WNV WHITE PAPER DRAFT FOR REVIEW BY THE SWS MEMBERSHIP, APRIL 2008

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> The Society of Wetland Scientists does not endorse the use of any specific management technique identified in this paper. Rather, the intent of the paper is to consider the wide range of options available to wetland scientists in addressing West Nile Virus vector species. This paper is provided for informational purposes and not as advocacy of any specific technique mentioned.

The Society of Wetland Scientists (SWS) Ad Hoc West Nile Virus Committee

Guide for Wetland Professionals: West Nile Virus (WNV) and Related Diseases, Wetlands, and Watershed Management

Covering: mosquito biology and ecology, mosquito control, risk assessment, and the effects of wetland management on mosquito abundance in the contiguous United States of America and adjacent areas of Canada.

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I. ABSTRACT

Mosquito-borne diseases such as West Nile virus (WNV) have raised public concerns about the relationships between wetlands and mosquitoes. We recommend that anyone working in wetlands gain a basic understanding of mosquito ecology so they can intelligently communicate with others on mosquito issues.

Mosquito larvae are a natural part of many kinds of wetlands (whether natural, restored, or degraded). Because of the many important environmental and socio-economic values and functions of wetlands, this does not mean that wetlands that produce mosquitoes should be drained or grossly altered, nor should the protection or restoration of wetlands be discouraged.

Changes to wetlands – either degradation or restoration – can change the likelihood that certain species of mosquitoes will use those wetlands as larval habitat. Restoration may or may not reduce the mosquito vectors of WNV or related diseases. Mosquito population responses to restoration depend upon the characteristics of the wetland processes that were degraded and the characteristics of processes restored.

Where unacceptable mosquito production situations are predicted or found, environmentally compatible

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control methods to reduce mosquito production may be considered and employed, as long as other important wetlands values and functions are not unduly diminished. Control can be effectively practiced in managed wetlands where water is routinely controlled, constructed wetlands for wastewater treatment, or wetlands created for or used as stormwater retention facilities. Some control measures may or may not be applicable or ecologically desirable in natural, unmanaged wetlands. The examples and practices described herein may require permits; the wetland practitioner should identify and comply with all laws applicable to their project area.

Effective mosquito control requires interdisciplinary efforts (e.g., entomologists, wetland ecologists, hydrologists, restorationists) and an integrated pest management approach. No one mosquito-control strategy fits all situations, and mosquito management should be addressed on a case-by-case basis that identifies local and regional differences in mosquito species, geographic setting, and watershed context. The optimal approach requires mixing and matching strategies using the best available science.

II. BACKGROUND

West Nile virus is a mosquito-borne virus that can cause serious illness and death in humans, wildlife, and domestic animals. It was first detected in the Unites States in 1999 and since then has spread across the entire contiguous USA and adjacent areas of Canada. (For the most recent information on WNV, its current distribution, virology, and clinical details, check the Centers for Disease Control (CDC) site at http://www.cdc.gov/ncidod/dvbid/westnile/index.htm). WNV's potential to cause human, wildlife, and livestock mortality and its rapid spread have resulted in significant public concern, sometimes even leading to calls for wetland drainage by uninformed parties. Wetland scientists now have to address disease issues when dealing with wetland permitting, mitigation, and restoration. There has been substantial research on mosquito ecology, the role of wetlands and other habitats in disease transmission, and mosquito control methods. However, this information is not always readily available to wetland scientists working in the field and is often not directed at the question of how wetland restoration efforts influence mosquito populations and WNV disease risks.

The purpose of this paper is to provide the following:

- a basic understanding of key technical issues associated with WNV and mosquito-borne related diseases,
- a summary of available tools for mosquito control,
- processes for developing wetland projects that include recognition of potential mosquito issues and design features that minimize mosquito production, and
- an understanding of some possible effects of wetland restoration.

III. SCIENTIFIC CONSIDERATIONS

1) ***West Nile Virus and its Vectors***

West Nile virus is a mosquito-borne viral infection that can cause fever, encephalitis, or polio-like symptoms. According to the CDC (2004), less than 1% of people who become infected with WNV will develop severe illness, but in those individuals where the virus invades the central nervous system, case-fatality rates range from 3% to 15% and are highest among the elderly. In horses, the fatality rate is much higher, but an effective vaccine is available.

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Mosquitoes implicated in transmission of WNV to humans in temperate and subtropical North America are primarily of the genus *Culex* [e.g. *C. erraticus* (Dyar and Knab)*, C. nigripalpis* Theobald*, C. pipiens* Linnaeus*, C. quinquefasciatus* Say*, Cx. restuans* Theobald*, C. salinarius* Coquillett*,* and *C. tarsalis* Coquillett]. However, at least 43 mosquito species in the U.S. and 10 in Canada have tested positive for presence of WNV (Artsob 2004, CDC 2004, Turrell et al. 2005). *Culex pipiens*, the northern house mosquito, and *C. restuans* are the most common vectors across the eastern U.S. and eastern Canada. Recent findings in Maryland, Delaware, and Connecticut also point to *Culex salinarius* as being an important vector of WNV to humans in the coastal areas of the Mid-Atlantic and New England. *Culex. salinarius* inhabits wetlands found in salt and brackish water habitats and occasionally in coastal freshwater wetlands. *Culex quinquefasciatus* is closely related to *C. pipiens* and is the primary vector in many areas of the southern U.S. *Culex tarsalis* is thought to be the primary vector in the western U.S. and western Canada (along with *Cx. erythrothorax* and *Cx. stigmatosoma)(* Goddard, L. B., A. E. Roth, W. K. Reisen, and T. W. Scott. 2002. Vector competence of California mosquitoes for West Nile virus. Emerg. Infect. Dis . 8: 1385-1391.) and seems to be more active circulating WNV within bird populations and across to humans and other animals than is *C. pipiens* in eastern Canada (Sibbald 2003).

2) Mosquito Ecology

Females of different mosquito species are highly selective to both the environment (e.g., shaded/open/stream/rice-field/pond/treehole/artificial container) and the water conditions (e.g., moving/still/polluted/saline/fresh) of oviposition sites. However, mosquitoes can be classified into two general groups based on their egg-laying and hatching behavior (Knight et al. 2003). These groups are referred to as either floodwater/ephemeral water mosquitoes or permanent/semipermanent aquatic habitat mosquitoes. Floodwater mosquito eggs are deposited on moist substrate (e.g., moist soil, treehole, inside of a used tire) and do not hatch until subsequently inundated. They include mosquitoes in the genera *Aedes*, *Ochlerotatus*, and *Psorophora* that are primarily daytime or crepuscular feeding mosquitoes and thought not to be primary WNV vectors. They can, however, be significant vectors for diseases such as EEE, WEE, or La Crosse encephalitis (Monath 1988). Floodwater mosquitoes are prevalent in sites receiving agricultural runoff and along wetland edges. Adults do not overwinter, but eggs laid in soil or in artificial containers do.

Permanent/semipermanent aquatic habitat (includes standing water) mosquitoes lay eggs singly (*Anopheles*) or in large rafts (*Culex*), often 100 eggs or more, on the water surface. These eggs hatch within a few days (often within 48 hours) without an external hatching stimulus. Typical water depths in which *Culex* mosquitoes lay eggs are 4-18 inches, although eggs can be laid outside the typical water depths.

