Road Drainage and West Nile Virus

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Meeting the Challenges of Stormwater Management and Vector Control

Integrating stormwater management and vector control in a Phase II city

By Kenneth E. Banks

Managing stormwater in Denton, TX, took a new direction on August 6, 2002, when a mosquito—captured as part of a local University of North Texas research project—tested positive for West Nile virus (WNV). Based on the cases of WNV being found in surrounding states, as well as in other areas of Texas, city officials suspected that it would be only a matter of time before the disease reached Denton. After August 2002, however, Denton's mosquito control philosophy shifted from being associated mainly with nuisance controls to potentially having major public health implications. The city needed a unified, coordinated approach to mosquito management that ensured the protection of both public and environmental health. This article outlines the rationale behind Denton's mosquito control program and describes how the city has attempted to meet the multiple—and sometimes conflicting—challenges of stormwater management, integrated pest management, and public health protection.

One of the immediate issues for the mosquito control program involved determining which control methods were most appropriate. Before WNV arrived in Texas, several groups of citizens had worked with the City of Denton to decrease the number of pesticides and herbicides applied in parks and other public places. The city has worked with these groups to adopt an integrated pest management approach to controlling both animal and plant pests within city properties. The approach for mosquito control was no different, and city staff members desired to put together a program based on preventative—rather than reactive—controls. The overriding goal of the program was to instigate scientific and appropriate responses for mosquito control, based on data about mosquito habitats, breeding seasons, and control measures and on the overall risk to public health. Staff also realized, however, that this type of program could not be administered solely by the City of Denton. Citizen involvement and guidance were needed, as was technical support.

Public health is an overriding goal in any municipal environment. In addition, relatively recent National Pollutant Discharge Elimination System (NPDES) regulations have challenged small to medium-sized (Phase II) cities to adopt measures to improve stormwater runoff quality by using myriad best management practices (BMPs). Although improving stormwater quality is the goal of the Phase II program, the public health implications of some stormwater improvements are often ill understood and in some instances might not be considered at all. This situation might become particularly pronounced in smaller cities that are struggling to meet the regulatory compliance deadlines of the Phase II program without the benefits of additional staff and resources. As resources become increasingly taxed and compliance deadlines approach, meeting the immediate stormwater-quantity and -quality requirements might become the only programmatic goal of stormwater management.

Stormwater Best Management Practices and Mosquitoes

Managing stormwater has traditionally involved activities related to the quantity and quality of stormwater runoff; recent concerns about disease vectors that might be associated with structural stormwater BMPs, however, have caused many stormwater professionals to begin to consider the potential public health impacts of certain structural BMPs. Those involved in BMP design, implementation, operation, and regulations are finding that the responsibilities of stormwater management go beyond simple compliance with urban runoff regulations. The challenge now has become an issue of maintaining compliance with state and federal stormwater regulations while simultaneously minimizing the potential impacts to public health. Many Phase II municipalities just becoming involved with a new and somewhat bewildering array of stormwater regulations, requirements, and BMPs might be unprepared to deal with the additional complicating factor of public health.

Most of the recent public health concerns about disease vectors have centered around mosquito control. On a global basis, there is no doubt diseases transmitted by mosquitoes are among the most significant causes of human illness and death, with millions of people being affected by mosquito-borne illnesses every year. These problems might be exacerbated in urban areas, which tend to have numerous human-made and natural mosquito-producing habitats. Habitats might include, but are certainly not restricted to, certain stormwater BMPs, particularly those that retain water for a designated period of time. Such systems might be designed to have relatively still water and/or densely vegetated areas to settle contaminants and provide areas where biological activity can mitigate pollutants. Unfortunately the same conditions can also provide optimum conditions for some mosquito life cycle stages.

A mosquito's life cycle consists of four stages—egg, larvae, pupa, and adult—and eggs must be laid in stagnant water or on damp soils likely to be flooded with water. Eggs typically hatch in 24–48 hours, and the resulting larval and pupal stages will typically last five to 18 days before producing an adult mosquito (Floore, 2002). The amount of time spent in any given life stage depends on environmental conditions, particularly temperature. Anything done to disrupt the cycle from the egg to the adult phase, however, can effectively prevent mosquitoes from being able to transmit diseases.

In some instances, the intensive media coverage concerning mosquitoes and their relation to human health produces the perception that any type of standing water is a breeding ground for large numbers of disease-infected mosquitoes. This perception might lead citizens or public officials to suggest that all sites having standing water should be filled, drained, sprayed, or otherwise managed to completely eliminate all mosquitoes. These concerns are not unfounded; some recent studies conducted in California have demonstrated that many common BMP designs are capable of providing breeding habitats for mosquitoes, some of which are capable of transmitting human diseases (Metzger et al., 2002). Studies have also shown, however, that proper design, construction, and maintenance of BMPs can dramatically reduce the suitability of these structures for producing mosquitoes (Kluh et al., 2002).

The relatively recent and rapid proliferation of WNV and the resulting impacts on public health have many municipal separate storm sewer system permittees concerned about the potential impact of stormwater BMPs on disease transmission. Although the newness of this illness has garnered a lot of media attention and created a general concern among many people, according to the national Centers for Disease Control and Prevention (CDC), the risk to any one person is extremely low.

WNV first appeared in the eastern United States in 1999 and rapidly spread westward, becoming isolated in birds, humans, and mosquitoes in 44 states and Washington, DC, by the end of 2002. The number of humans affected by the virus increased dramatically during 2002 and 2003 (see Table 1). Typical symptoms of WNV in humans are flulike, characterized by mild fever, headache, body ache, swollen lymph glands, and occasional development of a rash. According to the CDC, about 13% of those infected develop West Nile fever, with headaches and flulike symptoms from which they eventually recover. Some individuals who become infected with WNV (thought to be less than 1% of the total number of people infected) will develop meningitis, an infection of the membranes of the brain or spinal cord, or encephalitis, an infection of the brain. Both conditions can cause death or permanent injury, and advanced age seems to be an important risk factor for developing a life-threatening form of the disease. The fatality rate is approximately 3–15% among those who contract meningitis or encephalitis.

Table 1. Incidence of WNV in Humans in the US, January 1999–September 2003

Year	Number of States	Clinical Cases	Deaths
1999	4	62	7
2000	12+DC	21	2
2001	27+DC	66	9
2002	44+DC	4,156	284
2003*	37	3,659	67

* as of September 17, 2003

Note the large increase in cases from 2001 to 2002 (from the Centers for Disease Control and Prevention).

Based on mosquito biology, any standing water has the potential to promote mosquito growth. Because some stormwater management practices use standing water to promote water-quality improvements—or because they have a possibility of creating standing water if not properly maintained—there is a chance stormwater management practices will contribute to mosquito problems. Stormwater BMPs, however, are essential to minimizing the adverse water-quality impacts caused by development and thus are a vital component of urban surface-water conveyance systems. The challenge facing the City of Denton was to provide water-quality improvements through stormwater management without jeopardizing public health.

Denton Setting

The city of Denton occupies an approximately 64-mi.^{2} area in north-central Texas, about 30 mi. north of Dallas. Three major watersheds drain from Denton, and there are many ponds, wetland areas, streams, and stormwater conveyances within these watersheds. The city also has numerous parks and a large number of protected greenbelts and environmentally sensitive areas along riparian corridors. Denton is located in close proximity to Lake Lewisville, a large (45-mi.^{2}) multipurpose reservoir. Many of these areas have the potential to provide a mosquito habitat.

Soon after the discovery of the first WNV-positive mosquito sample, the City of Denton developed and implemented the Mosquito Surveillance and Response Plan. The plan is designed to establish the programmatic assessment of mosquito populations within the city and to guide the use of various control measures. City staff recognized that the magnitude of the mosquito control program required the cooperation and coordination of many different departments within the city, county, and state public health agencies and of the citizens of Denton. The city also decided that employing a proactive, targeted approach to mosquito management was much more desirable than merely responding to an outbreak once it occurred.

Mosquito Response Plan

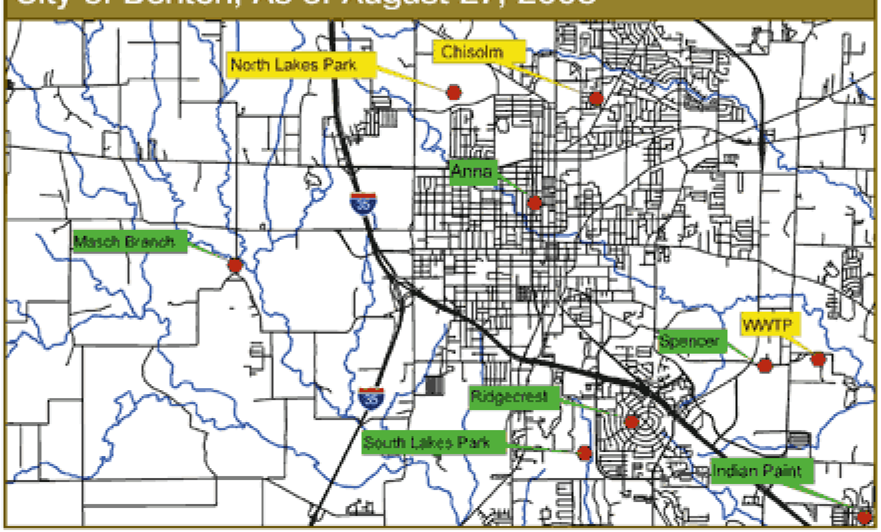
City staff recognized early in the process of developing the mosquito response plan that there was a potential for overlap between mosquito control and stormwater management. Because there is a real potential for vector production in stormwater BMPs, the City of Denton's Watershed Protection Department, which administers both the city's watershed monitoring program and its stormwater program, was chosen as the lead department for mosquito control issues. The Watershed Protection Department, acting as a general coordinator, works closely with the city's Drainage, Engineering, Animal Control, and Code Enforcement Departments and the Public Information Office concerning various aspects of control. The city staff also maintains close contacts with the Denton County Health Department. Cooperation among the various city and county departments has been crucial to providing the city with the best possible means of achieving clean-water goals without sacrificing public health.

Mosquito Surveillance
During the fall of 2002, the City of Denton entered into an agreement with the University of North Texas to begin an active adult mosquito monitoring program. Beginning in April 2003, several adult mosquito traps were deployed throughout the city. Two main types of traps are used: a CDC light trap baited with carbon dioxide and a gravid trap designed to collect ovipositing female mosquitoes. Light traps rely on a carbon dioxide attractant to lure mosquitoes into an area where a fan conveys the mosquitoes into a capture net. Gravid traps contain a pungent liquid mixture of water, hay, and other organic material that lures female mosquitoes ready to lay eggs. Currently almost all of the mosquitoes that have tested positive for WNV within Denton have been captured using gravid traps.

After capture, adult mosquitoes are transferred from the traps to specially designed transport boxes and then are sent to the Texas Department of Health for identification of species level and testing for the presence of viruses. If viral infections are detected, further testing is conducted to determine if the virus is West Nile or some other mosquito-borne virus, such as Saint Louis encephalitis or eastern equine encephalitis. Trapping is conducted approximately once a week using four fixed locations, four locations randomly chosen within four large geographic areas in the city, and two completely random locations. Some limited trapping has also been based on additional information, such as the number of complaint calls or observations of dead birds.

