projects began in Maryland in 1976. Results of the early projects were encouraging, but differences in hydrology and other factors between Maryland and New Jersey indicated that studies of OMWM under Maryland conditions were desirable. A four-year study (1979-1981) found that OMWM was about 99% effective in reducing populations of salt marsh mosquito larvae. The study also found that slight modifications to the New Jersey OMWM standards were required to preserve the habitat quality of Maryland marshes for waterfowl and other wetland wildlife. The OMWM technique received strong endorsement from mosquito control and wildlife interests as a result of the study.

From 1976 through 1989 a total of 22,412 acres of Maryland tidal marsh came under OMWM control. The average yearly progress was about 1600 acres. In 1981, a record 2,630 acres of work was completed. In 1989, the Natural Heritage Program (NHP) in the Maryland Department of Natural Resources (MDNR) raised several questions about the impact of OMWM and challenged the validity of any type of physical alteration to unaltered wetlands. The NHP was joined in their concern by the Chesapeake Bay Foundation and from 1990 to 1991 OMWM work was voluntarily halted, except on previously ditched marshes. On August 20, 1991 the Secretary of the MDNR issued an order to immediately stop all OMWM projects in Maryland. The legal basis for the stop-work order was the unknown effect of OMWM on the black rail (*Laterallus jamaicensis*), a species listed as "in need of conservation" on the state's list of threatened and endangered species. However, there are those in the mosquito control community who believe that OMWM was prohibited because of a change within the MDNR from an active resource management agency to a preservationist agency that was philosophically opposed to altering the physical appearance of any natural feature of the state.

No new OMWM has occurred on unaltered wetlands in Maryland since 1990; however, small projects retrofitting grid-ditched marshes with OMWM overlays have been permitted. As of 2007, a total of approximately 25,500 acres are under OMWM mosquito control in Maryland and OMWM continues to provide a high degree of mosquito control on 90% of this acreage. Approximately 10,000 acres of Maryland tidal marshes remain as good habitat for salt marsh mosquitoes.

OPEN MARSH WATER MANAGEMENT IN DELAWARE: 1979-2007

WILLIAM H. MEREDITH AND CHRISTOPHER R. LESSER
Delaware Mosquito Control Section, Division of Fish and Wildlife
Department of Natural Resources and Environmental Control
Dover, Delaware 19901

ABSTRACT: Open marsh water management (OMWM) is a selective ponding-and-ditching technique for saltmarsh mosquito control that encourages consumption of mosquito larvae by native larvivorous fishes while eliminating or reducing larval rearing habitats. OMWM has been successfully practiced in Delaware since 1979, and after 28 years of use actively continues today. After some refinement of the state's initial OMWM goals, a target universe of about 9% of Delaware's tidal wetlands (or about 9,000 acres of moderate to severe larval-production habitats in a total 95,000 acres of coastal wetlands) were identified for OMWM treatment. As of 2007, about 80% of Delaware's intended statewide OMWM work has been accomplished. Locations where open marsh water management (OMWM) work has been done in Delaware are reviewed with particular emphasis on habitat types and landowner categorizations, and the rate of OMWM installation is also examined. The types and mixtures of OMWM systems used in Delaware (open, sill, and closed systems) are discussed. OMWM's use in previously drained, parallel-grid-ditched marshes can have notable habitat restoration benefits for waterbirds (waterfowl, wading birds, shorebirds) and aquatic estuarine organisms.

The Delaware Mosquito Control Section has found OMWM to be a very effective, satisfactory approach for larval mosquito control, yielding >90% reduction in larval populations. The Delaware Division of Fish and Wildlife (of which mosquito control is part) views any possible adverse impacts to marsh plant communities or non-target organisms from OMWM to be quite inconsequential and readily acceptable, especially when viewed in light of greatly reduced larvicide use. How OMWM is regulated in Delaware and the Section's authority to perform OMWM work are discussed. The future use of OMWM in Delaware is examined. This includes our intention to pursue the remaining 20% of the initially targeted 9,000 acres of OMWM work, our need to maintain about 7,000 acres of completed OMWM work, our possibly making more use of OMWM within coastal impoundments, and a possible expansion of OMWM systems to contend with new larval habitats arising along marsh upland borders because of relative sea-level rise.

Origin and scope of OMWM work in Delaware

Open marsh water management (OMWM) started in Delaware in 1979, driven by a desire of the Delaware Division of Fish and Wildlife to reduce, to the extent practicable, the use of chemical larvicides for salt marsh mosquito control. OMWM must be installed in a manner such that satisfactory mosquito control is achieved (i.e. similar to or greater than the efficacy achieved with larvicide applications) and simultaneously not cause any unacceptable impacts to salt marsh ecological structure and function. The Delaware Mosquito Control Section (DMCS) is an integral part of our state's fish and wildlife management agency. Whenever more environmentally sound methods of mosquito control can be used, we try to adopt such approaches.

Delaware's OMWM efforts arose from the pioneering development and use of OMWM in New Jersey started in the mid-1960s (Ferrigno and Jobbins, 1968; Ferrigno et al., 1975). OMWM work that was started on Maryland's Eastern Shore in the mid-1970s (Lesser 1983) then further spurred Delaware to adopt OMWM as the preferred salt marsh mosquito control method. When OMWM started in Delaware, our primary goal was to lower the use of temephos, an organophosphate larvicide. Today with OMWM we want to lower, to the extent practicable, our use of methoprene, a larvicide that works as a juvenile hormone mimic, and our use of Bti, a microbial larvicide.

Delaware has a total of about 95,000 acres of tidal wetlands, covering about 8% of the state's surface area (Tiner 1985), yielding the highest percent surface cover by tidal wetlands of any state. This is due, in large measure, to Delaware's overall small size. Delaware has only about 1,950 sq. miles and ranks 49th in size among the states, while also containing a disproportionately large amount of coastal wetlands. Given these data, combined with Delaware's being in the top 10 states for human population density, and with so much of Delaware's populace within the typical 3-5 mile (sometimes up to 10-mile) flight range of salt marsh mosquitoes, Delaware's residents and visitors can be confronted with severe mosquito-related problems if salt marsh mosquitoes are not controlled. The saltmarsh mosquito guild of concern in Delaware includes *Aedes sollicitans*, *Ae. cantator*, *Ae. taeniorhynchus*, *Culex salinarius*, and *Anopheles bradleyi*.

