BEST MANAGEMENT PRACTICES FOR MOSQUITO CONTROL IN CALIFORNIA

A Manual for Landowners and Land Managers

May 2023

A companion document “Best Management Practices for Mosquito Control on California State Properties” is available from the California West Nile virus website (https://westnile.ca.gov).

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Purpose of this Manual

This manual provides California landowners and land managers with guidance and recommendations for the management of mosquitoes on their properties. Mosquito control Best Management Practices (BMPs) are specific, primarily non-chemical actions that can be implemented to reduce or eliminate mosquito production from different habitats. These actions are crucial to protect the public from mosquito-borne disease and mosquito biting nuisance that negatively impact quality of life, and may be necessary to remain in compliance with the California Health and Safety Code.

General Recommendations

- Use personal protective measures.
- Eliminate unnecessary standing water.
- Reduce stagnation in bodies of water with increased water flow and vegetation management.
- Consult and collaborate with local mosquito control agencies when necessary to develop and implement appropriate Integrated Mosquito Management (IMM) strategies that are most suitable for specific land-use type(s).



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Introduction

Controlling mosquitoes in the environment is critical to protecting people from mosquito--borne diseases such as West Nile virus (WNV) and preserving a high quality of life when outdoors by reducing mosquito biting nuisance. Local mosquito control agencies exist throughout the state for this purpose and cover approximately half the land area and 85% of the population.* However, state laws also require landowners and land managers to minimize mosquito production on their lands and these actions play a key role in reducing mosquito populations throughout the State.

This manual of Best Management Practices (BMPs) for mosquito control was developed by the California Department of Public Health (CDPH) in collaboration with the Mosquito and Vector Control Association of California to provide California landowners and land managers with guidance and recommendations to minimize mosquito production on their properties. Mosquito control BMPs are specific, primarily non-chemical, actions that can be implemented to reduce or eliminate mosquito production from different habitats. These BMPs incorporate an Integrated Mosquito Management (IMM) philosophy that emphasizes the use of physical, biological, and cultural control methods prior to the use of chemicals, and prioritizes long-term and sustainable solutions whenever possible.

California is a vast state with diverse climates, natural and modified environments, and varying human population densities. As a result, there exists a wide variety of land uses and more than 50 native and introduced mosquito species. Some mosquito control BMPs presented in this manual are specific to only certain land types, while others may have broader applications, or might even be considered “universal”. An understanding of the public health significance of mosquitoes, their biology, and the legal responsibility to mitigate mosquito production on certain lands is provided and is helpful when developing a plan. Additional information and resources contained in the appendices will aid in education, decision-making, and BMP implementation.

Three take-away recommendations that all landowners and land managers should consider are:

1) Minimize or eliminate standing water habitat that can support the development of mosquitoes,
2) consult and collaborate with local mosquito control agencies when developing a mosquito management plan for a specific property, and
3) use personal protective measures to minimize exposure to mosquito bites.

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* A jurisdictional map of local mosquito control agencies, with contact information, is available on the [Mosquito and Vector Control Association of California website](https://www.mvcac.org) (https://www.mvcac.org).

Responsibility of Landowners and Land Managers

According to the California Health and Safety Code (HSC), landowners and land managers in California are legally responsible for eliminating sources of public nuisance on their property, including mosquitoes. In areas that are within the jurisdictional boundaries of a mosquito control agency, landowners should work with agency staff to address mosquito problems and develop a comprehensive mosquito management plan. Those located outside these boundaries may seek advice from the nearest mosquito control agency or health department, or contact CDPH.

Under the HSC, mosquito control agencies have substantial authority to access private property, inspect known or suspected sources of mosquitoes, and abate the sources of mosquitoes. Landowners and land managers that are unwilling or unable to address mosquito production arising from their property may be responsible for reimbursing mosquito control agencies for work performed, and furthermore can be fined for each day a public nuisance remains unabated.

The California Health and Safety Code is available in its entirety (also searchable by code section and/or keywords) on the California Legislative Information website (https://leginfo.legislature.ca.gov/).

Mosquito Biology

The more than 50 species of mosquitoes in California share one common life history trait: the mosquito life cycle requires standing water. Management of standing water is the key component of most of the mosquito control BMPs presented in this manual and is one of the oldest and most cost-effective forms of mosquito control.

Mosquito species are broadly separated into two groups according to where they lay eggs, floodwater mosquitoes and standing water mosquitoes. Adult female floodwater mosquitoes lay eggs on previously submerged surfaces (e.g., mud, vegetation, manufactured materials) of intermittently flooded habitats. The eggs may remain dormant for days, months, or even years until they are flooded with water, which triggers them to hatch. In contrast, standing water mosquitoes lay eggs on the water surface. The eggs float on the surface for a few hours to a few days until the larvae hatch into the water.

Floodwater mosquito larval development (breeding) sites include irrigated pastures, rice fields, seasonally flooded duck clubs and other managed wetlands, tidal wetlands, riparian corridors, and snowmelt pools. These intermittent or seasonally flooded habitats can be among the most productive sources of mosquitoes because of their size and because they are often free of natural predators. A few species of floodwater mosquitoes use much smaller larval habitats (container breeders) such as seasonally flooded tree holes and rock pools. Recently introduced invasive container breeding mosquitoes only live in close association with humans and use small artificial containers in urban environments such as flower pots, used tires, bird baths, and subsurface sumps and basins.

Standing water mosquito breeding sites may include artificial containers, treeholes, catch basins, open ditches, retention/detention ponds, natural or constructed ponds and wetlands, stormwater management devices, and the edges of streams. Standing water mosquitoes will often replace floodwater species, or share habitat when water remains long enough to support the development of their larvae. Sources of water suitable for these mosquitoes are found everywhere from highly urban areas to natural wetlands, and often produce multiple generations of mosquitoes each season. In warmer areas of the state, urban sources can produce some species of mosquitoes all year.

Landowners and land managers can identify the presence of larval mosquitoes in water on their property. Mosquito larvae breathe air from above the water surface and hang at an angle from or lay parallel with the surface of the water while consuming small bits of organic matter. When disturbed, larvae swim down into the water column in a serpentine motion. Mosquitoes may remain as larvae for less than a week to over a month depending on the species, water temperature, and the amount of food available. When larvae reach maturity, they transform into a non-feeding stage called a pupa during which the mosquito changes into the winged adult form. The easily identified comma-shaped pupae hang from the water surface and move down through the water column in a rolling or tumbling motion when disturbed. This life stage typically lasts about a day, with the adult mosquito emerging from the back of the pupal case onto the water surface before taking flight (See Figure 1: Mosquito Life Cycle).

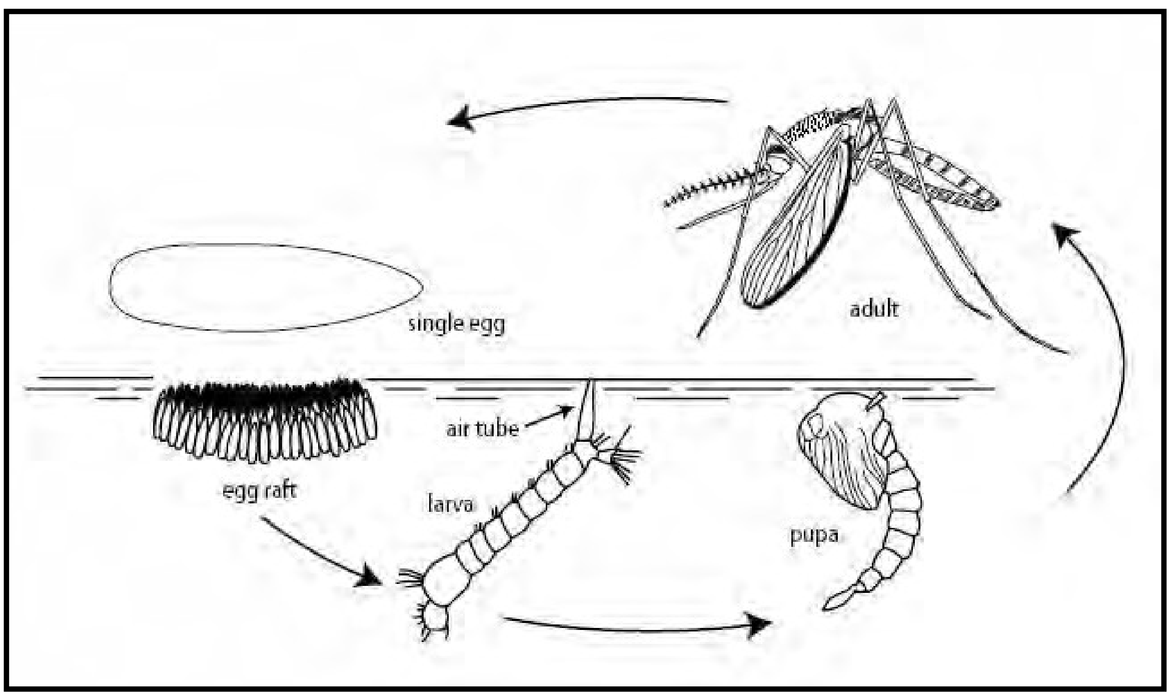

Figure 1. The life cycle of all mosquito species consists of four stages: egg, larva, pupa, and adult.

All adult mosquitoes feed on plant nectar; however, blood is essential for female mosquitoes to produce eggs. To take a blood meal, the female's mouth parts pierce the skin, inject saliva, and suck blood out. It is through the injection of saliva that a mosquito causes the typical itchy bump and can infect a person or domestic animal with a disease-causing organism. Depending on an individual's immune response, even a single bite can be a significant nuisance.

For information on mosquito control and arbovirus surveillance in California, please see Appendix A.

