Open Marsh Water Management
A Source Reduction Technique for Mosquito Control

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This article discusses the techniques of Open Marsh Water Management, a management tool used in coastal saltmarshes to control mosquitoes, improve habitat resources for fish and wildlife, and restore saltmarshes to the hydrological conditions as existed prior to the 1930's and the impacts of parallel grid-ditching.

In Delaware, mosquito control is performed through the multi-disciplinary techniques of Integrated Pest Management (IPM) that advocates and practices (in this preferential order): 1) *source reduction* (elimination of mosquito breeding sites); 2) *surveillance* (determining mosquito population sizes and in turn directing the need and specific areas for control by insecticides); 3) *larviciding* (controlling immature mosquitoes at the aquatic stages when they are highly susceptible using EPA-registered insecticides); and lastly 4) *adulticiding* (controlling adult mosquitoes using EPA- registered insecticides). While source reduction is the preferred method of mosquito control, in some situations and specific circumstances, source reduction is not a viable method of mosquito control; and as such, other forms of control such as larviciding and adulticiding must be employed. The remainder of this article discusses the techniques of source reduction on coastal saltmarshes.

What Is Source Reduction? All adult mosquitoes start life in water. The *source* of adult mosquitoes found around the home commonly arise from nearby clogged raingutters, used tires, abandoned swimming pools, un-maintained bird baths, and other containers that hold water for 5 or more continuous days. As such, the most effective means of controlling a *local* (around the home) mosquito population is to remove this standing water. Elimination of this mosquito-breeding habitat is the most basic form of source reduction and more effective than larviciding or adulticiding activities.

While it is important to control smaller yet local mosquito breeding issues, the single largest source of problematic mosquitoes in Delaware are the coastal saltmarshes along Delaware Bay and around the Inland Bays. Mosquitoes arising from these wetlands, with the most abundant species being the Common Saltmarsh Mosquito or *Ochlerotatus sollicitans*, have a typical flight range of 5-8 miles (and documented up to 40 miles) from the breeding site, are very aggressive day and nighttime biters of humans and domesticated animals, and are competent at transmitting several types of diseases.

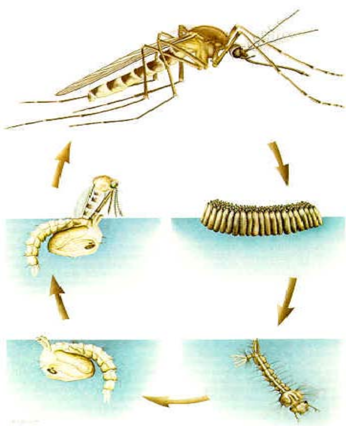
Saltmarsh mosquitoes of the *Ochlerotatus* genus have a unique life history in that females lay their eggs on moist muds within shallow depressions in the saltmarsh (see Figs. 1 & 2), rather than depositing eggs on standing water surfaces as performed by many other species of mosquitoes. These depressions can be as small as a coffee cup with others up to 1/10 of an acre in size, and range in depth from 2”-10”. A typical saltmarsh can have several hundred to several thousand of these potholes. The common feature of these potholes is that they all have a 10-14 day “wet-dry-wet” cycle during the summer months, where the wet portion of this cycle is driven by lunar tides and rainfall, and the dry portion is driven by high rates of evaporation.

Fig. 1: Aerial view of mosquito breeding potholes on a saltmarsh. Photo taken from 300-ft altitude. Larger potholes are 30 – 40 ft. diameter. Many of the small and much more numerous mosquito-breeding potholes on this marsh are not apparent due to altitude.

Fig 2: Close-up photo of a mosquito-breeding pothole. A depression of this size can produce over 1,000 mosquitoes about every two weeks, in synchrony with marsh surface tidal flooding, or as triggered by rainfall filling.