IV. MOSQUITO CONTROL STRATEGIES

Many of the control strategies offered below are based on the concept of "managed versus unmanaged" wetlands. For the purposes of this paper, managed wetlands are those that require significant and intensive human management, generally including active water-level manipulation. Natural or less managed wetlands are those that do not require such management and are intended to stay that way.

1) Risk Assessment

The first step in any control strategy should be to assess risk. We do not believe the mere fact that a wetland exists directly correlates to a general vector or West Nile Virus risk. Wetlands are only one facet of mosquito-borne disease. Approaches defined by this paper are not a total solution to the problem of mosquito-borne disease. Therefore, those assessing West Nile Virus and similar vector risks should determine the answers to the following questions:

How do local and regional wetlands fit into the overall mosquito vector problem?

a) When should mosquito problems within a wetland be addressed through management?
b) Examining potential control strategies, how will you best tailor a solution(s) to the situation?
c) Is there a phased or step-wise approach that can limit response to only that required to control specific situations?
d) How are you weighing alternatives, including the loss of valued wetland services, as well as potentially converting wetlands from one type to another, if the site would be altered to manage mosquitoes?

Ideally, any mosquito control program should follow an established Mosquito Management Plan that incorporates the principles of Integrated Pest Management. Such a plan should follow guidelines issued by CDC and establish threat categories that represent a hierarchical scale of increasing risk to human or wildlife health based on disease activity and mosquito-vector population numbers. The plan should then include appropriate actions to take for each threat-level category. Human and wildlife heath threats from mosquitoes will vary temorally and spatially and so threat must be determined locally.

Generally, mosquito management plans should consist of five parts: health threat determinations, mosquito population monitoring, surveillance for mosquito-borne disease, societal expectations, and treatment options. Mosquito monitoring or surveillance results should be used to determine the threat level identified in the mosquito management plan. Mosquito monitoring or surveillance is often carried out by professional mosquito control programs such as mosquito control districts (MCD), mosquito abatement districts (MAD), vector control districts (VCD), or county and state health departments. The objectives of such mosquito monitoring should be to establish both baseline and current data of mosquito species and abundance, map breeding and/or harboring habitats, estimate relative changes in population sizes, assess disease presence and levels, as well as nuisance levels.

Thresholds for treatment actions may be species specific for larval, pupal, and adult mosquito vectors and reflect the potential significance of a particular species or group of species in a particular health threat. For example, mosquito species known to be important in the transmission cycle of a disease, such as WNV in a particular geographic area, may have a lower action threshold than species with lesser transmission roles. It is also important to distinguish genuine disease-related health threats from public nuisance levels in considering control actions.

2) Steps to help reduce mosquito production from wetlands

Wetlands in areas with significant human occupancy that produce abundant mosquitoes may require immediate and sometimes continual attention, which often involves larval and adult mosquito surveillance and control responses provided by modern mosquito control programs. Wetlands managers, regulators, and scientists must recognize and deal openly with the fact that wetlands produce mosquitoes. Willott (2004) gives an overview about wetlands-associated mosquito production problems and the need for all involved parties to address them responsibly. In many areas having a history of mosquito production problems, organized mosquito control programs have existed for many years at state, county, or municipal levels. These programs can be a source of professional guidance and other assistance to parties who are commendably creating new wetlands, restoring degraded wetlands, or are being good stewards and managers of natural wetlands. In areas of the U.S. where mosquito control programs do not exist, or are only weakly funded or supported, the mosquito problems associated with wetlands become much more of a challenge to manage.

Many approaches and techniques are available to lessen mosquito production from wetlands, but the primary environmental, ecological, and regulatory reasons for wetland creation or restoration cannot be ignored. In some situations, a compromise between achieving all the desired wetland values and functions versus near-total suppression of mosquito production may be necessary. (Collins, J.N., and V.H. Resh. 1989.) For constructed or restored wetlands, design features and management practices that focus on basin configurations, water-level management, mosquito predators, and vegetation management can help reduce mosquito production (Knight et al. 2003, Mayhew et al. 2004). If such steps are taken but fail to achieve satisfactory mosquito control, then additional biological or chemical controls might be needed, which usually become the responsibility of organized mosquito control programs or licensed mosquito control professionals. The extra expense incurred by mosquito control programs for contending with mosquito production from created or restored wetlands should be viewed as another cost of having or creating wetlands, an expense that needs to be planned for as an element of responsible wetland stewardship.

The potential increase in mosquito production from restored wetlands can be minimal where the proportion of restored wetlands is relatively small relative to the overall wetland resource area. Furthermore, if environmentally compatible mosquito-control source-reduction measures are incorporated into a wetland restoration project's siting, design, construction, management, and maintenance, increases in mosquito production can be minimized. This will be most important where wetland restoration projects involve relatively large acreage and may help to avoid any increased need for more intrusive mosquito control measures.

a) Natural and Less Managed Wetlands

i. Non-invasive approaches

It must be recognized that removing target and non-target organisms from ecological communities lowers biological diversity and may impact ecological integrity by altering food webs and species composition. (Gwin, S. E., M. E. Kentula and P. W. Shaffer. 1999. Evaluating the effects of wetland regulation through hydrogeomorphic classification and landscape profiles. Wetlands 19:477-489.) This is true of both traditional control methods, and source reduction techniques depending on the ecological setting. In some cases, due to the unacceptable ecological impacts to natural or restored wetlands from control techniques, it may be desirable to restrict public access to the wetland rather than implement mosquito control. For example, the USFWS policy for mosquito control at National Wildlife Refuges states: “where appropriate, we will consider restricting or closing all or part of the refuge to visitors and restricting outdoor activities of employees” (USFWS 2007, Federal Register Vol 72, No 198, page 58330). The Illinois Nature Preserves Commission has a similar policy in place for all dedicated Nature Preserves in Illinois. Obviously, if there is a genuine health risk to the surrounding human population, then this approach may not be appropriate.

Two basic non-invasive methods of addressing human/mosquito interactions include the following.

Local advisories based on surveillance – Local heath departments and MCD/MAD/VCD’s often maintain mosquito surveillance programs of one sort or another. Having these organizations provide advisories and posting them at applicable locations can minimize potentially negative reactions.

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Access restrictions based on surveillance – A more intensive step beyond local advisories would be restricting access to places where human/mosquito interaction could become problematic.

In both methods, a wetland practitioner needs to be cautious so as to not create a perception with the general public that wetlands are inherently mosquito "factories." Rather, many of the citations in this paper clearly note that while mosquitoes, like other aquatic insects, are produced in wetlands, their number may rarely reach public health concern or even nuisance levels.

ii. Biological control and mosquitocides

If the approaches discussed above fail to achieve acceptable risk control or are otherwise unacceptable, then additional control efforts might be needed. The purposeful introduction (stocking) of mosquito larvae predators or the judicious use of insecticides (mosquitocides) are components of an integrated IPM approach used by most mosquito control agencies. Biological control is typically focused against the aquatic stages of the mosquito life cycle. Despite popular belief, there are no effective biological control agents for adult mosquitoes. Therefore, the use of adulticides by public agencies is ultimately less for control purposes and more for a sense of "public peace of mind". There is no credible scientific evidence that any avian (Kale 1968) or bat species (Whitaker and Long 1998, Tuttle 2000) can effectively control mosquitoes, especially when mosquito production is disproportionalty high. At present, the only effective and economically viable truly biological control agent for larval mosquitoes are small larvivorous fish (Kent et al. [undated], Coykendall 1980, Swanson et al. 1996).