For more information on mosquito biology and key mosquito species found in California, please see Appendix B.

For additional information on the larval habitats of California mosquitoes, please see Appendix C.

Mosquito Control Best Management Practices (BMPs)

Mosquito Control Best Management Practices At-A-Glance

- Urbanized Areas
    - Manage plant growth in ditches, ponds, and urban wetlands.
    - Ensure temporary sources of surface water drain within four days (96 hours) whenever possible.
    - Design water conveyance and water holding structures to minimize the potential for producing mosquitoes.
    - Eliminate water-holding containers and other smaller sources of standing water on private properties.
- Rural / Agricultural Areas
    - Manage plant growth in wetlands where permitted.
    - Time flood irrigation to minimize mosquito production.
- Use biological controls such as mosquitofish when appropriate and where permissible.
- Consult and collaborate with local mosquito control agencies when developing a mosquito management plan for a specific property.
- Use personal protective measures to prevent mosquito bites.

Each property is unique. Landowners and land managers should implement universally applicable mosquito control BMPs, and after evaluating their own property, also employ specific mosquito control BMPs that are suitable for their property and circumstances. Using appropriate BMPs is an efficient and effective way to minimize mosquito production.

Universally Applicable Mosquito Control BMPs

Eliminate Artificial Mosquito Breeding Sites and Harborage around Structures

- Examine outdoor areas and drain any unnecessary water that may stand longer than 96 hours.
- Dispose of unwanted or unused artificial containers.
- Properly dispose of old tires.
- If possible, drill drainage holes, cover, invert, or eliminate any outdoor container or object that may hold standing water (e.g., saucers under potted plants, buckets, jars, trash cans, tarps, boats).
- Clean clogged rain gutters and yard drains so they flow freely and drain completely.
- Keep water moving in ponds and other ornamental water features by using waterfalls, fountains, and/or aerators to minimize stagnant water.
- Completely drain and refill water in birdbaths, un-chlorinated fountains, and animal

troughs at least once per week.
- Regularly chlorinate swimming pools and keep pumps and filters operating. Unused or unwanted pools should be kept empty and dry, or buried.
- Add mosquito-eating fish such as *Gambusia affinis* to larger sources of water when possible (e.g., ponds, unmaintained "green" pools and Jacuzzis). Consult with the local mosquito control agency or the California Department of Fish and Wildlife regarding proper use of mosquitofish.
- Maintain irrigation systems to avoid ponding water and runoff into storm drains.
- Minimize harborage for adult mosquitoes by maintaining landscape vegetation (e.g., thinning branches, trimming and pruning ornamental shrubs, and keeping grass mowed short).

Use Personal Protective Measures

- Apply mosquito repellent registered by the Environmental Protection Agency for human use when outdoors, especially around dusk and dawn when mosquitoes are most active (see Appendix D and Appendix E for additional information and resources on mosquito repellents).
- Wear loose-fitting protective clothing including long sleeves and pant legs to prevent mosquito bites.
- Install and properly maintain fine mesh screens on windows and doors to prevent mosquito entry into homes.

Provide Mosquito Management Related Information to Property Managers

- Off-site landowners should provide property managers with basic information about mosquitoes and appropriate measures to minimize mosquito habitats.

Contact the Local Mosquito Control Agency

- Contact the local mosquito control agency to evaluate your property for mosquito breeding sites and work cooperatively to prevent a mosquito problem on your property. Local California mosquito control agencies can be searched on the Mosquito and Vector Control Association of California website (https://www.mvcac.org).

Where local mosquito control agencies do not exist, landowners may contact the California Department of Public Health for assistance or consult the California West Nile virus website (https://westnile.ca.gov/) for additional information about mosquito control.

Mosquito Control BMPs for Residential and Landscaped Properties

Many residential and commercial properties have potential mosquito sources around buildings and grounds associated with excess or poorly managed irrigation, poor drainage, and miscellaneous landscape features. Mosquitoes can develop in the standing water resulting from over-irrigation and irrigation breaks, as well as in ornamental ponds, neglected swimming pools and Jacuzzis, and water-holding containers such as rain barrels, trash cans, used tires, and flower pots.

Mosquito sources can be minimized by taking precautions such as regular inspection and proper maintenance of irrigation systems and other water features, and elimination of unwanted standing water on land and held in containers.

- Avoid over-irrigating to prevent excess pooling and runoff.
- Routinely inspect, maintain, and repair irrigation system components.
- All underground drain pipes should be laid to grade to avoid low areas that may hold water for longer than 96 hours.
- Back-fill tire ruts or other low areas that hold water for more than 96 hours.
- Improve drainage channels and grading to minimize potential for standing water.
- Keep drainage ditches free of excessive vegetation and debris to provide rapid drainage.
- Check and repair leaky outdoor faucets.
- Report any evidence of standing water to responsible maintenance personnel.
- Prevent mosquito breeding in rainwater catchment systems such as rain barrels by properly screening all openings, preventing mosquito access to the stored water.
- Remove all unnecessary containers and other items that could hold standing water.

Landowners should also review the *Stormwater Management and Associated Infrastructure* section of this manual because building rooftops, parking lots, and other landscaped areas may have stormwater management features that produce mosquitoes.

Mosquito Control BMPs for Rural Properties

Mosquito breeding on rural properties is highly variable due to differences in location, terrain, and land use. The list of mosquito control BMPs in this section is intended to provide general guidance, not site-specific requirements. BMPs that are most applicable and relevant to a specific mosquito source may be selected from the list and incorporated into the overall property management plan. Ideally, activities should be coordinated with those of a local mosquito control agency.

Flood irrigation is a common practice in rural areas throughout California and always poses the potential for creating mosquito breeding sites. Mosquitoes commonly develop within irrigation infrastructure including in ditches clogged with vegetation, irrigation tail water areas and return sumps, blocked ditches or culverts, vegetated ditches, and leaking irrigation pipes, head gates, pumps, and stand pipes. The fields, orchards, and pastures being irrigated may also produce mosquitoes, particularly where natural undulation or poor grading create low lying areas where water collects and stands.

Recommendations for rural properties are based on "Mosquito Reduction Best Management Practices" produced by the Sacramento-Yolo Mosquito and Vector Control District (http://fightthebite.net), and from Lawler and Lanzaro (2005).

Mosquito Control BMPs for Ditches and Drains

- Construct or improve large ditches to a slope of at least 2:1 (vertical: horizontal) and a minimum 4' wide bottom. Consider a 3:1 slope or greater to discourage burrowing animal damage, potential seepage problems, and prevent unwanted vegetation growth.
- Keep ditches clean and well-maintained. Periodically remove accumulated sediment and vegetation. Maintain ditch grade and prevent areas of standing water.
- Design irrigation systems to use water efficiently and drain completely to avoid standing water.
- Prevent wet areas associated with seepage by repairing leaks in dams, ditches, and drains.

Mosquito Control BMPs for Irrigated Pastures and Cropland

- Grade to eliminate standing water from pastures and fields. Use Natural Resource Conservation Service (NRCS) guidelines (http://www.nrcs.usda.gov): Laser leveling and periodic maintenance may be needed to allow proper drainage, efficient water flow, and reduce low-lying areas where standing water may accumulate.
- Reuse wastewater through return flow systems to effectively minimize mosquito production and conserve water. Eliminate and reuse excess water that may typically stagnate and collect at lower levels of irrigated fields.
- Irrigate only as frequently as needed to maintain proper soil moisture. Check soil moisture regularly.
- Drain water as quickly as possible following irrigation. Check slopes may be used to direct water movement and drainage. Drainage ditches may be used to remove water from the lower end of the field.
- Install surface drains to remove excess water that collects at lower levels of irrigated fields.
- Inspect fields for drainage and broken checks to see whether re-leveling or reconstruction of levees is needed. Broken checks create cross-leakage that may provide habitat for mosquitoes.

- If possible, use closed conduits instead of open canals for water conveyance.
- Do not over fertilize. Over-fertilization can leach into irrigation run-off making mosquito production more likely in ditches or further downstream.
- When possible, use sprinklers or drip systems rather than flood irrigation.
- Keep animals off the pasture while the soil is soft. Mosquito habitat is created in irrigated pastures when water collects in hoof prints.

Mosquito Control BMPs for Rice Fields

Flooded rice fields can always support the development of mosquitoes. As the rice stand develops and grows denser, the production of mosquitoes tends to increase while the ability for chemical control agents to penetrate the canopy decreases. The BMPs presented in this section attempt to balance the needs of the grower with the need to control mosquitoes.

In California there is a long-standing cooperative effort among the Rice Commission, individual growers, and mosquito control agencies to manage mosquitoes on rice lands. Close cooperation between growers and mosquito control is particularly important with organic rice producers. With severe limits on chemical control options and greater expense for organic-compatible larvicides, organic rice growers should implement as many mosquito control BMPs as possible.

- Wherever feasible, maintain stable water levels during mosquito season by ensuring constant flow of water into ponds or rice fields to reduce water fluctuation due to evaporation, transpiration, outflow, and seepage.
- Inspect and repair levees to minimize seepage.
- Drain and fill in borrow pits and seepage areas external to the fields.
- Wherever feasible, maintain at least 4” - 6” of water in the rice field after rice seedlings have begun to stand upright. Any drainage should be coordinated with the local mosquito control agency (where possible). Restocking of mosquitofish or use of alternative mosquito control measures should be instituted as soon as possible when fields are re-flooded.
- Whenever feasible, remove vegetation on the outer-most portions of field levees and checks, specifically where they interface with standing water.
- Control algae and weed growth as effectively as possible.
- Wherever feasible, maintain borrow pits (12” - 18” deep) on both sides of each check throughout rice fields to provide refuge for mosquitofish during low water periods.
- If a pyrethroid pesticide is to be applied to the fields stocked with mosquitofish, contact the local mosquito control agency for advice on minimizing fish mortality.
- If a pesticide is applied, fields should be inspected for mosquitofish afterward and if needed, fish should be restocked as soon as feasible.
- Communicate frequently with the local mosquito control agency regarding crop management activities.