When the potholes become dry, the female mosquito lays 50-200 individual eggs on the moist mud (see Fig. 3). After several days of an obligatory drying period, eggs are inundated with water and hatch into the first of five aquatic stages (4 larval stages plus a pupal stage), followed by adult emergence, with the immature life cycle taking from 7-10 days to complete depending upon water temperature. Immediately upon emergence, adults rest on nearby grasses to allow hardening of the exoskeleton. Mating occurs on the saltmarsh and the majority of the female population then migrates to upland areas in search of a bloodmeal, a source of protein used to develop eggs. With this protein, a single female can lay up to 200 eggs, but less than 15% of this amount without it. After obtaining the bloodmeal, the female returns to the saltmarsh, lays her eggs, and she again returns to the upland in search of another bloodmeal. Some longer-lived females can repeat this egg-laying cycle up to 3 times before death. It is these longer-lived and multiple-feeding individuals that are more capable of transmitting mosquito-borne diseases, in having acquired a disease organism such as a virus with a first or earlier bloodmeal, and then passing the disease organism onto another animal when the female mosquito takes a second or later bloodmeal.

Fig. 3: Life cycle of a saltmarsh mosquito. This cycle take 7-10 days to complete, and at the population level is performed 1-2 times per month from April through October.



Where on the Saltmarsh Do Mosquitoes Lay Eggs? Delaware has approximately 90,000 acres of saltmarsh that can be subdivided into three general categories: 1) intertidal saltmarsh or "low" saltmarsh; 2) high saltmarsh; and 3) coastal impoundments. Intertidal saltmarshes occur slightly below the elevation of mean daily high tide, and as such are typically flooded twice per day. This type of marsh is dominated by "saltmarsh cordgrass" (*Spartina alterniflora*) vegetation, and due to the daily tidal flushing is usually not good mosquito breeding habitat. This type of marsh accounts for approximately 80% of the total 90,000 acres.

The high saltmarsh is characterized by the "salt hay"(*Spartina patens*) grass and other types of plants, has a slightly higher elevation, and as such is flooded less frequently by tide – generally only a few flooding events per month associated with the full or new moons. Since slightly higher, the high marsh not only lacks daily tidal exchanges, but due to thick grasses and limited channels also precludes the free movement of mosquito-eating fish throughout the high marsh when flooding does occur. In addition, it is within this vegetation zone that the previously described mosquito-breeding potholes occur. Approximately 10-15% of Delaware's saltmarshes are classified as high marsh, yet account for more than 80% of the yearly saltmarsh mosquito production.

Finally, Delaware is home along the coast to approximately 10,000 acres of State, Federal or privately-owned saltmarsh impoundments. An impoundment is defined as any wetland or body of water that is created by the formation of an earthen dyke around the perimeter of a wetland surface such that water levels inside the dyke can be manipulated and maintained. Many State-owned impoundments in Delaware were originally constructed for the benefit of mosquito control and waterfowl habitat during the 1950's and 1960's. Manipulating and maintaining the standing water levels on impounded marshes at a higher than normal level eliminated the wet-dry-wet cycle needed by saltmarsh mosquitoes, and as such greatly reduced mosquito production. Today, these same impoundments are managed slightly differently for the benefit of many wildlife species and multiple uses, and sometimes breed more mosquitoes when compared to the 1950's-1980's management scheme, but the level of breeding observed today is still less than pre-impoundment numbers.

The majority of mosquito control source reduction activities takes place in high saltmarsh habitats, while some source reduction is also performed within impoundments.

How Intense Is Mosquito Breeding on the High Saltmarsh? As previously stated, the high saltmarsh accounts for approximately 80% of the total mosquito breeding in Delaware, involving an estimated 10,000 – 15,000 acres of breeding marsh. While at first glance this land area might not appear to be overwhelming, it is nonetheless equivalent to a single land mass measuring 10 miles long and 2 miles wide, with all of it breeding mosquitoes! Furthermore, each of these acres has the potential to produce approximately 1 million adult mosquitoes on 2-4 week intervals from April – October! And these mosquitoes have a routine and typical flight range of 5-8 miles, with distances up to 15 miles not being uncommon! So even if you do not live within eyesight of a saltmarsh, many of the mosquitoes around your home may be unwelcome arrivals from distant marshes. For all of these combined reasons, the State's Mosquito Control Section aggressively performs source reduction activities on these saltmarshes in ways that not only effectively controls mosquitoes, but also benefits wildlife and fisheries.