The primary predator species used for biological control has been the mosquitofish (*Gambusia* spp., family Poeciliidae); however, the efficacy of alternative species continues to be evaluated (Cech and Moyle 1983, Bay 1985, Offill and Walton 1999). Some of the controversies regarding the use of *Gambusia* are examined in Rupp (1996) and a group of replies (Gratz et al. 1996) to his paper in the same volume. Although there are drawbacks for using stocked non-native larvivorous fishes, there are still settings where this approach can be a practicable, cost-effective control method that avoids or reduces the need for insecticide treatments (Sakolsky-Hoopes and Doane 1998, Kent and Sakolsky-Hoopes 1999). Undocumented anecdotal evidence from a state fishery department suggests that native shad species may be just as effective in larval control. (Felton, 2002)

Modern mosquito control programs prefer to use larvicides because control efforts are focused on the source of the problem and the area treated with larvicides is typically much smaller than that needed for adulticides after adult mosquitoes have emerged and dispersed widely. The most commonly used larvicides include: 1) monomolecular films (MMF) to treat container-type habitats or other relatively small wetland areas, 2) bacteria that produce materials toxic to mosquito larvae, 3) juvenile growth hormone mimics, and 4) organophosphates (e.g., temephos).

1) MMFs spread across the water surface and drown immature mosquitoes. MMFs usually persist for a short period (~ 24-48 hr), and some formulations are approved for use on potable water supplies.

2) Bacteria that produce mosquito toxins must be ingested by the larvae to be effective. Two types that are toxic to mosquitoes are naturally occurring bacilli, *Bacillus thuringiensis* var. *israelensis* (Bti) (de Barjac) and *B. sphaericus* (Neide), whose toxins exhibit pathenogenicities to mosquitoes, present minimal risks to humans and other non-target organisms at current application rates and by common modes of contact, and degrade rapidly in the environment.

3) Insect growth regulators such as methoprene mimic insect hormones involved in molting. Immature mosquitoes exposed to sufficient dosages of methoprene do not molt into adults. Methoprene also

has very little (if any) effect on non-target wetland organisms when used in mosquito control formulations (Schmude et al. 1998, Balcer et al. 1999).

4) The organophosphate temephos is a chemical insecticide that for some mosquito control programs provides the only affordable, or the only practicably applicable and effective larvicide for treating large geographic areas. It can also be an alternative control product for mosquito species or in habitats where Bti or methoprene do not give efficacious control.

When timely and effective larvicide application cannot be performed (which is often the case in some areas where the extent or type of larval habitats do not practicably allow for larvicide use, or when weather conditions do not permit timely applications), or when larvicide applications fail to achieve satisfactory larval control (e.g., there might be a wash-out or dilution of product by heavy rainfall or tidal flooding), it might become necessary to resort to the use of adulticide. This method usually involves more widespread applications of insecticides, often directly over or within where people live, work, or recreate. The most commonly used adulticides include 1) organophosphates (e.g., malathion, naled) and 2) synthetic pyrethroids (e.g., permethrin, resmethrin, sumithrin).

The U.S. Environmental Protection Agency only allows the registration and use of mosquitocides (larvicides or adulticides) that the EPA has scientifically determined (when used in accordance with all product label instructions and requirements) do not pose unreasonable risks to human health, wildlife, or the environment. Information about how the EPA registers and authorizes the use of mosquitocides, and the agency's perspectives about any health or non-target risks of mosquitocide use to humans, wildlife, or the environment, are contained in the "Mosquito Control Fact Sheets" available online at http://www.epa.gov/pesticides/factsheets/health_fs.htm (2005), which also has links to other pertinent EPA factsheets.

The choice of which mosquitocide to use is a complex decision involving many variables, including types of mosquito species to be controlled, life stages involved, types of habitats to be treated, presence or absence of non-target species-of-special-concern, weather conditions for spraying, modes of spraying (e.g., ground-based vs. aerial applications), spray equipment or applicator availability, desire or need for fast temporary impacts versus more residual effects, management of insecticide resistance potential or problems, a host of intertwined cost factors, public acceptability of a product, and others.

iii. Water-level management

The flow of water through a wetland (and its related volumetric turnover rate) may help reduce mosquito production, but flow rates detrimental to immature mosquito survival are impractical for many types of wetlands. Managing wetlands for good water "flow-through" enhances mosquito control by helping to eliminate the accumulation of stagnant, organically-rich waters that attract standing-water mosquitoes such as *Culex* spp. Flowing water also maintains good water quality with higher oxygen levels and toxic metabolite reduction. These factors enhance the survival of the aquatic predators of mosquito-larvae. In many Midwestern wetlands, such as fens, sedge meadows, dolomite prairies, etc., groundwater contributions from seeps, springs, and upwellings can provide this slow flushing, as well as maintaining colder water temperatures not suitable for some mosquito species.

iv. Vegetation management

Thick and extensive emergent or floating vegetation surface cover creates refugia for mosquitoes as well as predators. Vegetation management helps to create open water areas, although this may interfere with the functions desired in many wetland types. Open water zones reduce mosquito production by creating

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unfavorable conditions for immature mosquito development and for adult mosquito resting. They enhance the effects of wind, deter oviposition, and reduce immature mosquito survival (e.g., by increasing mortality caused by predators, drowning of immature stages by wave action), and lower the accumulation of organic debris in a wetland system. Deeper water also discourages production of mosquitoes whose larvae stay attached to the roots of emergent plants, such as the aggressive biter and freshwater vector for EEE, *Coquilletidia perturbans* (Walker).

Vegetation management involving selective plant removal, limited controlled burning, or minimal applications of herbicide might become necessary where water depths cannot adequately prevent excessive growth of emergent plants. Limited mowing, disking, and grazing may also be used to alter plant species composition and abundance in order to enhance wildlife use (Payne 1992, Kwasny et al. 2004), although this could introduce opportunities for invasive species. In most instances, routine vegetation management offers a short-term solution for mosquito management and, if done incorrectly, can greatly enhance mosquito production. Razing macrophytes or inundating dried plant biomass for vegetation control purposes may increase mosquito production. Mosquito production is less severe if such vegetation management is performed in autumn rather than in spring or early summer (Walton and Jiannino 2005).

While vegetation suppression or clearing is desirable for mosquito control, it is not always favorable for wetland functions and values, such as wildlife habitat or water quality improvement. Site-specific characteristics, habitat-management objectives, cost, and land use are critical considerations at managed wetlands (Kwasny et al. 2004). Some type of compromise in vegetation cover may be required, depending on the balance between the desires for maintaining wetland functions and avoiding increased mosquito production.

v. Basin design and topographic configurations

Natural and less managed wetlands presumptively have little opportunity to be altered in their topographic configuration. Configurations that are found routinely in nature may create a vector production rate compatible with the predator controls that exist; however, wetlands that have been degraded or disconnected from a predator balance may be opportunities in which managers can reconfigure for vector control. This paper will treat such opportunities as significantly managed wetlands. Please refer to Section IV.2.b.iii for these options.

vi. Source Reduction

As a strategy generally of final recourse, implementing features or measures that are designed to reduce mosquito production by manipulating habitats to make them unsuitable for mosquito production is known as “source reduction.” Note that the term “source reduction” may infer different actions by different groups. The range of effects that source-reduction approaches have on wetland functions has not been fully assessed, however, the applications of some of these techniques may be problematic in some or even many situations commonly encountered by wetland practitioners. The application of source reduction techniques in natural wetlands requires careful consideration, by wetland practitioners, mosquito-control practitioners, regulatory agency personnel, and the public, of the relative tradeoffs among potential benefits for mosquito control as well as potential adverse effects on wetlands and their functions.

b) Significantly Managed Wetlands

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i. Non-invasive Approaches

Please refer to section IV.2.a.i above for a description of these techniques.

ii. Biological Control and Mosquitocides

Please refer to section IV.2.a.ii above for a description of these techniques.

iii. Basin Design And Topographic Configurations

Wetlands that lack deep water zones (water depth > 1.5 m) and that do not maintain sufficient mosquito predation (degraded and similar) are more prone to mosquito production problems than those that contain permanent deep water, although having deep water zones will not guarantee that high levels of mosquito production will not occur. These deeper water areas provide habitats for important predators of mosquitoes such as larvivorous fishes, predaceous aquatic insects, salamander larvae, and others.