Approximately 11,000 acres of Delaware's 95,000 acres of tidal wetlands are found in coastal impoundments no longer open to unfettered tidal flow (Meredith and Whitman 1994). Instead, these are now wetlands where marsh water levels and tidal exchanges are managed via water control structures for multiple resource purposes, including some management for mosquito control. Impoundments are created through the construction of dykes or levees to block or eliminate tidal flow across the marsh surface. Marsh water levels are thereby managed within the impoundments via water control structures at either higher or lower levels as opposed to in un-impounded marshes. Coastal impoundments are habitats where OMWM in a more traditional sense is not employed, reflected in the word "open" in the term "open marsh water management." This indicates that the technique does not involve the use of dykes, levees or other features to block or restrict free flow of tidal water over and across the general marsh surface (i.e. general marsh surface flooding in OMWM-treated marshes continues in the same manner as before OMWM treatment).

About 64,000 acres (or 69%) of Delaware's tidal wetlands are unimpounded salt marshes with salinities >5 ppt that are irregularly flooded by tides (one or less inundations per day), dominated by short-form salt marsh cordgrass (*Spartina alterniflora*) or salt hay grasses (*S. patens and Distichlis spicata*), along with marsh shrubs such as *Iva* and *Baccharis*. These 64,000 acres represent the universe in Delaware for salt marsh mosquito production of possible concern, and where the OMWM technique might be employed. They compose the "high marsh" zone within salt marshes as opposed to the "low marsh." The latter is typically dominated by tall-form salt marsh cordgrass and is usually flooded by tides twice per day, and, as such, is not salt marsh mosquito production habitat. The extent of low marsh habitat in Delaware is about 15,000-20,000 acres.

Approximately 44,000 acres of the 64,000 acres of high marsh have been parallel-grid-ditched, with grid-ditching starting in the early 1930s and maintained into the 1960s. Much of the low marsh acreage within Delaware has also been parallel-grid-ditched, despite low marsh not being mosquito production habitat. Of special note is that about 10,000 acres on Bombay Hook National Wildlife Refuge, established in 1937, were never parallel-grid-ditched.

Within Delaware's universe of 64,000 high marsh acres for potential salt marsh mosquito production, DMCS identified, in 1980, about 15,000 acres as moderate to severe larval habitat, almost all located downstate in Kent and Sussex counties. These 15,000 acres had a history of needing aerial larviciding from four to seven times per year. It was these 15,000 acres that were targeted for future OMWM work within a statewide scope, representing about 16% of all of Delaware's tidal wetlands. Approximately another 15,000 acres within this universe of 64,000 acres can, in a less severe manner, also produce problematic numbers of mosquitoes, needing aerial larviciding from zero to three times per year, but not at a frequency or intensity to warrant the cost and involvement of OMWM treatment. The 15,000 acres targeted for OMWM work typically contain high densities of "potholes" or tussocky sheetwater habitats, both being classic salt marsh mosquito larval habitats. About 9,000 of these 15,000 acres had been parallel-grid-ditched from the 1930s into the 1960s, but much mosquito production still occurred and required frequent larviciding. The remaining 6,000 acres had never been parallel-grid-ditched, and were almost all found in Bombay Hook National Wildlife Refuge in Kent County.

Regarding the 6,000 acres of severe larval production habitat on Bombay Hook National Wildlife Refuge, a policy decision was made by the U.S. Fish and Wildlife Service in the late 1980s to never allow any OMWM alterations within these 6,000 acres, thereby reducing our initial statewide 15,000 acres of OMWM-targeted areas to only 9,000 acres. The USFWS made this land management policy decision more on a philosophical basis rather than a scientific one. This is understandable since within the Northeast and mid-Atlantic states there is very little unditched salt marsh left, and what still remains the Service wants to maintain as undisturbed as possible. However, a consequence of this policy decision is that the USFWS must now commit to perpetually allow larviciding on Bombay Hook NWR, due to the severity of salt marsh mosquito production on the refuge and the its proximity to nearby populated areas. We can abide by this decision as long as we can effectively and practicably control, in some manner, the refuge's salt marsh mosquito production. Since our initial identification was made of 6,000 acres on Bombay Hook NWR for possible OMWM treatment, the DMCS has revised downward the amount of severe larval production habitat on the refuge, and today there are about 4,100 acres of such habitat that need frequent aerial larviciding.

Delaware's other national wildlife refuge, Prime Hook National Wildlife Refuge (PHNWR) in Sussex County (established in 1963), was extensively parallel-grid-ditched in the 1930s. Since PHNWR has been physically altered, the USFWS has permitted some limited OMWM work on this refuge. OMWM systems were installed by the DMCS in about 500 acres of refuge marsh during the late 1980s and early 1990s (in Units I and IV, respectively, at the northern and southern ends of the refuge), along with some additional minor OMWM work performed in the early 2000s in Unit I.

Figure 1 provides a statewide overview of OMWM's potential use in Delaware's tidal wetlands. Only two categories of high marsh habitats lend themselves to OMWM work – 1) about 9,000 acres of previously parallel grid-ditched marshes amounting to about 9% of state's tidal wetlands acreage, and 2) about 6,000 acres that were never grid-ditched, amounting to about 6% of state's tidal wetlands acreage (The latter primarily on Bombay Hook NWR, which by USFWS policy will probably never be treated with OMWM). It is clear in this diagram that DMCS does not intend to treat a large percent of Delaware's tidal wetlands with OMWM. Rather, it is selectively focusing on a relatively small percent where larval production is most severe and where OMWM work would be most warranted.

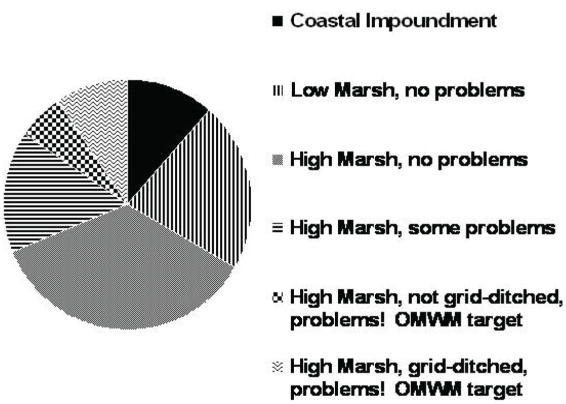

Figure 1. OMWM's potential statewide use in Delaware by habitat types. Only two categories of High Marsh habitats lend themselves to OMWM work – 1) some previously parallel grid-ditched marshes amounting to about 9% of state's tidal wetlands total acreage; and 2) some marshes that were never grid-ditched, amounting to about 6% of state's tidal wetlands total acreage (with the latter primarily on Bombay Hook NWR, and by USFWS policy to now never be treated with OMWM).