A Short History of Mosquito Control and Wetland Management. Beginning in the 1930's under the direction of then President Franklin D. Roosevelt and his economic-rebuilding "New Deal" initiatives, the Civilian Conservation Corps (CCC) hand-dug thousands of miles of parallel "grid ditches" (see Figs. 4-6) on 2/3's of Delaware's saltmarsh, spacing these ditches about 150 feet apart with the intention of removing standing surface water where mosquitoes might breed. The sound belief was that "without water, mosquitoes can't develop." While the theory was correct, the CCC mosquito control program's ditches were only moderately effective, since many breeding potholes where not drained dry, and the long-term negative ramifications of parallel grid-ditching on wildlife and saltmarsh ecosystems were dramatic. Many intertidal, non-mosquito breeding, low saltmarshes were needlessly ditched; and naturally occurring non-tidal saltmarsh ponds that once 'poke-a-dotted' the saltmarsh landscape and provided wildlife habitat, and supported submerged aquatic vegetation (waterfowl food) and macro-invertebrates (shorebird foods), were drained. In addition, since entire marshes were de-watered, saltmarsh vegetation communities were changed in some locations in large-scale visible manner, converting from a prairie-like salt hay and cordgrass landscapes into wetlands fragmented by shrubs and bushes. In addition, this dewatering negatively affected muskrat and waterbird populations, particularly through the draining of larger natural ponds. By the early 1960's, many individuals, including professionals in the mosquito control field, increasingly began to fully appreciate wetland values and functions, and questioned the value of parallel grid-ditching.

Fig. 4: Beginning the digging process of a parallel grid ditch in the 1930's along a Delaware coastal bay. By the late 1940's, this process became mechanical with cranes and crawlers.

Fig. 5: Hand digging a parallel grid ditch through *Spartina alterniflora* in the 1930's. Motivations for this effort were in part driven by putting people to work during the Great Depression, and of course for removing water from saltmarshes to reduce mosquito production – at the time, a wetland area such as this was considered to be a "wasteland."

Fig. 6: Network of parallel grid ditches located near Bowers Beach, Delaware. Photo taken in 1997; ditches were last cleaned in mid 1960's and remain functionally tidal today.

A New Beginning in Wetland Management and Mosquito Control. Recognizing the faults of the parallel grid-ditching techniques, a new mosquito control source-reduction technique called Open Marsh Water Management (OMWM) was developed and adopted, starting in New Jersey in the late 1960's, and then further developed and refined throughout the Northeast and Mid-Atlantic during the 1970's and early 1980's – this new approach has now been extensively studied by State, Federal and university scientists. The OMWM method involves the selective installation of small, shallow ponds and inter-connecting ditches superimposed on known mosquito-breeding habitats, in an effort to manage water conditions on saltmarshes to the extent that pothole breeding habitats with their wet-dry-wet cycles are eliminated; and any newly created permanent water habitats formed by OMWM ponds and ditches are unattractive for mosquito egg deposition, while simultaneously improving habitats for mosquito-eating larvivorous fishes. The principal biological control agent in OMWM systems in Delaware and elsewhere in the Mid-Atlantic is the native saltmarsh killifish or mummichog, *Fundulus heteroclitus*, which naturally quickly invades via tidal flooding any newly-created OMWM pond or ditch. In OMWM systems, scattered mosquito breeding depressions and sheetwater habitats are connected through pond and ditch excavations to allow unimpeded water flow and predatory fish movement, while isolated potholes are often filled with natural marsh soils to eliminate these smaller-sized breeding depressions.

The goals of OMWM are as follows: 1) control of saltmarsh mosquitoes; 2) reduce insecticide applications, and; 3) habitat enhancement for saltmarsh fish and wildlife. Efforts made towards achieving these applaudable goals must be made in a manner that does not have negative or secondary impacts to other saltmarsh resources. Of particular concern is that OMWM must not alter or adversely affect saltmarsh vegetation communities by significantly lowering subsurface marsh water levels, or by depositing any excavated marsh spoil too high.

In light of the sideboard parameters described above, in virtually all cases OMWM systems in Delaware are installed in a manner than creates infrequently-flooded or semi-tidal permanent water bodies in the high marsh. The type of OMWM system installed is largely determined in consideration of 2 factors – type of mosquito breeding being addressed, and concerns over long- term water quality within the OMWM ponds and ditches. Areas of the saltmarsh possessing high densities of individual mosquito-breeding potholes are most effectively managed via OMWM systems that make extensive use of infrequently-flooded ponds and spur ditches. On the other hand, mosquito breeding found in a large shallow "salt pannes" (large depressions up to a few acres in size, with a rather uniform shallow depth of only a few inches) may be best treated with a "sill" outlet that creates a semi-tidal OMWM system, where a small 4"-6" tidal range is created within the OMWM ponds and ditches landward of the sill, in which ephemeral sheetwater is removed from the marsh surface during ebb tides, thereby eliminating mosquito-rearing habitat.