Mosquito Control BMPs for Dairies and Animal Holding Operations

Infrastructure associated with dairies, feedlots, or other animal holding facilities such as watering troughs, ponds, wastewater lagoons, and irrigated fields frequently produce mosquitoes. Animal washing areas may also create mosquito problems, particularly drains, ditches, and sumps.

The following activities can reduce mosquito production and simplify control activities around dairies and animal holding operations:

- All holding ponds should be surrounded by lanes of adequate width to allow safe passage of mosquito control equipment. This includes keeping the lanes clear of any materials or equipment (e.g., trees, calf pens, hay stacks, silage, tires, equipment).
- If fencing is used around the holding ponds, it should be placed on the outside of the lanes with gates provided for vehicle access.
- Large ponds should be divided into a series of smaller ponds that can be drained for removal of solid waste material.
- Ponds and lagoons should be narrow enough to allow solid waste removal after drying.
- All interior banks of the holding ponds should have a grade of at least 2:1.
- If possible, an effective solids separation system should be utilized such as a mechanical separator or two or more solids separator ponds. If ponds are used, they should not exceed 60’ in surface width.
- Drainage lines should never by-pass the separator ponds, except those that provide for normal corral run-off and do not contain solids.
- When possible, floating debris should be removed from ponds prior to crust formation.
- If a thick crust exists, it should be left intact until the pond can be drained and the solid material removed.
- Vegetation should be controlled regularly to prevent emergent vegetation and barriers to access. This includes access lanes, interior pond embankments, and any weed growth that might become established within the pond surface.
- Dairy wastewater discharge for irrigation purposes should be managed so it does not stand for more than 4 days.
- Tire sidewalls or other objects that will not hold water should be used to hold down tarps (e.g., on silage piles). Whole tires or other water-holding objects should be replaced.

Mosquito Control BMPs for Stormwater Management and Associated Infrastructure

Federal and state environmental regulations require mitigation of the harmful effects of runoff water from storms, irrigation, or other sources prior to entering natural waterways. Mitigation may include water capture, slowing flow velocity, reducing volume, and removal of pollutants. The term “stormwater” is used as a generic term for runoff water, regardless of source.

Stormwater infrastructure typically includes conveyance systems (e.g., drain inlets, catch basins, pipes, and channels), storage and infiltration systems (e.g., flood control basins, percolation basins), and more recently, treatment structures designed and installed specifically to remove suspended and dissolved pollutants from runoff (e.g., vegetated swales, dry detention basins, ponds and constructed wetlands, media filtration devices, and trash capturing devices). The size and variability of stormwater infrastructure, inconsistent quantity and timing of water flows, and propensity to carry and accumulate sediment, trash, and debris, make these systems likely to have areas of standing water ideal for production of mosquitoes. Identification of the potential mosquito sources (often belowground) found within stormwater infrastructure is sometimes more difficult than the solutions needed to minimize mosquitoes. Some of the information within this section has been adapted from Metzger (2004).

General Mosquito Control BMPs for Stormwater Infrastructure

- Consider how to minimize mosquito production during the design, construction, and maintenance of all stormwater infrastructure.
- Whenever possible, design and maintain systems to fully discharge captured water in 96 hours or less.
- Design systems with permanent water sources such as wetlands, ponds, sumps, and basins to minimize mosquito habitat and plan for routine larval mosquito inspection and control activities with the assistance of the local mosquito control agency.
- Design systems to include access for inspection and control of mosquitoes.
- Inspect stormwater facilities weekly during warm weather for the presence of standing water or larval mosquitoes.
- Remove emergent vegetation and debris that accumulate water from gutters and channels.
- Minimize runoff entering stormwater infrastructure; manage sprinkler and irrigation systems; avoid washing sidewalks, driveways, and vehicles.

Stormwater Conveyance

- Provide proper grades along conveyance structures to ensure that water flows freely.

- Inspect on a routine basis to ensure the grade remains as designed and to remove accumulations of sediment, trash, and debris.
- Keep inlets free of accumulations of sediment, trash, and debris to prevent standing water from backing up on roadways and gutters.
- Design outfalls to prevent scour depressions that can hold standing water.

Stormwater Storage and Infiltration Systems (Aboveground)

- Design structures so that they do not hold standing water for more than 96 hours to prevent mosquito development. Features to prevent or reduce the possibility of clogged discharge orifices (e.g., debris screens) should be incorporated into the design. The use of weep holes is not recommended due to rapid clogging.
- Provide a uniform grade between the inlets and outlets to ensure that all water is discharged in 96 hours or less. Routine inspection and maintenance are crucial to ensuring the grade remains as designed.
- Avoid the use of electric pumps. They are subject to failure and often require permanent-water sumps. Structures that do not require pumping should be favored over those that have this requirement.
- Avoid the use of loose rock rip-rap that may hold standing water.
- Design distribution piping and containment basins with adequate slopes to drain fully. The design slope should take into consideration buildup of sediment between maintenance periods.

Stormwater Structures with Permanent-Water Sumps or Basins (Belowground)

- Where possible, seal access holes to belowground structures designed to retain water in sumps or basins (e.g., pickholes in manhole covers) to minimize entry of adult mosquitoes. If using covers or screens, maximum allowable gaps of 1/16 inch will exclude entry of adult mosquitoes. Inspect barriers frequently and replace when needed.
- If the sump or basin is completely sealed against mosquitoes, with the exception of the inlet and outlet, the inlet and outlet should be completely submerged to reduce the available surface area of water for mosquitoes to lay eggs (female mosquitoes can fly through pipes).
- Where possible, design belowground sumps with the equipment necessary to allow for dewatering of the unit.
- Contact the local mosquito control agency for advice with problem systems.

Stormwater Treatment Ponds and Constructed Treatment Wetlands

- Whenever possible, stock stormwater ponds and constructed wetlands with mosquito-eating fish such as *Gambusia affinis* available from most local mosquito control agencies (consult with the local mosquito control agency or the California Department of Fish and Wildlife regarding proper use of mosquitofish).
- Design and maintain accessible shorelines to allow for periodic maintenance

and/or control of emergent and shoreline vegetation, and routine monitoring and control of mosquitoes. Emergent plant density should be routinely managed so mosquito predators can move throughout the vegetated areas and are not excluded from pond edges.

- Whenever possible, design and maintain deep zones in excess of 4' to limit the spread of invasive emergent vegetation such as cattails. The edges below the water surface should be as steep as possible and uniform to discourage dense plant growth that may provide larval mosquitoes with refuge from predators and increased nutrient availability.
- Use concrete or liners in shallow areas to discourage plant growth where vegetation is not necessary.
- Whenever possible, provide a means for rapid dewatering if needed.
- Manage the spread and density of floating and submerged vegetation that encourages mosquito production (e.g., water hyacinth, water primrose, parrot's feather, duckweed, and filamentous algal mats).
- If possible, compartmentalize managed treatment wetlands so the maximum width of ponds does not exceed two times the effective distance (40') of land-based application technologies for mosquito control agents.

General Access Requirements for Stormwater Treatment Structures

- All structures should be easily and safely accessible, without the need for special requirements (e.g., Occupational Safety and Health Administration - OSHA - requirements for "confined space"). This will allow for monitoring and, if necessary, abatement of mosquitoes.
- If utilizing covers, the design should include spring-loaded or lightweight access hatches that can be easily opened.
- Provide all-weather road access (with provisions for turning a full-size work vehicle) along at least one side of large aboveground structures that are less than 23' wide, or both sides if shore-to-shore distance is greater than 23'.
  Note: Mosquito larvicides are applied with hand-held equipment at small sites and with backpack or truck mounted high-pressure sprayers at large sites. The effective swath width of most backpack or truck-mounted larvicide sprayers is approximately 20-25' on a windless day.
- Build access roads as close to the shoreline as possible to allow for maintenance and mosquito control crews to periodically maintain, control, and remove emergent vegetation and conduct routine mosquito monitoring and abatement. Remove vegetation and/or other obstacles between the access road and the structure that might obstruct the path of larvicides to the water.
- Control vegetation periodically (by removal, thinning, or mowing) to prevent barriers to access.

Mosquito Control BMPs for Right of Ways and Easements

Right of ways and easements for a variety of infrastructure exist throughout California. Roadways, power lines, pipelines, canals, bike paths, utility access, railroads, etc. have adjacent lands associated with them that may produce mosquitoes. It is the responsibility of the agency, landowner, or land manager associated with the infrastructure to prevent a public nuisance arising from the property, including a mosquito problem. Right of ways and easements are as varied as the terrain in California. As a result, mosquito breeding sites found on these properties will also vary and require the following steps be taken to identify appropriate mosquito control BMPs.

Inspection of Property and Identification of Mosquito Sources

The property must be inspected to identify potential mosquito habitats discussed elsewhere in this manual. Some rights of way and easements are very long and may include multiple types of mosquito larval habitats that fall within every category listed below, others will have none.

Review and Implement Mosquito Control BMPs as Appropriate

After inspecting the property, implement mosquito control BMPs found in the sections below appropriate for the identified mosquito larval habitat(s). It can be helpful to consult and collaborate with a local mosquito control agency.

