ERDC/TN EEDP-06-22
April 2013

The Association between Confined Disposal Facilities and Mosquitoes

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PURPOSE: Confined disposal facilities (CDFs), diked impoundments for disposal of dredged material, have the potential to support breeding populations of mosquitoes. It is therefore imperative that mosquito monitoring and control be conducted routinely at such facilities. In comparison to typical mosquito breeding sites (stagnant ponds, roadside ditches, etc.), CDFs contain unique mosquito habitats that require novel sampling and control techniques. Mosquito breeding predominately occurs in accumulated water in the soil fissures that develop following dredged material disposal as sites desiccate. Much of the guidance relevant to mosquito control in CDFs (e.g., Ezell 1978, Cofrancesco and Flosi 1988) was published decades ago. In the interim, new concerns related to mosquitoes as vectors of pathogens have arisen, particularly for CDFs in proximity to urban areas, creating a need for updated information on the topic. Likewise, the large numbers of birds associated with CDF habitats has heightened concern for transmission of viral infections through mosquitoes to humans. This technical note provides information necessary for planning and implementing mosquito monitoring and control efforts at CDFs. Topics include descriptions of larval habitats, mosquito species, sampling techniques, and control measures associated with CDFs.

BACKGROUND: "In fulfilling its mission to maintain, improve, and extend waterways and harbors, the US Army Corps of Engineers (USACE) is responsible for the dredging and disposal of large volumes of dredged material each year. Dredging is a process by which sediments are removed from the bottom of streams, rivers, lakes, and coastal waters; transported via ship, barge, or pipeline; and discharged to land or water" (Department of the Army 1987). Approximately 144 million yd^3 of material were dredged from waterways in the United States in 2011, with approximately 12% of those materials deposited in CDFs (USACE 2012). CDFs are diked impoundments that are designed to contain sediments and discharge water from dredging operations. Sites vary from as small as just a few acres to over 2500 acres (Bailey et al. 2010). The presence of larval mosquito habitats and, consequently, larvae indicates the ability of a CDF to support a breeding population of mosquitoes. There are several thousand CDFs across the United States and each has the potential for providing mosquito breeding habitats. References exist, from as early as the 1930's, of mosquito breeding and control activities at dredged material disposal sites (Brooks 1939).

Ezell (1978) identified and directly linked eight different dredged material (DM) stages (Table 1) to the onset, duration, and intensity of mosquito breeding at CDFs. The following is a summary of the association between DM stages and mosquitoes as determined by Ezell (1978). Supernatant liquid, DM-1, is the first stage post dredging disposal. During this stage, water begins to separate from the dredged material slurry and drain from the site. This stage is typically complete within six months, depending on the drainage system employed. It is important to note that CDFs can be utilized for decades and regardless of the current DM stage, sites revert to DM-1 upon the addition of new dredged material. Bare mud, DM-2, is present as soon as surface water has drained from the site. The duration of this stage is mostly dependent on the amount of rainfall and can be complete in as little as one day or can take up to two months. Larval mosquitoes are not encountered during either of the first two DM stages or for approximately eight months after dredging deposits have ceased.

Table 1. The description, duration, and mosquito breeding potential of the eight dredged material (DM) stages as identified by Ezell (1978).

Dredged Material (DM) Stage	Community Type	Duration	Description	Mosquito Breeding
DM-1	Supernatant liquid	≤ 6 months	Water separates from the dredged material slurry	None
DM-2	Bare mud	1 day - 2 months	Water has drained from the site, exposing bare mud	None
DM-3	Incipient fissure formation	4 - 6 weeks	Initial fissures are ≤ 1.3 cm deep and range from 25–100 cm deep by the end of the stage	None
DM-4	Mature fissures	1 - 3 years	Fissures widen and continue to deepen to 46–100 cm	High
DM-5	Vegetated mature fissures	2 - 8 years	Vegetation provides stability to fissures, slowing the weathering process	High
DM-6	Weathered fissures	1 - 3 years	As fissures collapse and fill with sediment, size and quantity decrease	Low
DM-7	Weathered fissures with vegetation	10 - 25 years	Vegetation continues to stabilize fissures and decrease the amount collapsed and filled with sediment	Medium
DM-8	Climax conditions	3 years	No fissures, loosely packed soil, plants present such as *Phragmites communis*, and various trees and shrubs	Low

Larval habitats begin to form during DM-3 and persist through DM-8, following the onset of fissures (Figure 1), a unique mosquito habitat common at CDFs. Incipient fissure formation, DM-3, is characterized by the drying of sediments and formation of fissures (desiccation cracks) and consequently larval habitats. As deposited sediments begin to dry, cracks or fissures capable of holding rain water begin to form. These fissures are a preferred oviposition site for floodwater mosquitoes, who oviposit on damp sediments with eggs hatching upon flooding. DM-3 conditions are typically first detected at 6 to 8 months following cessation of disposal operations and can persist for 4 to 6 weeks. During the beginning of incipient fissure formation, cracks are usually less than 1.3 cm deep, but quickly deepen to depths of 25 to 100 cm. These fissures become ideal larval mosquito habitats and support the greatest amount of mosquito breeding during DM stages 4 and 5 (mature fissures and vegetated mature fissures, respectively), as the fissures become wider and deeper (46-100 cm) and can hold larger quantities of rain water. DM-4 conditions first appear at approximately 7 months post dredging disposal and can persist for up to 8 years or until weathering begins. Vegetated mature fissures, DM-5, are not always present at a site and are dependent upon both the presence of seeds and soil that can support plant growth. Yet when vegetation is present, the duration of mosquito breeding is greatly lengthened as roots provide soil stability and decrease weathering rates. During DM-6 and 7, fissures begin to weather, collapse, and become partially filled with sediment, and therefore decrease in size and quantity. Weathering decreases the amount of suitable oviposition sites and available larval habitats for floodwater mosquitoes. Vegetated weathered fissures (DM-7) collapse and fill in more slowly and therefore support mosquito breeding for an extended time period. Without vegetation, fissures can successfully weather within 1 to 3 years, a relatively short time frame compared to weathering when vegetation is present, which can take 10 to 25 years. During DM-8, climax conditions, fissures are no longer present, having been converted to loosely packed soil, but a small amount of mosquito breeding still occurs in CDF microhabitats (see following section) that are capable of holding rain water, such as borrow pit swales, sumps, and surface depressions.