<u>Where is OMWM work done, and what's its implementation rate?</u>

DMCS has installed OMWM systems in Delaware on a wide variety of marshes in terms of land ownership. Much of our OMWM work has been done on private lands, including conservation-managed properties owned by The Nature Conservancy (TNC) and the Delaware Nature Society (DNS). Many private marsh landowners have invited and praised OMWM work not only for helping to eliminate or reduce larviciding over their wetlands, but also for the diverse wetlands habitats that are created or restored, particularly where there is an interest by a landowner in enhancing waterbird habitats (for waterfowl, wading birds, shorebirds). We have also done extensive OMWM work in state wildlife areas (e.g. Little Creek, Ted Harvey/Logan Lane, Milford Neck, Primehook, Assawoman) and in state parks (e.g. Cape Henlopen, Delaware Seashore). Marshes owned by local municipalities have been treated with OMWM. As already cited above, we have also done OMWM work on federal lands in Delaware at PHNWR. Essentially, we want to install OMWM systems wherever warranted to deal with severe salt marsh mosquito production problems regardless of who owns a property (since mosquitoes do not recognize man-made boundaries), and where our doing such OMWM work is practicable and permissible.

Of the 9,000 acres originally targeted for OMWM work in 1980, we have, over the past 28 years, treated about 7,000 acres with OMWM. This represents about 80% of the area we wanted to treat in 1980, which, as it happens, were permissible to be treat. We continue to work today on the remaining 20% (Note that the aforementioned 9,000 acres do not include the 6,000 acres originally targeted in 1980 on Bombay Hook NWR, and which now are not candidates for OMWM work due to a Service policy decision). Our OMWM installation rate statewide amounts to only about 200-300 acres per year. Thus, during any given year, we are affecting only about 0.2-0.3% of Delaware's tidal wetlands base.

Our OMWM projects take a while to realize for several reasons: time in securing landowner cooperation/concurrence, time for OMWM system planning and design, time for regulatory review and approval, and time for actual project installation. The DMCS employs two amphibious rotary excavators in our statewide program, along with several pieces of conventional equipment, (e.g. long-reach excavators, front-end loaders, bulldozers), all having relatively low ground pressures. We also pay a fair amount of attention to quality control when constructing our OMWM systems and this can slow down the installation rate, but we are comfortable with emphasizing quality over quantity.

One benefit of this relatively "go slow" approach in our OMWM work is that any new environmental disturbances associated with OMWM will occur during any given year on only a very small portion (0.2-0.3%) of Delaware's tidal wetlands, followed by a one to two year environmental recovery period. On a statewide basis, and with our estimating about a two year period for environmental recovery at OMWM-treated sites, at any given time there will only be about 0.4-0.6% of the state's tidal wetlands base subject to any adverse environmental impacts from initial OMWM installation work. Overall, any adverse impacts from OMWM installation to marsh fauna and flora are fairly temporary in nature and on a statewide basis relatively small and localized, such that any population-level adverse impacts within Delaware to non-target organisms are quite inconsequential.

Types of OMWM systems and alterations used in Delaware

Delaware makes use of a full range of OMWM alterations and systems, including:

1. "Open" tidally-connected ditches. This type of alteration primarily occurs in lower, more frequently flooded areas, and allows for daily, full tidal exchanges. Less than 10% of Delaware's OMWM work is done via "open systems" (essentially ditches about 30" wide and 30" deep directly connected to tide) out of concern for some potential adverse environmental impacts that overuse or poor placement of open systems can have. This is especially so in high marsh zones (whereby open tidal OMWM ditching can sometimes mimic the adverse environmental impacts of the old parallel-grid-ditches). Selectively re-cleaning and restoring to full tidal flow some of the old parallel-grid-ditch network in association with an OMWM project would also be considered as open system work.
2. "Semi-open" sill ditch outlets. Sill ditch outlets serve as shallow, partially restricted tidal connections (about 4-6" deep) for more landward OMWM pond and radial ditch systems behind the sill outlets. Sill ditches still allow for some daily tidal exchanges near times of high tide to help maintain good water quality within the more landward OMWM pond and radial ditches. These ditches also help to remove or eliminate "sheetwater" larval habitats within the marsh. Yet during low tides, sill outlets will help avoid any excessive lowering of the marsh's subsurface water table that might occur with fully open tidal ditches, and thus help avoid excessive marsh dewatering. About 45% of Delaware's OMWM work is done via sill systems.
3. "Closed" ponds and radial ditches. "Closed" systems are not subject to daily tidal exchanges, but rather are tidally flooded only during biweekly lunar/spring tides or by storm tides. OMWM ponds typically are about 0.1-0.25 acres in size and have irregular shapes, which is done to increase ecologically-beneficial edge effects and for habitat aesthetics. These ponds have fairly uniform shallow depths about 12-18" with sloping pond bottoms around the pond's outer margin when approaching marsh surface. About 10% of a pond's bottom area contains a sump up to 30" deep to help ensure fish survival during droughts or neap tide periods. Closed (non-tidal) radial ditches connecting to OMWM ponds are about 30" wide and 30" deep, and are used to provide fish access to outlying larval habitats. About 45% of Delaware's OMWM work is done via closed systems.

After a marsh is treated with OMWM, no more than about 10% of the marsh's original grassy area will have been converted into more open surface water habitats in the form of OMWM ponds and ditches, and such percent conversions are often much less than this. It is important to recognize that such a conversion is not a wetlands "loss" of any type, but rather a substitution of one type of jurisdictional wetland habitat for another, and typically is a very beneficial type of conversion, especially in previously parallel-grid-ditched marshes suffering from dewatering impacts.

More detailed descriptions of Delaware's OMWM systems, including guidelines for OMWM installation and use, are found in Meredith et al. (1985(c)). A general overview by Lesser (2007) of Delaware's approach to OMWM can be found on-line in our Mosquito Control Section's website (see references).

OMWM can play a role in salt marsh habitat restoration

The old parallel-grid-ditch approach to salt marsh mosquito source reduction often had an undesirable effect of draining or dewatering marsh surfaces, particularly for water held in natural shallow ponds or pannes. While such marsh drainage or dewatering might have been the primary purpose for installing parallel-grid-ditches in the 1930s and then maintaining them for several decades afterwards by govern ment programs trying to eliminate or reduce mosquito larvae habitats, open tidal grid-ditching also had an unavoidable corollary effect of eliminating (draining) larger marsh surface water bodies that did not produce mosquitoes. These natural shallow water areas often serve as important foraging or resting habitats for waterbirds (waterfowl, wading birds, shorebirds) and as nursery areas for estuarine fishes, crabs, shrimp, etc. This loss of such valuable fish and wildlife habitats was often doubly disturbing. In many areas the effects of parallel-grid-ditching still did not satisfactorily reduce larval production because many smaller larval habitats (e.g. "potholes") between the ditches (with grid-ditches typically spaced about 150 feet apart) were not drained and continued to produce large amounts of mosquitoes. Such areas often still needed frequent larvicide treatments. However, in many other areas the impacts of parallel-grid-ditching did help to somewhat reduce larval production but at the expense of some loss of valuable marsh surface water habitat as well.

