

Excerpts pertaining to permanent wetlands from:

**CENTRAL VALLEY JOINT VENTURE
TECHNICAL GUIDE TO BEST MANAGEMENT PRACTICES FOR
MOSQUITO CONTROL IN MANAGED WETLANDS**

Dean C. Kwasny¹, Mike Wolder², and Craig R. Isola²

BEST MANAGEMENT PRACTICES

The BMPs in this document are habitat-based strategies that can be implemented when needed for mosquito control in managed wetlands. These strategies represent a range of practices that wetland managers can incorporate into existing habitat management plans or in the design of new wetland restoration or enhancement projects. Ideally, BMPs can be used to decrease the production of mosquitoes and reduce the need for chemical treatment without significantly disrupting the ecological character, habitat function, or wildlife use in managed wetlands. It should be recognized that BMPs function as a first line of defense in deterring mosquito production and can be used in combination with other Integrated Pest Management (IPM) tools such as, biological controls, larvicides (Appendix A), and adulticides (Appendix B) when necessary.

In many cases, BMPs overlap with commonly used habitat management practices to conserve water and manage wetland vegetation for wildlife (Batzer and Resh 1992a, Batzer and Resh 1992b, Resh and Schlossberg 1996). Not all BMPs will be appropriate for a given wetland location or set of circumstances. Therefore, habitat managers are encouraged to work closely with both their local MVCD and agency biologists to select BMPs based on their potential effectiveness for regional or site specific conditions, and habitat management strategies. The implementation of BMPs will likely be limited by cost and personnel constraints, potential impacts on wetland habitat, and wildlife response to these measures.

In the following section, BMPs have been classified into five categories. These categories are not listed in order of importance and may be used in combination.

- Water Management Practices
- Vegetation Management Practices
- Wetland Infrastructure Maintenance
- Wetland Restoration and Enhancement Features
- Biological Controls

Following each category is a table summarizing the BMPs that outlines strategies, mosquito control objectives, advantages, and disadvantages (Tables 1 through 6).

Water Management Practices

Water management is one of the wetland manager's greatest tools for reducing mosquito populations (Table 1). However, it requires that water is readily available, of sufficient quantity and quality, and that the conveyance infrastructure is adequate to permit rapid flooding or drainage. In some instances, circumstances outside the control of wetland managers may limit the ability to implement water management BMPs. Such circumstances may include when agriculture drain water or delivered water is available for flooding, limited water quantity or poor water quality, and undersized water delivery or drainage infrastructure. In managed wetlands where these limitations are not an issue, the following water management practices should be considered.

Timing of Flooding: The timing of wetland flooding can greatly influence mosquito production (Fanara and Mulla 1974; Batzer and Resh 1992a). Delayed flooding may reduce mosquito production by shifting flooding schedules later in the year, when temperatures are cooler and mosquito production is less of a problem. Delayed flooding should be considered for wetlands with historic mosquito problems and those in close proximity to urban areas. However, delayed flooding means that less wetland habitat is available for wildlife during times of the year such as August and

September when wetlands are particularly limited. Delayed flooding may also have limited applicability for some properties that are required to take water on a “when available” schedule and have little control over the timing of flooding. Delayed flooding may be especially difficult for State and Federal areas that are obligated to provide “early” habitat to reduce crop depredation by waterfowl.

Given the limited feasibility of delayed flooding on some properties, phased flooding of wetlands may be useful to allow habitat managers to provide some level of early flooded habitat while delaying flooding on a portion of a property. Phased flooding involves flooding habitat throughout the fall and winter in proportion to wildlife need and takes into consideration other wetland habitat that may be available in surrounding areas.

For wetlands that are flooded early (August - early September) or in close proximity to urban areas, the use of vegetation and water management BMPs should be a high priority (Tables 1 and 2).

BMPs: Delayed or phased fall flooding, Early fall flood-up planning (see Table 1 for additional explanation)

Speed of Wetland Flooding: As a general rule, the faster water can be applied during fall flooding and spring/summer irrigation, the fewer generations of mosquitoes will be hatched. Slow feather-edge flooding, although beneficial to foraging waterbirds, can produce multiple, staggered hatches of floodwater mosquitoes and, if treatment is necessary, often requires MVCDs to visit wetlands over a number of days for control activities (Garcia and Des Rochers 1983). Such an intensive treatment effort is expensive and results in additional disturbance to wildlife.

BMPs: Rapid fall flooding, Rapid irrigation (see Table 1 for additional explanation)

Water Control: Once wetlands have been flooded, it is important for wetland managers to ensure that pond elevations do not fluctuate except during planned draw-down or periods of low mosquito production (i.e. winter months). Fluctuating water levels tend to expose wetland edges to drying and provide suitable habitat for floodwater mosquitoes to lay eggs (Garcia and Des Rochers 1983). When water levels are subsequently raised, a new cohort of mosquitoes may be hatched. Water levels should be maintained by checking water levels frequently, and adding water to offset any losses. A constant maintenance flow of water will also help maintain steady water levels, improve water quality, and reduce stagnation.