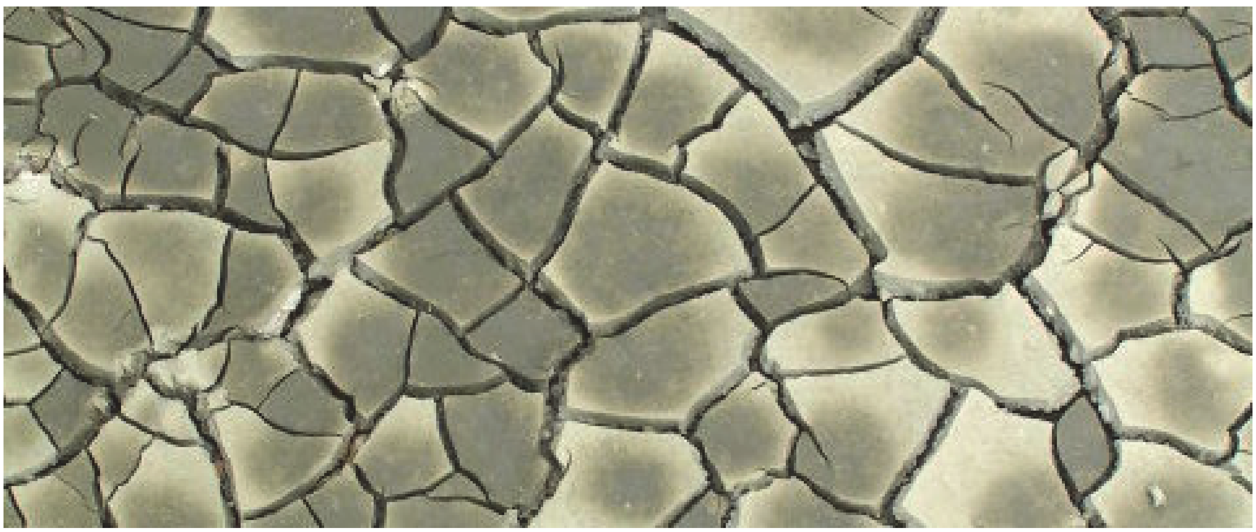

Figure 1. Soil fissures or desiccation cracks (KAT Umweltberatung GmbH 2012).

Mosquito monitoring and control at CDFs can be a decades-long commitment. Mosquitoes are not typically a problem at CDFs until dredging operations have concluded, the site has progressed through DM stages 1 and 2, and fissures have begun to form. It is also important to note that the entire area of a CDF is not typically uniform, due to gradients in elevation, age of the deposits, sediment composition, etc., and most CDFs can therefore support multiple DM stages concurrently. It is imperative that DM stage progression is monitored, that larval mosquito habitats are identified and monitored, and that control measures are taken if/when necessary.

MOSQUITO BIOLOGY: The mosquito life cycle includes four stages; egg, larva, pupa, and adult. While males do not bite, most females require the protein from a blood-meal to produce eggs. A single female can produce up to 500 eggs, which are oviposited in one of two egg-laying behaviors, either singly or in batches (Becker et al. 2010). Mosquitoes inhabit fresh, brackish, and saltwater environments and can lay eggs directly onto standing water, natural or artificial containers (tree holes, tires), or damp soil. Upon hatching, larvae feed on microorganisms, detritus, algae, protozoa, and/or invertebrates and progress through four larval instars (growth stages) (Becker et al. 2010). During pupation, the mosquito no longer feeds and the body of the adult is formed. Larvae and pupae are both capable of swimming but are typically located near the water's surface as most species depend on atmospheric oxygen to breath. The larvae and pupae of two mosquito genera, *Mansonia and Coquillettidia*, are not associated with the water's surface and receive oxygen by penetrating submersed parts of aquatic plants (Becker et al. 2010). The duration of each stage is temperature-dependent and can also be species-specific, but in general, mosquitoes can progress from egg to adult as quickly as in just a few days or in up to two weeks (Becker et al. 2010).

LARVAL MOSQUITO HABITATS: Through extensive surveys, Ezell (1978) identified 14 microhabitats within a CDF that were capable of supporting larval mosquitoes. Some of these are typical mosquito breeding sites, such as shallow pools formed in depressions, but some of the most productive habitats are unique to CDFs and therefore less obvious and more difficult to identify. For this reason it is important that mosquito control personnel are familiar with descriptions of these habitats so that larval breeding areas are quickly identified, monitored, and managed. Table 2 provides a brief description of each habitat and, as determined by Ezell (1978), designates each as a major or minor source of larval mosquitoes. All major sources of mosquito larvae will be discussed in the following paragraph. For complete descriptions of all habitats, see Ezell (1978).

Table 2. The 14 microhabitats, as identified by Ezell (1978), within a CDF that are capable of supporting larval mosquitoes.