- Implement *Universally Applicable Mosquito Control BMPs*.
- If the property is in an urban area and is managed as commercial property, refer to the following section:
  - *Residential and Landscaped Properties*
- If the property is associated with an irrigation canal or similar rural water conveyance, refer to the following sections:
  - *Rural Properties*
  - *Wetlands*
- If the property is associated with a variety of habitats like a railroad or pipeline right of way, refer to the following sections:
  - *Rural Properties*
  - *Wetlands*
- If the property is associated with a roadway or other structure that would require management of stormwater runoff, refer to the following section:
  - *Stormwater Management and Associated Infrastructure*

In many instances, right of ways and easements will simply fall to the local mosquito control agency or go completely unmanaged because they are very large, and it is not possible to determine the responsible party.

Mosquito Control BMPs for Wastewater Treatment Facilities

Wastewater treatment facilities are designed to collect and treat nutrient rich, highly organic water. These facilities implement practices appropriate to removing contaminants from wastewater, but which may be in direct conflict with BMPs intended to prevent development of mosquito larvae. Further, facilities managers are under intense pressure to meet water quality standards in effluent water and are frequently concerned that mosquito control BMPs will jeopardize compliance with effluent standards.

Wastewater facilities often include features that can produce mosquitoes. Examples include 1) a series of treatment or evaporation ponds, 2) the use of tules or other emergent vegetation to remove contaminants, 3) aerated and non-aerated ponds with emergent vegetation around the edges or throughout, 4) cracks and openings in crusted waste matter on the surface of treatment ponds, and 5) abandoned or unused pond basins that frequently hold shallow water. Certain activities may also create or enhance mosquito habitat including: 1) allowing evaporation of wastewater from treatment ponds for maintenance or as a standard treatment method, 2) release of wastewater into marshes or floodplains for evaporation or infiltration, and 3) distribution of sludge onto irrigated agricultural lands.

- Monitor all treatment ponds for mosquito larvae – particularly in areas of emergent vegetation.
- Remove emergent vegetation from edges of aerated ponds.
- Immediately incorporate sludge into soil through plowing or disking.
- Ensure all water distributed onto evaporation ponds dries completely in less than 96 hours.
- Check abandoned ponds or tanks weekly to ensure they are completely dry.
- Use mechanical agitation to prevent the formation of any crust on treatment ponds or tanks.

The facility and surrounding property must be inspected to identify other potential mosquito habitats not listed above but discussed elsewhere in this manual. It is likely that these facilities will have multiple types of mosquito habitats. After inspecting the property, implement mosquito control BMPs appropriate for the identified mosquito larval habitat(s). It can be helpful to consult and collaborate with a local mosquito control agency.

- Implement *Universally Applicable Mosquito Control BMPs*.
- For mosquito control around buildings and grounds, refer to the *Residential and Landscaped Properties* section.
- Certain BMPs included in the *Dairies and Animal Holding Operations* and *Wetlands* sections of this manual may be pertinent to wastewater management facilities, particularly those sections related to construction and management of treatment

ponds and wetlands and the use and distribution of wastewater or sludge onto agricultural lands.
- For mosquito control related to wastewater collection, conveyance, and distribution, refer to the *Stormwater Management and Associated Infrastructure* section.

Mosquito Control BMPs for Wetlands

Wetlands are an important source of mosquito production on public and privately owned lands. Under the California Wildlife Protection Act, the term "wetlands" is defined as any lands which may be covered periodically or permanently with shallow water, which include freshwater and saltwater marshes, open or closed brackish water marshes, swamps, mudflats, fens, and vernal pools. Many wetlands are protected by federal and state laws.

By definition, "natural" wetlands are not intensely managed and options for implementing mosquito control BMPs in these areas are very limited. Even in managed wetlands, not all BMPs listed below may be suitable for use in all wetlands. It is the responsibility of the landowner or land manager to become informed on timing and extent of acceptable activities in a given wetland habitat. Intermittently or seasonally flooded wetlands can produce formidable numbers of mosquitoes, whereas well-managed semi-permanent and permanent wetlands usually produce fewer mosquitoes because of their limited acreage, stable water levels, and abundance of natural predators of mosquito larvae. Always consult with the local mosquito control agency and the California Department of Fish and Wildlife before considering any land modification, vegetation management, the use of non-native fish (e.g., *Gambusia affinis*), or pesticides to control mosquito larvae in wetland habitats, as they may not be permitted.

Information in this section has been partially adapted from Kwasny et al. (2004). Based on the site activities and potential for mosquito production, the existing BMPs may need to be modified or supplemented to address public health risk, goals and management strategy issues, and requirements of California Department of Fish and Wildlife, the California Department of Public Health, and the local mosquito control agency.

> Due to the delicate and sometimes protected wetlands ecosystems, landowners, land managers, biologists, and staff from mosquito control agencies should collaborate to control mosquitoes. Source reduction and source maintenance can be combined with the judicious use of specific larvicides to minimize mosquito production from these wetlands.

General Mosquito Control BMPs for Wetlands

- Manage vegetation routinely; activities such as annual thinning of rushes and cattails and removing excess vegetative debris enables natural predators to hunt mosquito larvae more effectively in permanent wetlands. Vegetation in shallow, temporary wetlands can be mowed when dry.

- Time flooding of seasonal wetlands to reduce overlap with peak mosquito activity.
- Flood wetlands from permanent-water sources containing mosquito predators (e.g., mosquito-eating fish or invertebrate predators) to passively introduce mosquito predators. Permanent wetlands and brood ponds can be stocked with mosquitofish (where permitted) or native predatory species.
- Maintain permanent or semi-permanent water within the wetland to support populations of larval mosquito predators.
- Use fertilizers conservatively and manage irrigation drainage to prevent or minimize fertilizer and/or manure flowing into wetlands. Buffers between agriculture fields and wetlands should be established.
- Avoid the use of broad-spectrum pesticides.
- Comply with all Federal and State environmental laws and the HSC to prevent environmental harm while reducing or eliminating mosquito production.

Mosquito Control BMPs for Design and Maintenance of Wetlands

- Strategically locate wetlands identified for early flooding away from urban areas due to their tendency to produce great numbers of mosquitoes.
- Provide reasonable access on existing roads and levees to allow for monitoring, abatement, and implementation of BMPs. Make shorelines of natural and constructed water bodies accessible for periodic maintenance, mosquito monitoring and abatement procedures, and removal of emergent vegetation.
- Construct, improve, or maintain ditches with 2:1 slopes and a minimum 4' width at the bottom. Consider a 3:1 slope or greater to discourage burrowing animal damage, potential seepage problems, and prevent unwanted vegetation growth.
- Construct, improve, or maintain levees to quality standards that ensure stability and prevent unwanted seepage. Ideally build levees with >3:1 slopes and > 80% compaction; consider 5:1 slope or greater in areas prone to overland flooding and levee erosion.
- Provide adequate water control structures for complete draw-down and rapid flooding.
- When possible, include independent inlets and outlets in the design of each wetland unit.
- Construct or enhance swales so they are sloped from inlet to outlet and allow maximum draw-down.
- Excavate deep channels or basins to maintain permanent water areas (>2.5' deep) within a portion of seasonal managed wetlands. This provides year-round habitat for mosquito predators that can inoculate seasonal wetlands when they are irrigated or flooded.

Mosquito Control BMPs for Wetland Infrastructure Maintenance

- Inspect levees at least annually and repair as needed.

- Periodically inspect, repair, and clean water control structures.
  - Remove all debris, including silt and vegetation, which can impede drainage and water flow.
  - Ensure water control structures are watertight to prevent unnecessary water flow or seepage.
- Regularly remove trash, silt, and vegetation from water delivery ditches to allow efficient water delivery and drainage.
  - Remove problem vegetation that inhibits water flow using herbicides or periodic dredging.
  - If possible, use closed conduits instead of open canals for water conveyance.
- Periodically test and repair pumps used for wetland flooding to maximize pump output.

Mosquito Control BMPs for Wetland Vegetation Management

- Control floating vegetation conducive to mosquito production (e.g., water hyacinth, water primrose, parrot feather, duckweed, filamentous algae mats).
- Perform routine maintenance to reduce problematic emergent plant densities to facilitate the ability of mosquito-eating fish to move through vegetated areas and allow good penetration of chemical control agents.
- Manage vegetation based on local land management objectives and associated habitat uses to minimize mosquito production. Methods of vegetation control for managed wetlands include mowing, burning, disking, and grazing.
- Manage the spread and density of invasive, non-native emergent wetland vegetation to increase native plant diversity, increase the mobility of larval mosquito predators, and allow for more efficient penetration of chemical control agents.

Mosquito Control BMPs for Water Management in Seasonal Wetlands

- Timing of flooding
  - Delay or "phase" fall flooding of wetlands as long as possible in consultation with local mosquito control agencies to minimize late season mosquito production, particularly those in close proximity to urban areas. Fall flooding is known to produce large numbers of mosquitoes.
  - When possible, water in managed wetlands should be drawn-down in late March or early April.
  - Use a flood-drain-flood regime to control floodwater mosquitoes; flood to trigger hatching of dormant mosquito eggs, drain water and larvae into an area where they can be easily treated, drowned in moving water, or consumed by predators, and immediately re-flood wetland. This water management regime should be used only when it does not conflict with water quality regulations.
- Speed of flooding
  - Flood wetlands as quickly as possible to reduce the potential for large numbers of mosquitoes. Coordinate flooding with neighbors and/or the water

    - district to maximize flood-up rate.
- Water source
    - Flood wetlands with water from permanent water sources containing mosquito predators (i.e., mosquito-eating fish or invertebrate predators) to passively introduce mosquito predators. Permanent wetlands and brood ponds used as flooding sources can be stocked with mosquito-eating fish (where permitted) or maintained to encourage natural predator populations.
    - Maintain a separate permanent water reservoir that conveys water to seasonal wetlands and provides year-round habitat for mosquito predators that can inoculate seasonal wetlands when they are irrigated or flooded.
- Frequency and duration of irrigation
    - When possible, reduce the number and duration of irrigations to minimize standing water. The need to irrigate should be evaluated based on spring habitat conditions and plant growth. If extended duration irrigation (generally 14-21 days) is considered for weed control (e.g., cocklebur), additional measures to offset the potential for increased mosquito production may be needed.
    - Irrigate managed wetlands before soil completely dries after spring draw- down to discourage floodwater mosquitoes from laying eggs in the dry, cracked substrate.
    - Drain irrigation water into ditches or other water sources with mosquito predators instead of into nearby dry fields.
    - Maintain high ground water levels by keeping channels or deep swales permanently flooded for subsurface irrigation to reduce the amount of irrigation water needed during the mosquito season.
- Communicate with your local mosquito control agency (if there is one)
    - Advise your local mosquito control agency when you intend to flood so that they can make timely applications of larvicide if necessary.
- Emergency preparedness
    - Whenever feasible, have an emergency plan that provides for immediate drainage into acceptable areas if a mosquito-borne disease related public health emergency occurs.