Water quality concerns also dictate OMWM system designs, since *good water quality = good fish survival = good mosquito control*. Without a healthy predatory fish population, excavated OMWM ponds and ditches can sometimes become mosquito-breeding habitats. As such, successful OMWM systems rely upon periodic water renewal to maintain good water quality. In the high marsh, this might be only as infrequently as a few times per month in conjunction with tidal floodings near times of full or new moons, which actually then mimics what happens in natural ponds and channels found in high marsh areas. This is particularly important during the summer months when high rates of biological decay lead to low dissolved oxygen levels, and other factors can lead to the oxidation of sulfur and formation of sulfuric acid, causing pHs as low as 3.0. Both such conditions can kill saltmarsh fishes, and hence diminish good mosquito control. As such, knowledge of local saltmarsh hydrologic conditions, flooding cycles, and surface elevations and topography is necessary for designing a functional and productive OMWM system. To this end, OMWM systems found in close proximity to a medium or high energy tidal source are typically installed as infrequently-flooded systems, since tidally-borne estuarine water predictably crests the creek banks and floods the saltmarsh at least a few times per month on lunar cycles. It is this flooding that rejuvenates water quality in such OMWM systems. On the other hand, many marshes (or portions of larger marshes) in Delaware are located in areas where even these infrequent tidal exchanges might not occur often enough to maintain good water quality. These tidally-limited marshes may be completely natural areas, whereas other tidally- limited marshes might be anthropogenically created through road and canal construction or other means of habitat disruption. On marshes where at least some surface flooding cannot be predicted or reliably expected, water quality in OMWM systems can be ensured via installation of the semi-tidal sill outlets. The installed sills allow a limited amount of tidal exchange, while still maintaining a stable baseline water level within the designed system.

The primary advantage of OMWM is the reduction in mosquito-control insecticide applications. But while working towards this commendable goal, it is also important while designing and installing OMWM systems that great care be taken to ensure that the OMWM alterations do not adversely affect other saltmarsh ecological functions or significantly alter established vegetation patterns. Of particular concern is the alteration of pre-OMWM vegetation communities by significantly changing relative subsurface water levels, either through excessive drainage or excessive spoil deposition in association with creating the OMWM features. Saltmarsh vegetation communities occur in relatively distinct zones governed by water availability – low areas of the saltmarsh that receive daily tidal exchanges and which are well traversed by tidal channels will have a fluctuating sub-surface water table that varies by each tide stage, and are typically dominated by *Spartina alterniflora* (saltmarsh cordgrass); while slightly higher areas of the marsh that receive limited tidal exchanges often exhibit subsurface water levels that stay near the marsh surface for quite some time following infrequent tidal inundations, but then gradually become lower over time, and are typically dominated by *Spartina patens* (salthay) or other high marsh grasses. *Finally, there are* even higher areas of the saltmarsh that, save storm tides or unusually high lunar tides, receive very little tidal exchanges, and which typically have a more permanently lowered groundwater table, dominated by woody bushes or shrubs, giant reed or *Phragmites* grass, and other more upland-oriented vegetation.