Wetlands that have gently sloping margins or edges (e.g., a vertical:horizontal slope of <1:10) are prone to develop thick emergent vegetation across the shallow bottom. The increased physical structure provided by emergent vegetation provides several important wetland functions and wildlife habitat (Kadlec and Knight 1996, Mitsch and Gosselink 2000) and is frequently a goal in wetland mitigation and/or restoration, but it can also create refugia where mosquito larvae can hatch and survive to emergence as adults. In less disturbed systems, this increase in mosquito production may be offset with predation; however, more disturbed wetlands may not provide for this control. Steeper side slopes (e.g., >1:4) are less prone to develop thick vegetative cover across extensive areas of a wetland. Unfortunately, such slopes may be more susceptible to soil erosion and burrowing. Regardless of the side slope angle, if the intent of the slope angle is primarily to control mosquito production, the sides should uniformly and continuously taper downward from shallow edges towards a deeper central water body to prevent isolated pockets of standing water along a wetland's margins during drawdown or droughts, as well as after rainfall events that do not completely fill the wetland basin.

iv. Water-Level Management

Design features and operations that move water through wetlands are critical to managing mosquitoes; however, prior to selecting this technique, a wetland scientist must examine the type and functions of the wetland in question. Numerous types of wetlands are not suitable candidates for significant water-level management. In addition to maintaining a permanent pool of water, the margins of wetlands should not undergo extensive wet-dry-wet cycles that can lead to production of floodwater mosquitoes from peripheral micro-habitats that lack mosquito predators. When a wetland dries out (e.g., as in seasonal wetlands or vernal pools), many aquatic predators of mosquito larvae perish, while floodwater mosquitoes can survive as eggs that remain viable in moist mud or even in severely desiccated bottoms and then hatch soon after water is again present. The floodwater mosquitoes (*Aedes* and *Ochlerotatus* spp.) produced from such temporary waters are often capable of long-distance flights and can transmit the causative agents of serious diseases, although not typically WNV. When a wetland has permanent water cover, along with open channels or pathways through thick vegetation for mosquito-larvae aquatic predators to move around, the production of standing-water mosquitoes (e.g., *Culex* spp.) is lessened.

The flow of water through a wetland (and its related volumetric turnover rate) will help reduce mosquito production but flow rates detrimental to immature mosquito survival are impractical for many types of wetlands. Managing wetlands for good water "flow-through" enhances mosquito control by helping to eliminate the accumulation of stagnant, organically-rich waters that attract standing-water mosquitoes such as *Culex* spp. Flowing water also maintains good water quality with higher oxygen levels and toxic

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metabolite reduction. These factors enhance the survival of the aquatic predators of mosquito-larvae. In many Midwestern wetlands such as fens, sedge meadows, dolomite prairies, etc., groundwater contributions from seeps, springs, and upwellings can provide this slow flushing, as well as maintaining colder water temperatures not suitable for some mosquito species.

v. Vegetation Management

As noted in Section IV.2.a.iv, thick and extensive emergent or floating vegetation cover creates refugia for mosquitoes as well as predators. Vegetation management helps to create open water areas, although this may interfere with the functions desired in many wetlands.

Vegetation management involving plant removal, controlled burning, or judicious applications of herbicide might become necessary where water depths cannot adequately prevent excessive growth of emergent plants. Mowing, disking, and grazing may also be used to alter plant species composition and abundance in order to enhance wildlife use (Payne 1992, Kwasny et al. 2004), although this could introduce opportunities for invasive species. In most instances, routine vegetation management offers a short-term solution for mosquito management but if done incorrectly, can greatly enhance mosquito production. For example, razing macrophytes or inundating dried plant biomass for vegetation control purposes may increase mosquito production. Mosquito production is less severe if such vegetation management is performed in autumn rather than in spring or early summer (Walton and Jiannino 2005). Incorporating design features such as raised planting beds and deep water zones that limit the proliferation of emergent macrophytes (Thullen et al. 2002) provide more effective mosquito control than does repeated vegetation removal.

While vegetation suppression or clearing is desirable for mosquito control, it is not always favorable for wetland functions such as wildlife habitat or water quality improvement. Site-specific characteristics, habitat management objectives, cost, and land use are critical considerations at managed wetlands (Kwasny et al. 2004). Some type of compromise in vegetation cover may be required, depending on the balance between the desires for maintaining wetland functions and avoiding increased mosquito production. For example, a 50:50 "hemi-marsh" of open water and vegetated cover may promote wildlife diversity and reduce mosquito production by utilizing deep open water bodies that are connected to each other by open channels.

vi. Source Reduction

As a strategy of final recourse, implementing features or measures that are designed to reduce mosquito production by manipulating habitats to make them unsuitable for mosquito production is known as "source reduction." The range of effects that these source-reduction approaches have on wetland functions has not been fully assessed, however, the applications of some of these techniques may be problematic in some or even many situations commonly encountered by wetland practitioners. The application of source reduction techniques in natural wetlands requires careful consideration, by wetland practitioners, mosquito-control practitioners, regulatory agency personnel, and the public, of the relative tradeoffs among potential benefits for mosquito control and potential adverse effects on wetlands and their functions.

Source reduction approaches in modern-day mosquito-control integrated pest management (IPM) programs are always preferable to using insecticides, as long as source reduction practices can be practicably and effectively employed and do not cause unintended or unacceptable environmental impacts. The type and extent of source reduction possible depends upon how much water-management capability exists on-site, either for managing water flows or wetland water levels. For example, what is possible to achieve for mosquito control via source reduction in a coastal waterfowl impoundment that has an automated vertical lift gate allowing fine-tuned dynamic management of tidal exchanges and marsh water levels could differ greatly from what is possible in a coastal impoundment having only a simple riserboard structure. Another example would be a stormwater retention pond that has an adjustable riserboard water-control structure versus another retention pond having only a fixed-crest weir as an outlet. For many natural wetlands, especially groundwater-fed wetlands and those who hydrologic regime is saturated soils for a significant portion of the growing season, this technique is not appropriate or even possible without destroying the wetland or converting it to a completely different wetland type.

Source reduction in wetlands customarily encompasses three broad categories of control measures: (1) basin design/topographic configurations, (2) water-level management, and (3) vegetation management. These measures are most applicable wetlands that were constructed or developed for specific purposes, often focusing on a single wetland function, while often providing other wetland functions. Managed wetlands include wildlife refuges in which water control is routinely practiced, wetlands constructed for wastewater treatment, and wetlands constructed for or used as stormwater retention facilities, although there are many other wetland types that may fall under this category (e.g., wetlands created on golf courses). The source reduction measures specified may or may not be applicable to natural or less managed wetlands.