Mosquito Trap Information
To date, 28 different mosquito species have been identified within Denton, and more than 7,000 mosquitoes have been submitted for testing. As of September 9, 2003, 12 samples tested positive for WNV. All of the information collected by the trapping network is used to create maps showing sampling locations where WNV-positive samples were collected (see Figure 1). Sites where multiple samples were collected are color-coded so citizens can quickly tell where the disease appears to be more prevalent. Maps are posted on the City of Denton Web page as soon as the information is obtained.

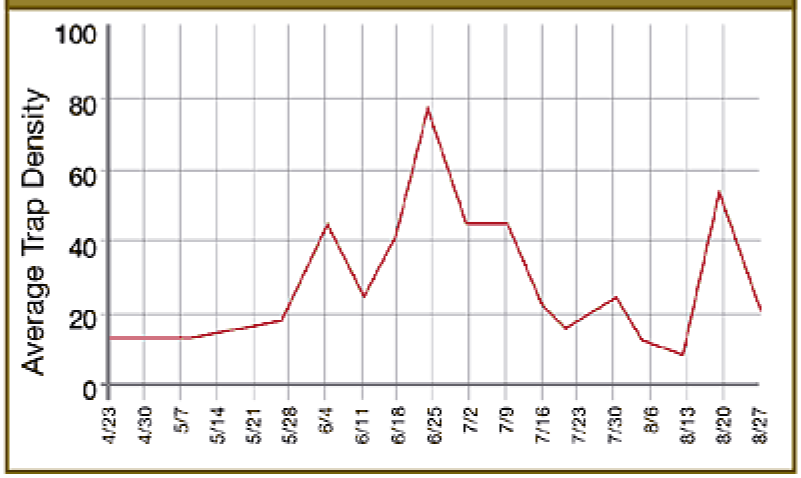
Figure 1. Map of WNV-Positive Samples Within the City of Denton, As of August 27, 2003



Green labels indicate a single positive sample. Yellow labels indicate two samples have tested positive from the same location.

Information concerning the dynamics of mosquito densities (see Figure 2) and the overall incidence of WNV (see Figure 3) can be produced quickly from trap results. This information gives city officials and citizens a better understanding of mosquito population densities within the City of Denton and a sense of the relative risk of WNV transmission to humans. Citizens are quickly informed about the appropriate city risk level and are provided with information concerning the most appropriate protection activities. The information is also used to direct city staff to areas that have consistently high mosquito population densities, to determine if target mosquito species appear to be associated with stormwater infrastructures or homeowner management practices, and to help determine the appropriate larviciding approach.

Figure 2. Average Number of Trapped Mosquitoes per Sampling Event, April–August 2003



Trapping information, along with information on animal or human cases of WNV, is used to establish risk levels for the city. Each risk level is triggered by data concerning the likely public health risk and coincides with a particular series of activities. Control activities become more pronounced as the threat to public health increases. An outline of triggers, associated risk levels, and resulting activities of the city's Mosquito Surveillance and Response Plan can be viewed by going to the Water Utilities Department page at www.cityofdenton.com.

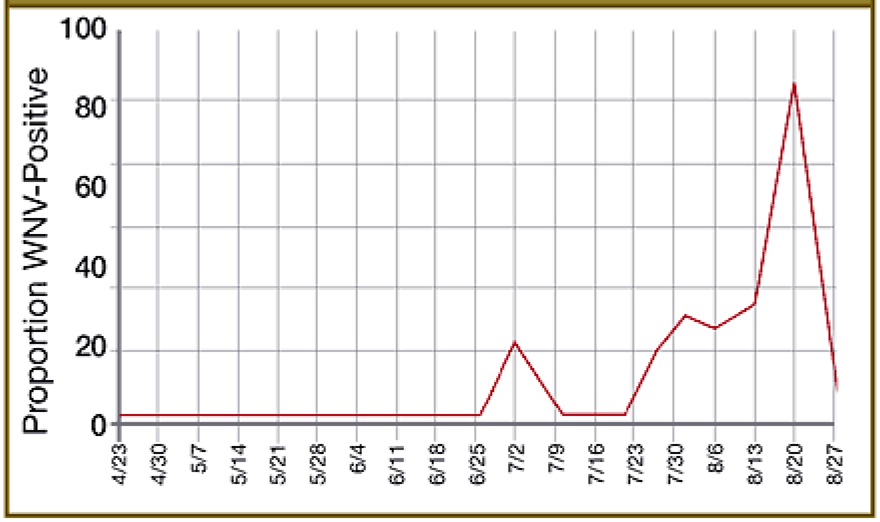


Figure 3. Proportion of Traps Testing Positive for WNV, April–August 2003

Adult Mosquito Control: To Spray or Not To Spray

The most important maintenance cycle from a public health standpoint involves humans and mosquitoes in urban and suburban environments. The principal vector of WNV in Denton, *Culex quinquefasciatus*, is a highly domesticated species that uses the transient waters common to the urban environment as larval habitat. Other mosquito species might be involved in suburban or rural maintenance cycles, but in Denton they do not seem to be a major contributor to the transmission of WNV.

Traditional mosquito control often uses insecticides as space sprays to kill adult mosquitoes. One of the most popular approaches to the application of these sprays in urban and suburban environments has been ultralow-volume (ULV) applications of either organophosphates—for example, Malathion—or synthetic pyrethroid products. Some research, however, suggests ULV applications—either by ground or by aerial equipment—have had little lasting effect on certain mosquito species (Hudson, 1986; Gubler, 1989).

One of the greatest concerns raised during the development of the mosquito response plan was that adulticiding operations—if used—would create a false sense of security among residents. Although minimal data exist concerning the efficacy of ULV applications in an urban environment under real field conditions, control that is anywhere near 100% is unlikely because of several factors: (1) the nature of the insecticide (the droplets produced by the ULV machinery must contact the mosquito to kill), (2) the large number of obstructions to ULV applications in an urban setting, and (3) the number of places a mosquito can hide in a typical urban environment. Citizens who are used to the relatively high level of insect control obtained by insecticide applications in home or yard settings, however, might not understand that the entire mosquito population will not be killed by broad-scale ULV spraying. The fast breeding cycle of mosquitoes during certain times of the year also makes it likely that a new generation of biting adults will appear soon after ULV applications.

Because of the many concerns about chemically based adult mosquito control, emphasis was placed on community-focused, integrated approaches. The rationale was that the best control could be achieved through source reduction and, in some cases, larviciding activities conducted by both community members and city staff. Through this approach, community members have a role in and a responsibility for program implementation and maintenance. It is important to realize, however, that the Mosquito Surveillance and Response Plan is not a no-spray program. At higher risk levels, limited spraying is considered a management option based on the flight range and densities of target mosquitoes, the prevalence of virus-positive mosquito pools, the perceived risk to the human population, and the time of the current weather patterns. If spraying is conducted, ULV applications with synthetic pyrethroid products are performed within areas of highest risk.

Although certainly the sustainability of disease control programs of this magnitude can benefit from a sense of community ownership, community members must find neighboring mosquito habitats unacceptable and must be convinced their best interest is to control mosquitoes both in their own backyards and in their neighborhoods. This requires education and continued reinforcement, and it might take some time for a substantial number of community members to become involved in actions that have traditionally been perceived to be a government responsibility. Denton's approach is somewhat top-down; citizens are provided with information on how to best accomplish source reduction and larval control. To date, this approach appears to be successful.

Larviciding: Stop Mosquitoes Before They Can Bite

Over the past few years, major advances have been made in the area of biological mosquito control. Biological control strategies involve natural predators, including *Gambusia affinis* (mosquito fish), fungi, protozoans, round worms, flat worms, and such bacterial agents as *Bacillus thuringiensis israelensis* (Bti). Each biological control agent has certain benefits and restrictions. To use a biological control agent successfully, the applicator must have a basic knowledge of its biology. Some biological control mechanisms, for example, are limited by salinity, temperature, or organic pollution, and some mosquito species are much more susceptible to specific types of biological control agents. All of these factors must be considered when choosing and applying biological control agents.

The perfect pesticide is easily applied, reasonably inexpensive, and nontoxic to nontarget organisms and eliminates the pest quickly before it becomes a threat. Although no single pesticide combines all of these factors, certain types of Bacillus bacteria have been developed into pesticides that are very close to the perfect model. Bti, for example, is a naturally occurring soil bacterium that produces a poison capable of killing mosquito larvae. Bti is considered ideal for mosquito management because of its specificity to mosquito larvae and because of its lack of toxicity to nontarget organisms.

Under adverse conditions, Bti bacteria form asexual reproductive cells, called *endospores*, which enable the cells to survive. The endospores of Bti also contain crystals of delta endotoxin, an insecticidal protein toxin. When eaten by a mosquito larva, the crystals dissolve in the larva's intestine and perforate the cells of its gut, disrupting its normal digestion and preventing it from feeding. When the larva stops feeding, its gut pH is lowered by equilibration with its blood pH. This lowered pH enables the bacterial spores to germinate, and the bacteria then invade the host, causing a lethal infection. Death typically occurs a few hours after digestion. Based on laboratory studies, the United States Environmental Protection Agency concluded that the toxicity and infectivity risks to nontarget animals are minimal to nonexistent (USEPA, 1998). Currently Bti is commercially available in powder, liquid, granular, capsule, and briquette formulations.

The City of Denton decided that biological control agents would be the main tools for mosquito control. Bti and the closely related bacterium *Bacillus sphaericus* (Bs) were considered the most environmentally acceptable and commercially available biological control agents because of their relative specificity for mosquitoes and their negligible toxicity to vertebrates (Rishikesh et al., 1983). Limited applications of larvivorous fish (*Gambusia affinis*) also were considered to be a valuable component of an integrated control program, either alone or together with other control agents (Walton et al., 1990; Walton and Mulla, 1991; Reed et al., 1995). It is very important, however, to consider the ecological implications of releasing mosquito fish into certain areas. Some states also might require permits for the release of these organisms.

Mosquito Control and the Construction Review Process

Cooperation and collaboration among various city and county departments are crucial in minimizing vector production from BMPs. By reviewing BMPs before implementation and by monitoring them after installation, the risk to public health from vectors can be decreased. Because the Watershed Protection Department staff is familiar with issues of vector control, members can request stormwater design modifications that will minimize the potential for producing vector breeding habitats.

The Watershed Protection Department staff also is involved in the acceptance of stormwater pollution prevention plans (SWPPPs) for projects within the city. Although the general permit to discharge stormwater within the state of Texas does not address the issue of mosquito control, the Texas Health and Safety Code specifically states that a collection of water in which mosquitoes are breeding in the limits of a municipality is not allowed (§341.011). Other states have similar codes. For Denton, the Texas Health and Safety Code is reinforced at the local level through ordinances and is used as justification for requiring mosquito control within the SWPPP review process. If a city believes mosquito control is an issue on a particular project, it can request the permittee to add mosquito control measures to the SWPPP. In these situations, most of the requested SWPPP activities involve source reduction.