Mosquito Control BMPs for Water Management in Permanent Wetlands

- Maintain stable water levels in wetlands that are flooded during summer and early spring to prevent intermittent flooding of shoreline areas favorable to mosquito production. Water level fluctuation can be minimized by maintaining a constant flow of water into the wetland.
- Circulate water to avoid stagnation (e.g., provide a constant influx of water equal to the net loss or discharge of water).
- Maintain water depths as deep as possible (18” – 24” or more) during the initial flood-up to minimize shallow habitats preferred by mosquito larvae. More shallow water levels can be maintained outside of the mosquito breeding season.

Mosquito Control BMPs for Saltwater Marshes

- Improve water flow through the wetland system to minimize stagnant water and facilitate movement of fish and other natural predators. For example, mosquitoes in coastal tidal wetlands can be managed by constructing and maintaining ditches that drain off the water when the tide falls.

Mosquito Control BMPs for Wildlands and Undeveloped Areas

California encompasses about 100 million acres of land. Approximately 75 million acres are classified as wildlands, which include all undeveloped and non-cultivated property in the state. In many cases the properties are remote and mosquito control is neither feasible nor warranted. However, landowners and land managers of these lands are responsible for mosquito production that may impact nearby persons or communities.

Mosquito Control BMPs that May be Applicable to Wildlands

- Work closely with a local mosquito control agency to accurately identify, map, and monitor areas that may produce mosquitoes and be notified if there is an adult mosquito problem on or near the property; tailor control measures for each site contingent on the species of mosquitoes that are present.
- Conduct routine mosquito surveillance by looking for immature mosquitoes in bodies of water.
- After rainfall, pay particular attention to temporary water sources and ponds that rise.
- Always consult with local mosquito control agencies and the California Department of Fish and Wildlife before considering the use of non-native mosquitofish (e.g., *Gambusia affinis*) in wildlands and undeveloped habitats, as they may not be permitted.
- Implement personal protective measures
  - Provide visitors and guests with information regarding the risk of mosquito-borne disease transmission and personal protective measures.
  - Install and maintain tight-fitting window and door screens on buildings.
  - If possible, minimize outdoor activities at dawn and dusk when mosquitoes are the most active.
  - Wear protective clothing such as long-sleeved shirts and long pants when going into mosquito-infested areas.
  - Use mosquito repellent when necessary, carefully following the directions on the label.

Evaluation of the Efficacy of BMPs

Landowners and land managers can evaluate the efficacy of the mosquito control BMPs they have implemented as follows:

- **Larval mosquitoes**:
    - Are mosquito larvae or pupae present in sources of standing water on the property? If the number of sources and/or larval mosquitoes has decreased or been eliminated, the mosquito control BMPs are working.
- **Adult mosquitoes**:
    - Compare the level of mosquito annoyance before and after BMP implementation. Ask guests or employees about their experience regarding mosquitoes. People become accustomed to a certain level of mosquito activity and commonly notice increases or decreases in that level. If the annoyance level is increasing, there is more work to do; if the number is decreasing or mosquitoes are not noticeable – good job! The mosquito control BMPs are working.

Landowners and land managers can make substantial progress in mitigating mosquito production on their own, but should work collaboratively with a local mosquito control agency when responsible for properties with large or complex aquatic habitats. The best way to evaluate the effectiveness of mosquito control BMPs is through a comprehensive surveillance program of larval dipping and adult mosquito trapping, including species identification. Some important strengths of local mosquito control agencies are their ability to evaluate treatment options, estimate treatment costs, and recommend those BMPs most appropriate for a property. Local mosquito control agencies also are familiar with indigenous mosquito species and therefore know the type of habitat those mosquitoes come from, often monitor adult populations, and can identify if there is a mosquito problem in a particular area.

Appendix A: Mosquito Control and Arbovirus Surveillance in California

Mosquito Control Practices

Mosquito control agencies in California work cooperatively with landowners and land managers to implement an Integrated Mosquito Management (IMM) approach to mosquito control. Source reduction (eliminating the places where mosquito larvae hatch and develop) is the most effective way of reducing the number of adult mosquitoes in the environment; however, it may be possible to reduce or eliminate mosquito production through other modifications of habitat and/or water management. Biological control agents, including native and introduced predators of larval mosquitoes, are often utilized in combination with water management practices. Pesticides are an important part of an IMM program and mosquito-specific larval control products are often used to supplement other source reduction activities. When source reduction and larval control do not adequately reduce the mosquito population, the application of pesticides to control adult mosquitoes may be necessary. Personnel working for mosquito control agencies who apply pesticides in California are certified by the California Department of Public Health (CDPH) after demonstrating the knowledge necessary to control mosquitoes safely and effectively using IMM techniques.

Larval Control

Larval control is the foundation of most mosquito control programs in California. Whereas adult mosquitoes can be widespread in the environment, larvae must have water to develop; control efforts therefore are most effective when focused on aquatic habitats.

Minimizing the number of adults that emerge is crucial to reducing the incidence and risk of disease. The three key components of larval control are environmental management, biological control, and chemical control.

Environmental Management

Manipulating or eliminating potential mosquito breeding sources can provide dramatic reductions in mosquito populations. There are three levels of environmental management.

1. Source elimination: This approach completely eliminates potential larval habitats for mosquitoes. This strategy is generally limited to artificial habitats created by urbanization. Examples of source elimination include emptying or turning over containers that can hold water, filling in holes containing water with sand or gravel, cleaning drainage ditches of debris, and covering or inverting structures and

vessels that could hold water.

2. Source reduction: This strategy aims to alter and sometimes eliminate available habitat for larvae which substantially reduces mosquito breeding and the need for repeatedly applying pesticides. Unlike source elimination, standing water may exist but the total amount of water, or the time the water is left standing, is greatly reduced. Source reduction may require some maintenance (see below) to prevent further mosquito breeding. Examples of source reduction include limiting the growth of emergent vegetation in wetlands and ponds, constructing drainage ditches to remove water from areas prone to flooding, and clearing stormwater channels of silt and debris. Routine larval monitoring can indicate whether these efforts are effective or need further action.

3. Source maintenance: When eliminating or significantly altering mosquito breeding sources is prohibited and/or inappropriate, routine habitat maintenance can help to reduce the number of sheltered, predator-free habitats suitable for mosquito development while having minimal impact on the surrounding environment. Source maintenance can include water management, vegetation management, wetland infrastructure maintenance, and wetland restoration. Strategic, focused plans must be developed for each site.

Biological Control

Biological control uses predators, parasites, or pathogens to reduce populations of mosquito larvae and is often combined with environmental management to enhance results. The mosquitofish (*Gambusia affinis)* has been used to control mosquitoes in California since 1921 and is the most widely used biological control agent in the world. These small fish are effective against mosquito larvae because they grow and reproduce rapidly, feed at the water surface where mosquito larvae are found, and tolerate a wide range of temperature and water quality conditions. Other species of fish are occasionally used in California with mixed success.

Fish are most effective in permanent ponds and wetlands, but are also used in rice fields and stormwater canals with permanent water, and “neglected” swimming pools. Many local mosquito control agencies propagate mosquito-eating fish.

Although many other predators and parasites have been evaluated for mosquito control, and in natural wetlands predation is an important factor in reducing mosquito production, biological control by the intentional addition of mosquito predators other than mosquitofish is largely experimental rather than operational.

Chemical Control

Pesticides that control mosquito larvae are called larvicides. Four types of larvicides (bio-rational, surface films, growth regulators, and chemical products) are registered for use in California. Larvicides are applied by hand, from hand-held or vehicle-mounted engine-driven blowers, or by aircraft, depending on the product, the formulation, and the target habitat. In California, applicators of any of these products must be certified by CDPH or the California Department of Pesticide Regulation.

1. Bio-rational products

   Bio-rational products exploit insecticidal toxins found in certain naturally occurring bacteria. These bacteria are cultured in mass and packaged in various formulations. The bacteria must be ingested by mosquito larvae so the toxin is released; therefore bio-rational products are only effective against larvae since pupae do not feed. The bacteria used to control mosquito larvae have no significant effects on non-target organisms when applied for mosquito control in accordance with product labels.

   Two products that are used against mosquito larvae singly or in combination are *Bacillus thuringiensis israelensis* (Bti) and *Lysinibacillus sphaericus* (formerly *Bacillus sphaericus*). Manufactured Bti contains dead bacteria and remains effective in the water for 24 - 48 hours; some slow-release formulations provide longer control. In contrast, *L. sphaericus* products contain spores that can remain effective for more than 30 days in favorable conditions. Both products are safe enough to be used in water that is consumed by humans.