Many excellent papers or reports have been published that describe sets of "best management practices" (BMPs) for achieving source reduction in wetlands. While the reports often are written for particular geographic regions of the country, similar approaches and recommendations are applicable across regions. Some publications that could be consulted, but which are by no means the only literature available about these topics, include the State of New Jersey's BMPs for stormwater management that address, in part, mosquito production issues (NJDEP 2004). Attention to the need for such considerations in New Jersey was generated by reports from Shisler and Charette (1986) and others. Dorothy and Staker (1990) examined similar problems in Maryland. Overviews of problems in Florida with stormwater management facilities and mosquito production are given by O'Meara (1997) and University of Florida (1998). Similar problems and remedies for these matters in Colorado are reviewed by Deatrich and Brown (undated webpage). Some more recent publications from California address similar topics in considerable depth – Metzger (2004) examines ways to reduce mosquito production in stormwater treatment devices, while Walton (2003) addresses these problems for surface-flow constructed wetlands. Another pertinent publication from California is a set of BMPs for mosquito control in seasonal, semi-permanent, and permanent wetlands managed for waterfowl and other birds (Kwasny et al. 2004). A recent EPA-sponsored workshop examined mosquito production problems, plus source reduction methods to help remedy such problems, for stormwater management facilities in Maryland and Delaware, with the workshop's presentations available at the EPA website www.epa.gov/maia/html/swmprog.html (EPA 2005).

The source-reduction technique known as "open marsh water management" (OMWM) is a selective ponding-and-ditching technique to encourage mosquito-larvae predation by native fishes that may be used for saltmarsh mosquito control in tidal wetlands. The technique is described by Meredith et al. (1985) for Delaware, with other states such as Massachusetts, New Jersey, Maryland, and Florida having their own OMWM guidelines. Note, however, that QMWM can effectively alter the functional type of a wetland. This is not a technique applicable to all locations or one that would be accepted in all locales. "Runnelling" is a modification of OMWM (Hulsman et al. 1989) that may be used in acid sulphate soils. Runnelling involves the selective excavation of shallow channels that provide tidal circulation and larvivorous fish access to mosquito-breeding depressions. OMWM and its impacts are reviewed by Wolfe (1996); the long-term impacts of runnelling are described by Dale (2005).

It should be noted that the old parallel-grid-ditching method of source reduction for salt marsh mosquito control, which involved non-selective excavation of open tidal ditches geometrically placed over vast acreages, had significant negative impacts on coastal marshes, including substrate disturbances that led to the introduction of invasive species (e.g., *Phragmites*), drying of marsh surfaces that led to increased oxidation and loss of marsh substrate, and changes in plant communities and wildlife habitat values that were associated with modifications to marsh hydrology, particularly from drainage of larger ponds used by waterbirds and estuarine fish and invertebrates. The modern technique of OMWM, when properly employed, avoids almost all of these past adverse impacts. In fact, in previously parallel-grid-ditched marshes, the installation of OMWM systems is often viewed as a habitat-restoration technique by restoring standing water to marsh surfaces that have been dewatered by the parallel-grid-ditches.

Besides offering prescriptions for applying source reduction techniques to control mosquito production in wetlands, some of the works cited above also contain citations of studies and surveys that have documented the types and extent of mosquito production found in natural wetlands, stormwater management basins, wetlands mitigation projects, waterfowl impoundments, and other kinds of wetlands.

V. SUMMARY

With respect to the number of humans affected, WNV is not currently the most deadly of emerging or extant diseases associated with mosquito vectors. At the same time, one cannot easily overlook that there have been 1,065 deaths and at least 27,500 serious cases of WNV in humans in the U.S. between 1999 and 2007 (CDC 2007). The medical community has documented that for some survivors of serious cases of WNV, there is an alarming number of individuals who had or who continue to have long-term, debilitating medical complications. Understandably, public perception of the issue, influenced by popular media, is in part currently focused on the prevalence and spread of WNV, including how this is influenced by wetlands. The history of wetland loss in the U.S. includes, in part, the drainage of these habitats as a method to control vector-borne disease at the expense of other wetland functions (Willott 2004). If society wishes to sustain the mandate of "no net loss" of wetlands through preservation, creation, or restoration of these valuable ecosystems, then wetland professionals must address the public perception of mosquito production and vector-borne disease with an integrated approach that includes providing public education and outreach while soliciting public input. Additionally, society must confront development that significantly degrades wetlands, juxtaposing humans with unstable biological systems.

Wetland professionals, regulatory agencies, public health organizations, and mosquito control agencies should consult with one another, *and especially with the local public*, during the planning, design, implementation, management and maintenance phases of wetland restoration projects. One price of restoring wetlands will be continuous monitoring for mosquito production. Criteria for the long-term success of wetland restoration projects must include the minimization of mosquito production to the extent practicable, done in an environmentally-compatible manner consistent with the achievement of other objectives specified for a particular project (Willott 2004).

Mosquito species have evolved to exploit a wide variety of habitats. Because mosquitoes are a natural part of wetland ecosystems, permanent and total elimination of mosquitoes from wetlands is not a realistic or achievable goal. However, current scientific understanding supports the position that we can take environmentally-compatible measures to help minimize mosquito production from natural, restored, altered, or created wetlands, and especially from many types of degraded wetlands. The SWS advocates **science-based** use of system design concepts that encourage ecological diversity and, ultimately, natural mosquito predators within all types of wetlands, balanced with minimizing to the extent practicable the creation or perpetuation of site features that promote mosquito production in the first place.

Finally, a great deal of work and understanding on these issues continues to evolve. The authors strongly urge anyone evaluating West Nile Virus oreiented vector control measures to review the most recent literature available.

APPENDIX A – ADDITIONAL BACKGROUND INFORMATION

1. Additional West Nile Virus and Similar Disease Information

The West Nile Virus is named for the West Nile district of Uganda where it was first isolated in 1937. It was not until an outbreak in 1957 in Israel that WNV became implicated as a cause of severe human encephalitis. The disease was first noted in horses in Egypt and France in the early 1960s. Subsequently, WNV has been found in Africa, Europe, the Middle East, west and central Asia, North and Central America, and the Caribbean.

It was detected for the first time in North America in 1999 and began to spread rapidly. By 2004, WNV had been detected in humans, birds, domestic animals, and mosquito populations in all states of the continental U.S., in all provinces and territories of Canada, and in six states in the north-central part and the Gulf coast of Mexico (Estrada-Franco 2003, CDC 2004, Health Canada 2004).

The West Nile virus belongs to the Flavivirus group of arthropod-borne viruses, most of which are maintained in non-human vertebrate hosts. Birds tend to be the major reservoir host for WNV, and those that do not die may develop life-long immunity. To date, WNV has been detected in 284 bird species; however, a smaller number of species that carry or manifest a viremic load of WNV are infective to mosquitoes. The ability of bird species to develop viremia is affected by multiple factors, including genetics, foraging ecology, immunocompetancy, phylogenetic history, breeding ecology, and degree of allopreening (van Riper et al. 2002, Marra et al. 2004). Members of the Corvidae (jays, magpies, crows, and ravens) seem to have the poorest ability to develop immunity and most often die.