Larval Habitats	Description	Major or Minor Source of Larvae
Borrow pit swale	Swales that develop when dike material is collected from a borrow pit on site	Major
Fissured soil	Cracked, dry sediments	Major
Fissured soil with vegetation	Vegetation growing on cracked, dry sediments	Major
Sump	Flooded areas of fissured soil located in the lowest elevations at a CDF	Major
Dike swale	Area where dredged material falls away from the dike proper and collects water from dike runoff	Minor
Dike seepage	A pool of seepage water	Minor
Depression	Fissured soil within sunken areas commonly formed near the center of CDFs	Minor
Hummock	Areas between two upraised sections of dredged material	Minor
Blockage of tidal drainage	Pooled water outside of CDFs that occurs when sites are located over tidal creeks, blocking tidal flushing and drainage	Minor
Dike failure	Fissured soil flooded by tidal water due to dike failure	Minor
Outfall	Pooled water located outside the CDF below a drainage weir	Minor
Localized breeding outside CDFs	Shallow depressions caused by tidal erosion and dike slumping	Minor
Surface distortion	Depressions created by heavy machinery	Minor
Discharge site	Semi-permanent pools formed by scouring action as material is released into the CDF	Minor

While most of the potential larval habitats at CDFs were only minor sources of mosquitoes, four habitats (borrow pit swales, fissured soil, fissured soil with vegetation, and sumps) consistently contained significant larval breeding (Ezell 1978). Borrow pit swales develop when dike construction material is taken from a borrow pit on site. When dredged material is deposited in the site, the borrow pit initially fills in, but as the sediments dry and condense, a swale forms along the exact location of the borrow pit. Borrow pit swales tend to collect and retain water, making it possible for larval mosquitoes to inhabit them. Borrow pit swales are typically only found at CDFs that have been used more than once or have undergone dike reconstruction (Ezell 1978).

The remaining three major larval habitats are all represented by soil fissures and include sumps, fissured soil, and fissured soil with vegetation. Drying soil begins to form fissures as early as 6 to 8 months after dredging deposits have ceased and fissures can provide larval habitats for several decades depending on the presence of vegetation and the subsequent rate of weathering (Table 1). Sumps are flooded areas of fissured soil usually associated with drainage weirs. Sumps are almost never dry as they are typically located in the lowest elevations of a CDF, making draining difficult and larval breeding possible.

MOSQUITO SPECIES: While CDFs may contain habitats suitable for oviposition and larval development, not all mosquito species utilize these sites. Eleven mosquito species have been collected as larvae at CDFs (Table 3) and at least seven more species have the potential to occur at CDFs (Table 4) (Ezell 1978). Some of these species are simply a nuisance as they aggressively and actively feed during both day and night or readily bite humans (e.g., *Anopheles atropos* Dyar & Knab, *Ochlerotatus atlanticus* (Dyar & Knab), *Psorophora horrida* (Dyar & Knab), and *Ps. howardii* Coquillett), yet 10 of these species are known to vector pathogens that may cause diseases such as malaria, various types of encephalitis, and canine heartworm (Becker et al. 2010). Many variables such as ability to reach hosts outside of CDFs, propensity for ovipositing at CDFs, and likelihood that the carried pathogen is transmitted to hosts must be considered when deciding which of these species pose a serious threat to humans and animals. For instance, while *An. quadrimaculatus* Say, one of the two primary vectors of malaria in North America, is normally associated with permanent bodies of water, it has been rarely collected at CDFs (Ezell 1978). Therefore it is highly unlikely that an outbreak of malaria would originate from mosquitoes breeding at a CDF in the United States.

The three most commonly collected mosquito species in CDFs are *Oc. sollicitans* (Walker), *Oc. taeniorhynchus* (Weidemann), and *Culex salinarius* Coquillett (Ezell 1978). All three are considered nuisance species as *Cx. salinarius* readily bite humans and *Oc. sollicitans* and *Oc. taeniorhynchus* bite during both day and night. Besides being considered a nuisance, all three are also known to be pathogen vectors. *Culex salinarius* vectors West Nile virus (WNV) and canine heartworm, *Oc. sollicitans* vectors Eastern Equine Encephalitis (EEE) virus, and *Oc. taeniorhynchus* transmits canine heartworm and Venezuelan Equine Encephalitis (VEE) virus (Becker et al. 2010). WNV infects humans, equines, and avian species. In humans, symptoms range from flu-like ailments to severe meningitis and encephalitis, which can cause death. EEE and VEE viruses can also be fatal to equines, humans, and avian species (EEE only), while canine heartworm is fatal only to dogs and cats and does not cause any symptoms in humans. Of these three mosquito species, *Oc. sollicitans* and *Oc. taeniorhynchus* have the greatest chance of infecting hosts outside of CDFs due to their strong flight ability. Both species have been known to

Table 3. Nuisance attributes, diseases, and potential diseases of the 11 mosquito species collected at CDFs by Ezell (1978).			
Mosquito Species	**Nuisance Attributes**	**Diseases**	**Potential Diseases**
Ae. vexans	One of the most voracious biters in the United States	EEE WNV Canine heartworm	California encephalitis group WEE
An. atropos	Bites during day and night	None	None
An. bradleyi	None[1]	None	None
An. quadrimaculatus	Bites readily	Malaria Canine heartworm	None
Cx. restuans	None[1]	WNV	EEE WEE
Cx. salinarius	Bites readily	WNV Canine heartworm	None
Oc. atlanticus	Bites readily	None	None
Oc. sollicitans	Bites during day and night	EEE	None
Oc. taeniorhynchus	Bites during day and night	Canine heartworm VEE	None
Ps. horrida	Bites during day and night	None	None
Ps. howardii	Bites during day and night	None	None

[1] Species without nuisance attributes do not typically feed on humans or are not typically a species that acts as a pest to humans (i.e. do not exist in large enough quantities or do not reside near humans).