Public Education and Citizen Involvement Efforts

A common misperception among citizens is that distant water bodies are contributing to local mosquito densities. Although some species of mosquitoes are strong fliers capable of many-mile flights, most mosquito species collected in Denton’s trapping operations are considered weak fliers. For Denton, as for many areas of the southern US, the mosquito species that represents the greatest risk for WNV transmission is the Southern house mosquito, *Culex quinquefasciatus*. Because this mosquito has an average flight range of approximately 0.5 mi. from its breeding habitat, it is crucial to inform the public of the importance of eliminating local mosquito habitats and treating local, private sources of water for larval control.

The City of Denton encourages active citizen participation in localized control and provides Bti materials free of charge to all citizens aiding in local private-property larviciding activities. This program has been a great success and has fostered a sense of partnership among citizens and city staff. Citizen phone calls have also proven to be a very useful source of information for Denton staff. Although the number of calls can become overwhelming during the peak of the mosquito season, they provide useful information regarding the density of localized mosquito populations, the presence of dead birds, and the notification of potential mosquito breeding habitats.

Public information distributed by the city directs citizens to the Watershed Protection Program staff for mosquito-related issues. Because the program staff is familiar with the city's stormwater infrastructure and mosquito surveillance plan, this process has been very efficient in determining the relationship between the mosquito problem and stormwater systems. If the problem seems to be related to a component of the stormwater infrastructure, city staff will conduct a site visit and perform source reduction, vegetation maintenance, or larviciding activities. If the problem does not seem to be related to the stormwater system, the staff will provide information on how citizens can minimize mosquito populations around the home. If many complaints are received from a single area, workshops on mosquito control may be conducted through neighborhood organizations. The city's Public Information Office distributes additional information, including fliers, newspaper ads, notices in public buildings, and public service announcements on local cable channels. This approach has proven to be an efficient way to convey information to a large number of citizens.

Poorly designed culvert and eroded area with standing water likely to produce large amounts of mosquitos

Poorly dsigned underground stormwater junction where hundreds of mosquito larvae were found after a large storm

Maintenance of City Stormwater Facilities

For the most part, wet facilities within the city do not appear to create significant mosquito habitats, as long as the quantity and quality of water is sufficient to maintain sufficient mosquito predators. If inspections reveal the presence of mosquito larvae or a large number of adults, limited treatments of these facilities may be warranted, particularly when excessive plant growth creates isolated areas where mosquitoes can proliferate. In these situations, treatment with granular forms of Bti might be more effective than using briquettes.

For permanent bodies of water, the city takes an active role in vegetation management and might introduce mosquito fish. The goal is to manage emergent vegetation so it does not reach density levels that prevent predators from being able to effectively locate mosquito larvae. In situations where mosquito larvae are present and vegetation removal is impractical or undesirable, granular Bti might be used.

Drainage swales and structures that maintain standing water in sumps or basins have proven to be some of the more problematic areas for mosquito control. Often swales will have some undercutting associated with poorly designed or eroded culverts, which can retain water long after the rest of the swale is dry. Underground stormwater conveyances that retain water can also produce similar habitats. The resulting pockets of water usually are still and highly organic and have minimal mosquito predators. The city's Drainage Department monitors and treats these areas as a part of normal stormwater infrastructure maintenance. Drainage staff are trained to recognize potential breeding sites and mosquito larvae and to appropriately treat these areas. Treatment usually involves either repair of a system malfunction or treatment with Bti or Bs. Maps and records concerning which locations were treated are maintained to make the process more efficient.

Table 2. Mosquito Species Commonly Found in Denton and Control Measures Associated With Stormwater Infrastructure Types

Infrastructure Type	Target Mosquito (General)		Control Measures
Permanent Water	*Anopheles pseudopunctipennis* *Anopheles quadrimaculatus* *Uranotaenia sapphirina*	*Anopheles punctipennis* *Coquillettidia perturbans*	Larviciding via Bti or Bs Possible treatment with mosquito fish
Wetlands	*Anopheles crucians* *Culex quinquefasciatus* *Culex salinarius* *Psorophora ciliata* *Psorophora howardii*	*Culex coronator* *Culex restuans* *Culex tarsalis* *Psorophora ferox*	Vegetation management Larviciding via Bti or Bs Possible treatment with mosquito fish
Temporary or Floodwater	*Aedes vexans* *Psorophora columbiae* *Psorophora longipalpis*	*Ochlerotatus trivittatus* *Psorophora cyanescens* *Psorophora signipennis*	Source reduction Vegetation management Treatment with Bti or Bs
Artificial Containers and Tree Holes	*Aedes aegypti* *Ochlerotatus [illegible]* *Anopheles crucians* *Culex quinquefasciatus* *Culex salinarius* *Psorophora ciliata* *Psorophora howardii*	*Aedes albopictus* *Ochlerotatus triseriatus* *Culex coronator* *Culex restuans* *Culex tarsalis* *Psorophora ferox*	Public education for source reduction Treatment using Bti or Bs

Table 2 summarizes some of the common mosquito species in Denton, their respective stormwater habitats, and control measures used for particular types of stormwater controls.

Regulatory Requirements of Larvicide Applications

Stormwater managers not only must face the regulatory requirements of NPDES, but if they become involved with mosquito control they also need to understand the regulatory requirements for vector control agents. Although Bti and Bs are both bacterial agents, they are listed by EPA as registered pesticides. From a regulatory standpoint, therefore, most states treat them no differently than chemical agents. Typically, municipal pesticide applicators have to obtain a noncommercial applicator's license in vector control from the appropriate state agency to legally apply mosquito pesticides. The licensed applicator then can provide a relatively extensive training program for nonlicensed individuals to work under the applicator's license.

Some states do not require extensive training for the application of certain types of pesticides. The Illinois State Department of Agriculture, for example, enacted an emergency rulemaking provision on August 16, 2002, to allow individuals who have been trained for at least one hour by a licensed mosquito applicator to apply Bti and Altosid products (products containing the insect-growth regulator methoprene) during certain times of the year. The training must cover pesticide labels, use restrictions, application rates, application methods, and any other information the trainer feels is appropriate for the safe and effective use of insecticides.

Critical Review of the Program

Mosquito control programs realistically cannot eliminate mosquitoes entirely; rather, they serve to reduce numbers and thus the risk of disease transmission. For situations that warrant control measures, it is more efficient to control mosquitoes where they are produced as larva than to attempt to control adult populations through spraying programs. It also is important to realize that public perception is a critical part of both stormwater control and mosquito management. Public education efforts should strive to demonstrate how a properly maintained and treated stormwater BMP can actually work to reduce mosquito populations. Areas that appear to be good larval habitats will attract laying adults, which will deposit their eggs in the area. If proper maintenance and/or treatment activities are performed, however, the chance of the eggs developing into biting adults is greatly reduced. This is not the case in habitats where there are no predators and where no treatments or other management activities are performed.

West Nile virus usually becomes a more pronounced human health issue in late summer or early fall, when mosquito populations are larger and the number of infected mosquitoes increases (see Figures 2 and 3). The best time to prevent problems, however, is earlier in the season, when source reduction and larviciding can be effectively employed. If your community is at risk for WNV, start these programs early and maintain a consistent effort throughout the mosquito season. Coordinated source reduction and larviciding efforts involving cooperation among stormwater managers, municipal staff, county agents, citizens, and businesses are likely the best approach in an urban setting. As with many municipal issues, vector control is a problem shared by many different entities and will likely require a concerted effort to reach an acceptable resolution. Through cooperation among multiple city departments and public health agencies, the City of Denton has made substantial progress toward accomplishing the dual goal of protecting water quality and human health.

Addressing the threat of an emerging infectious disease like WNV depends on sustained and coordinated efforts of many parties. Undoubtedly the control of WNV depends on establishing and maintaining effective integrated pest management control systems; however, collaboration among state and local health departments, academic centers, city staff, and citizens is also crucial for program success. A strong and flexible plan involving all of these partners is the best defense against WNV outbreak or other vector-borne illnesses that might result from stormwater BMPs.

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Guest Editorial

Mosquitoes, West Nile Virus, and Stormwater

by Edward McGowan

In reviewing some of my medical journals, I found that subjects relating to the mosquito-borne West Nile virus (WNV) and other emerging diseases are cropping up more and more frequently. Although WNV appeared in the US only a little more than four years ago, clinicians are now being alerted to the possibility of having to diagnose this viral infection in their patients.

The virus was first identified in Uganda during the late 1930s and was later noted in epidemic proportions in Eastern Europe, circa the 1990s. It was not noted in America, however, until the heat wave and consequent drought of 1999. By 2002, again during hot, dry summer conditions, it had spread from the wetlands of New York across the US to 44 states, to the District of Columbia, and to five Canadian provinces. On October 9, 2003, the state health director announced the first probable human case of WNV in California.

During 2003, the total number of human cases exceeded 6,500, causing hundreds of deaths. Despite these mortality statistics, recovery from the disease is not without its serious consequences.

Additionally, once the virus settles into an area, other routes can spread it. There is concern over transmission through blood products, organ transplants, the placenta in utero, and breast milk.

The virus is capable of jumping species barriers. Currently it has spread to at least 230 species of animals, of which 130 are birds.

Death among wildlife and livestock or pets, including horses, is an area where few accurate statistics are kept; nonetheless, these numbers are presumed large. The virus is carried over large distances by migrating birds infected by Asian tiger or Culex mosquito bites. Once the virus is introduced into an area, local mosquitoes distribute it among the local nonmigrating bird population. These nonmigrating birds are then monitored along with sentinel (marker) hosts, such as caged chickens, to help track the spread. Crows and jays are particularly populous in the urban environment and are highly susceptible to WNV, and locating dead crows or jays is one way to track the disease. However, the virus has been detected in other wild birds, which are fed upon by other mosquito species.

Public health experts indicate that active surveillance of susceptible animal and bird populations is the first line of defense, along with control of standing water bodies that could provide breeding areas for the mosquito. In many ways, we are lucky that smaller jurisdictions have been required to develop stormwater plans, but even if such plans were not requisite, small jurisdictions should be aware that stormwater can supply excellent habitat for the mosquitoes as vectors of disease.

Mosquitoes are strong flyers but also can be moved long distances on winds. Accordingly, no jurisdiction is exempt from the virus. The mated but unfed female, capable of overwintering in a hibernating state, normally lives for about two weeks before being eaten by predators, but the lucky can survive for two to three months. Most mosquitoes, both males and females, are nectar feeders, but the female also needs a protein-rich blood meal for egg development.

For the two main vectors of WNV, Asian tiger and Culex (of which there are at least three important species), the female mosquitoes prefer to lay eggs on aged, stagnant, or putrid water—

that is, the type often found at the outlet of stormwater drains. A single pool can generate tens of thousands of mosquitoes, as mosquitoes can produce numerous generations within one season.

The eggs can be washed into other water bodies by rain or merely by yard irrigation or other washings that find street drains. When the eggs hatch after about two weeks, the adult mosquitoes are ready to fly, feed on birds and other intermediate hosts, pick up the virus, and feed on unsuspecting human or livestock hosts. Thus, the cycle is repeated.

WNV has also been found in several species of floodwater mosquitoes, common in meadowlands, woodland pools, floodplains, and marshes. Again, these are areas receiving upland drainage, which often is nothing more than drain and wash water of municipal origin. During droughts or dry seasons, these waters also may be the sole source of drinking water for bird and animal hosts on which the mosquitoes feed. As a result, there is a tight circular multiplication among vector, virus, and animal-bird hosts that amplifies the viral risk to humans of the area.