Uninfected mosquitoes become infected with the WNV after obtaining a blood-meal from an infected host, usually birds. The infected mosquito vector will continue to infect or reinfect bird hosts, or will transport the virus to humans, domestic animals, or other mammals when it takes another blood meal. Humans, domestic animals, and other non-bird hosts are not known to develop infectious levels of the virus in the bloodstream and so are regarded as “dead-end” or incidental hosts (CDC 2004).

Besides concerns with WNV, it should be noted that there are many species of mosquitoes (in the genera *Aedes, Ochlerotatus, Culex, Anopheles, Coquillettidia, Psorophora*) that utilize a variety of wetland habitats (both natural and man-made wetlands having permanent standing water or ephemeral floodwaters) during their life cycles that can transmit other diseases of human health concern, including encephalitides that can cause eastern equine encephalitis (EEE), western equine encephalitis (WEE), St. Louis encephalitis (SLE), or La Crosse (LAC) encephalitis (Monath 1988, Turell et al. 2001, 2005, CDC 2004). Malaria historically was quite problematic in the southeastern U.S. and in more temperate climates as far north as the Ohio River Valley, with freshwater wetlands and swamps being the source of malarious *Anopheles* mosquitoes. Sporadic yellow fever outbreaks occurred along the eastern seaboard as far north as New York City and Boston during colonial and antebellum times. Local epidemics with high human death tolls were associated with shipborne arrivals of virus-infected *Aedes aegypti* (Linnaeus) and persisted until cold weather terminated transmission of the viral pathogen. While mosquitoes that transmit yellow fever or dengue fever are sub-tropical or tropical in distribution and are not associated with wetlands, summertime temperatures in many temperate areas would be conducive to disease outbreaks if an appropriate mosquito vector and the viral pathogen were re-introduced and allowed to increase unabated. Public and media attention to WNV outbreaks across the USA has refocused attention on mosquito-borne diseases in general, but to mosquito control professionals, these older and broader concerns about mosquitoes, human disease, and wetlands have always been present. Wetlands scientists, managers, and regulators should also be concerned that

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wetlands management, restoration, or creation practices do not unduly promote these other mosquito-borne diseases, and not focus solely on reacting to or contending with the public concern about WNV.

2. Additional Mosquito Ecology Information

The complete life cycle from egg to adult varies widely depending on species and water temperature. Mosquitoes require water to complete the life cycle and pass through four larval instars and a pupal stage in water. Rueda et al. (1990) reported temperature-dependent development rates of Culicidae from egg hatch to time of completion of the 4th instar ranging from 25 to 5 days, at constant temperatures between 15 and 30°C, respectively. The duration of the pupal stage may take as few as 1.5 days under optimal warm summer temperatures, after which the adult emerges and leaves the water. Males live only for a few weeks; females sometimes live for 2 to 3 months. Both *Culex* and *Anopheles* can overwinter as adults, being able to lay fertile eggs in the spring. Only females seek a blood meal and therefore only females can transmit WNV. Adult mosquitoes typically rest during the day in shaded often humid places, and blood-feeding activity for most species peaks around dusk and dawn. Overwintering habitats include outbuildings, barns, chicken coops, and underground drains/sewers (Knight et al. 2003).

For comprehensive and species specific details of mosquito ecology and sampling methods, refer to *The Biology of Mosquitoes* Volumes I-II (Clements 1992, 1999) and *Mosquito Ecology: Field Sampling Methods* (Service 1993).

Many types of natural, unmodified wetlands produce mosquito populations that can be problematic near areas populated by humans. Mosquitoes evolved to deposit eggs and to have larvae develop in aquatic habitats that provide spatial and temporal refugia from predation. In wetland habitats, predators of mosquito larvae (such as predacious diving beetles, water striders, whirligig beetles, backswimmers, dragonfly naiads, salamander larvae, and native planktivorous/larvivorous fishes) often do not achieve control sufficient to avoid mosquito population levels that lead to complaints. Similarly, larval mosquito mortality caused by naturally occurring viruses, bacteria, protozoa, fungi, or nematodes often is not large enough to yield adequate control. Adult mosquitoes can emerge continuously at relatively modest rates from standing water habitats and still cause considerable local nuisance problems. They may appear from temporary waters in sporadic but huge synchronized eruptions that quickly drive people away.

When mosquito emergences occur, humans living nearby may experience problems that include a lowering of quality-of-life from nuisance biting by mosquitoes, public health threats from mosquito-borne diseases, and adverse impacts to local economies that are based upon tourism, outdoor recreation, or animal husbandry. The geographic region affected by mosquitoes is always greater than the area of the wetland or aquatic site *per se,* and the impact of mosquito emergence on "nearby" humans is often determined by the typical flight ranges of adult female mosquitoes seeking bloodmeals, which can be quite variable by species. Some container-breeding species (including natural containers like treeholes) might only be a problem within a few hundred yards of their natal habitats, while some freshwater wetland species might cause problems within 1-2 miles of their places of origin. Some long-distance-flying saltmarsh or prairie species routinely cause problems 3-10 miles from their breeding marshes, and occasionally as far as 10-15 or even up to 20 miles away, depending upon meteorological conditions.

It should not be surprising that man-made wetlands and constructed wetlands designed to simulate the important environmental values and functions of natural wetlands for habitat or for water treatment purposes

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can also cause mosquito problems. Stormwater management basins, such as detention or retention ponds built for improving water quality of upland runoff, or mitigation wetlands created to provide wildlife habitats to compensate for wetlands losses to development, can produce substantial numbers of mosquitoes. Depending upon how man-made systems are designed, constructed, and managed, their mosquito production can sometimes greatly exceed that of natural wetlands (Mayhew et al. 2004).

Man-made wetlands and constructed wetlands are frequently designed with characteristics that mimic ideal mosquito-breeding habitat. A wetland design virtually guaranteed to produce significant numbers of mosquitoes has shallow water (e.g., water depth ≤ 25 cm) and gentle side slopes (e.g., side slopes 1:10 [vertical: horizontal]), lacks deep open-water habitats, has a water surface that is almost completely filled with emergent or floating vegetation, and contains organic-rich water. These mosquito-breeding habitats are also created in flood-irrigated pastures, rice fields, and agricultural ditch systems in many parts of the U.S. Mosquito production problems can recur or be aggravated if a wetland periodically or even partially dries out and holds surface water for 7 or more consecutive days after reflooding, or if there are many isolated areas that restrict access to larvivorous fish but continue to harbor the larval or pupal stages of mosquitoes (Mayhew et al. 2004). Mosquito issues are exacerbated by encroachment of human development within the flight distances of the resident mosquitoes or by placement of these types of wetlands adjacent to areas of dense human habitation.

Irrigated agriculture in the western US produces a number of products such as grass hay, pasture for cattle, rice, row crops, alfalfa and fruits. Irrigation practices (e.g., drip, sprinkler, controlled flood, uncontrolled flood) vary considerably according to product type and region. The type of irrigation has a large effect on the mosquito species produced, as it affects the frequency, duration and depth of flooding. For example, undocumented anecdotal evidence from the Merced County, California Mosquito Abatement District suggests the mosquitoes produced by controlled flood, sprinkler or drip-irrigated agriculture in some southern California counties are overwhelmingly (>99% of individuals) nuisance species (*Psorophora columbiae* and *Aedes vexans*) that do not play a significant role in WNV transmission (Walton, 2006). In contrast, mosquitoes of human public health concern (*Culex* species, particularly *Culex tarsalis*) are often produced from flood-irrigated pastures where standing water persists for 3 to 7 days, as well as associated ditches (CDC 2002), which is often the case in the Intermountain region. California's Sacramento River valley (between Redding and the Sacramento- San Joaquin delta) is a premier agricultural region that includes large acreages of flood - irrigated rice fields (350,000 to 400,000 acres between the mid-1980s and the late 1990s). Here rice is produced under conditions of constant shallow flooding in high temperature (100-degree) conditions. As a result, these fields can be a significant source of mosquitoes, especially *Culex tarsalis* one of the primary vectors of WNV (Fritz 2007). These fields are commonly treated by mosquito/vector-control districts to reduce the production of mosquitoes utilizing Integrated Pest Management (IPM) approaches that include many of the practices identified in this white paper (SYMVCD 2007)."

