily at the water's surface, where larvae can be found. They can tolerate a significant range in water temperature and water quality. They are also easy to handle, transport, stock, and monitor. Correct use of this fish can provide safe, effective, and persistent suppression of a variety of mosquito species in many types of mosquito sources. As with all safe and effective control agents, the use of mosquitofish requires a good knowledge of operational techniques and ecological implications, careful evaluation of stocking sites, use of appropriate stocking methods, and regular monitoring of stocked fish. Mosquitofish reproduce in natural settings, for at least some time after release. District policy

is to limit the use of mosquitofish to contained sources such as, ornamental fish ponds, water troughs, water gardens, fountains, waste ponds, and neglected swimming pools. Limiting the introduction of the mosquitofish to these sources should prevent their migration into habitats used by threatened, endangered, or rare species. On average, the District releases about 30 pounds of mosquitofish annually.

3.5.5 <u>Chemical Control</u>

Chemical control is a Program tool that consists of the application of nonpersistent insecticides (and herbicides noted in Section 2.3.3 above) to directly reduce populations of larval or adult mosquitoes and other invertebrate threats to public health. If and when inspections reveal that mosquitoes or other vector populations are present at levels that trigger the District's guidelines for chemical control – based on the vector's abundance, density, species composition, proximity to human settlements, water temperature, presence of predators and other factors – District staff will apply pesticides to the site in strict accordance with the pesticide label instructions.

3.5.5.1 Synthetic Insecticides

Synthetic insecticides are pest management products produced in a laboratory and in some cases may also be a synthetic version of naturally occurring pesticides (e.g., pyrethroids that are a synthetic version of naturally occurring pyrethrin). The District currently uses the product Zenivex (Etofenprox when it is necessary to treat for adult mosquitoes. A diluent, such as BVA 13, may be used to increase the application volume.

The District currently has a relatively small amount of the product Scourge (Resmethrin) to apply when necessary for adult mosquito control.

The District may also consider the use of additional synthetic adulticides if necessary (e.g. if adulticide resistance issues arise). Adulticides the District may consider are listed in Table 2-3 in the PEIR.

3.5.5.2 Natural Insecticides

Natural insecticides are those materials made directly from plants or other organisms such as bacteria. Some of these materials, such as Bti, are highly host specific, while others such as pyrethrin are not.

Botanical insecticides are derived from plants (e.g., pyrethrins from chrysanthemum flowers). The District uses pyrethrin to manage adult mosquitoes and yellowjackets. The District currently uses Pyrocide (i.e. MGK 7067) when it is necessary to treat for adult mosquitoes. The active ingredient (pyrethrin) is derived from natural sources.

 Pyrethrins break down rapidly (usually within hours) when exposed to sunlight. The District recognizes that pyrethrins are not selective for mosquitoes. Therefore, use near beehives is restricted. Additionally, wind restrictions also apply to minimize unwanted drift when making ULV fogging applications. Pyrethrin for adult mosquito control is applied at a rate of less than 1.0 ounce per acre using a ULV fogging machine. Pyrethrin dust for the treatment of yellowjacket nests is applied at a maximum rate of 2 ounces per nest and is performed with a handheld bulb duster that blows the pyrethrin directly into the nest.

Insecticides derived from bacteria (e.g., Bti) typically consist of a chemical by-product and/or protein spore produced directly from the organism. The bacterium Bti produces spores containing protein molecules or crystals that are toxic to most immature mosquitoes. The various formulations of Bti used by the District contain no live bacteria but only the spores with protein molecules. Bti efficacy is reduced in highly organic or polluted waters, low temperatures, areas with high larval densities or when dense vegetative cover interferes with application at the mosquito-breeding site. Additionally, timing of the application is critical to maximize effectiveness as the adult, pupal, and late 4th instar larval stages of mosquitoes are not susceptible to Bti. Even with the above limitations, Bti is highly effective and, therefore, a preferred method for the management of mosquito populations when predators, biological control, and habitat manipulation strategies are ineffective. This material comes in liquid, granular, water