Table 4. Nuisance attributes and diseases of seven mosquito species considered by Ezell (1978) to have a high potential to breed within CDFs.		
Mosquito Species	**Nuisance Attributes**	**Diseases**
An. crucians	None[1]	None
Cq. perturbans	Fierce biters	EEE WNV
Cs. melanura	None[1]	EEE
Cx. territans	None[1]	None
Oc. tormentor	Bites readily	None
Oc. triseriatus	None[1]	La Crosse Encephalitis
Oc. trivittatus	None[1]	Trivittatus WNV

[1]Species without nuisance attributes do not typically feed on humans or are not typically a species that acts as a pest to humans (i.e. do not exist in large enough quantities or do not reside near humans).

travel many kilometers in search of a blood source. Due to the propensity for all three of these mosquitoes to breed in CDFs, the potentially deadly pathogens they vector, and their ability to reach hosts great distances away, CDFs should be closely monitored for larval populations of these three species.

Floodwater species of mosquitoes are well adapted for CDFs as their eggs are laid on damp soil, are able to withstand desiccation, and hatch after rain events when water becomes available. In total, five floodwater mosquito species have been collected at CDFs. The viruses vectored by two of these species, *Oc. sollicitans* and *Oc. taeniorhynchus,* were previously discussed. *Psorophora horrida* and *Ps. howardii* are not associated with any mosquito-borne diseases. *Aedes vexans* (Meigen) vectors EEE virus, WNV, and canine heartworm (Becker et al. 2010). *Aedes vexans* is known to fly great distances in search of a blood source so it is likely that adults emerging from a CDF could travel to nearby populated areas. *Aedes vexans* is also a notorious nuisance species that topped the chart of most voracious biters in the United States (McKnight 2005).

Mosquitoes with the potential to vector pathogens have been detected with natural viral infections, but the likelihood that the virus is replicated within and transmitted from the species has either not been determined or is very low compared to the primary vector species. Two of the mosquito species associated with CDFs have the potential to transmit viruses. *Culex restuans* Theobald is known to vector WNV and has the potential to vector EEE and Western Equine Encephalitis (WEE) viruses (Becker et al. 2010). *Aedes vexans* also has the potential to vector WEE virus as well as viruses of the California encephalitis group (Becker et al. 2010). WEE virus can cause death in both horses and humans, but in comparison to mortality rates of EEE virus, mortality is low. Symptoms of viruses of the California Encephalitis group include headache and seizures, and viruses of this group may result in encephalitis, meningitis, and coma. Populations of both of these species should be closely monitored at CDFs due to their known and potential vectoring abilities.

Ezell (1978) lists seven species of mosquitoes that, although not collected at CDFs, have a strong potential to breed within these sites (Table 4). Four of these are known to vector pathogens. EEE virus is vectored by both *Coquillettidia perturbans* (Walker) and *Culiseta melanura* (Coquillett), WNV is vectored by *Cq. perturbans* and *Oc. trivittatus* (Coquillett), the La Crosse Encephalitis virus is vectored by *Oc. triseriatus* (Say), and the Trivittatus virus is vectored by *Oc. trivittatus* (Becker et al. 2010). Although not as common as some of the other diseases, La Crosse Encephalitis and Trivittatus are both serious illnesses which, respectively, can affect the central nervous system and lead to coma. While *Cs. melanura* is the primary mosquito species involved in the natural cycle of EEE virus, it is not considered a vector of the pathogen to humans due to its preferential feeding on avian hosts. Of the species with potential to occur at CDFs, *Cq. perturbans* poses the highest risk to humans and animals outside of CDFs as they are capable of flying great distances in search of hosts.

Because of the known potential for mosquitoes to breed at CDFs, mosquito control personnel should be aware of the species that utilize CDFs and their potential as nuisance species or vectors. This information can help to streamline the monitoring and management procedures necessary to eliminate any outbreaks of mosquitoes in highly populated urban areas. Depending on which mosquito species are causing problems, CDFs can be immediately eliminated or confirmed as a potential source of adult mosquitoes.

MOSQUITO MONITORING/SAMPLING TECHNIQUES: It is imperative that mosquito monitoring be conducted to confirm the presence and determine the extent of onsite mosquito populations at CDFs. Methods for surveying mosquito eggs, larvae, pupae, and adults exist. Egg sampling is used to determine the habitats and sites that mosquitoes utilize as oviposition sites. This would be unnecessary at most CDFs, as Ezell (1978) performed extensive research to determine the mosquito breeding habitats at CDFs. Egg sampling could be warranted if a habitat or mosquito species not previously associated with CDFs is encountered, but in general, egg sampling is considered too labor-intensive for regular monitoring (Connelly and Carlson 2009). The primary objective at CDFs should be to survey larval mosquitoes to confirm onsite mosquito breeding. Adult monitoring should be used only as a supplement to larval sampling or to monitor disease vectors if evidence of virus transmission is detected. While no true standards exist for mosquito surveillance, there are commonly accepted methods. The most common equipment and techniques used for larval and adult assessment will be discussed in the following paragraphs.

The most commonly used tool for collection of larval mosquitoes is the dipper (Connelly and Carlson 2009, Becker et al. 2010). Dippers are typically small, white plastic containers with a capacity of about 350 ml. Dippers can be attached to poles of various lengths for ease of sampling. At CDFs, Ezell (1978) and Kent et al. (1987) both used the dipper as well as a novel tool for sampling larvae in areas with a narrow access, such as soil fissures. For these areas, a turkey baster or a medical syringe attached to surgical tubing was employed. Samples taken with various devices can be standardized by collecting the same volume each time. Number of larvae per volume (or dipper) is typically recorded and, if possible, per mosquito species. While no standards exist, several samples per distinct larval habitat should be taken at each CDF. Larvae should be preserved in 70% ethanol if not immediately counted or identified. While only fourth instar larvae can be confidently identified by use of a taxonomic key, most experts can make a strong educated guess with younger larvae. Another option is to allow the larval mosquitoes to complete development to the adult stage and then identify the adult. For further details of larval sampling techniques, see Silver (2008) and Becker et al. (2010).