The installation of shallow ponds and ditches in association with OMWM sill or closed systems when superimposed over previously parallel-grid-ditched marshes can help to restore some valuable fish and wildlife habitat. Colonization of OMWM ponds by lush beds of submerged aquatic vegetation (SAV, e.g. widgeongrass, *Ruppia maritima*) provides food for aquatic herbivores such as waterfowl, and SAV beds plus floating algal mats (e.g. *Cladophora*) in OMWM ponds provide good structural habitat for estuarine aquatic organisms (Mahaffy et al. 1985). The role of OMWM alterations for marsh restoration in a quantitative sense might not always fully restore or compensate for previously lost surface water habitats in a parallel-grid-ditched marsh. This restorative aspect is, however, almost always true at least in a qualitative sense. The OMWM technique is not viewed by regulatory agencies (nor by resource management agencies) as being a habitat restoration technique per se since OMWM is primarily a salt marsh mosquito source reduction method. This is a method that most wetland regulators want to see implemented with a minimum amount of marsh disturbance, for in a quantitative sense it is usually not possible to do the additional habitat manipulations that would be necessary to fully compensate for all the habitat loss caused by parallel-grid-ditching. The installation of OMWM sill or closed systems typically involves blocking or "plugging" some grid-ditches with marsh spoil. But wherever OMWM sill or closed systems are installed over previously parallel-grid-ditched marsh, the end result has more standing (or "permanent") water on the marsh than before.

The use of OMWM in marshes that have never been parallel-grid-ditched lacks the type of habitat restoration benefit discussed above, since such marshes have never been negatively affected by grid-ditching. OMWM would not have a habitat restoration component in such wetlands. However, depending upon one's perspectives, along with natural conditions found within any given undisturbed or unaltered marsh, the installation of OMWM systems might be viewed as some type of habitat enhancement for selected or favored marsh fauna (e.g. for waterbirds or estuarine aquatic organisms).

A case study of the impact of an old parallel-grid-ditch network is available from the Great Marsh near Lewes, Delaware (Meredith and Saveikis 1987). By comparing a set of aerial photos taken in 1927 (pre-parallel-grid-ditching) to a set of aerial photos taken in 1979 (post-parallel-grid-ditching), it was determined that the 2,000 acre Great Marsh contained 34 miles of natural tidal channels both before and after grid-ditching was done. However, the amount of artificial tidal channels (i.e. parallel-grid-ditches) in this 2,000 acre marsh went from none before grid-ditching to 157 miles after grid-ditching. Artificial tidal channels are now 4.6 times greater than natural tidal channels, clearly altering the hydrology of the marsh via drainage of larger marsh surface water bodies. Natural shallow-water ponds from 0.1-0.25 acres in size containing permanent standing water decreased from 78 ponds pre-ditching to only 9 ponds post-ditching. Ponds from 0.25-0.5 acres in size declined from 16 to only one; and all three ponds from 0.5-2.0 acres in size were drained. Overall change in the Great Marsh was a reduction in the number of shallow ponds >0.1 acres in size from 97 ponds in 1927 to only ten in 1979. The Mosquito Control Section performed OMWM work in the Great Marsh during the 1980s, involving our creating dozens of OMWM ponds. Of course we did this, however, only in areas of the Great Marsh where larval production was actually occurring, unlike the old parallel-grid-ditch approach that dug grid-ditches almost everywhere over the entire marsh, including of course in many lower marsh areas where larvae are not produced. In terms of marsh surface water habitat, our use of OMWM in the Great Marsh was at least a qualitative step in the direction of marsh restoration, if not a fully compensatory one in a quantitative sense.

OMWM provides effective mosquito control

In areas of heavy mosquito production, OMWM drastically reduces larval mosquito populations in almost all cases by >90%. OMWM is as effective as larvicide spraying for salt marsh mosquito control and once installed does not require repeated treatments. Early in our use of OMWM in Delaware we observed these excellent control results (Saveikis et al. 1983, Meredith et al. 1985a). Overall reductions in average larval densities per dip (i.e. per sampling effort) of 92% were observed, and the overall frequency of finding any larvae per dip (per sampling effort) was 78% lower. Systematic observations of larval production for three consecutive years following OMWM installation indicated excellent mosquito control, and, in an operational sense, whatever larvae were still produced would not have warranted larviciding. These findings were not surprising since they were similar to what had been earlier observed in New Jersey and Maryland.

Table 1 provides an example of the effectiveness of OMWM for controlling larval mosquito production for a specific case at Prime Hook NWR. Some mosquito production areas of Prime Hook's marsh in Unit I on the northern end of the Refuge were missed during initial OMWM treatment, and these areas continued to produce large numbers of mosquitoes for several years after the initial OMWM work was completed. An example of the intensity of larval production occurring in these areas is shown in the top half of Table 1 from the summer of 2000, with average larval dip counts on some sampling days of 8-30 larvae/dip, extending up to 80 larvae/dip. Whenever we encounter larval production that averages >5 larvae/dip over widespread areas, we operationally know that larviciding will then quickly be necessary in order to avoid eventual emergence of unacceptably high adult mosquito populations. After some remedial OMWM work was performed by the Mosquito Control Section at these sites during the spring of 2001, Table 1 on the bottom presents five-years' worth of post-OMWM average larval dip counts. This shows that, for both the OMWM features themselves and for wet marsh areas nearby the OMWM features, the average larval densities were always acceptably low (averaging <5/dip). OMWM installation now provides the level of larval control needed at these sites.

A striking example of the effectiveness of OMWM in controlling larval mosquito production also comes from Prime Hook NWR over a 22-year period (from 1985-2006) as shown in Figure 2. This example is not, however, for larval dip-count data, but rather from reduction in the amount of marsh acreage needing larviciding each year. During a 4-year period from 1985-1988 prior to OMWM's installation at Prime Hook NWR, the cumulative marsh acreage needing aerial larviciding during each pre-OMWM year ranged from about 2,000-8,000 acres per year. With reference to this, OMWM was later installed over about 500 acres of marsh within the 2,200 acres combined that compose Units I and IV at Prime Hook.