dispersed granule, and water-soluble packet formulations. The liquid formulations of this insecticide are applied using hand, truck, boat, or ATV-mounted application equipment, or by fixed wing or rotary winged aircraft. Historically, powdered formulations were mixed with sand and a small amount of mineral oil to act as a binding agent, and then the mix was applied with a handheld granular spreader. The District may in the future use powdered Bti, if and when it becomes available again, and,- therefore,- makes mention of it here to keep it as an available option for larval mosquito control. Water soluble packets are used to help control larval mosquitoes that are present in small containers, ornamental water gardens, stormwater detention systems- and storm drains. Water-soluble packets are only applied by hand.

Another bacterium, *Saccharopolyspora spinosa*, produces compounds known as spinosyns, which are toxic to immature mosquitoes. Like Bti some physical and environmental conditions can limit the effectiveness and use of this material. Unlike Bti, rates near maximum label rates have been shown to affect a few species of nontarget organisms, while lower rates appear to be more specific to immature mosquitoes. Research has demonstrated that mosquito larvae are highly sensitive to spinosyns, although additional research is needed to confirm minimum effective field rates for mosquito control purposes. Although relatively new as a mosquito control product and not currently used, the District reserves the right to include and use this material as a part of its IVMP.

3.5.5.3 Insect Growth Regulators

IGRs target immature insect populations. IGRs can be target specific, depending on the formulation used and the concentration that is applied to the target population of insects being managed. Therefore, adhering to label requirements and used in the manner for which they are designed, IGRs affect the juvenile stages of the target organisms while causing little or no effects to the nontargets present (e.g., methoprene and mosquitoes). Unlike many traditional insecticides, IGRs do not affect an insect's nervous system, nor do they kill adult mosquitoes. Rather, IGRs prevent the ability of the immature stages to complete their final molt from the pupal stage to adult (prevent adult emergence).

Methoprene is a synthetic juvenile hormone that is used by the District to manage mosquito populations. This insecticide is most effective on the late instar larval stages. It is absorbed on contact and causes an imbalance in the hormone system of the mosquito resulting in its inability to complete metamorphosis to the adult stage. The maximum label rate for application of this insecticide for mosquito control is many magnitudes below the levels that could impact other nontarget organisms, specifically invertebrates, amphibians, and fish, making it a good tool for use in the District's IVMP. Persistence and bioaccumulation in the environment are also insignificant as methoprene readily biodegrades in the presence of ultraviolet light and is also readily metabolized; hence, the timing of applications for this material are essential for optimal effectiveness. The half-life of methoprene is about 2 days in water, 2 days in plants, and 10 days in soil. Formulations used by the District are liquid, granules, and briquets. Both the granules and briquets are slow release formulations that allow for concentrations just sufficient to prevent adult emergence of mosquitoes to occur for up to 150 days. Methoprene formulations are applied using hand, boat, truck-or ATV-mounted application equipment, or by fixed wing or rotary winged aircraft. Briquette formulations are applied by hand to mosquito sources such as, small man-made containers, water gardens, fountains, abandoned swimming pools, stormwater detention systems, and storm drains.

3.5.5.4 Mineral Oils/Surfactants

Mineral oil and ethoxylated alcohol formulations (also known as surfactants) are used to control immature stages of mosquitoes (larvae and pupae). This control is accomplished by changing the surface tension of the water resulting in suffocation. These materials can also affect any adult mosquito that tries to land on the water to rest or lay eggs. The current surfactants the District currently utilizes are BVA-2 Oil and Coco Bear Oil. Agnique MMF is currently not being manufactured, although it is possible that it or a like material may become available in the future and it is, therefore, included as a part of the District's IVMP. The active ingredient in BVA-2 is mineral oil. Coco Bear Oil is comprised of 10 percent mineral oil with the remaining oil content consisting of food grade coconut and vegetable oils. Agnique MMF is 100 percent

ethoxylated alcohol. All of these materials can be applied using hand, truck , boat or ATV-mounted application equipment.