Light traps are the most commonly used tool for adult collections (Connelly and Carlson 2009, Becker et al. 2010). The two most widely used models are the New Jersey and Center for Disease Control (CDC) light traps. Mosquitoes are attracted to the light emitted from the traps and once inside cannot escape. Some traps use a fan to blow insects into a collection container such as a nylon bag for live collections or a "kill jar." To create a "kill jar," cotton balls are soaked in ethyl acetate and placed inside a container. Ethyl acetate vapors are deadly to the insects. Because New Jersey light traps require AC power, battery-operated CDC light traps are becoming more popular. Another benefit of CDC traps is that they can be equipped with both light and carbon dioxide attractants. While light will attract many types of insects, carbon dioxide is more specific to host-seeking female mosquitoes; carbon dioxide is the primary attractant to mosquitoes looking for a blood meal. Carbon dioxide is provided via bottled gas, or more commonly, through dry ice. Commercially available models of both traps can be equipped with sensors or timers that start the trap at dusk and turn it off at dawn. Traps are usually operated for an entire night, but no guidelines exist as to the number of traps per site or frequency of trapping (Connelly and Carlson 2009). Traps are also operated at various heights, but usually between 1.2 and 1.7 m off the ground (Ezell 1978, Connelly and Carlson 2009). For identification, adult female mosquitoes should be pinned if possible (the identification of males requires a key to the morphology of the genitalia and is not a method that is common or easy to use). If freshly killed adults are left in collection containers and handled gently, identification may be possible without pinning. Taxonomic experts become very familiar with the particular species associated with certain states and even individual sites and can oftentimes perform species identification rapidly on site.

Various other adult collection techniques exist. Some are specific to certain mosquitoes (resting boxes for *Culiseta* and *Anopheles* spp.) or are specific to disease vector surveillance programs. For further information, review Silver (2008), Connelly and Carlson (2009), or the CDC's Guidelines for Arbovirus Surveillance Programs in the Unites States at: http://www.cdc.gov/ncidod/dvbid/arbor/arboguid.pdf.

Additional information on mosquito identification can be found at the online, dichotomous key created by Michele M. Cutwa-Francis and George F. O'Meara, University of Florida, Florida Medical Entomology Laboratory, http://fmel.ifas.ufl.edu/key/. This key uses actual photographs of the most common mosquitoes of Florida to aid in identifications (Figure 2). Another important taxonomic publication is *Identification and Geographical Distribution of the Mosquitoes of North America, North of Mexico* by Darsie and Ward (2005).

MOSQUITO CONTROL: For mosquito control efforts, Integrated Pest Management or, in this case, Integrated Mosquito Management (IMM), has been used since at least the late 1970s (Frank et al. 1980). Most mosquito control entities agree that to effectively control mosquitoes, one control method alone is not sufficient and integrated means must be utilized (Floore 2006, Connelly and Carlson 2009, Becker et al. 2010). There are four components to IMM: 1) source reduction, 2) biological control, 3) larviciding, and 4) adulticiding (Floore 2006).

Source reduction. CDFs are designed to retain solids and expel liquids, i.e. source reduction (Department of the Army 1983). Standard techniques and equipment such as perimeter and interior trenching, progressive trenching, underdrains, wick drains, and telescoping weirs are used to dewater CDFs (Department of the Army 1987, Francingues et al. 2000). Progressive trenching techniques and telescoping weirs are of special concern to mosquito control efforts, as both contribute to dewatering the bottom of areas of fissured soil, thereby providing source reduction of suitable larval habitats. Although many techniques are used to drain water from a CDF, as long as soil fissures continue to form and hold water, mosquitoes can breed.

Biological control. Many potential biological control agents for mosquito larvae and adults exist. There are numerous predators, including fish, amphibians, microcrustaceans, nematodes, birds, bats, and invertebrates. Although many options exist, *Gambusia affinis*, the mosquito fish, is the most widely distributed and in most instances, the only distributed organism for mosquito control (Floore 2006, Becker et al. 2010). Although there are areas at CDFs that are capable of holding water, these areas are intermittent, dependent upon rain water, and therefore not suitable for the introduction of fish. There is a paucity of biological control agents for mosquito control, mostly because of the difficulties and high costs involved in mass-rearing a living organism (Becker et al. 2010). Several pathogens (fungi, protozoa, and viruses) exist for mosquito control but are not yet fully developed, have proven ineffective in lab experiments (low persistence or low pathogenicity), or are too difficult to mass-produce (complex life cycles) (Becker et al. 2010). Bacterial agents such as *Bacillus thuringiensis* and *Saccharopolyspora spinosa* have proven very successful

Figure 2. Photographs of *Oc. taeniorhynchus* larvae (a and b) and adults (c and d) from the online dichotomous key created by Michele M. Cutwa-Francis and George F. O'Meara, University of Florida, Florida Medical Entomology Laboratory, http://fmel.ifas.ufl.edu/key/. At each step in the dichotomous key, actual photographs are presented to help users determine identifications. All photographs by Michele M. Cutwa-Francis.

at mosquito control. For the purposes of this technical note and to avoid confusion with the general public, these bacterial agents will be included with pesticides, as they are commercially available as larvicides.

Larviciding. Of all currently available control methods, pesticides are the most applicable to CDFs. It is generally accepted by mosquito control agencies that larviciding is preferential to adulticiding (Floore 2006, Connelly and Carlson 2009). Larvicide applications can be easier to apply and more effective as larval populations are concentrated and larvae cannot vacate the treatment area. In contrast, adults can disperse over large areas (Floore 2006). Larvicides also have less environmental impact, especially when the fairly new bacterial pesticides are used (Connelly and Carlson 2009). Emphasis should be directed at controlling larvae, with supplemental adulticiding on an as-needed basis to protect populated areas from disease vectors. Tables 5 and 6 summarize currently available (as of 2012) pesticides available to licensed applicators for larval (Table 5) and adult (Table 6) control of mosquitoes in CDFs. Pesticides were included from applicable chemical groups with a sampling of active ingredients within each group. Some commercially available products were not described, but are listed in Tables 7 and 8.