The Asian tiger mosquito actively feeds throughout the daylight hours. It is also the vector for dengue fever, which in its hemorrhagic form is highly destructive. In contrast, the Culex mosquito bites from dusk to dawn and is also a vector for St. Louis encephalitis.

Because of its particular behavior, the Asian tiger is one of the most difficult mosquitoes to avoid. Indeed, the all-day feeding habits of the Asian tiger mosquito increase the risk of spreading West Nile virus; as the disease becomes established in an area, however, other local mosquito species may, as previously mentioned, become vectors.

Since both the Asian tiger and Culex mosquitoes prefer a stagnant-water habitat, they have a distinct competitive and survival advantage over other species that require cleaner water. Thus, stormwater plans need to examine this issue from several perspectives.

Edward McGowan has a degree in medicine and a doctorate related to water-quality control. He was the US Agency for International Development regional environmental officer for the eastern and southern half of Africa, an area covering 22 nations. In that capacity, he interacted with numerous governments, various United Nations agencies, WHO, US Department of Agriculture, USEPA, international donors, and US Foreign Service staff on issues of water quality and public health.

***Stormwater* - January/February 2003 - http://www.forester.net/sw_0301_letters.html**

Letters to the Editor

Surface Hydrocarbons vs Mosquito Control

Editor:

Stormwater BMPs as a source for vectors is not a new issue (March/April 2002 Stormwater, "The Dark Side of Stormwater Runoff Management: Disease Vectors Associated With Structural BMPs" and "Stormwater, BMPs, and Vectors"). It has been suggested that because of the accumulation of hydrocarbons (e.g., motor oil, ethylene glycol, gasoline) in BMPs, standing water would be rendered unsuitable for larvae. The hydrocarbon film would prevent the larvae from being able to breath through specialized mouth parts. Is this true? How much oil is adequate? Was this observed during your survey of any of the BMPs?

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Two of the coauthors of the articles respond:

As a general rule, the accumulation of hydrocarbons on the surface of standing water in BMPs does not provide reliable mosquito prevention. However, to best answer this question, we first need to review some basic mosquito biology.

The life cycle of mosquitoes involves a process known as complete metamorphosis. This describes a process of dramatic change from egg to immature (larvae and pupae) to adult, where the immature stages do not even remotely resemble the adult stage. Perhaps the most well-known complete metamorphosis occurs in butterflies and moths when they change from eggs to caterpillars to winged adults. A pupal stage occurs between the larval and adult stages during which changes in physiology and morphology take place. When complete, adults emerge from the pupal skin and carry on life as sexually mature insects.

Although best known for the females' need to feed on blood, mosquitoes spend most of their life as wingless immatures. Adult female mosquitoes lay their eggs in carefully selected locations either on the surface of standing water or in areas subject to flooding. After they hatch, the immature stages (larvae and pupae) are completely reliant on water. Larvae feed on microorganisms and organic material in the water and eventually develop into pupae, which are also aquatic but do not feed. Adults then emerge from the pupal skin onto the water surface from where they take flight, mate, and start the cycle over again. There are currently 176 recognized species of mosquitoes in the United States. Each has a preferred or specific habitat type.

Aquatic stages of nearly all species of mosquitoes breathe atmospheric air through specialized body structures called "siphons" in larvae and "trumpets" in pupae. These breathing structures function much like a diver's snorkel: They are essentially hollow tubes that work by breaking the surface tension of the water and allowing air to enter the body. This is one of the main reasons mosquitoes require relatively tranquil standing-water habitats. Wave action, turbulence, or significant currents prevent mosquitoes from maintaining a connection with the water surface to breathe. This critical water-to-air connection needed by immature mosquitoes was recognized early on by mosquito control experts as a vulnerability that could be used in integrated control efforts. Hydrocarbon surface films, such as kerosene, were found to interfere with the immature mosquitoes' ability to connect with the water surface, causing them to drown. There are several commercially available materials used today for professional mosquito control that work on this basic principle; one is a petroleum oil-based material and the other is classified as a monomolecular film.

However, oils that accumulate in sumps, catch basins, and vaults of BMP devices do not provide reliable mosquito prevention. Oily sheens present on the water surface are rarely uniform and usually contain a multitude of “breaks” through which mosquito larvae can access surface air. The La Brea Tar Pits, in western Los Angeles County, form natural ponds that produce mosquitoes despite the fact that crude oils seep into them from belowground sources. Likewise, oil-contaminated wastewater sumps in oil fields are often major mosquito breeding sources. Manmade habitats in storm sewer systems including catch basins and, more recently, in stormwater BMPs also frequently provide usable habitat for certain mosquito species despite the presence of oils. Unfortunately, the mosquitoes most likely to utilize “dirty water” are in the genus Culex and are both public nuisances and competent vectors of viruses, including St. Louis encephalitis and West Nile virus.

It should be concluded, then, that although “runoff-derived” hydrocarbon accumulations in stormwater BMPs, sumps, and other structures might occasionally inhibit or even prevent mosquito breeding from taking place, the efficacy of such accumulations in preventing breeding cannot be relied upon with any degree of confidence. Our research studies in southern California clearly support this, as mosquitoes are detected regularly in BMP devices that hold oil-contaminated urban water runoff. We are not aware of any public health or vector control agencies that rely upon these kinds of accumulations to inhibit mosquito production.

Stormwater BMPs, especially those that hold permanent sources of standing water by design, pose a difficult challenge for public health officials and vector control agencies. We feel very strongly that the best solution to the problem of mosquito breeding in stormwater structures lies in fostering cooperation between BMP designers, municipal planners, public health officials, and vector control agencies. It is essential that new stormwater BMP designs incorporate features that suppress or prevent vector breeding and harborage. Through creative engineering we might be able to eliminate or deny access to the habitat that mosquitoes and other vectors need from BMPs: standing water. The state or local public health/vector control agency can discuss specific vector issues in your area and provide input and consultation into siting, design, and maintenance of proposed BMPs.

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***Stormwater* March/April 2002 - http://www.forester.net/sw_0203_dark.html**

The Dark Side of Stormwater Runoff Management: Disease Vectors Associated with Structural BMPs

It's difficult to argue against the benefits of cleaner water, but at what cost? Can current approaches potentially make matters worse?

By Marco E. Metzger, Dean F. Messer, Catherine L. Beitia, Charles M. Myers, and Vicki L. Kramer

It's fascinating how our attitudes toward particular issues change over time, sometimes completely shifting direction. These changes are usually a direct result of an increase in awareness and knowledge of a particular subject matter, which in turn influences changes in priorities, values, and opinions. A dramatic and rapid evolution has been occurring with regard to the health of the nation's waters and their surrounding environments over the past half century. There has been increasing awareness of the value of our water resources for a wide variety of reasons, including recreation, aesthetics, critical wildlife habitat, and the important environmental functions they provide.

A significant portion of recovery and mitigation plans promulgated by the enforcement of the Clean Water Act requires massive reductions in the quantity of pollutants and sediments that enter receiving waters. One of the primary strategies being used to achieve these goals is the use of structural, nonstructural, and managerial techniques, or best management practices (BMPs), recognized to be the "most effective and practical means" of reducing water contamination while still allowing the productive use of resources. Unfortunately, the strategies to achieve clean-water goals are extensive and complex and have many obstacles.

One issue associated with modern water-related programs that has not received much attention until recently is the potential public health risk created by the use of certain BMPs. If not designed and managed properly, restored or created wetland habitats and pollution- and flood-control devices can provide abundant habitat for the propagation of mosquitoes and other vectors within major urban areas. This is an issue of prime concern because of the existing and widespread presence of endemic vector-borne diseases and the continual invasion of exotic vectors and pathogens. In addition, we have entered an era in which most of the pesticides that once provided us with protection from these disease-transmitting organisms have either become ineffective or are being removed from use through litigation and legislation. Statistically, as vector populations increase, so does the risk of disease transmission.

So, What the Heck Are Vectors?

When they hear talk of "vectors," many people think of physics. Broadly defined, a vector is a quantity that has magnitude and direction and that is commonly represented by a directed line segment whose length represents the magnitude and whose orientation in space represents the direction. When used in biological terms, however, a vector refers to any organism that can transmit an infectious disease pathogen to another organism. As in physics, the vector and its associated pathogens also have magnitude and direction. The ability of the vector to transmit disease is analogous to magnitude, whereas the disease pathogen travels in a direction, represented by a line, from the vector to a new organism. Infections acquired from vectors are referred to as vector-borne diseases.

Figure 1 shows a typical vector-borne disease cycle: the St. Louis encephalitis (SLE) virus, a common pathogen in the United States. Certain species of mosquitoes can pick up virus particles by biting infected birds and later can transmit them to uninfected birds, maintaining the disease cycle in nature. These birds are generally not harmed by the virus and serve as the disease reservoirs. Unfortunately, infected mosquitoes also bite other animals. In humans, infection with SLE virus can cause a serious and potentially fatal inflammation of the brain.

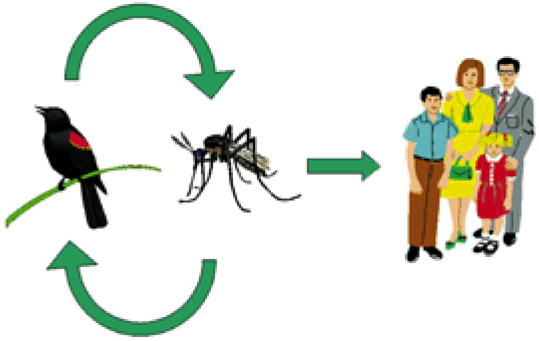

Figure 1. Typical Vector-Borne Disease Cycle (St. Louis encephalitis virus)

Dozens of diseases, many of which are harmful or fatal to humans, are transmitted by hundreds of vector species worldwide. These diseases are caused by a wide variety of pathogens, including viruses (e.g., dengue, yellow fever, West Nile virus), bacteria (e.g., Lyme disease, babesiosis, plague), protozoa (e.g., malaria), and nematodes (e.g., dog heartworm). Vectors that frequently get media attention in the US include mosquitoes, ticks, and fleas.

Mosquitoes are the world's most significant vectors. Diseases transmitted by mosquitoes are responsible for the deaths of millions of people every year. Nonfatal infections can cause severe and debilitating illness that, if widespread, can affect local economies by reducing the number of available people in the work force and increasing the cost of health care. Based on global estimates by the World Health Organization, each year 50 million cases of dengue are diagnosed (24,000 deaths), as are 200,000 cases of yellow fever (30,000 deaths) and 300 million to 500 million cases of malaria (more than 1 million deaths). Fortunately, not all mosquitoes transmit disease; however, some species can become so abundant that they might impact tourism, make residents miserable, and even kill small animals by literally sucking all their blood.

Mosquitoes form a group of extremely successful insects. Approximately 3,000 mosquito species have been described from around the world; the US is home to about 200 of these. Mosquitoes have adapted to practically every conceivable ecological niche, from the tropics to both the Arctic and Antarctic Circles, because of the tremendous variation in the biology and ecology of individual species. One unifying feature of this group is that they all have obligate aquatic larvae and pupae (immature stages); thus, they absolutely must have water to complete their life cycle. We humans also need water for survival (although we don't raise our children in it), and our cities always provide abundant natural and artificial sources of water. As a result, mosquitoes thrive in our communities and surrounding habitats as unwelcome guests. In the US, mosquitoes are undoubtedly the most important urban vectors.