Installation of OMWM systems, regardless of the technique's mosquito control effectiveness, must be done in a manner that does not significantly contribute to marsh vegetation changes. Towards this end, spoil management is of paramount concern. Excavated materials ("spoils") are deposited on site. Some of this material is used to fill adjacent mosquito-breeding potholes, while the remainder is spread in a thin veneer across the saltmarsh surface. Spoil that is deposited to an initial depth of no more than 4" will eventually settle to a depth of 2" or less, and when such is achieved then does not cause vegetation change on most saltmarshes. Spoil deposited at depths greater than this amount may lead to a lower *relative* water table and drier surface soils, which in turn may lead to vegetation changes towards species such as *Phragmites* grass or *Baccharis* and *Iva* shrubs. In addition to spoil deposition, physical removal of subsurface water and lowering of the subsurface water table through a network of created tidal ditches can also change marsh vegetation communities, often times more significantly and over a larger area than excessive spoil deposition alone. As such, open tidal ditches in OMWM are very judiciously employed, limited primarily only to those relatively unusual areas of *S. alterniflora* saltmarsh that still breed mosquitoes, but which characteristically also have more variable natural swings in subsurface water table elevations, and thus are not so prone to vegetation changes that open tidal ditches might induce. It should be recognized that a single tidal ditch transversing a low *S. alterniflora* saltmarsh will usually have no adverse effects on marsh vegetation communities, and will actually increase productivity of native communities through increased nutrient cycling, and can also increase marsh faunal diversity by allowing better access for estuarine organisms; while a network of open tidal ditches through a high *S. patens* marsh will most certainly contribute to vegetation changes, via a permanent lowering of the subsurface water table. For a more detailed scientific discussion on the how's and why's of OWMW systems and their functioning, please see the technical article from the journal Wetlands that's posted on the Mosquito Control Section's website at: http://www.fw.delaware.gov/NR/rdonlyres/936CCDC4-4B37-4730-A550-0878E1FA556A/0/MosquitoControlWetlands198560.pdf

Non-Mosquito Control Benefits. Parallel grid-ditching on Delaware's saltmarshes removed many of the non-tidal ponds that once 'poke-a-dotted' the marsh landscape and provided a significant amount of wildlife habitat. These ponds provided protected feeding, resting and nesting habitats not found near the higher energy tidal creeks and rivers along the Delaware River or Bay. The complete extent of these once-present marsh water habitats will never be fully replaced, but the results of OMWM systems do provide some mitigation in replacing lost or restoring some stable, permanent water habitats in the high saltmarsh. As an added benefit to mosquito control, many of these shallow water ponds (and even ditches) are quickly colonized by widgeon grass (see Fig. 7), macroinvertebrates and fish (see Fig. 8), all of which are very attractive foods for waterfowl and other waterbirds, as well as for estuarine fishes. OMWM habitats also provide ideal nesting for ducks and geese, plus lodging locations for fur-bearing mammals. During the excavation process, it is typical to observe many species of shorebirds foraging within OMWM pond-edge mudflats and in freshly-deposited spoil areas. Waterfowl and wading birds will utilize OMWM ponds and ditches as feeding habitats, with ducks sometimes found nesting on islands left in the middle of OMWM ponds.

How is it Done? OMWM ponds and ditches are typically installed using a specialized piece of heavy equipment called a "rotary excavator" (Fig. 9). This machine is similar to a typical hydraulic excavator found on any construction site, but is structurally modified for use on saltmarshes by the addition of 2 large water-tight tracking pontoons that not only makes the unit amphibious, but also reduces the ground pressure to less than 2 psi (a 175-pound human has a foot imprint of approximately 3.8 psi). Pond and ditch excavation is realized through a snowblower-like hydraulically controlled rotary cutting head (Fig. 11) powered by a dedicated 175-hp diesel engine. The cutting head emulsifies soils with available marsh water and shoots this mixture across the saltmarsh in a thin veneer, broadcasted up to 40 feet from the site of excavation (Fig 12). Thus, materials (spoil) excavated from created ponds and inter-connecting ditches are deposited and spread on-site in a thin veneer adjacent to the excavated OMWM features. This material is carefully managed in an effort to ensure that any marsh elevation changes do not cause widespread, undesirable vegetation changes as previously described. Depending upon the spoil type, revegetation typically requires 1-2 years in marshes of high organic content (see Fig 12), and in 1-3 years in marshes with higher sand and clay content such as what as exists around the Inland Bays. Overall, the Delaware Mosquito Control Section has been extremely successful in installing and managing OMWM systems. Inspections of 4-year old OMWM systems by the U.S. Fish and Wildlife Service and U.S. Army Corps of Engineers have found good vegetation recovery and no vegetation changes of any concern – the reviewing staff were extremely satisfied and encouraged by the OMWM techniques practiced in Delaware.