What then followed during a six-year period from 1989-1994, when OMWM work was undertaken in Units I and IV, was a drop in annual aerial larviciding acreage to a range of 100-2,500 acres per year. Then for the twelve-year period from 1995-2006 after the initial OMWM work was fully completed, annual larvicide acreage typically ranged from only about 50-300 acres per year with some small spikes to about 900 acres during 2000 and 500 acres during 2004. [The spikes in 2000 and 2004 were caused by our need to make larvicide applications to some impounded areas within Unit IV that usually do not

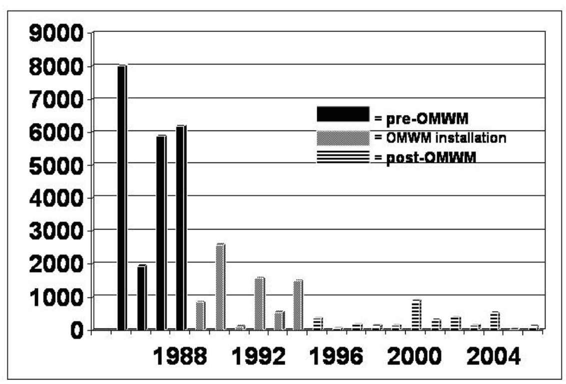

Figure 2. Annual larvicide acreage treated at Prime Hook National Wildlife Refuge over a 22-year period (1985-2006) within Units I and IV (combined total acreage of 2200 acres). Annual larvicide acreage reflects cumulative treatments within any given year, with any given marsh site receiving one or more larvicide treatments per year. OMWM systems were installed over a 6-year period from 1989-1994.

Table 1. Larval dip counts from "missed" OMWM areas within Unit I at Prime Hook National Wildlife Refuge, both before and after additional OMWM work. Several larval production areas in Unit I inadvertently were not treated during the initial OMWM effort, but remedial OMWM work was performed during the spring of 2001. Top of table shows representative larval mosquito production (from year 2000) prior to OMWM work (presenting some averages and ranges). Post-OMWM average dip counts in lower left column are from OMWM features themselves (OMWM ponds or ditches), and in lower right column are from wet marsh locations adjacent to OMWM features.

Pre-OMWM dip counts in OMWM-missed areas (average >5/dip = trouble!)
June 30, 2000 (potholes) = average 15-30/dip, >80/dip in many locations
July 19, 2000 (potholes) = average 8-15/dip near upland fringe, 1-3/dip in other areas
July 28, 2000 (sheetwater) = average 8-15/dip from many locations
Sept 5, 2000 (potholes & sheetwater) = average 1-3/dip from many locations

Post-OMWM Average # larvae/dip in OMWM features (n)				**Post-OMWM Average # larvae/dip in marsh adjacent to OMWM features (n)**		
May 2002	0	(50)		May 2002	0.00	(0-dry)
Sept 2002	0	(43)		Sept 2002	1.34	(38)
May 2003	1.18	(70)	fishkill	May 2003	0.57	(45)
Aug 2003	0	(55)		Aug 2003	0.03	(61)
June 2004	0	(46)		June 2004	0.45	(80)
Aug 2004	0	(42)		Aug 2004	2.10	(86)
May 2005	0	(69)		May 2005	0.70	(102)
Aug 2005	0	(79)		Aug 2005	0.79	(58)
June 2006	0	(62)		June 2006	0.00	(0-dry)
Sept 2006	0	(73)		Sept 2006	0.02	(198)

produce large numbers of mosquitoes and are not considered high priority areas for OMWM work. Additionally, these impounded areas are managed by the USFWS via "moist soil management" techniques for select wildlife habitat purposes, and as such are not physically amenable to OMWM treatment.] Larvicide treatments that occur on-refuge today within Units I and IV, with almost all of necessity limited mainly to Unit IV, primarily involve either aerial spot-spraying via helicopter, or ground larviciding via backpack sprayer. The sites on-refuge still needing minor larvicide treatments are primarily locations that unfortunately were missed during the initial OMWM work, or which, due to other refuge management objectives, could not accommodate (permit) OMWM alterations. However, the close proximity of these marsh sites to small communities along the shoreline of Delaware Bay still necessitates such larviciding work. The Mosquito Control Section is willing to undertake some additional "touch-up" OMWM work within Unit IV, and we have proposed this to the U.S. Fish and Wildlife Service. This would probably amount to about 100 acres of additional OMWM work. So far the Service has not accepted the Section's offer. It seems rather to prefer that we continue to spot larvicide as needed.

The overall reduction in average annual larvicide acreage at Prime Hook NWR from about 5,500 acres/yr before OMWM to only about 250 acres/yr after OMWM (Figure 2) represents about a 95% reduction in larvicide use within Units I and IV at Prime Hook, a quite laudable accomplishment. The outcome of our OMWM work on Prime Hook NWR prompted the U.S. Fish and Wildlife Service and the Delaware Division of Fish and Wildlife to hold a joint press conference on site in 1995 touting the success of this initiative. An important point to keep in mind is that prior to OMWM work starting on Prime Hook NWR in 1989, the refuge's marshes had been extensively and intensively aerially larvicided each year for many years, going back to before Prime Hook NWR was established in 1963 and then for each year after its establishment. Doing such larviciding achieved satisfactory larval control with concomitant reductions in adult mosquitoes. This was done for the sake of people who were living or visiting nearby or even in distant areas off refuge. As such, there was not then a huge reduction in adult mosquitoes coming off the refuge after completion of our installing OMWM systems on refuge. What did occur was a major shift in how larval control is achieved on refuge, going from a heavy past reliance upon larvicide spraying to an approach that now utilizes source reduction in the form of OMWM.

Non-target environmental effects of OMWM

The most significant environmental disruptions associated with OMWM involve excavating OMWM ponds and ditches and disposal of marsh spoil generated by the excavations. The aquatic features themselves associated with OMWM, namely small, shallow ponds and narrow, shallow ditches, are purposely created and viewed as beneficial alterations. However, what to do with excavated marsh spoil is often another matter. The trick with handling marsh spoil is to dispose of it in a manner that essentially allows for the recovery of marsh vegetation to closely mimic the original plant species composition, spatial occurrence, density and biomass that existed prior to OMWM installation. Careful effort must be made not to deposit marsh spoil too deeply over any given location. It is usually too expensive to transport excavated marsh spoil off site and dispose it in upland areas. Even perhaps where this could economically be done, a lot of transit of heavy equipment over the marsh in relocating large amounts of spoil would then damage marsh vegetation quite radically. Furthermore, it is often difficult to locate permissible disposal sites in uplands. As such, almost all OMWM-generated marsh spoil has to be deposited within the marsh where it was generated.