Larval pesticides were included in this report based on their applicability to the unique environmental conditions (intermittently flooded) and mosquito habitats (soil fissures) present at CDFs. For instance, oils and surface films were not included since they can only be applied and are only effective in flooded areas. Most of the included larvicides can be applied prior to a wetting event and alternate wet and dry periods do not reduce their effectiveness. Larvicides from all major groups are discussed: organophosphates, insect growth regulators (IGRs), and bacteria (Table 5).

Organophosphates, such as Temephos (Abate®), kill insects on contact by inhibiting cholinesterases, a group of enzymes, and affecting the insect's central nervous system (Becker et al. 2010). Temephos is lethal to all larval stages of mosquitoes, but can also affect immature dragonflies (*Odonata*), mayflies (*Ephemeroptera*), beetles (*Coleoptera*), and midges (Diptera: *Chironomidae*) (Becker et al. 2010). Temephos is available in a liquid formulation, but granular and plaster pellet formulations are preferable for CDFs, as they can be applied prior to flooding (Clarke 2010).

(S)-Methoprene (Altosid®), an IGR, mimics the action of an insect growth-regulating hormone and prevents the normal maturation of insect larvae (Becker et al. 2010). This larvicide is consumed or absorbed by mosquito larvae, who then continue to develop to the pupal stage, where they die.[1] (S)-Methoprene is highly selective for mosquitoes and is one of the most environmentally safe products (Becker et al. 2010). Some of the available commercial formulations of this IGR provide control for up to 150 wet days and are not depleted when dry (Wellmark International 2010). Applicators have the freedom to apply this product at basically any time, regardless of the presence or absence of water or larvae. As long as the product is present upon flooding, mosquitoes will be controlled.

[1] Pesticide label for Altosid briquets, 2010, Wellmark International, Schaumburg, IL.

Table 5. Examples of currently available (as of 2012) pesticides representing applicable formulations for larval control of mosquitoes in CDFs.[1]

Chemical Group and Name	Product & Source(s)	Commercial Formulation(s)	Formulation	Days of Control	Pre-flood Applications
Organophosphate Temephos	Abate® Clarke Mosquito Control Products, Inc. www.clarke.com	1% Skeeter Abate®	Granules	7 – 30 days	Yes
		5% Skeeter Abate®	Plaster Pellets	7 – 30 days	Yes
		Abate® 2-BG	Granules	7 – 30 days	Yes
		Abate® 5-BG	Granules	7 – 30 days	Yes
Insect Growth Regulator (S)-Methoprene	Altosid® Clarke Mosquito Control Products, Inc. www.clarke.com & ADAPCO, Inc. www.myadapco.com	Altosid® Briquets	Briquets	30 days Only depleted when wet	Yes
		Altosid® XR Briquets	Briquets	150 days Only depleted when wet	Yes
		Altosid® Pellets	Pellets	30 days	Yes
		Altosid® XR-G	Granules	21 days	Yes
Bacterial *Saccharopolyspora spinosa* (Spinosad)	Natular™ Clarke Mosquito Control Products, Inc. www.clarke.com	Natular™ G	Granules	Provides control for a single brood	No
		Natular™ G30	Granules	30 days	Yes
		Natular™ T30	Tablets	30 days Only depleted when wet	Yes
		Natular™ XRT	Tablets	180 days Only depleted when wet	Yes
Bacterial *Bacillus sphaericus & B. thuringiensis israelensis*	Four Star™ Briquets ADAPCO, Inc. www.myadapco.com	Four Star™ Briquets (45 day)	Briquets	45 days	Yes
		Four Star™ Briquets (90 day)	Briquets	90 days	Yes
		Four Star™ Briquets (180 day)	Briquets	180 days	Yes

[1]This table does not represent all commercial formulations or sources but rather representative examples from applicable chemical groups. Citation of trade names does not constitute an official endorsement or approval of the use of such products. Trademark owners are listed in Table 9.

Bacterial agents containing Spinosad (Natular™), *Bacillus sphaericus*, and *B. thuringiensis israelensis* (Four Star™) also provide a lengthy term of control, up to 180 days (ADAPCO 2010, Clarke 2011). Spinosad represents a unique chemical class and novel mode of action; it alters the function of insect nicotinic acetylcholine receptors, causing continuous nervous impulses that result in paralysis and death (Clarke 2011). Larvae are affected by both ingestion of the pesticide and contact with it (Clarke 2011). Spinosad is environmentally safe and is the only mosquito larvicide listed by the EPA as a Reduced Risk pesticide (Clarke 2011.) *Bacillus sphaericus*, and *B. thuringiensis israelensis* contain protein crystals that, when ingested, rupture the gut wall of larvae resulting in death (ADAPCO 2010). In recent years, *Bacillus sphaericus* and *B. thuringiensis israelensis* have become some of the leading larvicides, due in part to their selectivity for mosquitoes (Lacey and Orr 1994). Other than mosquitoes, *B. thuringiensis israelensis* and *B. sphaericus* are fatal to only two other fly families, Simuliidae and Psychodidae, respectively (Becker et al. 2010).