If possible, wetlands can be flooded to deeper water depths during the fall and allowed to recede during the cooler winter months to provide shallow water depths for foraging waterbirds. Deeper water depths (24 inches) at initial flooding have been shown to significantly reduce mosquito densities at Grizzly Island Wildlife Area (Batzer and Resh 1992a, b).

When flooding wetlands, water sources containing mosquito predators should be used to help colonize wetlands with predacious insects or mosquitofish that are passively transported by water from upstream locations (Collins and Resh 1989). Predator populations can be maintained in permanent waterways used to flood seasonal wetlands. In the Suisun Marsh, where water is readily available for flooding, seasonal wetlands are often initially flooded, and if mosquitoes become abundant, water levels are drawn down to concentrate mosquito larvae in ditches for biological control, larvicide treatment, or to drown larvae through turbulent water movement (Chappell pers. comm). Following this action, wetlands are immediately re-flooded.

BMPs: Maintain stable water levels, Circulate water, Use deep initial flooding, Subsurface irrigate, Utilize water sources with mosquito predators for flooding, Flood and drain wetland (see Table 1 for additional explanation)

Frequency and Duration of Irrigation: Spring and summer irrigation is a common wetland management practice used to increase seed production and biomass of moist-soil plants (Naylor 2002), and reduce competition from undesirable plants in seasonal wetlands. The need to irrigate seasonal wetlands should be assessed closely by wetland managers. During years with above average spring precipitation, irrigations may not be necessary to maximize moist-soil plant production. When possible, managers should shorten the duration of irrigation to 4 to 10 days to reduce the likelihood of hatching floodwater mosquitoes and eliminate the possibility of creating habitat for standing water mosquitoes. However, shorter irrigations may not always be feasible, especially when growing more water intensive plants such as watergrass and smartweed, or when conducting flooding to control undesirable plant species. In the case of weed control, plants should be monitored and water held only long enough to eliminate weeds. The necessary timing can be determined when weeds have turned black or have disintegrated. Finally, following wetland irrigations, water should be drawn down into waterways containing mosquito predators that can consume any mosquito larvae which may have hatched.

BMPs: Reduce number of irrigations, Use rapid irrigation, Draw down and irrigate in early spring, Irrigate prior to field completely drying, Drain irrigation water into ditches or other water sources with mosquito predators, Use subsurface irrigation (see Table 1 for additional explanation)

Table 1. Water Management Practices to reduce mosquito production in managed wetlands.

Best Management Practice	Strategies	Mosquito Control Objective	Advantages	Disadvantages
<i>Delayed or phased fall flooding</i>	Delay flooding of some wetland units until later in the fall. Delay flooding units with greatest historical mosquito production and/or those closest to urban areas.	To delay initiation of floodwater mosquito production in seasonal wetlands by reducing the amount of mosquito habitat available during optimal breeding conditions (warm summer/early fall weather). Reduce the time available for standing water mosquito production in seasonal wetlands.	Depending on flood date, can reduce the need or amount of additional treatment. Delayed flooding can provide “new” food resources for wildlife later in the season when wetlands are finally flooded.	Reduces the amount of habitat for early fall migrants and other wetland-dependent species, and may increase potential for waterfowl depredation on agricultural crops (especially rice). Flooding is often dictated by water availability or contractual dates for delivery. Delayed flooding may still produce mosquitoes in warm years. Private hunting clubs can’t lease blinds that aren’t flooded.
<i>Early fall flood-up planning</i>	Apply BMPs to wetlands identified for early flooding. To the extent possible, areas targeted for early fall flooding should not be near urban centers and should not have a history of heavy mosquito production.	To reduce the early season production of mosquitoes or to reduce their encroachment on urban areas.	Allows for the provision of early flooded habitat while minimizing mosquito production and conflicts with urban areas.	Some additional effort required to monitor and identify suitable areas. Requires the extensive use of BMPs to ensure mosquitoes are not produced.
<i>Rapid fall flooding</i>	Flood wetland unit as fast as possible. Coordinate flooding with neighbors or water district to maximize flood-up rate.	To minimize number of mosquito cohorts hatching on a given area.	Reduces the need for multiple treatments needed by synchronizing larval development and adult emergence. In turn, reduces wildlife disturbance by MVCDS.	Requires coordination & ability to flood quickly. Reduces slow, feather-edge flooding that is heavily utilized by waterbirds.
<i>Rapid irrigation</i>	4-10 day irrigation (from time water enters the pond to complete draw-down).	Shorten irrigation period to reduce time available for mosquitoes (especially <i>Culex tarsalis</i> and <i>Anopheles freeborni</i>) to complete lifecycle.	Provides some level of wetland irrigation while reducing the time available for mosquitoes to complete lifecycle.	Requires ability to rapidly flood & drain wetland. If flooding is used for weed control, rapid irrigation may not be feasible.