3.6   Future Tools under Development and Stud

Saccharopolyspora spinosa (i.e. Spinosad) is currently under study and consideration for potential future use. Additional insecticides may also be studied and implemented into the IVM program as necessary (e.g., see Tables 2-1, 2-2, and 2-3 in the PEIR). ATSBs are also under evaluation.

4   No Project Alternative

No Project is defined as what would reasonably be expected to occur in the foreseeable future, based on current plans and consistent with available infrastructure and community services, if the project was not approved and implemented. For the District, the Proposed Program is to continue current activities and introduce similar pesticides to those currently in use if needed. The No Project/No Program condition assumes that the current activities would cease and result in a "do-nothing" alternative. It must be evaluated in comparison to the existing condition for California Environmental Quality Act compliance.

Key assumptions for the No Project alternative are:

> Current regulatory controls would continue and expand as needed; however, the District would not engage in implementing any of these regulations concerning public health and management of vectors carrying potential pathogens. For all practical purposes, the District's office would close and public education and other outreach activities would cease along with the control activities.

> Private landowners would manage mosquito and/or vector problems on private land without any state or federal oversight with pesticides approved for use.

> Private landowners would also manage vector habitats (clearing, brushing, and draining) with potentially little or no oversight.

4.1   Implications of No Project Alternative

"Doing nothing" as the No Project Alternative has potentially serious implications for public health, economic, and environmental conditions in the District's Program Area.

4.1.1   Public Health

A wide range of public health issues would occur with the No Project Alternative, First, risk of human cases of vector-borne disease and vector interaction issues for humans, pets and wildlife would increase. The San Francisco Bay Area has a well-documented history concerning human-vector interaction, especially with mosquitoes. The earliest written record dates back to the 1772 diaries of Father Juan Crespi who described the "swarms of mosquitoes" in the Warm Springs Area of the City of Fremont and below the hills of Berkeley (Bolton 1927; Gray 1951). Additional records include the 1810 journal entry of mosquitoes attacking a detachment of soldiers near the Albany Hills as well as references indicating that the indigenous peoples of the Bay Area would take action to avoid the large numbers of mosquitoes present during certain times of the year. Note that these interactions took place at a time when the Bay's wetlands and sensitive habitats were essentially pristine, having limited human habitation and little or no draining, filling or modification, or loss of wildlife including predators of mosquitoes.

Second, the lack of any form of coordinated surveillance reduces the ability of any agency to perform disease risk assessments and, therefore, predict potential outbreaks. Although vector-borne disease is not as prevalent as in other areas of the world, vector-borne pathogens are still present. The city of San Francisco has had a history of plague (Anderson 1978; Link 1955; Stimson 1939), and the plague organism is still present in the San Bruno Hills (CDPH 2004, 2002, 2001; Kartman 1964; Kartman et al. 1958; Murray 1964; Quan et al. 1960). Other rodent-borne pathogens such as Hantavirus have also been detected in mouse populations in Alameda, Contra Costa, Marin, Napa, and San Mateo counties (CDPH 2007, 2006, 2005, 2001). Tick-borne pathogens for diseases such as lyme borreliosis, tularemia, ehrlichiosis, and rocky mountain spotted fever have also been found in tick populations throughout the Bay Area, with human cases also reported. West Nile virus, although introduced in 2005, is present throughout the Bay Area, with positive birds, human cases, and some infected horses still detected and reported every year. Malaria continues to be a concern as introduced cases are detected in travelers

returning from malaria-infected regions and some recent immigrants every year. The vector for this pathogen can be found in many areas of the San Francisco Bay region, and reintroduction of the malaria organism into local mosquito populations is monitored closely. The last known endemic transmission of malaria occurred in the Putah Creek area of Napa and Solano counties in 1939.