As shown in Figure 2, mosquitoes undergo a complete metamorphosis from aquatic larvae to winged adults. Eggs are laid in or near water, and larvae and pupae are completely aquatic. Larvae feed on microscopic items, such as bacteria, and grow rapidly–eventually becoming pupae. Winged adults emerge from pupae, mate, and begin the cycle again. Only female mosquitoes feed on blood, which is used to provide the nutrients needed for the development of eggs. Males are more short-lived and feed on plant juices. It is because of their need for blood that mosquitoes have caused discomfort, suffering, and death throughout history.

The Unpleasant Relationship Between Mosquitoes and Humans

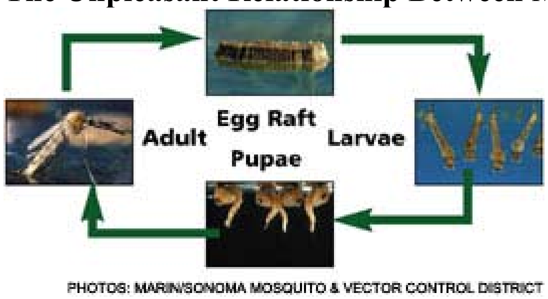

Figure 2. Mosquito Life Cycle

Mosquitoes have played a prominent role in the history of the US, both as pests and carriers of disease. Historically, many coastal regions of the US with salt marshes, swamps, or wetlands were uninhabitable during certain times of the year as a result of the presence of millions of mosquitoes. In addition, outbreaks of such diseases as malaria and yellow fever took a tremendous toll in human suffering and death and occasionally decimated developing cities and local economies. Interestingly, it was not until the very end of the 1800s that the role of mosquitoes, ticks, and other vectors as carriers of infectious diseases was discovered.

The early 1900s brought many changes with regard to public health. Widespread campaigns were implemented to eliminate disease-carrying mosquitoes. In 1910, successful malaria- and mosquito-control programs in California received widespread publicity, and throughout the country civic groups began to improve the overall health of their communities through organized mosquito control. The California state legislature passed the Mosquito Abatement Act of 1915, which allowed communities faced with serious mosquito problems to form their own regional abatement districts separate from other government agencies. Under the act, landowners or those responsible for water sources that supported the development of mosquitoes became responsible for abatement. Mosquito abatement districts had the authority, if necessary, to act on behalf of the district's residents and, following a public hearing, could charge individual landowners for the costs of controlling mosquitoes on their property. The first mosquito-control district was officially launched in northern California in 1915, covering both Marin and Sonoma Counties. Today the state has 51 mosquito- and vector-control districts. In other states, similar scenarios ensued: for example, New Jersey created county mosquito-extermination commissions in 1912, and Florida's first mosquito-control districts were created in 1925.

Early mosquito-control efforts focused on hand-ditching, diking, dredge and fill, and dewatering aquatic habitats to permanently eliminate breeding sources. Thousands of miles of ditches were built to drain salt marshes and other wetland habitats. This land was often converted for agricultural use or provided valuable and desirable real estate for developing towns and cities. Aquatic habitats that remained were periodically inspected and abated for mosquito larvae. Before the discovery of modern pesticides, abating mosquito larvae and pupae (larviciding) was effectively carried out by applying petroleum-based liquids, such as diesel oil and kerosene, to the water surface to create a suffocating oil layer. After World War II, pesticides became available, and DDT (dichlorodiphenyltrichloroethane) quickly became the material of choice for both adult and larval mosquito control. Initial results were good, and many believed this chemical was the answer to mosquito-control problems; however, mosquitoes rapidly developed resistance to DDT and many other closely related insecticides, making their use almost completely ineffective. In the decades that followed, many new classes of insecticides were developed for mosquito control, each with decreasing toxicity to the environment.

It was soon recognized that relying solely on chemicals for mosquito control was doomed to failure. In the 1950s, additional programs targeted permanent control of breeding sites through elimination of more aquatic habitats and the creation of many new mosquito-control programs. By the 1970s, disagreements began to arise among mosquito-control agencies and environmental agencies concerning such mosquito-control practices as wetland elimination. Today modern mosquito control is much more sophisticated. Integrated management practices combine several techniques, including the judicious use of environmentally friendly larvicides, biological control agents such as fish, and well-planned habitat management rather than habitat elimination. As harmful as some of the early ideologies and methodologies might seem to us today, many coastal cities and towns in places such as Florida, New Jersey, the Gulf Coast, and California owe their existence and success in large part to mosquito-control efforts.

The Existing Urban Mosquito Problem

Earlier we mentioned that wetland habitats, flood-control devices, and structural BMPs might provide suitable habitats for the propagation of mosquitoes in and around urban areas if not designed and managed properly; however, this is not to imply that mosquito problems don't already exist. What we must understand is that the construction of new habitats has the potential to make an already bad situation worse.

The urban environment is filled with sources of standing water suitable for mosquito development. Even in arid areas of the Southwest that would normally not support many mosquitoes, humans have created urban oases using imported water and exotic plants. Urban environments provide mosquitoes with a vast array of new habitats: humid and arid, above and below ground, small water-holding containers and large ponds, polluted and clean water. Aquatic habitats are found around people's homes (birdbaths, jars, flower pots, neglected pools and Jacuzzis and clogged rain gutters), in unregulated waste dumps (used tires, barrels, bottles, and cans), in parks (ponds, lakes, and streams), and in the city's own infrastructure (storm drains, sewer systems, catch basins, and culverts). Many of these sources are replenished frequently by stormwater and urban runoff (e.g., irrigation, washing cars). Adding to this, increasingly stringent urban stormwater runoff regulations have recently mandated the construction of structural BMPs for both volume reduction and pollution management, many of which have created additional sources of standing water. This abundance of habitats has favored mosquitoes and allowed many species to greatly expand their range and increase in number.

Aquatic habitats are chosen and utilized by different mosquito species based on many factors, including nutritional requirements of the larvae, egg-laying behavior of adult females, and location. Any source of standing water, however, will usually provide suitable habitat for at least some mosquito species. Unfortunately, opportunistic mosquito species likely to breed in urban sources are often important vectors of human and animal diseases. Many mosquito larvae can develop in extremely shallow water and might even survive short periods of time without water as long as the environment remains moist. Complete development from egg to adult can occur in less than one week, allowing mosquito populations to increase at alarming rates under optimal conditions.

There are two basic groups of mosquitoes that may utilize aquatic habitats in the urban environment: permanent water species and floodwater species. Permanent water species lay their eggs directly on the water surface or on the leaves of aquatic plants. Floodwater species deposit eggs on moist soil or the substrate around aquatic systems, and the eggs hatch only when submerged by rising water levels. These behavioral and biological differences have major impacts on the species that use different manmade structures. For example, floodwater mosquitoes will seldom be attracted to structures, such as retention ponds, that experience minimal or infrequent water-level fluctuations. However, structures such as extended detention basins that frequently fill and empty provide the requirements they need.

Vectors and BMPs: Results of a Nationwide Investigation

In 1998, the California Department of Health Services's Vector-Borne Disease Section (VBDS) entered into an agreement with the California Department of Transportation (Caltrans) to provide technical expertise regarding vector issues within its stormwater BMP Retrofit Pilot Study (described in detail in the March/April 2001 issue of *Stormwater*). As part of the overall pilot study, VBDS conducted a two-year study of vector production associated with the 37 operational stormwater BMP structures in southern California, in collaboration with local vector-control agencies and stormwater management consultants. Before this study, little or no information was available on the actual or potential vectors associated with these kinds of structures. To enhance the study and obtain further information, an extensive nationwide investigation was conducted. The primary objectives were to develop an understanding of the relationship between vectors and stormwater management structures (BMPs) and to gather information on solutions (besides traditional mosquito control using larvicides) used to prevent, reduce, or eliminate vectors from these sites.

More than 150 agencies in 28 states were contacted by phone or mail or visited in person. These included a wide variety of state, county, and municipal agencies representing vastly different interests, such as vector control, public works, transportation, and environmental issues. In addition, contacted agencies were located in areas with dramatically different climates, ecosystems, and population densities. The data collected allowed a preliminary assessment of the potential public health risks from mosquitoes and other vectors associated with stormwater BMPs or BMP-like structures. Few agencies had experience with novel preventative measures against vectors within structures, but many provided important information describing factors that encouraged vector production.

The results of the investigation left no question that a variety of vector species, particularly mosquitoes, utilize the habitats created by stormwater BMP structures throughout the US (Figure 3). For example, of 72 agencies that completed a VBDS questionnaire, 86% reported mosquito production associated with local BMPs. At least six groups (genera) of mosquitoes have been identified, representing several dozen species. Other species, including midges, rodents, black flies, and cockroaches, were also reported from certain stormwater management structures. Midges, nuisance insects that can cause allergy problems in sensitive people, were the most common species breeding in BMP structures, second only to mosquitoes. Unexpected findings from the study included the discovery that in Portland, OR, beaver systematically "reengineer" retention structures to serve their needs rather than allowing them to perform their intended function, and in Florida, "pollutants" collected by stormwater structures sometimes include snakes and alligators.

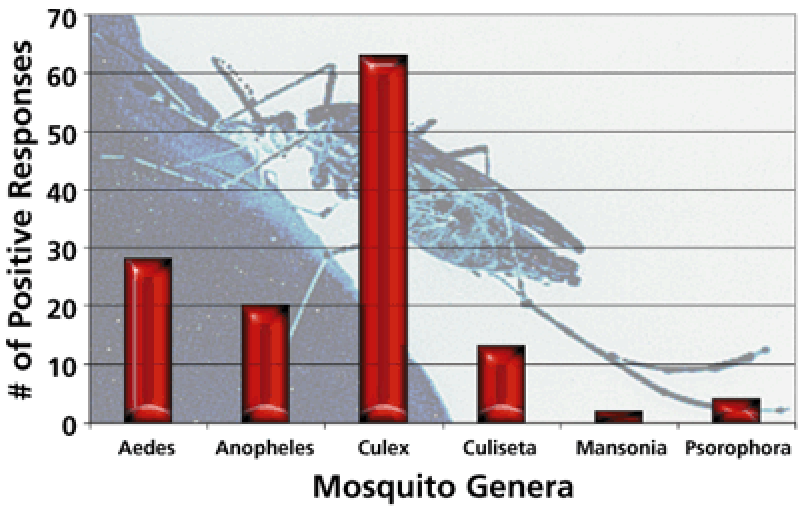

Figure 3. Mosquitoes Associated With Stormwater BMP Structures in the US (based on the responses of 72 agencies)

Overall, a variety of stormwater BMP structures were implicated as significant sources of vectors. Unfortunately, it was impossible to accurately assess the relative importance of one design over another with regard to vector production without detailed studies. However, the mosquito production study conducted in southern California provided data to make a qualitative and quantitative preliminary assessment of vector production within many different stormwater BMP structures.