OMWM-generated marsh spoil can be beneficially used to fill in (to marsh surface level) potholes that serve as ideal larval habitats, thereby most desirably eliminating such habitat. Marsh spoil can also be used to help fill in stretches of parallel-grid-ditches that no longer serve any mosquito control purposes, or where there is a management objective to restore marsh habitats to more pre-parallel-grid-ditch conditions. But such type of pothole or ditch filling can accommodate only so much spoil. Most spoil associated with OMWM work is handled by its broadcast deposition over marsh surfaces in the form of a thin slurry of soupy mud generated by a rotary excavator’s cutting head, dispersed (in broadcast fashion) in bands up to 50 feet wide adjacent to an OMWM pond or ditch. Such deposition over a marsh surface (and of course over marsh vegetation too) is essentially a form of thin-layer disposal. If initial spoil deposition can be kept to depths <4” above marsh surface (which expert use of a rotary excavator can readily achieve), then in almost all cases and locations the original marsh vegetation will fully recover within 1-2 growing seasons, typically growing upwards through the thin overburden of rotary-broadcast spoil. There will be little reliance on the need for any new seed set or vegetative outgrowth from adjacent areas. If more conventional equipment (e.g. long-reach excavators, backhoes) is used to undertake OMWM excavations and generate marsh spoil, then considerable care must be taken to spread or “blade” the spoil over marsh surfaces at depths <4”, using front-end loaders or bulldozers to do so. After some time for spoil settling and oxidation of marsh peat within the spoil overburden, any final thickness of deposited spoil should result in a permanent increase in marsh surface elevation of <2”. If final elevations are unfortunately higher than this, than drier marsh surface conditions (as compared to pre-OMWM conditions) might result, especially in marsh zones having attenuated tidal amplitudes. Such drier conditions can invite some vegetation change that might be manifested by conversion of short-form cordgrass to salt hay habitat, or lead to colonization of salt hay areas by marsh shrubs, or even promote some incursions of phragmites grass. In most areas of peaty marsh soils, OMWM-generated spoil that is initially broadcast deposited at depths <4” will within 1-2 years “meld” back down to original marsh surface elevations, and wherever not fully melding back to original contours will still not result in any permanent marsh surface elevation increase >2” in height. This is all conducive to good recovery of a site’s original vegetation cover. However, care must be taken in marshes having soil with more mineralogical content (i.e. with relatively higher concentrations of sand, silt or clay and lower amounts of organic peat). In these situations soil deposited on a marsh surface might not readily meld to the original marsh surface level. When dealing with marsh soils high in mineral content, it is prudent to keep any initial spoil deposition <2" deep (Meredith et al. 1982, Meredith et al. 1985b, Saveikis et al. 1985).

The key to marsh recovery following OMWM treatment is having wetlands emergent vegetation return to pre-treatment conditions. Obviously, at marsh locations where OMWM ponds and ditches are newly created this will not happen within the footprints of the ponds and ditches, since the intention was to install these aquatic features for mosquito control purposes. Restoration of aquatic communities is an additional benefit of OMWM. Furthermore, even for intensively OMWM-treated marshes, the amount of open water vis-à-vis shallow ponds and ditches never exceeds a conversion of about 10% of a site's emergent wetlands vegetation. What is really occurring is substitution of one type of jurisdictional wetlands (shallow-water wetlands with marginal mudflats) for another type of jurisdictional wetlands (emergent grassy wetlands). If following OMWM treatment the original emergent vegetation returns in areas that were temporarily buried under OMWM spoil, then the original marsh faunal communities will also return. This will include marsh semi-aquatic or terrestrial invertebrates (e.g. snails, crustaceans, insects, spiders, etc.), marsh birds (e.g. sparrows, wrens, blackbirds, rails), or marsh mammals (e.g. voles). Wolfe (1996) provides a review of these types of OMWM impacts, and Lesser and Saveikis (1979) and Lesser (1982) provide pertinent information specific to Maryland Eastern Shore marshes.

An example of how marsh fauna will recover following OMWM treatment at sites where the original emergent vegetation cover also returns is provided by Meredith and Saveikis (1987) for passerine marsh birds. Table 2 presents the total abundances of marsh sparrows (for seaside sparrows, *Ammospiza maritima*, and sharp-tailed sparrows, *A. caudacuta*, at about a 3:1 ratio, respectively) and red-winged blackbirds (*Agelaius phoeniceus*) observed during late May flushing counts from the early 1980s at two experimental (demonstration) OMWM study sites in Bombay Hook NWR. Each study site consisted of 64 acres and had very similar marsh habitats. One site was treated with OMWM in the fall of 1981 and the other served as a continuous control. The first flushing census was performed in late May, 1981 prior to any OMWM work being done on the treatment site. This established a baseline relative to future treatment. Three more late May flushing censuses were then conducted at various times: The first was six months after OMWM in late May, 1982 (when OMWM spoil was still very fresh during the first spring following OMWM work from the autumn before, at a stage when very little emergent vegetation recovery had yet occurred, since a growing season had not yet happened). The second occurred in May, 1983 at 18 months post-OMWM treatment (or one full growing season). Finally, the third took place 30 months post-OMWM during late May, 1984 (or two full growing seasons) after OMWM. The 1981 census counts showed comparable numbers for pre-OMWM treatment and control sites for both marsh sparrows and red-winged blackbirds, establishing some good baseline conditions to then examine the impacts of OMWM alterations. Census counts during late May, 1982 plummeted by about 57% for marsh sparrows and by about 29% for red-winged blackbirds, while counts for both categories of birds remained about the same in the control plot. This was at a time when OMWM spoil still freshly covered much marsh surface within the OMWM treatment plot, and when there was not yet any time for emergent vegetation recovery.