   Another bio-rational product available for mosquito control is derived from the soil bacterium *Saccharopolyspora spinosa,* which produces natural metabolites called spinosyns during fermentation. These metabolites are lethal to mosquito larvae when ingested or by contact. The most active metabolites are formulated into a product called “spinosad”. The product affects the central nervous system of the mosquito causing uncontrolled nervous impulses, ultimately killing the larvae.

2. Surface agents

   Mosquito larvae and pupae breathe atmospheric air through tubes called “siphons” that extend above the water surface. Surface agents such as highly refined mineral oils can spread across the surface of the water to prevent mosquitoes from breathing. Depending on the product, the film may remain on the water’s surface from a few hours to a few days. Surface films are the only available products that are effective against very late stage larvae and pupae.

3. Insect growth regulators

   Insect growth regulators (IGRs) disrupt the physiological development of larvae thus preventing adults from emerging. The most widely used products in this category contain the active ingredient methoprene. The effective life of these products varies with the formulation; granular, liquid, pellet, or briquette. Methoprene has minimal non-target effects and no use restrictions. IGRs for mosquito control can be used in sources of water that are consumed by humans.

4. Chemical larvicides

Chemical pesticides are rarely used to control mosquito larvae. Organophosphate larvicides are used infrequently because of their potential non-target effects and label restrictions.

Adult Control

IMM programs initiate adult mosquito control when action levels or thresholds are reached or exceeded. Thresholds are based on local sampling of the adult mosquito population and/or when the risk of mosquito-borne disease increases above levels established by a local agency, often following guidelines established in the California Mosquito-borne Virus Surveillance and Response Plan (available at https://westnile.ca.gov). Thresholds are an integral component of mosquito control because they provide a range of predetermined actions based on quantified data. Thresholds also establish expectations and boundaries for responses that ensure appropriate mosquito control activities are implemented at the appropriate time. The threshold for adult mosquito control depends on several factors including:

- How local citizens tolerate nuisance mosquitoes by evaluating public service requests
- Overall mosquito abundance
- Presence of mosquito-borne disease in the region
- Abundance of mosquito species that are vectors of disease
- Local acceptance of adult mosquito control activities
- Climate data

Adult mosquitoes can only be controlled with adulticides. Many mosquito control agencies in California include adulticiding as an integral component of their IMM program. Adulticiding falls into two categories – residual applications (sometimes called barrier treatments) and ultra-low volume (ULV) applications. Residual applications target resting mosquitoes by applying pesticides to vegetation and other surfaces where mosquitoes may come into contact with the insecticide. Residual applications typically cover relatively small areas and are applied to alleviate specific problems rather than an area-wide adult mosquito problem.

ULV applications are used to control adult mosquitoes over large areas. An “ultra-low volume” (typically less than 2 oz / acre total volume) of tiny oil or water droplets carrying an insecticide are emitted from specialized equipment mounted to trucks or aircraft. The droplets kill adult mosquitoes on contact. ULV applications are made after sunset or before sunrise to coincide with the time that mosquitoes are most active, when non-target insects are least active, and when temperature inversions are most likely to occur. These applications are employed when mosquito populations must be reduced immediately to halt disease transmission or alleviate biting nuisance. Multiple applications in a particular area may be utilized when the objective is to kill a high enough proportion of older adult mosquitoes to break a disease transmission cycle. Adverse effects from ULV applications are rare; however, people with health problems should be aware when and where the applications are being conducted. This information can be obtained by contacting the local mosquito control agency. Chemicals currently registered for ULV applications against mosquitoes in California (as of March 2023) include organophosphates, pyrethrins, and pyrethroids. Except for the active ingredient etofenprox, formulations of both pyrethrins and pyrethroids include the synergist piperonyl butoxide (PBO), which increases their activity against mosquitoes.

1. Organophosphates

   These compounds are neurotoxins that act by blocking the enzyme cholinesterase, inhibiting neurologic transmission. They may be used in rotation with products containing pyrethrins / pyrethroid insecticides to help prevent development of pesticide resistance.

2. Pyrethrins

   Pyrethrins are neurotoxins that act by causing uncontrolled firing of neurons. Pyrethrum is a natural insecticide derived from chrysanthemum flowers. Adult mosquitoes are rapidly paralyzed and killed on contact. Pyrethrins are degraded rapidly by sunlight and chemical processes. Residual pyrethrins from ULV applications typically remain less than one day on plants, soil, and water.

3. Pyrethroids

   Pyrethroids are manufactured pyrethrins and share a similar mode of action against mosquitoes. They have very low toxicity to birds and mammals but are toxic to fish if misapplied.

Pesticide formulations registered for larval and adult mosquito control in California are available from the California Department of Regulation (www.cdpr.gov). A searchable database (https://apps.cdpr.ca.gov/docs/label/sitecode.cfm) will generate a current list of registered products; enter 68502 (code for mosquito control agencies) in the “Site Code” box.

Arbovirus Surveillance

Mosquito and Mosquito-Borne Disease Monitoring

Monitoring mosquito populations and mosquito-borne disease levels provides the necessary data to make informed management decisions to protect public health. Collecting baseline data on mosquito populations and mosquito-borne disease also helps target educational efforts.

The application of any pesticide to control mosquitoes in an IMM program is done after establishing the need to do so through mosquito population monitoring (surveillance).

Larval mosquito surveillance is the process of identifying and checking aquatic sites for larval mosquitoes and treating the water to kill the mosquitoes prior to them emerging as flying, biting adults.

Adult mosquito surveillance is accomplished through a network of traps and through mosquito annoyance reports. Adult mosquito surveillance is a critical component of determining where mosquitoes are coming from, the potential for disease transmission in an area (adult mosquitoes can be tested for pathogens), and the need for adult mosquito control. Mosquito control agencies also use adult surveillance as a feedback or quality control mechanism to determine how effective the overall program is in reducing mosquito populations.

Mosquito Surveillance Techniques

1. <u>Larval surveillance</u>

   Larval surveillance is the routine sampling of aquatic habitats for developing mosquito larvae. The primary tool is the "dip count" which indicates whether a habitat is producing mosquitoes and estimates larval density. A one-pint cup attached to a long handle is used to collect a standard volume of water ("dip sample"). The "dip count" may be expressed as the number of immature (larvae and pupae) mosquitoes per dip, per unit volume, or per unit surface area of the site.

2. <u>Adult surveillance</u>

   Several types of traps are used for adult surveillance because mosquitoes are attracted to different traps depending on their species, sex, and physiological condition. The most common traps use light, carbon dioxide, water for egg laying, and a shaded resting area. Trapped adults provide information about local distribution, density, and identity. The size of an adult mosquito population can also be assessed by the number and distribution of service requests from the public. Data are used to help locate new sources of mosquitoes or known sources with a recurrent problem

Annoyance Biting

Many species of mosquitoes are not important as vectors of disease but can cause serious injury and discomfort to humans and animals. Each time a female mosquito pierces the skin to take blood, she contaminates the wound with her saliva, creating the potential for a mild allergic reaction. The common symptom of mosquito bites is irritated and swollen skin surrounding the bite with persistent itching for several days. Scratching these bites to alleviate the itching can result in secondary bacterial infections. In addition, when mosquito populations explode, the sheer number of mosquitoes attempting to bite can make life miserable.

Mosquitoes as Disease Vectors

Mosquitoes are the most important insect vectors of disease worldwide, causing millions of human deaths every year. Mosquito-borne pathogens are typically transmitted or “vectored” when a female mosquito ingests a disease-causing organism, the organism reproduces inside the mosquito, and is subsequently injected along with saliva into another animal or human host during blood feeding. The potential or “competence” to vector any particular disease causing organism varies greatly among mosquito species.

California has a long history of mosquito-borne disease. Mosquito control agencies were first developed in the early 1900s to combat malaria and other diseases, and to reduce populations of nuisance mosquitoes. There are approximately a dozen mosquito-borne viruses recognized in California; however, currently only West Nile virus (WNV) and St. Louis encephalitis virus (SLEV) are significant threats to public health. Global trade and travel will continue to provide an avenue for introducing or re-introducing other mosquito-borne pathogens and their vectors into California and the United States. Three non-native species of mosquitoes have recently been introduced and become established in dozens of California cities and are spreading; *Aedes aegypti* (the yellow fever mosquito), *Ae. albopictus* (the Asian tiger mosquito), and *Ae. notoscriptus* (the Australian backyard mosquito). These are highly specialized mosquitoes that live in close association with humans and have the potential to transmit viruses and nematodes that cause human and animal disease. The diseases of greatest concern include dengue, chikungunya, Zika, and dog heartworm.

Virus Surveillance

In 2000, CDPH collaborated with the University of California, Davis, the California Department of Food and Agriculture, local mosquito control agencies, and other state and local agencies to develop a comprehensive statewide surveillance program to detect and monitor WNV activity. More than 70 local mosquito and vector control agencies, environmental health agencies, and county public health departments throughout California routinely contribute to the program. Surveillance includes testing for WNV infections in humans, horses, mosquitoes, wild birds, and “sentinel” chicken flocks located throughout California. The program also includes testing dead birds reported by the public for infections with WNV. A website (https://westnile.ca.gov) and toll-free number (877-WNV-BIRD) are maintained by CDPH to support this surveillance program. The information from the program allows CDPH and local agencies to identify conditions conducive to WNV transmission and areas with elevated risk. This information is used by local mosquito control agencies to reduce the threat of WNV transmission to humans.

Mosquito Transmitted Diseases

Landowners and land managers throughout California, mosquito and vector control agencies, health departments, and CDPH work together to protect Californians from mosquito-borne diseases. Work to minimize the risk of disease transmission includes 1) comprehensive mosquito surveillance and control efforts on private and public lands, 2) agencies providing technical guidance and information to the medical and veterinary communities, and 3) educating the public about mosquitoes, the diseases they carry, and personal protective measures.