Vectors and the Caltrans BMP Retrofit Pilot Study

The design of certain Caltrans biofiltration swales included concrete depressions used to house rocks for energy dissipation. These depressions held standing water for weeks and provided suitable habitat for hundreds of mosquito larvae. A workable solution entailed filling the depressions with concrete and embedding the rocks into it. This provided the necessary energy dissipation while eliminating the mosquito habitat. No mosquitoes have been detected at these sites since October 1999.

In 1997, Caltrans began an extensive program plan to retrofit 33 selected facilities with 39 structural BMPs to improve water quality in Los Angeles and San Diego Counties. Eight categories of BMPs were constructed: (1) biofiltration strips and swales; (2) filtration devices (Austin-type and Delaware-type sand media filters, multichambered treatment train sand media filters (MCTT), StormFilter canister filter by Stormwater Management Inc.); (3) extended detention basins; (4) infiltration devices (basins and trenches); (5) continuous deflective separators (CDS) by CDS Technologies Inc.; (6) an oil/water separator; (7) drain-inlet inserts (Fossil Filter by KriStar Enterprises Inc. and Stream Guard by Foss Environmental); and (8) a constructed wetland (retention pond). VBDS coordinated a comprehensive vector surveillance and monitoring study in collaboration with four southern California mosquito- and vector-control agencies and stormwater management consultants to identify which stormwater BMP designs were least conducive to vector production. During the study, modifications to BMP structures were recommended in an attempt to reduce or eliminate their potential to produce or harbor vectors. Weekly monitoring data were used to make short-term assessments regarding the efficacy of the modifications. It was anticipated that the outcome of this study would have significant implications on methods that may be mandated for the proper management of stormwater runoff.

During the two-year study, mosquitoes were the dominant vector species present within Caltrans BMP structures. (Occasionally, presence or evidence of other vector and nuisance species was observed, including rodents, cockroaches, and midges.) Eight mosquito species were found breeding in BMP structures, four of which are known vectors of human disease. Of the eight different BMP technologies implemented by Caltrans, those that maintained permanent sources of standing water in sumps or basins (i.e., MCTT, CDS, and the retention pond) provided excellent habitat for immature mosquitoes and frequently supported large populations relative to other structural designs. In contrast, BMPs designed to drain rapidly (i.e., biofiltration swales and strips, Austin-type sand media filters, infiltration basins and trenches, and extended detention basins) provided less suitable habitats and rarely harbored mosquitoes.

Design Recommendations: Permanent or Temporary Solutions?
Design features and other factors that created suitable habitat for the propagation of vectors within BMPs were addressed, and corrective and/or preventive recommendations for future designs were provided. In addition, factors that inhibited vector surveillance and abatement efforts in and around BMP structures were also addressed. During the two-year study, numerous design features and operational breakdowns resulted in standing water within BMP structures for various lengths of time. Consequently, these habitats were usually found to be supporting mosquito larvae within a few days of accumulating water. Caltrans attempted to resolve the design issues that allowed vector breeding based on recommendations made by VBDS and the local vector-control districts, and it implemented these solutions to many of the BMPs. The short-term evaluation of the "vector-proofing" efforts made by Caltrans to certain BMPs has been promising. Continued monitoring of these structures will determine if these modifications provide permanent or temporary solutions. (See sidebar - "Designing and Building a Better BMP")

Importance of Proper Design and Maintenance

CDS devices have a permanent water sump where trash and debris are separated from incoming stormwater runoff. This belowground habitat was attractive to certain species of mosquitoes and provided suitable habitat for thousands of mosquito larvae. Mosquito-proofing efforts were undertaken that included sealing off all entry points to the sump by using foam seals on lids and fine-mesh nets on the effluent pipe. No mosquitoes have been detected since January 2001.

One of the primary concerns of vector-control personnel is the potential for the progressive decline or maintenance failure of BMP structures over time. Stormwater BMP structures are subject to myriad physical and environmental factors that can contribute to reduced performance or complete failure. Poor performance and failure not only defy the purpose of building these structures, but they also frequently result in sources of standing water that can harbor vectors, particularly mosquitoes. Agencies that contributed to the nationwide BMP/vector study discussed earlier provided information on structures that had been in service for years, sometimes decades. Not surprisingly, one of the primary concerns from engineers and vector-control personnel was irregular maintenance or complete lack of maintenance. Regardless of the reasons for this (public works agencies being understaffed, underfunded, and so on), the lack of emphasis on maintenance resulted in a breakdown in constituent and trash removal efficacy and was a main factor contributing to vector production.

Two main factors contribute to the suitability of BMP structures to produce vectors: design and maintenance. Conceptually, some BMP designs might look and function great on paper but might not be "adaptable" to changing environmental conditions, both short term and long term. In general, any design that includes standing water or requires more than 72 hours to drain will eventually become a source of mosquitoes and other vectors. From years of research and field observations, vector-control personnel throughout the country have found that aquatic habitats that last only three to five days generally do not permit complete development of mosquito larvae. As a result, in California and many other states, the general recommendation has been for structures to drain completely in 72 hours or less. This alone, if applied to all BMPs, could prevent vector production by eliminating the habitat needed by larvae.

Unfortunately, without proper maintenance, even the most "perfect" stormwater BMP designs will eventually degrade and witness a deterioration in pollutant-removal efficiency. Stagnant water that might accumulate in these structures will likely have high concentrations of organic material and be attractive to egg-laying female mosquitoes. These habitats are also usually free of predators. Structural damage over time can reduce BMP performance and create standing water. In addition, the accumulation of vegetation, silt, and debris within structures is inevitable and is the primary reason why they must be maintained to prevent the occurrence of standing water. Emergent vegetation can completely overrun and clog retention ponds that are not deeper than 3-4 ft., and even concrete-lined structures will fill with sediment, providing a matrix for roots of opportunistic plants to grow, which might lead to further clogging. In addition, BMPs built in urban areas usually receive large quantities of nonstormwater runoff (e.g., from landscape irrigation, residential pool cleaning, washing vehicles), which can contribute to vector production by prolonging the occurrence of water within these structures. In general, it is recommended to plan for routine inspections of all BMP structures to prevent the unexpected.

Finally, location and climate must always be taken into consideration when building stormwater BMPs. Rainfall data are important in design, but an understanding of environmental and biological factors of the surrounding area are equally important. A knowledge of basic local biology and ecology will help in designing and building the best BMP for a given location. The presence of certain plants and animals should influence design factors.

Lessons Learned

The multichambered design of MCTT media filter devices prevented all but the last few feet of water to be pumped from the sedimentation chamber to the sand media chamber. The remaining water stagnated for months and provided habitat for tens of thousands of mosquito larvae. The retrofitted cover has been successful in excluding mosquitoes since March 2001.

Trees growing out of this concrete influent channel leading into a large extended detention basin in Austin, TX, indicate that maintenance has not been performed regularly at this site. In addition, the design of the channel allows a permanent pool of standing water to form behind the concrete riser. The combination of stagnant water and vegetation is highly attractive to mosquitoes.

Devices designed to completely dewater are prone to clogging over time if not regularly maintained. This giant Austin-type sand media filter in Austin, TX, was completely clogged. The resulting shallow lake was rich in organic debris and free of predators, providing a perfect mosquito and midge habitat capable of supporting millions of larvae. One of the most important lessons learned from the nationwide study was the recognition of the huge number of agencies nationwide that are involved with some aspect of stormwater runoff management. Based on the size and scope of the many stormwater programs, it is clear that vector issues have yet to be adequately addressed. It is important to realize that the thousands of currently deployed and planned structural BMP devices across the country will provide new breeding habitat for mosquitoes and other vectors. This might result in an increase in the number of local vector species and might provide habitat for exotic species to become established. Several agencies in Maryland, New Jersey, and Virginia reported that the rapid spread of West Nile virus, transmitted by mosquitoes, is causing them to rethink some of their BMP strategies. Even if individual BMP structures produce only a small number of vectors, the cumulative impact from a large number of "small" breeding sites could produce large numbers of vectors and create significant health risks.

The contributions made by participating agencies in this study provided a wealth of information on both BMP structures and their associated vector issues in widely disparate regions of the US. These results leave little doubt that many stormwater management structures can and do provide suitable habitats for vectors, with both local and exotic vector species utilizing them for reproduction. Determining how to best manage vectors in the potentially large number of BMP structures will take time, but will depend largely on the operation and maintenance plans for these structures. Unfortunately, the study clearly demonstrated that these issues have yet to be thoroughly examined. Because of the constant pressure to meet EPA stormwater program deadlines, "crisis management" seems to be the current maintenance paradigm used by many agencies across the country. This is clearly not a suitable long-term solution. Regular and appropriate maintenance is required to both preserve the intended level of BMP performance and reduce or eliminate the production of vectors. Many participating agencies felt it inevitable that some sort of new local stormwater utility agencies must be established to regularly manage and maintain BMPs. It also seems clear that the initial costs of structural BMP construction are insignificant when compared to the large financial burdens necessary to provide the routine maintenance required to keep structures functioning properly over several years or even decades.

To date, few studies have addressed vector issues in artificial habitats created by structural BMPs built specifically for reducing nonpoint-source pollution in stormwater runoff. Results from the two-year study with Caltrans BMP structures indicate that much research remains to be conducted to better satisfy water-quality improvement goals while preventing vector production. The study found that vector production in the Caltrans BMPs was influenced not only by specific design features but also by location, immediate and distant land use, nonstormwater discharges (e.g., irrigation runoff), site maintenance, and various other unexpected events. Therefore, direct comparisons among structures of similar design were difficult. However, general design features that contributed to vector production were identified: (1) the use of sumps, catch basins, or spreader troughs that did not drain completely; (2) the use of loose riprap; (3) pumps or motors designed to "automatically" drain water from structures; and (4) effluent pipes with small-diameter discharge orifices prone to clogging. Data also suggest that BMP structures can support additional vector species as they age and "mature" over time.

Final Thoughts

This concrete-lined extended detention basin in a residential area of Portland, OR, has several serious design flaws. The 1:1 slope around the perimeter of this deep structure makes maintenance access to the bottom difficult. A small frontloader was lowered into the basin at one time using chains, but sediment was only pushed into a corner rather than removed. In addition, water is constantly present because the effluent pipe is located several inches above the invert. As a result, the local vector-control agency must regularly abate this site to prevent severe mosquito production.

Building BMP structures below ground is an alternative solution to large aboveground devices, especially in areas where real estate or space is at a premium. Unfortunately, many species of mosquitoes find and use these habitats. This proprietary BMP device in urban Los Angeles was built at the edge of a large parking lot and covered by a 200-lb.-plus steel cover. The water surface of the permanent sump was 18 ft. below the surface but contained hundreds of developing mosquito larvae. Adult mosquitoes were accessing this source through a hole the size of a nickel in the steel cover.

Managing vectors in stormwater BMPs is an urgent need that must be addressed. Rapid construction and poor interagency communication and cooperation place an increasing burden upon vector-control agencies, most of which have very limited resources. The fact that widely different opinions exist as to which BMP structures are most appropriate to a given application or specific site illustrates that BMPs are probably being constructed at rates exceeding our understanding of the long-term implications of their use. Some agencies are encouraging the use of nonstructural BMPs that provide performance similar to that of structural BMPs while reducing cost and maintenance, though these might not be suitable for all applications.