Third, lack of coordinated surveillance increases the risk of emerging infectious diseases or vectors going undetected until they have become established. The appearance of West Nile virus in New York City in 1999 is an excellent example. For budgetary and other reasons, New York had significantly reduced their vector surveillance and management program many years prior to 1999. By the time the virus had been identified, a number of human cases had already occurred and the virus had become well established. Now the virus is endemic throughout the US and results in numerous cases nationwide. Similarly, the reintroduction of vector-borne diseases such as malaria and dengue that had not been present for many years or even decades could also go undetected until their reestablishment or an outbreak of human cases (Brunetti et al. 1954; Gubler and Clark 1995; Maldonado et al. 1990; Radke et al. 2012; Singal et al. 1977).

Fourth, lack of public outreach results in less current information being available about vectors and vector-borne disease risk reduction. This lack can lead to increased production of vectors on private property as well as increased cases of vector-borne disease in humans, their pets, and livestock. Additionally, the increase in vector-human interactions would result in an increased risk of severe reactions to the bites and stings of vector organisms (e.g., mosquitoes, ticks, and wasps) in sensitive and immunocompromised individuals. Research over the last 75 years has documented cases of hypersensitivity and/or severe reactions to mosquito bites in children, immunocompromised individuals, and persons infected with the Epstein-Barr virus or being treated with zidovudine for the AIDS virus. (Brown et al. 1938; Diven et al. 1988; Galindo et al. 1998; McCormack et al. 1995; Peng et al. 2004; Seon et al. 2013; Simmons and Peng 1999; Smith et al. 1993; Weed 1965). Crisp and Johnson (2013) provide a review of mosquito allergy including immunology, diagnosis, and treatment and conclude (1) treatment should focus on avoidance including limiting breeding sites for mosquitoes as well as the use of repellents and protective clothing, (2) local immediate reactions can be managed with the use of prophylactic antihistamines, (3) individuals with severe or anaphylactic reactions to mosquito bites should carry with them Epi-Pens (autoinjectable epinephrine), and (4) more research is needed in a number of areas concerning management and treatment of patients with hypersensitivity to mosquito bites.

The reaction of persons to vector stings and bites, especially mosquito bites, clearly brings into question the use of the terms "nuisance" and "pest" that have commonly been used in the past to define the difference between those vector organisms that transmit vector-borne diseases (i.e., malaria, West Nile virus, Tularemia, Lyme Disease, Plague) and those that do not. The use of these terms is a misnomer and should not be used to characterize the importance of one vector over another. Human-vector interactions result in a wide range of mental, emotional, and physical responses, all of which have health implications even in the absence of pathogenic organisms. California Health and Safety Code, Division 104, Part 11, Chapter 1, Section 116108 defines a vector as "any animal capable of transmitting the causative agent of human disease or capable of producing human discomfort or injury including, but not limited to, mosquitoes, flies, other insects, ticks, mites, and rats." This definition inherently recognizes that human discomfort and injury as a result of human-vector interactions, is by its own nature, an issue of health just as important as any vector-borne agent of human disease.

4.1.2   Economic Conditions

A number of economic issues are associated with the No Project Alternative. First, with increased human-vector interactions comes an increase in the number of cases of vector-borne disease. The short-term medical and lost workplace, school, and home time associated with illness can cost governments, businesses, families, and individuals upwards of many thousands of dollars (Armien et al. 2008; Barber et al. 2010; Clark et al. 2005; Gubler 2002; Halasa et al. 2012; Meyers 1922; Shepard et al. 2011; Suaya et al. 2009; Tam et al. 2012; Torres 1997; Von Allmen et al. 1979; Vora et al. 2014; Wettstein et al. 2012).

For long-term severe cases that result in paralysis, persistent fatigue, muscle weakness, and/or decreases or loss of cognitive function, this cost can mean millions of dollars to families and federal and state governments (Staples et al. 2014; Utz et al. 2003; Villari et al. 1995). Although not as common, no monetary value can be adequately calculated for the loss of life due to vector-borne disease. Additionally, the loss of valuable livestock (e.g., horses) and decreased farm productivity can also be significant (Abbitt and Abbitt 1981; ASTHO no date; Byford et al. 1992; Cattell 1916; Gadsen Times 1980; Geiser et al. 2003; Herrick 1903; Hoffman and McDuffie 1963; Howard 1909; Mongoh et al. 2008; Steelman et al. 1973, 1972; Williams et al. 1985).