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APPENDIX B - PROCESSES FOR DEVELOPING CREATION, RESTORATION, AND ENHANCEMENT PROJECTS

This section suggests procedural guidelines that wetland practitioners (WPs) may follow when developing wetland creation, enhancement, or restoration projects that incorporate design criteria to minimize potential mosquito-breeding habitat. These steps describe a process that ensures that mosquitoes are considered during the design phase, so that the unintentional creation of habitat that supports mosquitoes is mitigated during construction. At each phase, consultation with the local MCD/MAD or mosquito professional is useful and may be essential.

1) Design phase. Identify any pest and vector mosquito species in the region or watershed. This may require consultation with the state, county, or local MCD/MAD or other qualified agency. Also identify whether the project will be in an urban, residential, or rural setting, as this will influence what mosquito species may be present. In urban areas, street catch basins, natural cavities such as tree holes in parks, and man-made containers (e.g., dumpsters, discarded tires, refuse that holds water) will usually be primary sources of mosquito breeding. The stagnant, organic-rich water that accumulates in these settings can be prime breeding habitat for *Culex* mosquitoes. Wetlands in urban settings are often used for stormwater storage and can become degraded and overrun with exotic, invasive plants such as *Phragmites*. Where outlets and channels get filled with debris (due to lack of maintenance), water can form stagnant pools that can lead to *Culex* breeding, or flood intermittent moist areas that can result in hatches of floodwater (*Aedes* and *Ochlerotatus*) mosquitoes. Such areas are often degraded ecosystems that lack significant mosquito-predator populations.

In suburban settings, natural and man-made wetlands are often intermixed in residential areas around homes and where people congregate, such as parks, walking trails, and nature areas. These same wooded and wet settings are home to many species of peridomestic birds that may act as reservoir hosts of disease agents for WNV, EEE and WEE (Monath 1988, CDC 2004). It is often this combination of mosquito-breeding wetlands and peridomestic bird habitat in close proximity to areas used by people that can lead to mosquito outbreaks that result in serious disease risk or nuisance complaints.

In rural or agricultural settings, mosquito-breeding areas and human habitation are not as close as in urban or suburban environments, although human development will continue to encroach on these areas with suburban sprawl (Walton et al. 1999). In these areas, the primary mosquito-producing habitats often occur in flood-irrigated agricultural areas (e.g., rice fields), in constructed wetlands for wastewater treatment, in stagnant ditch systems, and in areas receiving organic-rich return flows. Agricultural wetlands that breed mosquitoes can be a significant local problem, as these areas may have susceptible domestic animals such as horses, donkeys and pen-raised birds (e.g., pheasants, chukars, emus) that can succumb to EEE, WEE, or WNV.

2) Identify nearby potential mosquito habitats. Knowledge of the types of habitat in the watershed and in proximity to the wetland site (e.g., tidal salt marsh, freshwater swamp, managed impoundment, storm-water basin) helps to identify the types of mosquitoes that might be present. Local mosquito professionals are a valuable resource for such information.

3) Identify the existing mosquito-breeding potential of the site. Address how the proposed project might change this breeding potential both within the immediate site and within the larger landscape (e.g., watershed, area of influence). A review of aerial imagery and photographs may help identify potential areas

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within the site; however, ground-truthing and mapping the potential breeding habitat is the most effective means of identifying the extent and severity of potential mosquito breeding.

4) Incorporate mapping and surveillance data in the wetland project plan. In many instances, changes in elevation or bottom topography through excavation, or changes in hydrology or hydroperiod, can eliminate the egg-laying habitat of many floodwater mosquito species in significant portions of the wetland. These are techniques that can create more permanent open water to allow fish and other aquatic predators to have access to mosquito larvae and pupae. Incorporating this information into the project plan may compromise to some extent the environmental goals of the project. All parties that are involved in wetland-related projects have to decide whether the compromise of wetlands values and functions is acceptable in order to achieve adequate mosquito control. They must also be prepared to address potential problems via alternative approaches.

5) Develop a mosquito control plan. If minimization of mosquito-breeding habitat is incorporated into the wetland design, the need for further mosquito control may be greatly diminished. However, to ensure that potential mosquito issues are addressed, a mosquito control plan should be developed as part of a project's Operation and Maintenance (O&M) Plan. This may involve changing the wetland design somewhat to incorporate features that would reduce mosquito-breeding potential. Monitoring the completed project site for mosquito breeding should be conducted for two years during the mosquito seasons following project completion. Because wetlands are not static, the phenology and abundance of immature mosquitoes during the first year are unlikely to be the same during the second and subsequent years (Thullen et al. 2002). Monitoring should be accomplished by an inspector performing larval dip counts in the wetland site and possibly supplementing those data with adult mosquito trapping. A contingency plan should be in place (perhaps as a condition of a wetlands permit) to mitigate any increase in mosquito-breeding problems. This plan should allow for some fine-tuning of bottom topography or hydrology. If further altering the physical features of the site is not an acceptable alternative, the plan could also allow for periodic application of an approved larvicide for mosquito control to areas that are found to have larval numbers that exceed an acceptable predetermined threshold. Depending on the nearness of the site to human habitation and the pest or vector mosquito species present, the plan could also allow for periodic applications of an approved adulticide to control adult mosquito populations, if such application is warranted as determined by established thresholds. In many areas where organized MCDs/MADs exist, control applications will occur under these programs' authorities regardless of what an O&M Plan states, but the wetland practitioner's O&M Plan should aim to achieve conditions that minimize the necessity for MCD/MAD intervention.

6) Be prepared to respond to public comment to address any local concerns. If the project has had the involvement of the local MCD/MAD, then potential mosquito-breeding issues should have been addressed. This also provides a level of comfort to the general public that these issues have been considered during the planning process and that a contingency plan exists to address potential mosquito problems. In public forums the mosquito-control professional can provide valuable information on mosquitoes, mosquito-borne diseases, pesticides, and related concerns.

APPENDIC C - MOSQUITO PRODUCTION IN DEGRADED WETLANDS VS. RESTORED WETLANDS

1) Degraded Wetlands, Restored Wetlands, and Mosquitoes

A variety of definitions have been published for the term "degraded wetlands." (1) The Association of State Wetland Managers (ASWM) online glossary defines degraded as when the condition of the quality of water has been made unfit for some specified purpose (ASWM 2003). (2) The Office of Ocean and Coastal

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Resource Management (OOCRM), a division of the National Oceanic and Atmospheric Administration (NOAA) states that a degraded wetland is "a wetland with one or more functions reduced, impaired, or damaged due to human activity" and that "consideration should be given to physical alteration, including the conversion of a wetland from one system (e.g., estuarine) to a different system (e.g., upland); chemical contamination; and biological alteration, including the significant presence of non-indigenous, invasive species" (OOCRM 2000).