It was estimated in this study that fresh spoil generated by OMWM work in the treatment site covered about half of the site's surface. Census counts for both marsh sparrows and red-winged blackbirds then rebounded in the OMWM-treated site during both late May, 1983 (after one full growing season post-OMWM) and late May, 1984 (after two full growing seasons post-OMWM), while census counts in the control site still stayed relatively constant throughout the entire study period. The number of marsh sparrows in the treatment site following one full growing season's recovery was well above the pre-OMWM count, but after two full growing seasons was almost identical to the pre-OMWM count. Red-winged blackbird populations recovered a little bit slower by the end of one full growing season, but after two full growing seasons were back to pre-OMWM levels. This study showed that marsh sparrows and red-winged blackbirds will not inhabit (i.e. not feed, rest or nest) nor frequent marsh areas relatively barren of emergent wetlands vegetation, such as occurs in marsh areas freshly covered with OMWM spoil. However, once emergent marsh vegetation recovers to pre-OMWM conditions along with faunal prey assemblages and environmental

Table 2. Total numbers of marsh sparrows (seaside sparrow + sharp-tailed sparrow) and red-winged blackbirds encountered during late May flushing surveys on two 64-acre study plots on Bombay Hook National Wildlife Refuge -- before OMWM installation (1981) and after OMWM installation (1982-84) for treatment plot, but with no OMWM installation on control plot. Numbers in parenthesis are average number of birds flushed per acre. (Meredith and Saveikis 1987)

	1981 Before OMWM	**1982 OMWM +6 months**	**1983 OMWM + 18 months**	**1984 OMWM + 30 months**
Sparrow spp.				
Control	175 (2.7)	160 (2.4)	204 (3.1)	177 (2.7)
Treatment	168 (2.7)	72 (1.1)	254 (4.1)	162 (2.5)
R-W Blackbird				
Control	45 (0.7)	40 (0.6)	45 (0.7)	52 (0.8)
Treatment	38 (0.6)	27 (0.4)	31 (0.5)	47 (0.7)

conditions, marsh sparrow and red-winged blackbird populations will then also return to pre-OMWM levels. In this particular case, avian recovery essentially occurred after only one full growing season post-OMWM, reflecting how rapidly original vegetation cover conditions had returned following OMWM work. This status was then also documented as having been maintained after a second full growing season.

OMWM systems if not carefully designed or installed can lead to undesirable vegetation changes. OMWM practitioners should take care to avoid this type of adverse change. Such an undesirable change is caused primarily by excessive drying of marsh surfaces. This can happen if a high marsh zone is too intensively treated with open tidal OMWM ditches (that then mimic the deleterious dewatering impacts of parallel-grid-ditching, having a net effect of lowering average height for the subsurface water table) or if OMWM spoil deposition is too deep or high. This makes marsh surfaces higher and less susceptible to tidal inundation. This excessive drying can also occur because of both types of unwanted impacts as cited above (i.e. excessive drawdown of the subsurface water table plus excessive deposition of marsh spoil). Such types of marsh drying can then allow for expanded growth (incursions) in high marsh areas of marsh shrubs (*Iva*, *Baccharis*) or even *Phragmites* grass. Causes of such unwanted "bush" or "phrag" invasions, along with avoidance measures to take when designing or installing OMWM systems, include:

1. Installing too many open tidal OMWM ditches in high marsh areas. Do not do this, but instead rely more on sill and closed OMWM systems in the high marsh.
2. Excessive sill depths, caused by installing sill outlets too deeply or by water scouring effects over time at sill outlets. Install sill outlet depths <4-6" deep, and periodically check for excessive scouring (and if need be, then remedy any excessive sill depths by use of sand-bags or marsh fill).
3. Excessive spoil deposition. It is important to keep initial OMWM spoil depths <4" deep (and even lower for marsh soil having higher mineralogical content), so that final melding of deposited spoil (from settling or oxidation) will result in marsh surface elevations <2" above pre-treatment elevations (and in most cases marsh surfaces will return via melding to original elevations).

<u>OMWM Project Regulation and Authority in Delaware</u>

Delaware's OMWM program operates under a federal Section 404 statewide wetlands permit issued by the U.S. Army Corps of Engineers on a renew able basis for five-year periods, and we have followed this schedule ever since 1979 (although some earlier statewide permits were issued by the Corps for only three-year periods). Review and approval of this five-year OMWM permit is handled by the Corps with advisory input from several federal and state regulatory or resource management agencies, all done within the context and under the auspices of Delaware's federal/state Joint Permit Processing Committee (JPPC), which also allows for full review and comment from the public as well. In issuing our statewide OMWM permit, the Corps wisely recognizes within the permit that our OMWM work will be conducted in accordance with Delaware's OMWM guidelines (i.e. per Meredith et al. 1985c). It must also be kept in mind that, as with all Section 404 wetlands permits, the U.S. Environmental Protection Agency (EPA) still has final "veto authority" over these types of Corps-issued wetlands permits. Additionally, any OMWM work proposed for National Wildlife Refuge lands also necessitates receiving a special use permit (SUP) from the U.S. Fish and Wildlife Service (or more specifically from the local refuge manager). This SUP, depending upon the scope of any proposed OMWM work on a refuge, could become quite involved, including possibly needing to perform [under the National Environmental Protection Act (NEPA)] an environmental assessment (EA), or even an environmental impact statement (EIS), as part of the SUP application.

Our OMWM work, and really all of our mosquito control work, is exempt by state statute from needing a State of Delaware wetlands permit when working in tidal wetlands (per action of the Delaware General Assembly during creation of the state's "Wetlands Act of 1973"). The Mosquito Control Section, however, still keeps our colleagues in the state's wetlands regulatory program (in DNREC's Division of Water Resources, Wetlands and Subaqueous Lands Section) quite involved in permit/project review and commenting relative to our OMWM work. Part of our getting the Corps' Section 404 wetlands permit to allow us to operate statewide in five-year cycles involves receiving from our state's wetlands regulatory program a Section 401 Water Quality Certificate. Another aspect of the Corps' federal five-year permit involving a state agency is our getting approval for coastal zone consistency review from the Delaware Coastal Management Program (in DNREC's Division of Soil and Water Conservation). A representative from the State Historic Preservation Office (SHPO), which is part of Delaware's Department of State, also participates in the Corps' permit review and approval process, providing comments regarding archaeological considerations and concerns.

The statewide OMWM permit from the Corps also has several special conditions that we must abide by when working under the permit. These include:

1. Our provision of documentation showing onsite mosquito production that warrants control for any specific marsh where an OMWM project is proposed.
2. Giving advance notice to the U.S. Fish and Wildlife Service for any OMWM project proposed to occur on state or private lands within one mile of a national wildlife refuge.
3. Undertaking some post-OMWM aerial photographic documentation of the OMWM systems that were installed, along with our doing some ground-level photography to document both pre- and post-OMWM emergent wetlands vegetation cover.
4. Reacting in a prescribed manner to any significant historical or cultural resource findings that we might unearth associated with OMWM excavations, etc.