Table 6. Examples of currently available (as of 2012) pesticides for adult control of mosquitoes in CDFs.[1]

Commercial Formulation(s)	Chemical Group and Name	Application Techniques: Aerial	Application Techniques: Ground	Synergist	Source(s)
Anvil® 2+2 Anvil® 10+10	Synthetic Pyrethroid d-Phenothrin	Fixed-wing or rotary aircraft	Non-thermal, portable, motorized backpack equipment Truck-mounted thermal fogging equipment Hand-carried foggers	Piperonyl butoxide	Clarke Mosquito Control Products, Inc. www.clarke.com
Aqua-Reslin® Permanone® (4 formulations available)	Synthetic Pyrethroid Permethrin	Fixed-wing or rotary aircraft	Thermal aerosols or fogs ULV (ultra-low volume) cold aerosol or non-thermal aerosol (cold fog)	Piperonyl butoxide	ADAPCO, Inc. www.myadapco.com
Biomist® (7 formulations available)	Synthetic Pyrethroid Permethrin	Fixed-wing or rotary aircraft	ULV cold aerosol or non-thermal aerosol (cold fog)	Piperonyl butoxide	Clarke Mosquito Control Products, Inc. www.clarke.com
Scourge® 4-12 Scourge® 18-54	Synthetic Pyrethroid Resmethrin	Fixed-wing or rotary aircraft	Vehicle-mounted ULV cold aerosol generators or vehicle-mounted non-thermal aerosol (cold fog)	Piperonyl butoxide	ADAPCO, Inc. www.myadapco.com
Fyfanon® ULV Mosquito	Organophosphate Malathion	Fixed-wing or rotary aircraft	Thermal aerosols or fogs Non-thermal aerosols		ADAPCO, Inc. www.myadapco.com Van Diest Supply Company www.vdsc.com
Dibrom® Concentrate Trumpet® EC	Organophosphate Naled	Fixed-wing or rotary aircraft	ULV Rarely applied via ground due to difficulty in providing required engineering controls: see label or contact company		ADAPCO, Inc. www.myadapco.com
Aquahalt™	Natural Pyrethrins Pyrethrins	Fixed-wing or rotary aircraft	Non-thermal aerosol Non-thermal, portable, motorized backpack, or hand-held equipment	Piperonyl butoxide	Clarke Mosquito Control Products, Inc. www.clarke.com

[1]This table does not represent all commercial formulations or sources but rather representative examples from applicable chemical groups. Citation of trade names does not constitute an official endorsement or approval of the use of such products. Trademark owners are listed in Table 9.

Table 7. Other *B. sphaericus* and *B. thuringiensis israelensis* bacterial larvicides.[1]

Commercial Formulation	Chemical Name	Source(s)
Vectolex®	*B. sphaericus*	ADAPCO, Inc. Clarke Mosquito Control Products
Spheratax®	*B. sphaericus*	ADAPCO, Inc.
Vectobac®	*B. thuringiensis israelensis*	ADAPCO, Inc. Clarke Mosquito Control Products
Vectomax™	*B. thuringiensis israelensis* and *B. sphaericus*	ADAPCO, Inc.
Aquabac®	*B. thuringiensis israelensis* and *B. sphaericus*	ADAPCO, Inc.

[1]This table does not represent all commercial formulations or sources but rather representative examples from applicable chemical groups. Citation of trade names does not constitute an official endorsement or approval of the use of such products. Trademark owners are listed in Table 9.

Table 8. Other organophosphate and synthetic pyrethroids for adult mosquito control.[1]

Commercial Formulation	Chemical Group	Chemical Name	Source(s)
MosquitoMist™	Organophosphate	Chloropyrifos	Clarke Mosquito Control Products
Zenivex® E20	Synthetic Pyrethroids	Etofenprox	ADAPCO, Inc.
Zenivex® E4 RTU	Synthetic Pyrethroids	Etofenprox	ADAPCO, Inc.
Duet™	Synthetic Pyrethroids	d-Phenothrin (Sumithrin®) and Prallethrin (ETOC®)	Clarke Mosquito Control Products

[1]This table does not represent all commercial formulations or sources but rather representative examples from applicable chemical groups. Citation of trade names does not constitute an official endorsement or approval of the use of such products. Trademark owners are listed in Table 9.

Adulticiding

At CDFs, adult mosquito habitats are less unique than larval habitats and greatly resemble areas commonly treated with adulticides. Therefore the adulticides included within are applicable in a variety of environments. At least one product was included from each of the three leading chemical groups of adulticides; organophosphates (see previous paragraph), synthetic pyrethroids, and natural pyrethrins (Table 6). Synthetic pyrethroids and natural pyrethrins are neurotoxic to insects and are often applied with a synergist such as piperonyl butoxide (Becker et al. 2010) (Table 6). Synergists are not insecticidal by themselves, but when applied with pesticides they increase the product’s efficacy by inhibiting biodegradation. Most of the included adulticides can be applied with aerial (fixed-wing or rotary aircraft) or ground equipment. Each product’s label should be referenced for specific application instructions, restrictions, and precautions. For instance, many products have a very specific requirement for volume median diameter (VMD) of spray equipment, droplet size, appropriate liquids for dilution, application height when conducting aerial applications, ground wind speed, and temperature. Additionally, several products cannot be applied to or near waters containing fish because of their toxicity to fish.

Table 9. Pesticide trademarks listed by owner.

Owner	Name
Advanced Microbiologics, LLC 11146 North West 69th Place Parkland, FL 33076	Spheratax®
Amvac Chemical Corporation 4100 East Washington Boulevard Los Angeles, CA 90023	Dibrom® Concentrate Trumpet® EC
BASF Corp. 100 Park Avenue Florham Park, NJ 07932	Abate®
Bayer AG 2 TW Alexander Drive Research Triangle Park, NC 27709	Aqua-Reslin® Permanone® Scourge®
Becker Microbial Products, Inc. 11146 North West 69th Place Parkland, FL 33076	Aquabac®
B2E Microbials LLC 2711 Centerville Road #400 Wilmington, DE 19808	FourStar™ Briquets
Cheminova, Inc. One Park Drive, Suite 150 Research Triangle Park, NC 27709	Fyfanon® ULV Mosquito
Clarke Mosquito Control Products, Inc. 159 N. Garden Avenue Roselle, IL 60172	Anvil® Aquahalt™ Biomist® Duet™ MosquitoMist™ Natular™
Valent BioScience Corporation 870 Technology Way Libertyville, IL 60048	Vectobac® Vectolex® Vectomax™
Wellmark International 1501 East Woodfield Road 200W Schaumburg, IL 60173	Altosid® Zenivex®

Management of pesticide resistance.