Encephalitis

Several mosquito-borne viruses that occur in California can cause encephalitis. The majority of human infections with these viruses have no symptoms. Those with so-called mild symptoms can still have significant illness and face prolonged recovery, and severe cases can be fatal or cause permanent neurological damage. There are several species of mosquitoes in California that can transmit WNV, SLEV, and Western equine encephalomyelitis virus to people and animals. The most important species belong to the genus *Culex*. Specifically, *Cx. tarsalis*, *Cx. pipiens*, and *Cx. quinquefasciatus* are significant public health concerns because of their widespread distribution throughout the state, their proximity to humans, and their capacity as very efficient vectors.

West Nile Virus

West Nile virus has become an endemic disease in California and like other encephalitic viruses, can cause serious illness. Many people who are infected do not get sick or may have a variety of symptoms that can include fever, head and body aches, nausea, vomiting, swollen lymph glands, and skin rash. Only about one in 150 infected people will develop a serious illness that may require hospitalization. Elderly people are at highest risk of developing the severe form of WNV and are at an increased risk of long-lasting physical and mental disorders. The severe form of the disease can be fatal.

Malaria

Malaria is caused by four species of protozoa. The parasites destroy red blood cells causing severe fever and anemia. Left untreated, malaria can cause kidney failure, coma, and death. Malaria was once a common public health threat in California and much of the southern United States, but it was eradicated by intensive mosquito control efforts and the discovery of anti-malarial drugs. However, the disease still occurs in many other countries worldwide, creating a perpetual risk of re-introduction, especially from infected travelers and immigrants. The *Anopheles* mosquitoes capable of transmitting malaria still occur in many areas of California.

Dengue, Chikungunya, Zika, and Yellow Fever

Dengue, chikungunya, Zika, and yellow fever are viruses that cycle primarily between mosquitoes and humans. Small outbreaks of dengue, chikungunya, and Zika have occurred sporadically in the United States where invasive *Aedes aegypti* and *Ae. Albopictus* have established. These viruses do not currently exist in nature in the USA, and all outbreaks have been linked to infected visitors or returned travelers from endemic areas. Although the Americas have a long history with yellow fever, the last U.S. outbreak occurred over a century ago. The virus continues to exist in tropical and subtropical areas of Africa and South America but is a very rare cause of illness in U.S. travelers, in part due to the availability of an effective vaccine. *Aedes aegypti* and *Ae. albopictus* are capable vectors of these viruses and occur in many urban areas of California.

Canine Heartworm

Canine heartworm occurs worldwide. It is caused by a filarial nematode transmitted by *Aedes* and some *Culex* mosquitoes that can infect domestic dogs, wild canines (e.g., foxes, coyotes, wolves), and cats. The tiny worms migrate through the body to the heart and cause thickening and inflammation of the heart, which can lead to difficulty in breathing, chronic cough, vomiting, and can sometimes be fatal.

Appendix B: Mosquitoes of California

The biology and key characteristics of the four major mosquito genera in California are described below.

Aedes

There are about 80 species of *Aedes* mosquitoes in the continental United States; approximately 27 species occur in California. Certain species are widespread, may occur in very large numbers, and are among the worst biting pests. A few are recently introduced invasive species from other countries, including *Ae. aegypti* and *Ae. albopictus*, and are limited to urban areas. *Aedes* mosquitoes do not lay their eggs directly on the surface of standing water. Instead, they lay single eggs on intermittently flooded surfaces such as the damp soil around irrigated pastures and fields, along the edges of coastal tidal marshes, and inside dry treeholes and artificial containers. Eggs are extremely resistant to drying and will lie dormant on dry surfaces until flooding occurs (eggs of *Ae. vexans* have been documented to lie dormant for up to three years). This can lead to many generations of eggs in a given habitat if female mosquitoes lay successive batches of eggs before the area is flooded. When flooding occurs, large numbers of eggs hatch spontaneously and develop rapidly to adults. Although larval developmental sites vary greatly, the most productive include transient ground pools, flooded areas along overflowing streams, flood and stormwater control basins, intermittently flooded agricultural lands, and container habitats such as tree holes, wheel ruts, and discarded tires.

Native *Aedes* are primarily summer-breeding mosquitoes, but invasive species may extend their breeding season in urban areas to include parts of spring and fall. Because of their rapid larval development in newly flooded habitats, adults often emerge before predators can colonize the water source. Most *Aedes* complete two to several generations per year depending on the frequency of habitat flooding from natural and artificial events. Adults cannot survive in colder weather. Therefore, the majority of *Aedes* overwinter as eggs.

Typically, *Aedes* mosquitoes found in California will not enter buildings and homes; however, they are strong fliers and are known to travel many miles from their aquatic developmental sites to search for hosts. The exceptions are the non-native *Ae. aegypti* and *Ae. albopictus*, which regularly enter structures and have very short flight ranges within the urban environment. *Aedes* mosquitoes are diurnal (i.e., active during the day) during mild weather, especially around shaded areas, but will also bite at dusk. Most *Aedes* females feed on large mammals like cattle and horses but will readily feed on humans. *Aedes* mosquitoes are aggressive and persistent biters causing people and animals to avoid areas where their numbers are great. One example is the species *Ae. nigromaculis*, which are currently not known to vector disease, but are considered a serious pest because they will seek out human hosts and bite during the day when people are most likely to be outdoors and active.

Anopheles

Approximately 22 species of *Anopheles* are found in the continental United States and of these, 5 occur in California. When feeding, *Anopheles* adults rest with their abdomens positioned at a distinct angle to the surface of the skin, whereas other species orient their bodies parallel. Females lay single floating eggs directly on the surface of permanent or semi-permanent standing water. A female can lay successive batches of up to 300 eggs during the breeding season. Eggs are not resistant to drying and typically hatch within two-three days, although hatching may take up to two-three weeks in colder climates. Larvae develop in 12 to 20 days but can take longer in cooler weather. Preferred larval habitats include clear, fresh seepage water in sunlit or partly shaded pools, wetlands, roadside ditches, rice fields, and poorly maintained water troughs.

Adult females bite at dusk and dawn and prefer to feed on mammals. Many *Anopheles* mosquitoes prefer to feed on rabbits but will also feed on large mammals such as livestock and humans. In California, *Anopheles* species may undergo two or more generations per year. Most species over-winter in protected areas as mated females, resuming activity the following spring. These are among the first mosquitoes to emerge and bite humans each year.

Historically, *Anopheles freeborni*, the western malaria mosquito, was a vector of malaria in California. Currently, with the disease eradicated from California and the United States, it is considered a nuisance mosquito. This species is widespread throughout California and females will lay their eggs in any standing fresh water, although it is abundant in rice fields or other wetlands during late summer. While most adult mosquitoes stay within a few miles of their breeding source, *Anopheles* mosquitoes will migrate further when seeking hibernation sites in fall. This can lead to a large influx of mosquitoes from uncontrolled areas to residential areas during September and October.

Culex

Culex, with 11 species found throughout the state, is the second largest genus of mosquitoes in California, second only to *Aedes*. Females can lay up to seven rafts of eggs over a two-month life span; each raft contains from 100-300 eggs which are laid on the surface of standing water. *Culex* larvae occur in a broad range of aquatic habitats ranging from containers such as discarded tires, water barrels, and flower pots to clogged gutters, catch basins, water for irrigation and urban wastewater, and wetlands. During summer and periods of drought, areas without regularly flowing water, street drainage systems, and contaminated streams, ponds and pools become productive larval habitats. *Culex* larvae are known for thriving in polluted sources of water with a high organic content.

Culex mosquitoes prefer to take blood meals at dusk or after dark and can be painful and persistent biters. *Culex* preferably feed on birds but also feed on mammals including humans and horses. They readily enter houses and buildings in search of a suitable host. Two or more generations of *Culex* can occur per year. Females that emerge in late summer will mate and overwinter until the following spring or mid-summer.

Several species of *Culex* can transmit viruses that can cause encephalitis (i.e., inflammation of the brain), including West Nile virus (WNV), St. Louis encephalitis virus (SLEV), and Western equine encephalomyelitis virus (WEEV). These mosquitoes are efficient and effective vectors of these diseases among birds, humans, horses, and many other wild and domestic animals.

Culex tarsalis

Culex tarsalis, the Western encephalitis mosquito, is one of California's most important and efficient vectors of WNV, SLEV, and WEEV. This species is widespread in California. *Cx. tarsalis* prefer to lay their eggs on fresh or lightly polluted standing water such as rice fields, ditches, pastures, wastewater ponds, and seasonal wetlands. Other more urban freshwater sources include ornamental ponds, storm drains, and flood control channels. Larvae usually develop into adults in approximately 8-14 days; warmer water can shorten the developmental period. *Cx. tarsalis* are active from spring through fall; however, the population in the Central Valley peaks in June to July with a secondary, smaller peak in September coinciding with flooding of seasonal wetlands. *Cx. tarsalis* survive through the winter as adults in barns, culverts, caves, and similar dark, protected places.

Adult *Cx. tarsalis* can disperse a great distance up to 10-15 miles in search of blood meals, generally traveling along riparian corridors, but most stay close to the site where they emerged. Adults rest by day in shaded areas such as animal burrows and treeholes. Females prefer feeding between dusk and dawn but may bite during the day in deep shade. Females obtain blood meals from birds or mammals and can transmit diseases between these groups.