Not all OMWM excavation work is done by the rotary excavator, since in some locations marsh soils that have high sand or clay content might not be easily dug with the rotary's cutting head, necessitating use of more conventional excavation equipment like bulldozers or cranes to construct the OMWM features, especially for OMWM ponds. Conventional equipment is also often employed to help spread and smoothly grade or level-out excavated spoil, often involving use of a front-end blade on a marsh ATV, once again primarily to treat marsh spoils having high mineral content. Finally, source reduction work involving creating shallow ponded areas and relatively narrow circulation channels within the interiors of coastal impoundments is also performed, involving an amphibious machine known generically as a "cookie-cutter" that has rotary cutting blades, but this is best left for another story.

Fig. 7: Widgeon grass collected from shallow-water OMWM pond 1 year after excavation.

Fig. 8: Collection of mosquito-eating fishes and grass shrimp from an OMWM pond.

Fig 9: Hydraulic rotary cutting head. Spoil enters the front, is emulsified with available marsh water, and the slurry is discharged from the port located on the left-hand side of the cutter head.

Fig. 10: A recently completed but not yet re-vegetated OMWM pond located on lands owned and managed by The Nature Conservancy. This aerial photo was taken from an altitude of 300 ft., 3 days after excavation. Note the presence of spoil distributed from 40-50 feet on both sides of each pond. Full revegetation is expected to occur in 1 – 2 years.

Fig 11: This is an aerial photograph of the same OMWM system shown in Figure 11 but taken 4 years after the original excavation. Notice the full vegetation recovery around all OMWM excavations. Prior to the CCC-era grid ditching of the 1930’s through 1960’s, open bodies of water (ie “non-tidal ponds”) were typical throughout saltmarshes. Tidal ditches largely removed these features from saltmarshes. The techniques of OMWM restore these non-tidal bodies of water back to saltmarshes offering numerous wildlife management benefits to include waterfowl, wading bird, shorebird, fur-bearing mammal and aquatic invertebrates.

Fig 12: This is a close-up aerial photograph of the same OMWM system shown in Figures 11 and 12.

Effectiveness? It has been our experience that properly designed and functioning OMWM systems result in 95-98% mosquito reduction – this favorably compares to the best-expected 90% mosquito control found with larvicide spraying. In addition to being more effective, OMWM is a less expensive form of mosquito control as compared to repetitive larviciding. OMWM also returns standing water and valuable wildlife habitats to saltmarshes removed during the CCC-era. In summary, OMWM systems have been documented in the scientific literature and observed in Delaware to provide effective mosquito control, while restoring saltmarshes to pre-grid ditching environments by providing increased wildlife and fisheries habitats. OMWM is a win-win program for cost-efficient mosquito control and Delaware's wetland resources.

Fig 13: This is a "BEFORE" photograph of a saltmarsh located in Rehobeth Beach, DE taken in 2001 before OMWM was installed in 2003. In this photograph, the saltmarsh is being treated with a bacterial larvicide for the control of larval mosquitoes. This particular saltmarsh is located within an upscale residential neighborhood called "Pine Bay". Notice the large mosquito breeding potholes to the left of the applicator.

Fig 14: This is the "AFTER" photograph of the Pine Bay saltmarsh. OMWM was installed in 2003. As evident in this 2007 photograph, the vegetation has fully recovered. The house in the background of this photo was not present in the 2001 photo but the dead swamp oak tree in the background of each photo serves as a position reference. These type of non-tidal ponds installed on saltmarshes mitigates the loss of naturally-occurring, non-tidal ponds found on saltmarshes prior to CCC-era grid ditching from 1930's to early 1960's.

Fig 15: A ground-level photograph of an OMWM system located on the Delaware Coastal Bays south of Dewey Beach. This pond was installed in 2002 and the photograph was taken in 2007. As a point of interest, just before this photo was taken, 5 black-ducks took flight from this pond being used as a feeding/resting area.

Fig 16: A small OMWM pond near the Indian River Inlet. This pond was installed in 2002 and this photograph was taken in 2007.

Fig 17: A series of 3 OMWM ponds located on one of the State's larger saltmarshes near the Mispillion River. Only selective portions of this large saltmarsh were breeding mosquitoes and therefore, only these breeding portions were treated with OMWM. This OMWM system is 8 years old. These OMWM ponds, while primarily installed for mosquito control, also serve a wetland restoration purpose by mitigating the loss of non-tidal ponds subsequent to CCC-ear grid ditching.