Second, increased vector populations can lead to reduced outdoor recreation activities by the public (Halasa et al. 2014), resulting in increased usage of electricity for air conditioning and indoor entertainment such as television, video games, computers, lighting, etc. These increases could also lead to a reduction in revenues for recreational areas such as parks, campgrounds, marinas, and other areas that depend on usage fees to help with their maintenance and staffing. Outdoor activities are also significant to tourism, which for many areas is an important part of their economy. Large vector populations and/or reported cases of vector-borne disease can impact tourism and potential revenues (Gaiser 1980; Kirka 1989; Merco Press 2008; The Hindu 2007; Wagner and Magee 1977; Williams 1986).

Third, increased vector populations not only lead to increased levels of vector-borne disease but can also result in decreased property values (Herms and Gray 1944; Howard 1909). Within San Francisco Bay, historical mosquito populations were at times so severe as to impact real estate sales (Gray 1951). The impact of mosquito control work on property values is also illustrated by Headlee (1945), who summarized the economic effect of mosquito control work in New Jersey. Here property valuations from 1915 to 1930 had increased by $555,345,000.00 over what was expected for those communities that had received mosquito control work. Property values form an essential part of the revenue stream for government services such as schools, police, fire, libraries, parks, and health and welfare programs.

Fourth, the cost of hiring private contractors to provide vector control services on a site-specific basis can end up more costly than the costs associated with the current program (with economies of scale). More significant are the costs associated with having to reestablish a program that has been eliminated. These costs include equipment, staffing, staff training, and the initial environmental costs associated with a new program working to restore vector levels to the healthful level that existed with the old program prior to its elimination. A loss of institutional memory and understanding of local vector populations, their habitats, and the local citizenry cannot be replaced when a program is eliminated. When a program is reestablished, less environmentally friendly measures will be employed during a period of time to bring vector populations down to a level where maintenance and control measures that have little or no environmental impact can be effectively employed (e.g., New York and West Nile virus).

4.1.3 Environmental Conditions

The environmental issues associated with the No Project Alternative cannot be understated. First, in the absence of organized mosquito and vector control programs, unlicensed individuals could begin applying over the counter pesticides on their own. Most of these individuals have little or no training in the proper and effective use of these materials, meaning a reasonable possibility exists of over- or under-application as well as the potential for creation of unrecognized resistance issues. This possibility is especially true for the indiscriminate use of aerosol foggers as well as concentrated pesticides that require mixing with water prior to application. Additionally, the health and well-being of sensitive individuals (e.g., asthmatics and chemically sensitive people) and their pets (especially birds and fish) could be affected by the unexpected drift of these pesticides into their yards, open windows, and neighborhood parks.

Second, the potential exists for increased use of inappropriate or unregistered materials such as bleach, oil, gasoline, diesel fuel, etc., in an effort to deal with vectors, especially mosquitoes and yellow jackets. Their use can cause significant environmental harm compared to materials applied in accordance with label requirements by trained, licensed professionals.

Third, many members of the public lack a general understanding of IPM practices and procedures. Therefore, increased vector-human interactions could lead to the increased use of non-IPM practices to provide rapid relief from vector bites and stings as well as address any fears concerning reports in the media of increased vector-borne disease.

Fourth, as mentioned earlier, some vector-borne diseases such as West Nile virus pose a risk to native bird species, including some species of concern such as yellow-billed magpies, hawks, and owls (Crosbie et al. 2008; Fitzsimmons 2013; LaDeau et al. 2007; Nemeth et al. 2007, 2009; Sovada et al. 2008).

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[To be completed with full citations. Attract and Kill and Mass Trapping citations to be added.]

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