By contrast, restored wetlands include any degraded or otherwise altered wetland that has been rehabilitated or repaired to its original (i.e., pre-disturbance, pre-degraded) state. The Society of Wetland Scientists defines restoration as "the reinstatement of driving ecological processes" in wetlands. These fundamental forces are identified as the hydrology, geomorphic setting, and physical, biological, and biogeochemical processes (SWS 2000).

Using the OOCRM definition for degraded wetlands, it is apparent that numerous sources contribute to a wetland ultimately becoming degraded. Similarly, the effects of restoration on a variety of wetland functions, including mosquito production, depend on which processes are restored and how they are restored. The following examples illustrate how wetland degradation or restoration could affect mosquito production or composition.

An example of physical alteration might include cutting a forested wetland for harvest or utility right-of-way clearing. Typically, when trees are removed from a forested wetland and hydrology is not otherwise altered, the area may become wetter for longer periods of time. This is primarily due to the loss of evapotranspiration. Generally, the impact on mosquito production may be a shift in genus composition rather than in total mosquito populations (e.g., from floodwater *Aedes* to semi- or permanent water *Culex* or *Anopheles*); a longer period of mosquito production; or a shift from univoltine, early-season floodwater species (e.g., *O. excrucians* (Walker)) to a multivoltine floodwater species such as *A. vexans* (Meigen).
Chemical contamination may be the result of receiving inorganic or organic-laden runoff in excess of what the wetland can assimilate without becoming impaired. The contaminant loading may be point source or non-point source, and may be intentional (e.g., routing urban stormwater runoff through natural wetlands) or unintentional (e.g., accidental releases). Once a wetland's capacity to assimilate chemical contaminants is exceeded, the resulting conditions may include oxygen-depletion, bacteria and/or nutrient-laden waters, or death of vegetation that might further aggravate the problem through decomposition. Where a functional palustrine emergent marsh might have once produced relatively few mosquitoes, a chemically degraded wetland may exhibit a significantly higher production of mosquitoes. Chipps et al. (2003) indirectly documented this phenomenon when comparing reference and degraded wetlands in North Dakota. The degraded wetlands of this study were primarily impacted by agricultural practices (e.g., grazing, plowing, or cropping). The authors suggested that a disturbance of natural wetland functions and processes contributed to increased mosquito levels by reducing suitable habitats for other invertebrates (e.g., natural mosquito predators). Although greater than 95% of the mosquitoes collected in their study were in the genus *Aedes*, the authors did not differentiate a species shift between reference and degraded wetlands.

Wetlands constructed for wastewater treatment can have mosquito production characteristics similar to those of degraded natural wetlands. Increasingly common across the nation, these treatment systems are frequently designed to consist of monotypic vegetation stands and are loaded with high-strength wastewater (i.e., wastewater high in organics) that results in conditions that mimic degraded natural wetlands (e.g., low dissolved oxygen, low biodiversity of aquatic vertebrates and invertebrates, etc.). Dip samples from constructed wetlands treating agricultural wastewater in Tennessee yielded average larval densities of two and three orders of magnitude greater than those typically associated with nuisance complaints in regional reservoirs (Gartrell et al. 1981, Mayhew et al. 2004). West Nile vector *C. pipiens* was the principal species collected during the Tennessee study; therefore, the health and safety of populations around these types of wetlands are of concern.

An example of biological alteration occurs in riparian and other freshwater wetlands that have been impacted by beavers. Wetlands in which beavers (and ultimately their dams) have been removed may experience a significant reduction of surface water, resulting in stream downcutting and loss of riparian-floodplain connections. There is public concern that beaver activity that impounds water will result in increased mosquito production; however, there are few published studies that support this opinion. Undocumented observations from the Northeastern U.S. suggest that although there may be a change in mosquito species' dynamics, there appears to be no significant change in overall mosquito production (W. Crans, R. Wolfe, pers. comm.). Butts (1992) observed a drastic reduction in univoltine, temporary pool mosquitoes following impoundment by beavers in New York State. He later noted (2001) that this reduction in numbers of anthropophilic mosquitoes was sustained for over 30 years with no evidence of permanent-water mosquitoes becoming established. In contrast, Duckworth and Musa (2002) documented overall increases in mosquito numbers with only slight increases in floodwater mosquitoes and considerable increases in *Culex* and *Anopheles* mosquitoes in a New Jersey beaver-dam wetland. They noted an increase in shallow, intermittently-flooded edges following beaver dam construction in the relatively flat, riparian floodplain, which increased potential egg-laying habitat for both floodwater and permanent water mosquitoes. This contrast in changes in mosquito population dynamics following beaver activity further demonstrates the direct relationship between the topography of the area that is flooded and the resulting change in mosquito activity.

*2) **Wetland Restoration***

The U.S. Army Corps of Engineers (USACE) is the federal agency with primary jurisdictional authority for maintaining the presidential mandate of ”no net loss” of wetlands within the U.S., and restoration of degraded wetlands is frequently permitted as mitigation for unavoidable losses (wetland creation and enhancement projects are also accepted mitigation). To date, the USACE has issued no formal guidance or memorandum concerning wetland restoration, creation, or enhancement projects as they relate to vector production/control. Wetland restoration resulting from USACE regulation may also be affected by the requirements of a number of other federal laws, such as the federal Endangered Species Act, that introduce additional constraints to wetland design and management.

In addition to restoration projects that mitigate for regulated losses, non-profit and environmental interest groups across the U.S. actively participate in and fund wetland restorations of all sizes and for varying philosophical and scientific reasons. Regardless of the primary motivation underlying restorations, the health and safety of the public living near a wetland restoration site must be considered.

The impacts on mosquito production due to restoration or enhancement will also depend on prior conditions. For example, if coastal wetlands isolated from tidal flow contained isolated pools that bred mosquitoes, restoration of tidal flushing would likely decrease mosquito production. On the other hand, if a wet meadow habitat that only periodically and briefly held water during the early spring had its hydrological conditions changed so that a permanent pool of water with dense emergent vegetation was formed, mosquito production could be increased.

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Successfully "restored" wetlands mimic or reestablish many of the environmental conditions and features found in unmodified wetlands, including mosquito production. While restored wetlands in many situations might be less problematic mosquito producers than degraded wetlands, mosquito control needs in restored systems should be considered, especially in view of modern society's expectations and demands for mosquito control. In some cases, mosquito control actions involving water management or larvicide application may be necessary after a wetland is restored from a degraded condition.

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ABBREVIATIONS

ASWM	Association of State Wetland Managers
Bti	*Bacillus thuringiensis* var. *israelensis*
BMPs	best management practices
CDC	Centers for Disease Control
EEE	eastern equine encephalitis
EPA	U.S. Environmental Protection Agency
IPM	Integrated pest management
LAC	La Crosse encephalitis
MAD	mosquito abatement districts
MCM	mosquito control districts
MMF	monomolecular films
NJDEP	New Jersey Department of Environmental Protection
NOAA	National Oceanic and Atmospheric Administration
OMWM	open marsh water management
OOCRM	Office of Ocean and Coastal Resource Management
O&M	operation and maintenance
SLE	St. Louis encephalitis
SWS	Society of Wetland Scientists
USACE	U.S. Army Corps of Engineers
VCD	vector control districts
WEE	western equine encephalitis
WNV	West Nile virus
WPs	wetland practitioners