Fig 18: A low level aerial photograph of a 6 year old OMWM system installed on the U.S Fish & Wildlife Service, Primehook National Wildlife Refuge. Dominate vegetation recovery at this site is *Spartina patens*. The density of *S. patens* at this site after OMWM is higher than prior to OMWM installation.

Fig 19: This is a large OMWM system consisting of multiple OMWM ponds located on lands owned and managed by The Nature Conservancy. These ponds were installed in 2001. The mosquito breeding in this saltmarsh was tremendous before OMWM installation. After OMWM installation, this site has not been found to be breeding any mosquitoes and does not require chemical larviciding. The dead Phragmites cane on the upland edges of this photo were not promoted or killed by OMWM installation but rather killed by the aerial-application of the herbicide glyphosate. After several applications and growing cycles, more native and beneficial floral communities return.

Fig 20: OMWM Ditch installed in November 2006. This ditch was 8-months old at the time of this photograph being taken. Notice the full vegetation recovery.

Fig 21: This is a small OMWM pond located on the Primehook National Wildlife Refuge. This pond, like others nearby, contains a high density of SAV grasses.

Fig 22: An aerial photograph of a series of OMWM ponds and ditches installed at the Primehook National Wildlife Refuge. These OMWM systems are the same shown in Fig 21. There are approximately 8 small OMWM ponds visible in this photos and several OMWM ditches connecting ponds-to-ponds and ponds-to tidal sources.

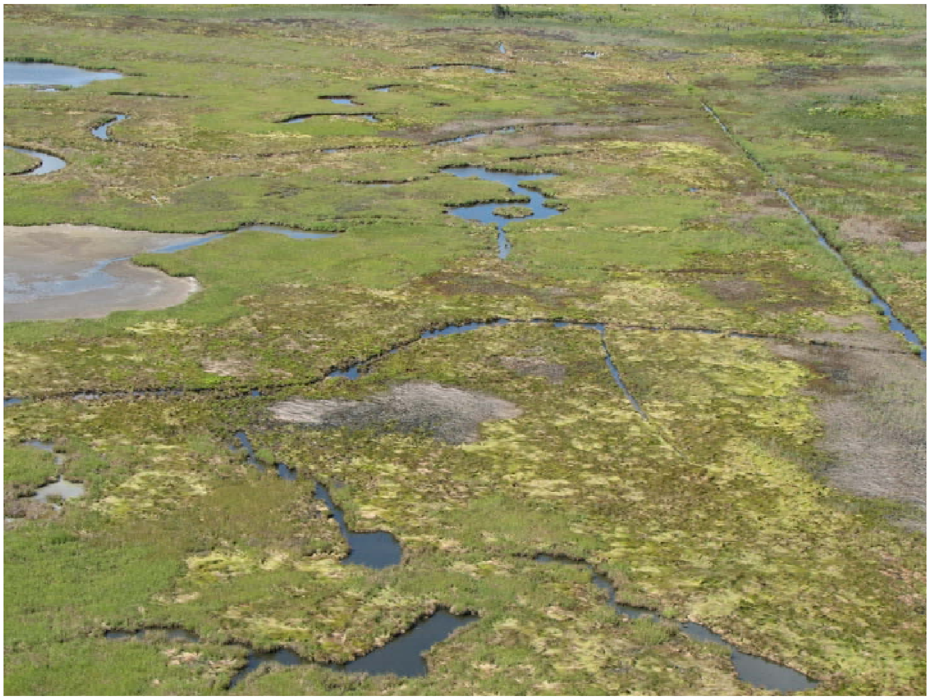


Fig 23: This is OMWM system is just 3-days old as evident by the spoil visible through.   Notable are the 3 major components of OMWM evident in this photograph: an OMWM pond, ditch and sill. The pond is in the background and has an "island" left within the center, the ditch is located directly off the pond and continues to the foreground of this photo, and a sill is located where this man is standing. The sill allows daily exchange of tidal water to ensure fish health and year-round survival.

Fig 24: This is a small OMWM pond located in the State-owned Milford Neck Wildlife Management area.

Fig 25: An OMWM pond located at the saltmarsh/upland interface.

Fig 26: This is a semi-tidal OMWM ditch.

Fig 27: A small OMWM pond located on the Primehook National Wildlife Refuge.