Culex pipiens and Culex quinquefasciatus

Culex pipiens (the northern house mosquito) and *Cx. quinquefasciatus* (the southern house mosquito) appear to be identical. *Cx. quinquefasciatus* occurs in southern California, whereas *Cx. pipiens* is found along the coastal regions and in northern California and is the most widely distributed mosquito species in the world. Both species can transmit encephalitis viruses. They are common in and around households and prefer to lay eggs in polluted water that is high in organic content such as dairy runoff, wastewater catchment basins, stormwater ponds, dirty flower pots, bird baths, or any drainage systems where standing water exists.

In California, *Cx. pipiens* and *Cx. quinquefasciatus* typically do not disperse from where they emerged. Females feed at dusk or after dark, readily enter homes and prefer avian hosts but will also feed on large mammals including humans. *Cx. pipiens* and *Cx. quinquefasciatus* are vectors of WNV and SLEV, and have also been implicated in transmitting canine heartworm.

Other *Culex* mosquitoes
Culex stigmatosoma, the foul water mosquito, *Cx. restuans* and *Cx. erythrothorax* can also be infected with WNV, but their distributions are limited (e.g., *Cx. erythrothorax* is mainly found close to bodies of water with tules).

Culiseta

Only eight species of *Culiseta* mosquitoes occur in the continental United States, of which four are found in California. Females lay clusters of floating eggs (rafts) on the surface of standing water. *Culiseta* mosquitoes are moderately aggressive biters, attacking in the evening hours or in shade during the day. Peak populations occur during the cooler months. These mosquitoes prefer to feed on larger domestic animals, such as cattle and horses, but will also feed on humans. The distribution of *Cs. inornata*, an unusually large mosquito, is widespread and can be found at elevations of up to 10,000 feet. Larvae of *Cs. inornata* develop in permanent water habitats, including shallow marshes, peat bogs, roadside ditches, abandoned gravel pits, and in standing water in soil cavities left by fallen trees. The common name of this mosquito— the Large Winter mosquito—reflects that it is most active in cool weather habitats.

Appendix C: Typical Larval Habitats of California Mosquitoes*

Riparian	Vernal Pools	Foul Water	Salt Marsh	Treehole
Aedes atropalpus	*Aedes bicristatus*	*Culex pipiens*	*Aedes dorsalis*	*Aedes deserticola*
Aedes washinoi	*Aedes campestris*	*Culex restuans*	*Aedes squamiger*	*Aedes purpureipes*
Aedes pullatus	*Aedes fitchii*	*Culex stigmatosoma*	*Aedes taeniorhynchus*	*Aedes sierrensis*
Aedes sticticus	*Aedes hemiteleus*	*Culex tarsalis*	*Anopheles occidentalis*	*Orthopodomyia signifera*
Aedes vexans	*Aedes increpitus*	*Culiseta impatiens*	*Culex tarsalis*	
Anopheles franciscanus	*Aedes niphadopsis*	*Culiseta incidens*	*Culiseta incidens*	
Anopheles occidentalis	*Aedes ventrovittis*	*Culiseta inornata*	*Culiseta inornata*	
Anopheles punctipennis	*Aedes washinoi*			
Culex apicalis	*Culex tarsalis*			
Culex boharti	*Culiseta incidens*			
Culex reevesi	*Culiseta inornata*			
Culex tarsalis	*Psorophora columbiae*			
Culex territans	*Psorophora signipennis*			
Culex thriambus				
Culiseta impatiens				
Culiseta incidens				
Culiseta particeps				
Culiseta inornata				
Small Container	**Freshwater Marsh**	**Rock Pools**	**Pools and Ponds**	**Snow Melt Pools**
Aedes sierrensis	*Aedes flavescens*	*Aedes sierrensis*	*Aedes sierrensis*	*Aedes cataphylla*
Aedes aegypti	*Anopheles freeborni*	*Anopheles punctipennis*	*Culex pip/quinq*	*Aedes clivis*
Aedes albopictus	*Anopheles hermsi*	*Culex tarsalis*	*Culex stigmatosoma*	*Aedes communis*
Aedes notoscriptus	*Anopheles occidentalis*	*Culiseta impatiens*	*Culex tarsalis*	*Aedes hexodontus*
Culex pip/quinq	*Coquillettidia perturbans*	*Culiseta incidens*	*Culiseta impatiens*	*Aedes increpitus*
Culiseta incidens	*Culex erythrothorax*		*Culiseta incidens*	*Aedes pullatus*
	Culex tarsalis		*Culiseta inornata*	*Aedes schizopinax*
	Uranotaenia anhydor		*Culiseta particeps*	*Aedes sticticus*
				Aedes tahoensis
				Aedes ventrovittis
				Culiseta incidens
Woodland Pools	**Irrigated Pastures**	**Permanent Ponds**		
Aedes bicristatus	*Aedes dorsalis*	*Aedes niphadopsis*		
Aedes increpitus	*Aedes melanimon*	*Aedes schizopinax*		
Aedes washinoi	*Aedes nigromaculis*	*Anopheles occidentalis*		
Aedes punctipennis	*Aedes thelcter*	*Culex anips*		
Culex apicalis	*Aedes vexans*	*Culex erythrothorax*		
Culex tarsalis	*Anopheles freeborni*	*Culex reevesi*		
Culex thriambus	*Culex tarsalis*	*Culex tarsalis*		
Culiseta incidens	*Culiseta inornata*	*Culiseta impatiens*		
Culiseta inornata	*Psorophora columbiae*	*Culiseta incidens*		
Culiseta particeps	*Psorophora signipennis*	*Culiseta particeps*		
		Culiseta inornata		
		Coquillettidia perturbans		
		Uranotaenia anhydor		

*Compiled from: Identification of the Mosquitoes of California. Rev. 1998. Mosquito and Vector Control Association of California

Appendix D: Mosquito Repellents

A number of products that repel adult mosquitoes and thus reduce the chances of mosquito bites have been registered by the Environmental Protection Agency for human use. The most commonly used mosquito repellents contain the active ingredient DEET (N,N-diethyl-meta-toluamide), which has been formulated and sold under a variety of trade names. Repellents are available in a variety of concentrations and formulations including sprays (aerosol and pump), lotions, and wipes/towelettes. Spray repellents can be used on outer clothing as well as exposed skin to ensure complete coverage. Repellents should not be used under clothing. The percentage of DEET in the repellent reflects the approximate length of time the product will repel mosquitoes; products with a higher percentage of DEET (e.g., 20-30%) will provide protection for a longer period of time, up to several hours, whereas products with a lower percentage of DEET (e.g., less than 10%) will protect for shorter periods, often only 1-2 hours. Studies suggest that DEET efficacy tends to peak at a concentration of ~50%, and concentrations above that do not offer a marked increase in protection time against mosquitoes.

Topical repellents that contain picaridin, IR-3535, oil of lemon eucalyptus, and para-menthane-diol are similar in efficacy to those with DEET, though some may have restrictions for use on young children. Clothing and other materials treated with permethrin during manufacture are also available. It is important to always carefully read and understand the benefits and limitations of repellents listed on the product label before use. By law, all repellent products must be used according to their labels.

The California Department of Public Health maintains an informational “toolkit” for mosquito repellents with additional information (https://www.cdph.ca.gov/Programs/CID/DCDC/Pages/Mosquito-Repellent.aspx).

Appendix E: Additional Resources and Information

Mosquito Biology, Mosquito-Borne Diseases, Mosquito Control, and Personal Protection

Additional information on mosquito biology and ecology, mosquito-borne diseases, mosquito control, and personal protection from mosquito bites is easily obtainable from a variety of reputable sources including:

- The United States Centers for Disease Control and Prevention (https://www.cdc.gov/mosquitoes/)
- The California Department of Public Health (CDPH) (https://www.cdph.ca.gov/ and https://westnile.ca.gov/)
- The American Mosquito Control Association (https://www.mosquito.org)
- The Mosquito and Vector Control Association of California (MVCAC) (https://www.mvcac.org)

California mosquito and vector control agencies and their respective websites can provide detailed information about local mosquito species.

- An interactive jurisdictional map, with agency website and contact information, is available on the MVCAC website (https://www.mvcac.org).
- Local agency contact information can also be searched by entering the ZIP code of the area of interest on the California West Nile virus website (https://westnile.ca.gov/) under "*Lookup Local Vector Control Agency*".

Information regarding past and present activity of West Nile virus and St. Louis encephalitis virus in California is available on the California West Nile virus website.

Past and present results of surveillance for mosquitoes and mosquito-borne diseases in California can be viewed on the California Vectorborne Disease Surveillance System (VectorSurv) website (https://vectorsurv.org/).

A large number of mosquito-related resources and reports, including this manual and the companion document "Best Management Practices for Mosquito Control on California State Properties", are available on the California West Nile virus website (https://westnile.ca.gov/).

Health Department Websites

- The United States Centers for Disease Control and Prevention (https://www.cdc.gov/)
- The California Department of Public Health (https://www.cdph.ca.gov/ and

https://westnile.ca.gov/)

- The Vector-Borne Disease Section, California Department of Public Health (https://www.cdph.ca.gov/Programs/CID/DCDC/Pages/VBDS.aspx)
- Local California health services / offices (searchable listing by local areas) can be found using the California Department of Public Health website (https://www.cdph.ca.gov/Pages/LocalHealthServicesAndOffices.aspx#)

California Health and Safety Code

The California Health and Safety Code is available in its entirety (also searchable by code section and/or keywords) on the California Legislative Information website (https://leginfo.legislature.ca.gov/).

Pesticides Currently Registered for Mosquito Control in California

Pesticide formulations registered for larval and adult mosquito control in California are available from the California Department of Regulation (www.cdpr.gov). A searchable database (https://apps.cdpr.ca.gov/docs/label/sitecode.cfm) will generate a current list of registered products; enter 68502 (code for mosquito control agencies) in the "Site Code" box.

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