There is also a pressing need for increased communication and collaboration between agencies interested in promoting water-quality improvement and local and state-level vector-control agencies. Many vector-control agencies have expressed interest in being involved in the design and implementation of stormwater BMPs in their local areas. It seems clear that some structures could have been improved if vector issues had been considered prior to construction. Local and state vector-control personnel should be directly involved in development and implementation of BMPs for the construction and maintenance of economically efficient, biologically acceptable, and environmentally compatible stormwater management structures. Vector-control agencies can provide valuable information on the biology and ecology of the local area and make design recommendations that minimize vector production. This input can help create structures that reduce public health risks with only minimal, if any, decreases in BMP pollutant-removal efficiency. This proactive rather than reactive approach to preventing potential vector problems will ultimately result in cost savings, minimize long-term vector production and associated surveillance and control, and ensure compliance with health and safety codes.


Emergent vegetation such as cattails can rapidly overrun and clog retention ponds and constructed wetlands less than 4 ft. deep. This Caltrans site in San Diego County requires annual clearing of cattails that fill all but the deepest sections of the pond. This maintenance is necessary to reduce vector production and maintain the function of the BMP.

Deposition of silt and debris can result in pools of standing water over time. This is the influent pipe leading from a major freeway interchange into a Caltrans biofiltration swale in Los Angeles County. This debris accumulated over the course of one year.

Currently, stormwater BMP structures are designed with emphasis on minimizing operational oversight and maintenance. For instance, VBDS and local vector-control agencies throughout California currently recommend against the construction of stormwater BMP structures that hold permanent or semipermanent sources of standing water; however, it is understood that some designs require this for water-quality purposes and/or for proper operation. Therefore, it is critical that operation and maintenance protocols that reduce or prevent vector production should be incorporated into operation and maintenance manuals. Adequate funding for plan review, structure maintenance, and vector surveillance and control activities should be secured before BMP construction. Continued cooperation between agencies responsible for construction and/or maintenance of stormwater management structures and vector-control agencies will be needed to ensure that public health is not compromised.

We hope this article provides those working to improve our nation's water quality with an understanding of the potential public health risks associated with aquatic habitats in the US. The benefits of improving water quality cannot be contested; however, in the process of achieving these goals, we should not compromise our own health and safety. The fact remains that certain aquatic habitats support blood-sucking mosquitoes and other vector species that have caused the death of countless millions of people worldwide from the many diseases they transmit. The diseases that we have subdued and eliminated from our country have the potential to become reestablished if we are not cautious with our approach to water and habitat restoration. The addition of thousands of new stormwater management structures could eventually result in vector populations that equal or exceed historical levels.

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Sidebar
Designing and Building a Better BMP

Times are changing rapidly in the field of vector prevention and control. The number of pesticides available for mosquito control are dwindling fast, and biological-control agents (e.g., mosquito fish) often have limited application. Neither approach generally provides a long-term solution. The best solution to minimizing vector production is through prevention, by "engineering them out" of structural devices and enforcing proper and regular maintenance. The following criteria should be considered in the design of all structural BMPs to reduce the probability of mosquito breeding and allow for routine vector surveillance (or abatement if necessary) and maintenance.

Dry Systems

1. Structures should be designed such that they do not hold standing water for more than 72 hours to prevent mosquito development. Provisions to prevent or reduce the possibility of clogged discharge orifices (e.g., debris screens) should be incorporated into the design. The use of weep holes is not recommended due to rapid clogging.

2. The hydraulic grade line of each site should be a primary factor in determining the appropriate BMP that will allow water to flow by gravity through the structure. Pumps are not recommended because they are subject to failure and often require sumps that hold water. Structures that do not require pumping should be favored over those that have this requirement.
3. Designs should avoid the use of loose riprap or concrete depressions that can hold standing water.
4. Distribution piping and containment basins should be designed with adequate slopes to drain fully and prevent standing water. The design slope should take into consideration buildup of sediment between maintenance periods.
5. The use of barriers or diversions that results in standing water should be avoided.

Systems With Sumps or Basins

1. Structures designed with sumps or basins that retain water permanently or longer than 72 hours (e.g., CDS, Delaware-type sand media filters) should be sealed completely to prevent entry of adult mosquitoes. Adult female mosquitoes can use openings as small as 1/16 in. to access water for egg laying. Screening can be used to exclude mosquitoes but is subject to damage and is not a method of choice.
2. Structures should be designed with the appropriate pumping, piping, valves, or other necessary equipment to allow for easy dewatering of the unit if necessary.
3. If the sump or basin is completely sealed, with the exception of the inlet and outlet, the inlet and outlet should be fully submerged to reduce the available surface area of water for mosquitoes to lay eggs (female mosquitoes can fly through pipes).

Permanent Ponds

1. Permanent ponds should maintain water quality sufficient to support surface-feeding fish such as mosquito fish (*Gambusia affinis*), which feed on mosquito larvae.
2. Permanent pond shorelines should be accessible to both maintenance and vector-control crews for (1) periodic maintenance and/or control of emergent and pond-edge vegetation and (2) routine monitoring of mosquito immatures and abatement procedures if necessary. Emergent plant density should be controlled so that mosquito predators are not inhibited or excluded from pond edges (i.e., fish should be able to swim between plant bases).
3. If possible, permanent ponds should be maintained with depths in excess of 4 ft. to preclude invasive emergent vegetation such as cattails. Emergent vegetation provides mosquito larvae with refuge from predators and increases nutrient availability. The pond edges below the water surface should be as steep as practicable and uniform to discourage dense plant growth and reduce favorable mosquito habitat.
4. Concrete or liners should be used in areas where vegetation is not necessary to prevent unwanted plant growth.
5. Permanent ponds should be designed to allow for easy dewatering of the basin when needed.

General-Access Requirements

1. All BMP structures should be easily and safely accessible, without the need for special requirements (e.g., Occupational Safety & Health Administration requirements for "confined space"). This will allow vector-control personnel to effectively monitor and, if necessary, abate vectors.
2. If covers are used, the design should include spring-loaded or lightweight access hatches that can be opened easily. Covers should seal completely.
3. All-weather road access (with provisions for turning a full-size work vehicle) should be provided along at least one side of large aboveground BMPs that are less than 7 m wide.

BMPs that have shoreline-to-shoreline distances in excess of 7 m should have a perimeter road for access to both sides. (Mosquito larvicides are applied with handheld equipment at small sites and with backpack or truck-mounted high-pressure sprayers at large sites. The effective swath width of most backpack or truck-mounted larvicide sprayers is approximately 7 m on a windless day.)

4. Access roads should be built as close to the shoreline as possible. It is important to not have vegetation or other obstacles between the access road and the BMP that might obstruct the path of larvicides to the water.
5. Vegetation should be controlled (removal, thinning, or mowing) periodically to prevent access barriers.

***Stormwater* March/April 2002 - http://www.forester.net/sw_0203_editorial.html**

Editor's Comments

More Than One Risk From Mosquitoes

By Janice Kaspersen

Here's a question that's soon to be important for urban planners and BMP designers: Do some stormwater BMPs provide ideal breeding habitats for mosquitoes that can transmit human disease? (The answer is yes, according to a recent national study carried out by the California Department of Health Services and reported on page 24 of this issue.) Even if the risk seems small now, what happens when these structures and devices become more prevalent in urban areas?

Fortunately, changes in BMP design and improved maintenance procedures can help eliminate the risks. Public health agencies are available to work with stormwater managers on such issues as design and siting of BMPs and monitoring of existing structures to see if improvements are needed. With some slight modifications and careful planning, the problem is surmountable. But the mosquitoes are carrying another threat, not to public health but to public perception.

Thee years ago, attention was focused on the West Nile virus. The mosquito-transmitted, sometimes-fatal, encephalitis-causing virus was found for the first time in the US in the summer of 1999. Dozens of people on the East Coast were infected, and the virus was responsible for at least seven human deaths in the New York City area. People panicked; the New York City Department of Health set up a 24-hour line to answer questions and quell fears.

In terms of the number of people so far affected in the US, the West Nile virus is a relatively small problem; by comparison, about 20,000 people die in the US each year as a result of the flu. As public health agencies and vector-control specialists point out, it's not the comparatively rare and exotic diseases that pose the greatest danger but, rather, the ubiquitous problems that, through years of effort, have been carefully controlled, such as malaria and St. Louis encephalitis. As a frightening and news-garnering issue, however, the West Nile virus has greater impact: We're afraid of–and inherently interested in–the new and the unknown.

Those who design and place BMPs, and the municipalities who rely on those BMPs to achieve water-quality standards, should be aware of–and should be seen to be taking steps to prevent–the "mosquito problem" for two reasons. First, of course, an outbreak of a mosquito-related disease could be costly in both dollars and detriment to human health. Second, if the outbreak can be linked, even tenuously, to a stormwater management practice, the costs in terms of public perception of stormwater treatment efforts–so vital in these days of NPDES Phase II compliance and achieved in many communities with such effort–would be extremely high as well. BMP designers and their clients might even face liability suits. We could all easily end up in the spotlight for exactly the wrong reasons.

Manufacturers of stormwater treatment systems that have been identified as potential standing-water breeding grounds for mosquitoes have actively participated in finding solutions–some surprisingly easy, such as sealing potential entry points to an underground unit–and we applaud their rapid efforts to fix the problem. *All* manufacturers should now be addressing the issue–ensuring their systems pose no risk and publicizing the fact that they do not–not only for the sake of public safety, but also for the sake of the stormwater industry and the progress made so far.

It can take a stormwater utility or public education program months of effort to work its way into the public consciousness by mounting ad campaigns and stuffing educational fliers into utility bills. A single headline ("Killer Insects Lurking in Stormwater Treatment Pond") will do more to fix stormwater efforts indelibly in the public mind than all the previous months of work and will place there an image much harder to erase.

http://www.forester.net/sw_0203_stormwater.html

Stormwater, BMPs, and Vectors: The Impact of New BMP Construction on Local Public Health Agencies

How will new BMPs affect those responsible for maintaining them? A look at the situation from the public health agency point of view.

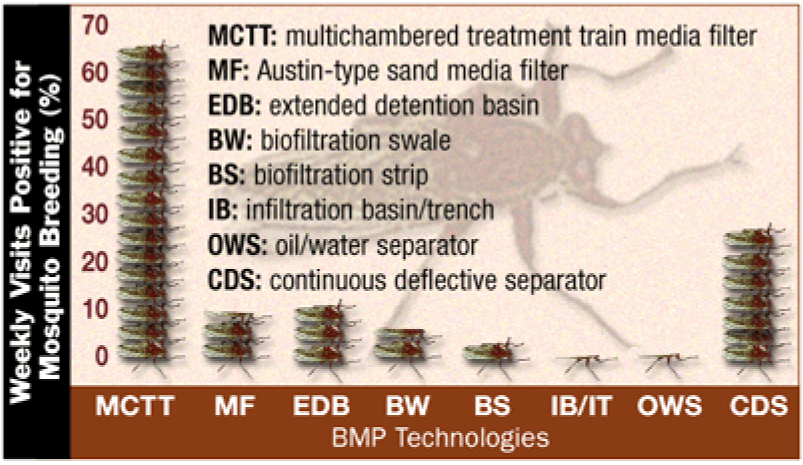
By Susanne Kluh, Marco E. Metzger, Dean F. Messer, Jack E. Hazelrigg, and Minoo B. Madon

Public health agencies in the United States provide a broad range of services, with one unifying feature: protecting the health of the American people. Human health hazards come in many forms, but diseases transmitted by mosquitoes are among the most significant causes of human death and suffering around the world. Millions of people are affected by mosquito-borne illnesses each year, and it is because of this that the control of mosquitoes in the US is not taken lightly. As a result, almost anywhere you choose to live within the US, chances are there is a local public health agency near you that is responsible for the control of mosquitoes and other vectors. In some cases, a division of the city or county health department may administer a vector-control program; or perhaps an independent special district, such as Greater Los Angeles County Vector Control District (GLACVCD), is watching over your health by protecting you from vector-borne diseases. Ultimately, the goal of these programs and special agencies is to suppress vector populations using currently acceptable surveillance, management, and control techniques to break the cycle of disease transmission.