<i>Maintain stable water level (summer and early fall flooding)</i>	Ensure constant flow of water into pond to reduce water fluctuation due to evaporation, transpiration, outflow, and seepage.	To reduce conditions for additional floodwater mosquito production in summer and fall.	Provides a stable wetland environment for breeding wildlife during spring and summer. Discourages undesired excessive vegetative growth which could also become additional mosquito breeding substrate.	Requires regular monitoring and adjustments to water control structures. May be difficult if water availability is intermittent or unreliable. Reduces mudflat habitat that is attractive to shorebirds and waterfowl.
<i>Water circulation</i>	Provide a constant flow of water equal to discharge at drain structure.	To keep water fresh and moving to deter stagnant conditions for mosquito production; reduces water level fluctuation and potential production of floodwater mosquitoes.	Discourages warm water conditions associated with avian botulism outbreaks.	Requires landowner to purchase additional "maintenance" water. May be difficult if water availability is intermittent or unreliable.
<i>Deep initial flooding (18-24")</i>	Flood wetland as deep as possible at initial flood-up.	To reduce shallow water habitat for mosquito breeding. May provide more open water by over-topping vegetation, thereby facilitating mosquito predation or wind action that drowns larvae.	Potentially slows mosquito development by eliminating warm, shallow water habitat.	Requires additional water and infrastructure adequate to flood deeply. Reduces shallow water foraging habitat for shorebirds and waterfowl.
<i>Utilize water sources with mosquito predators for flooding wetlands</i>	Flood wetlands with water sources containing mosquito fish or other invertebrate predators. Water from permanent ponds can be used to passively introduce mosquito predators.	To inoculate newly flooded wetlands with mosquito predators.	May establish mosquito predators faster than natural colonization.	Requires source of water with already established mosquito predators. Not applicable to wetlands flooded with well water.
<i>Drain irrigation water into ditches or other water bodies with abundant mosquito predators</i>	Drain irrigation water into locations with mosquito predators as opposed to adjacent seasonal wetland or dry fields.	To reduce the amount of larvae through natural predation and minimize the number of adults that emerge.	Already a common wetland management practice.	Must have ditch or water body with established predator population available to accept drain water.

<i>Flood & drain wetland</i>	Flood wetland and hatch larvae in pond. Drain wetland to borrow or other ditch where larvae can be easily treated, drowned in moving water, or consumed by predators. Immediately reflood wetland.	Hatches mosquito larvae and moves them to a smaller area for treatment before they can emerge as adults.	Can eliminate or reduce the need for additional mosquito control efforts.	Additional cost to purchase water to re-flood wetland. Timing is critical. Requires monitoring and is labor intensive.
<i>Reduce number of irrigations</i>	Evaluate necessity of irrigation, especially multiple irrigations, based on spring habitat conditions and plant growth. Eliminate irrigations when feasible.	To eliminate unneeded additional irrigations which could provide potential habitat for mosquitoes.	Reduces potential need for additional mosquito control. Saves water and manpower costs. Discourages excessive growth of undesirable vegetation (i.e. joint and bermuda grass)	May reduce seed production or plant biomass with less irrigation.
<i>Early spring draw-down and irrigation</i>	Draw-down wetland in late March or early April. Irrigate in late April or early May when weather is cooler and mosquitoes are less of a problem.	To reduce need for irrigation in June, July, and August, when potential for mosquito production would be higher.	Wetland irrigation can be accomplished without creating potential mosquito problems. May allow moist-soil plants to take advantage of natural rainfall during the spring.	Reduces shallow wetland habitat for migratory shorebirds and waterfowl in April and May, during a major migration period. Newly germinated wetland plants may be impacted by cold weather conditions. May stimulate germination and growth of undesirable wetland plants.
<i>Don't let field completely dry and crack between spring draw-down and irrigation</i>	Irrigate wetland before soil completely dries.	To eliminate necessary drying period for floodwater mosquito to lay eggs.	May reduce mosquitoes produced from irrigation	Requires close monitoring of soil moisture to correctly time irrigation.
<i>Subsurface irrigation</i>	Maintain high ground water levels by keeping boat channels or deep swales permanently flooded.	To reduce amount of irrigation water during mosquito breeding season.	Reduce need for surface irrigation while maintaining soil moisture to promote moist-soil plant production.	Requires deep swales or boat channels to be effective. Requires additional pipes in channels for equipment access. May not produce intended irrigation result if water table is naturally low. Requires that water be maintained longer than normal in swales. May promote unwanted vegetation growth in swales or promote irrigation of non-target plants in wetland.