Effective mosquito control strategies must include plans to minimize pesticide resistance. At least 125 mosquito species have shown resistance to pesticide active ingredients, i.e. decreased susceptibility to normal lethal doses (Clarke 2010). Cases of resistance to many of the above listed pesticides have been documented, but in general, US cases are less frequent. For instance, pyrethroid resistance in *Cx. quinquefasciatus* Say is widespread in most of the tropics and Africa and permethrin resistance has been documented in an *Anopheles* species in Zimbabwe and California (Connelly and Carlson 2009, Becker et al. 2010). Florida has used pyrethroids since the 1970's and they are currently the preferred chemical group for ground control of adults (Connelly and Carlson 2009). Yet, other than California, no other published accounts of pyrethroid resistance in the United States exist (Becker et al. 2010). Widespread resistance to organophosphates was first discovered in the 1970's, but this chemical group is still actively employed for mosquito control

(Becker et al. 2010). Although malathion resistance was identified in Florida in the late 1960's, very few cases of organophosphate resistance have occurred since that time (Connelly and Carlson 2009). Temephos resistance has been reported in France, Spain, India, and the Dominican Republic (Becker et al. 2010), but after over 30 years of use in Florida, there are no accounts of resistance (Connelly and Carlson 2009). It also important to note that resistance can be associated with chemical formulations in general and not just chemical groups. Slow-release formulations have been implicated in creating resistance due to their potential to expose larvae to sub-lethal doses (Connelly and Carlson 2009). The relatively limited amount of resistance reported for US populations is likely due to the use of resistance management strategies.

While it is tempting from a budget standpoint to choose the least expensive pesticide or one that provides the most days of control or residual activity, pesticide use must be coordinated to manage resistance. The most important procedure for decreasing resistance, and the most applicable to CDFs, is product rotation (Connelly and Carlson 2009). Products used in a rotational cycle must be from different chemical groups, i.e. have distinct modes of action. When treating both larvae and adults, it is also important to use different chemical groups for larval versus adult control. Bacterial agents such as Spinosad (Natular™), *Bacillus sphaericus*, and *B. thuringiensis israelensis* (Four Star™) are applicable to CDFs and are great candidates for product rotation with the more widely used organophosphates and insect growth regulators. Spinosad is particularly applicable to resistance management as it is in a completely unique chemical group that is fairly new to the market. Furthermore, there are currently no reports of resistance to *B. thuringiensis israelensis* or Spinosad. Resistance management through product rotation is fairly simple and could be easily incorporated into mosquito management plans at CDFs.

SUMMARY: CDFs often occupy large parcels of land adjacent to population centers. With their potential to support mosquito breeding for decades, these sites should be monitored and control measures taken as needed. The greatest potential for mosquito breeding at CDFs occurs after disposal operations have ceased, the soil has begun to dry, and fissures have formed. Some of the most productive mosquito breeding habitats (soil fissures) are unique to CDFs, and therefore oftentimes overlooked. It is imperative that agencies responsible for the control of mosquitoes at CDFs be prepared. Personnel must be trained to identify the eight DM stages, 14 larval habitats, and the species associated with CDFs. They must also be familiar with sampling techniques and control measures applicable to CDFs. Also, it is good practice for personnel to pay close attention to local health department and mosquito control monitoring programs. In many areas, there are active surveillance programs that inform the public when there is an increased risk for mosquito-borne disease transmission. If this occurs close to a CDF, mosquito monitoring and control should be top priorities.

There is much room for the development of novel mosquito control practices at CDFs. Although Ezell (1978) performed a pilot study and found that soil amendments could prohibit fissure formation, it appears that no further research has been conducted on this topic. Research on inhibiting the growth of vegetation as a means to accelerate weathering and decrease the life of fissures could also be applicable to many sites. Another topic with a paucity of contemporary literature is efficient and effective larval control within the unique conditions at CDFs. Cofrancesco and Flosi (1988) investigated the effectiveness of aerially applied mosquito larvicides within vegetation canopies of difference densities and heights at CDFs in Texas and concluded that

effective control could be achieved, but a clear understanding of the factors that influence mosquito populations was critical. Although CDFs present unique challenges for mosquito management, lessons could potentially be learned from similar habitats to arrive at cost-effective options. For example, Knight et al. (2003) describe control strategies for constructed wetlands. Applied research in topics such as the efficacy of different pesticide formulations as well as best pesticide application methods should be tested at CDFs. In general, research directed particularly at mosquito control in CDFs would lead to the development of a set of best management practices for CDFs. There is still much room for improvement and development of mosquito monitoring and control guidelines at CDFs.

ADDITIONAL INFORMATION: Technical reviews of this document were provided by Dr. R. Michael Smart, Dr. Roxanne Connelly, and Susan Bailey. For additional information, contact Julie G. Nachtrieb (972-426-2215, Ext. 234), *Julie.G.Nachtrieb@usace.army.mil*, or the manager of the Dredging Operations Technical Support (DOTS) Program, Cynthia Banks (601-634-3820; *Cynthia.J.Banks@usace.army.mil*). This technical note should be cited as follows:

> Nachtrieb, J. G., and M. J. Grodowitz. 2013. *The association between confined disposal facilities and mosquitoes.* DOER Technical Notes Collection. ERDC/TN EEDP—06-22. Vicksburg, MS: US Army Engineer Research and Development Center.

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