Vector-control services provided by local public health agencies are essentially an extension of your health coverage. These agencies employ a proactive approach to disease management rather than merely responding to a disease outbreak. Unfortunately, providing successful vector-control services often leads local residents to believe that there are no vector problems in their neighborhood. As a result, many vector-control agencies become victims of their own success. An excellent example of this is New York City. Two decades ago the city had a vector-control program in place, but because mosquito numbers were kept low and mosquito-borne diseases did not occur, local officials decided that the program was expendable and therefore discontinued funding. Twenty years later, a disease agent known as West Nile virus, never before present in the US, found its way into New York City. There, the disease spread rapidly by means of a thriving population of mosquitoes fully capable of transmitting it among humans, birds, and horses. This erroneous decision resulted in a widespread epidemic (67 human cases, including seven fatalities).

Mosquito- and Vector-Control Programs in the US

Figure 1.

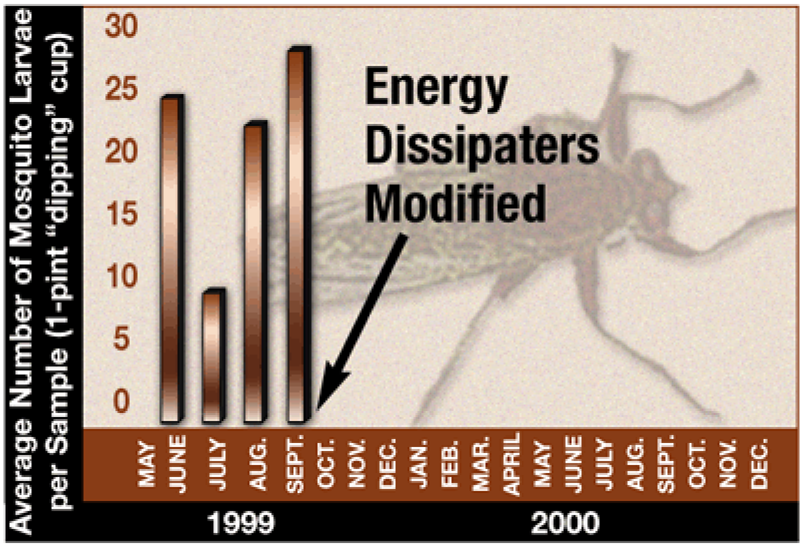


Public health agencies in the US are organized at several levels of government and specialization. At the federal level, the US Public Health Service's Centers for Disease Control and Prevention (CDC) is the agency that oversees and provides consultation, surveillance, and epidemiological investigations (in conjunction with local agencies) on vector-borne diseases nationwide, as well as on exotic vectors and vector-borne diseases that might be imported into the US. Each state generally has its own agency that conducts similar functions as the CDC at the statewide level. Finally, at the local level, mosquito- and vector-control programs and special districts conduct the routine vector-borne disease and nuisance vector surveillance, management, and control functions.

Local public health agencies across the country function in accordance with local and state legislation, but they generally share many similarities. For example, in California most mosquito- and vector-control programs are organized into local governmental agencies known as independent special districts, meaning they are separate, autonomous agencies, accountable only to their local constituents; they have been created by election or by public petition out of need for a special service. Most are also nonenterprise districts, which means they provide specialized services that benefit one or more communities (not just individual citizens) without imposing user fees. To raise revenue, they are permitted by law to implement one or more communitywide property tax mechanisms, including *ad valorem* and/or benefit assessment. A board of trustees, who serve without compensation, performs governance and policy making of a mosquito- and vector-control district. By law, a trustee must be an elector from an area (city or county) within the district and is appointed by city council or county board of supervisors for a two- to four-year term; a district is required to have a minimum five-member board of trustees. Districts comprising four or fewer cities have one or more trustees appointed by the county board of supervisors. All mosquito- and vector-control districts in California derive their formation, enabling, organization, and authoritative powers from state law: the state's Health and Safety Code.

Effect of New Stormwater Regulations on Local Public Health Agencies

Figure 2.



Mosquito breeding at a biofiltration swale before and after modifying the riprap energy dissipaters to prevent accumulation of standing water

With the requirement of structural best management practices (BMPs) designed to mitigate pollutants in urban runoff, local public health agencies are bracing themselves for an increased workload. Urban and industrial areas throughout the US are already plagued by numerous manmade and natural mosquito-producing habitats. Breeding habitats in residential areas, flood-control channels, catch basins, and underground storm drain systems are regularly monitored and controlled for mosquitoes. Increased international travel, as well as growing national and international commerce, provided avenues for importation of exotic vectors and the diseases they transmit; this ensures the need for vector-control programs and special districts to continually monitor for public health vectors. To cope with the expected increase in habitats conducive to vector production as a result of BMP implementation, public health agencies will have to establish working relationships with stormwater engineers and seek increased funding. Strategies to achieve these goals are being considered and implemented by many public health agencies as you read this.

GLACVCD recently had an opportunity to experience the potential impact that BMP structures could have on day-to-day operations. In 1999, GLACVCD became involved in a study spearheaded by the California Department of Transportation (Caltrans). This study had many objectives, one of which focused on vectors associated with selected BMPs. The latter part of the study was conducted in collaboration with the California Department of Health Services's Vector-Borne Disease Section (VBDS), three other southern California vector-control agencies, and stormwater management consultants. (See the related article in this issue with details of the study results.) The role of GLACVCD was to conduct weekly vector monitoring and control services for 16 operational stormwater BMP structures, representing eight different technologies, built within district boundaries. Data collected during a two-year period (May 1999—April 2001) were used to make a preliminary assessment of vector production potential, design and maintenance recommendations to minimize vector breeding, and estimates of vector-control costs.

Many of the BMP technologies employed in the Caltrans study were found to breed mosquitoes at some point during this study (Figure 1). BMPs that held permanent standing water as a result of their design (i.e., multichambered treatment train media filter devices) produced mosquitoes most frequently. Other designs, such as Austin-type sand media filters, only occasionally held standing water suitable for mosquito breeding, often as a result of clogging or mechanical failures (i.e., malfunctioning sump pumps). During the study, GLACVCD and other agencies recommended design modifications and "mosquito proofing" that made a significant impact on the number of mosquitoes breeding in modified structures. For example, biofiltration swales, which initially provided mosquito habitat within riprap energy dissipaters, were modified to prevent water ponding. Figure 2 illustrates the dramatic results these changes had on the suitability of these structures to produce mosquitoes.

The results of the study clearly indicate that proper design and construction, in conjunction with routine quality maintenance, have a significant impact on vector habitat and subsequent vector breeding within BMP structures. One of the most important design considerations is minimizing water accumulation and retention (water-retention periods not exceeding 72 hours) to achieve mosquito control. However, the study also showed that other problems, such as improper sloping in settling basins and sump-outlet drains placed higher than the invert of the inlet pipe, might allow mosquitoes to breed. Significant consideration should also be given to the possibility of nonstormwater runoff (i.e., irrigation, vehicle washing, and spills) collecting within BMP structures, particularly in urban areas. For example, BMPs built within housing developments might hold standing water suitable for mosquito breeding far longer than intended by design (more than 72 hours) because of frequent replenishment from irrigation runoff.

Conclusions

Those involved in BMP implementation, operation, and maintenance have many responsibilities that need to be addressed, reaching far beyond simply trying to comply with new urban runoff regulations. Some structural BMPs create potential dangers inherent in their design or location. Deep wells, vaults, basins, and ponds can be dangerous to those who are unaware of their presence (both children and adults), as well as to those involved in cleaning and maintaining these structures. BMPs that collect trash or hold standing water might provide habitat for rats and mice and might also produce vectors. Eventually, stormwater engineers, public works and transportation agencies, and other BMP owners will have to face these issues. To prevent vector production, they will have to interact with local public health agencies to achieve a solution.

By involving local public health agencies in the BMP design, construction, and maintenance process, including monitoring for vectors and vector habitat, public works and transportation agencies can ensure that these installations will not contribute to creating additional habitat suitable for breeding vectors. Maintaining these partnerships will also allow new BMP designs and new deployments to be comprehensively assessed for both their water-quality improvement and their potential public health hazard. Such monitoring efforts should take into account even BMP designs that have shown little propensity for vector breeding, since designs that might be a minor problem in one region could prove to be a major problem at a different location because of varying environmental conditions. For example, local irrigation runoff can significantly alter the expected function of a BMP by providing an unexpected and often continuous influx of water.

It seems clear that vector-control agency involvement should be considered for a variety of reasons. At a minimum, public works agencies should consider monitoring newly constructed BMPs for vector production. The following guidelines are recommended:

- Monitoring should take place for at least the first year of deployment on all new BMP structures, particularly those that are new or untested designs.
- Monitoring should be undertaken for the entire pilot deployment of any proprietary devices that might hold permanent pools of water.
- Monitoring should be undertaken when existing BMPs are retrofitted or substantially modified in some manner.

We all want to live in an ecologically sound and healthy environment. Improving our water quality will significantly contribute to enhancing our marine and freshwater environments. However, though water cleanup enhances public health to a certain extent, diminishing the public's safety from vector-borne disease should not be countenanced. Intensive cooperation between stormwater engineers and public health agencies should lead to an acceptable compromise between clean water and a healthy populace.

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Sidebar

Benefiting From Local Public Agencies

The holistic approach to urban stormwater-quality management now being embraced often fails to take into account the effects of various stormwater improvement devices upon overall public health. However, considering the multitude of BMP structures that will have to be put in place under the new standard urban stormwater mitigation plan regulations, this can no longer be the case. Therefore, it is advisable that consultation regarding potential public health concerns should be sought during the design process.

How can local public works and transportation agencies best interact with local public health agencies?

- Investigate which local public health agency (city-/county-administered program or independent vector-control district) is responsible for vector control in your jurisdiction.
- Contact those agencies and define the guidelines under which public health officials should be consulted regarding your project.
- Form an interagency advisory committee that considers design and site selection before implementation of new structures.

How can local public health agencies help?

- Their extensive knowledge of biology and ecology of various disease vectors will be useful during design plan review. They might be able to detect factors conducive to vector production or harborage that have been overlooked.
- They can provide site/location advice (certain BMP designs might be unsuitable for specific locations–i.e., ecological factors, near schools).
- They can provide monitoring services for a period of time after completion of construction that will help pinpoint features conducive to vector breeding. Improvements can be made based on these observations.