Wetland Infrastructure Maintenance

Wetland infrastructure is the foundation for habitat management. A properly functioning water delivery and drainage system, well maintained levees, correctly operating water control structures, and efficient pumps are key to avoiding the unnecessary production of mosquitoes through simple neglect (Table 3). Time and money invested in these proactive maintenance activities will reduce mosquito production and help landowners avoid additional costs of controlling mosquitoes and unwanted vegetation when fall flooding or irrigating wetlands.

Levee and Water Control Structure Inspection and Repair: Levees and water control structures should be inspected on an annual basis to identify problem areas that may inadvertently leak water and produce mosquitoes. This includes identifying weak spots or rodent damage in levees that may seep water during flooding. Water control structures should be water-tight and properly sealed to prevent seepage.

Ditch and Swale Cleaning: Vegetation in water delivery ditches and swales can be problematic by creating habitat for mosquitoes or by simply impeding the flow of water that facilitates rapid flooding or drainage. Typical maintenance activities of water delivery and drainage ditches include the use of herbicides or periodic dredging to remove problem vegetation that inhibits water flow. Ditches and swales should be cut to grade to prevent the unintentional trapping of water. Likewise, silt that accumulates in front of outlet structures should be removed so it does not trap water in drainage swales.

Pump Tests and Repair: If wetland managers use pumps for flooding, periodic pump testing should be conducted to make sure pumps are operating at optimum efficiency. This will ensure that pumps are providing maximum output, and will facilitate rapid flooding.

Table 3. Wetland infrastructure maintenance activities used to reduce mosquito production in managed wetlands.

Best Management Practice	Strategies	Mosquito Control Objective	Advantages	Disadvantages
<i>Levee Inspection & Repair</i>	Walk or drive levees, flag problem spots, repair as needed. Consider design elements to improve integrity of levee (see levee design in Table 4).	To reduce mosquito habitat/production caused by seepage into adjacent fields or dry ponds.	Allows for early identification of problem spots. Helps conserve water and reduces growth of unwanted vegetation.	Requires annual monitoring and funding for repairs.
<i>Water Control Structure Inspection, Repair, & Cleaning</i>	Inspect structures and repair or replace as needed. Remove silt and vegetation build-up in front of structures. Adequately close, board or mud-up controls.	To reduce mosquito habitat/production caused by seepage into adjacent ponds or drainage ditches. Remove silt blockages that may trap water and impede drainage.	Enhances water management capabilities and limits unwanted vegetation or standing water.	Requires annual monitoring and funding for cleaning or repair.
<i>Ditch Cleaning</i>	Periodically remove silt or vegetation from ditches to maintain efficient water delivery and drainage.	To allow for rapid flooding/drainage & reduce vegetation substrate for breeding mosquitoes.	Enhances water management capabilities and limits unwanted vegetation or standing water.	Requires funding for ditch cleaning. Excessive vegetation removal on ditch banks can result in negative impacts to nesting birds and other wildlife.
<i>Pump Tests & Repair</i>	Test pump efficiency and make any necessary repairs to maximize output.	Could identify output problems and if corrected, allow managers to flood more rapidly.	May promote faster irrigation and flood-up if output can be improved.	Requires pump test. May be costly to repair or replace pump/well.

Wetland Restoration and Enhancement Features

All well planned wetland restoration and enhancement projects begin with an initial survey and design phase. It is during this phase that landowners and restoration biologists have the opportunity to discuss design features with MVCDs and incorporate BMPs to reduce mosquito production. Time spent at the design stage can save thousands of dollars in annual operation and maintenance costs and prevents problems resulting from poor water management and unintended mosquito production.

Wetland design typically focuses on aspects of water control that promote vegetation beneficial to wildlife, conserve water, and allow for periodic vegetation control. In turn, water control is also an important mosquito BMP (Sacramento-Yolo Mosquito and Vector Control District 2008, Contra Costa Mosquito and Vector Control District 2001). **Wetland design features to reduce mosquito**

production: Wetland design features that reduce mosquito production include independent flooding and drainage capabilities of wetland units, size considerations in the design of wetland units to facilitate rapid flooding, and the incorporation of design features that promote habitats for mosquito predators and allow those predators access to mosquitoes. Water delivery ditches, water control structures, and levees should be designed and built to specifications that prevent wind and water erosion, provide equipment access for maintenance activities, and reduce damage caused by burrowing animals (Table 4). These design features will facilitate other mosquito BMPs such as water and vegetation management practices, infrastructure maintenance, and natural mosquito predation.

BMPs: Independent water management, Adequately sized water control structures, Swale construction, Wetland size consideration, Ditch design, Levee design & compaction, Deep channels or basins constructed in seasonal wetlands, Permanent water reservoir that floods into seasonal wetlands