Another major aspect of regulatory oversight in Delaware for our OMWM work is that as a condition of the Corps' five-year statewide OMWM permit, the Mosquito Control Section for each specific OMWM project site must convene a meeting of the Delaware Mosquito Control Advisory Committee (DMCAC). The DMCAC consists of the following participants:

1. OMWM biologist from the Delaware Mosquito Control Section.
2. U.S. Army Corps of Engineers (USCOE).
3. U.S. Environmental Protection Agency (EPA).
4. U.S. Fish and Wildlife Service (USFWS).
5. National Marine Fisheries Service (NMFS), part of the National Oceanic and Atmospheric Administration (NOAA).
6. Delaware Wetlands and Subaqueous Lands Section (DNREC Division of Water Resources), our state's wetlands regulatory agency.
7. Delaware Natural Heritage Program (DNREC Division of Fish and Wildlife) regarding issues for

any species that are of special concern.

8. Archaeologist from DNREC's Division of Parks and Recreation, in part to help oversee our OMWM agreement with the State Historic Preservation Office (SHPO).
9. Public lands managers where applicable, e.g. for OMWM work proposed to be done in state wildlife areas (involving Fish and Wildlife regional managers), state parks (involving park supervisors), or within one mile from national wildlife refuges (involving USFWS biologists) or upon national wildlife refuge lands (involving refuge managers), and for refuge-located projects where we have an SUP from a refuge manager to undertake OMWM work.

For each proposed OMWM project, the Mosquito Control Section presents to DMCAC our proposed OMWM system design (in the manner of a mapped layout) along with other supporting documents (e.g. aerial photos, larval production data, habitat descriptions, etc.). This information enables advisory review and comment by DMCAC members. Our proposed OMWM system designs might then be modified as warranted based upon comments received from DMCAC. If DMCAC members are not pleased by how we react to their input or concerns, they can then request to the Corps that their recommendations be adopted (as a possible Corps-imposed condition) before we could proceed. Depending upon the location, type, and extent or intensity of proposed OMWM work, a project-specific DMCAC review quite often will necessitate a field trip for DMCAC members so they can observe first-hand in the field our OMWM system proposal. Sometimes when a proposed OMWM project is relatively small or not very complicated, DMCAC review and comment can be achieved via an office meeting of DMCAC members, or alternatively merely by desk-top audits independently conducted by DMCAC members, using mapped and written information they receive from the Mosquito Control Section. It is safe to say, given the aforementioned processes, that OMWM work in Delaware is an intensively scrutinized, well-regulated activity.

The authority for the Mosquito Control Section to conduct OMWM work (as well as for all mosquito control work, whether using source reduction methods such as OMWM or other approaches such as insecticide use) derives from our enabling statute found in Delaware Code Title 16, Chapter 19. Our state-based statutory authority allows us to undertake OMWM work on state, county, municipality, or privately-owned lands (but not on federal lands) without needing permission or consent from the land manager or landowner to do so. There are provisions within this statute to provide advance notice to a landowner concerning our intentions to undertake OMWM work on his property. There are also provisions for a landowner to protest such intentions if he so desires, and to then be followed by a public hearing conducted by the DNREC secretary to try to resolve any concerns or grievances. The final decision about whether to proceed with any proposed OMWM work is then left to the DNREC secretary. However, as a matter of policy and practice, the Mosquito Control Section never exercises such authority in undertaking its OMWM work, but rather always first seeks the cooperation and concurrence of landowners before proceeding with OMWM. We operate this way since we know that marsh conditions immediately following OMWM installation can be rather unsightly and messy, in that some significant (but still only temporary) landscape disturbances indeed occur, and we do not want to impose this condition on any landowner unwilling to tolerate such temporary conditions. Other landowners simply do not want to put-up with a period of construction activity on their land and the coming and going of our staff and heavy equipment, even if this too is only temporary. In some cases there can also be landowners who do not want to accept OMWM's more permanent changes to their wetlands (although these types of folks are relatively uncommon).

For situations where a landowner will not give such cooperation and concurrence for OMWM work for whatever reasons, we will then simply continue to use larvicides to deal with mosquito production problems on their property (with the use of larvicides thereby avoiding any visual disruptions to a landowner's marsh, even if the visual disruptions of OMWM are only temporary in nature). We will use our statutory authority to do such larviciding without a landowner's permission, cooperation or concurrence, since we are mandated to deliver for public good some mosquito relief and human health protection by some means. In relation to our larviciding practices, and both thankfully and really as an absolute necessity for how we have to operate, landown ers do not have in statute a complaint or grievance mechanism to then stop or hinder our necessary larvicide (or adulticide) treatments.

Are we done yet with OMWM in Delaware?

Over the past 28 years (since the start of OMWM in Delaware in 1979), we have treated about 7,000 acres out of the 9,000 acres statewide originally targeted for OMWM work (not including the 6,000 acres at Bombay Hook National Wildlife Refuge that were also originally targeted for OMWM). This amounts to about 80% of our original statewide OMWM goal. If all OMWM work in Delaware were to stop tomorrow, we would probably say that "for the most part, we have now completed our OMWM work," and then simply "declare victory!" However, there is more necessary or desirable OMWM work to accomplish, which we still intend to tackle or at least consider, including:

* Maintenance of about 7,000 acres of existing OMWM work, almost all downstate within Kent and Sussex counties. OMWM systems typically have about 15-25 years of functional longevity before some upkeep is needed.
* Continue to "chip away" at the remaining 2,000 acres within our originally targeted 9,000-acre universe for OMWM work, almost all of which is downstate within Kent and Sussex counties:

  o About 1,000 acres left in small, widely scattered blocks.
  o About 1,000 acres left where we still need landowner cooperation/concurrence.

* Examine in better detail the potential need or opportunity for OMWM upstate in several New Castle County marshes.
* Treat salt marsh mosquito larval habitats newly forming in upland fringe areas that are caused by relative sea-level rise (rising about 1-2" per decade).
* Try to make more use of OMWM within coastal impoundments. However, in terms of achieving good control, this is more challenging to do than in open marshes. Potential target impoundments include (occurring in New Castle, Kent, and Sussex counties):

  o Thousand-Acre Marsh
  o Augustine Creek
  o Taylor's Gut
  o Port Mahon
  o Little Creek
  o Logan Lane (building upon some OMWM systems already installed)
  o possibly Prime Hook NWR (within grid-ditched areas of Units II and III)
  o Assawoman

* Possibly reconsider trying to install some OMWM systems at Bombay Hook NWR (up to 4,100 acres). Given the Service's current OMWM use policy, however, this is not probable.

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