# OPEN MARSH WATER MANAGEMENT: A REVIEW OF SYSTEM DESIGNS AND INSTALLATION GUIDELINES FOR MOSQUITO CONTROL AND INTEGRATION IN WETLAND HABITAT MANAGEMENT

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ABSTRACT: Open marsh water management (OMWM) is a method of saltmarsh mosquito control that advocates long-term water management through the use of selective channel and pond creation as opposed to indiscriminate ditching and drainage or temporary chemical insecticide control. This technique has been used for over 40 years in certain areas of the eastern United States and similar techniques have been utilized in other parts of the world. The use of OMWM has been extensively studied for target and non-target impacts and has been shown to provide excellent control of mosquitoes and to have neutral to beneficial impacts on selected marsh resources with a concomitant reduction or elimination of chemical insecticide use. Guidelines and procedures for several states have been developed and provide a useful template for agencies developing a course of action for mosquito control. This paper is a culmination of previously published guidelines, studies and reviews which can be used by a new generation of mosquito control practitioners, land managers, and regulators to better understand what OMWM is and is not, how it can be utilized, and how it can be integrated into a more holistic integrated marsh management (IMM) program. In addition to this paper, a PowerPoint presentation is available with photos, figures and text.

## INTRODUCTION

Open marsh water management is a method of selective ditching and pond creation to be used primarily in tidal saltmarsh mosquito habitat. The technique has been extensively used since its inception in the mid-1960's (Ferrigno and Jobbins, 1968). However, since that time, many federal, state and non-governmental regulatory or restoration management programs involving tidal and non-tidal wetlands have been developed. There has also been a great deal of turnover in mosquito control, federal and state regulatory, and wetland management agencies. Because of this, there have been instances of confusion and contention between county and state mosquito control agencies and state and federal regulatory agencies as well as non-governmental agencies on the semantics and use of OMWM; what it is and is not. Likewise, it would be helpful to review the basics of OMWM with the new generation of mosquito control biologists. Therefore, this paper is intended to provide the reader with background information, based on a review of the literature, to be used as guidelines for implementing OMWM. Standardized guidelines for OMWM have been written for New Jersey (Bruder 1980), Maryland (Lesser 1982) and Delaware (Meredith et al. 1985). The effects of OMWM on selected marsh resources have also been extensively reviewed in earlier publications (Dale and Hulsman 1990, Wolfe 1996). While this paper will review and cite much of the work done previously, the reader is encouraged to read the original reports and studies to gain a more thorough knowledge of OMWM and its effects on various biotic and abiotic metrics.

While reviewing these guidelines, the reader should bear in mind that there is no single "right way" to do OMWM and that, if the basic concept of source reduction and biological control is adhered to, the actual design of the ditch system or shape of

**Figure 1.** Restoring marsh hydrology by plugging of old mosquito ditches in Connecticut (ca.1938).

the pond is inconsequential and as varied as the designer. Also, local factors such as tidal regime, salinity, soils, human disturbance, and even the target pest species must be taken into account to customize the system to achieve local goals. Because of this, one set of guidelines developed for a particular region of the United States may not be directly applicable to other regions of the country or world. Furthermore, it is noted that OMWM is not the "end-all" in mosquito control. Open marsh water management is yet another tool which can be integrated into a more holistic IMM program to not only provide source reduction and biological control of mosquitoes but also to enhance habitat for a variety of wetland-dependent species and to help restore degraded wetlands.

## BACKGROUND

The concept of using a predators to control mosquitoes was first noted by John B. Smith (1904) in New Jersey in the early part of the 20th century when he observed that not all areas of the salt marsh were a source of mosquitoes. He found shallow depressions located in areas of high marsh that are infrequently flooded by high or storm tides and dominated by salt hay grasses to be prime mosquito-habitat primarily for the salt marsh mosquitoes *Ochlerotatus sollicitans* (Walker), *Oc. cantator* (Coquillett) and *Oc. taeniorhynchus* (Weidmann). From these observations he went on to advocate biological rather than continuous chemical control by noting that "the killies [killifish] that swarm in every ditch … are great wiggler [mosquito larvae] hunters." Furthermore, because "oil is useful as a temporary expedient only… permanent improvements [i.e., water management] should be the objective."

Even during the extensive grid-ditching era, further attempts using biological control were investigated. In 1938, Price proposed using closed (or not directly tidal) "blind" ditches that would serve as fish reservoirs. The killifish [mainly *Fundulus heteroclitus* (L.)] that naturally inhabited the creeks and ditches would swim out and consume mosquito larvae in the vicinity of the ditch on flooding tides. In this way, permanent fish habitat was created to ensure the presence and survival of the biological predator.

One of the most significant negative impacts of grid ditching was the conversion of more typical saltmarsh vegetation (*Spartina alterniflora* Loisel, *S. patens* (Ait.), *Distichlis spicata* (L.), *Juncus gerardii* Loisel, *J. roemerianus* Scheele) to vegetation that favored a drier, more well drained condition (*Iva frutescens* (L.), *Baccharis halimifolia* (L.), *Phragmites australis* (Cav.). In addition a loss of shallow surface water ponds and pannes used by myriad fish and waterbirds including shorebirds, wading birds, and waterfowl occurred. In an early attempt to restore some of this lost habitat Bradbury (1938) used clumps of previously-excavated spoil to plug some of the old grid ditches to a depth of 23 cm below the marsh surface in Massachusetts marshes to restrict tidal exchange, retaining some surface water, yet still providing adequate mosquito control. Figure 1 shows an example of this type of ditch plugging done in Connecticut around the same time period.

In addition to excavated or plugged blind ditches, small ponds were either excavated or blasted using dynamite in areas of multiple mosquito habitat depressions. The goal again was to create permanent fish habitat to sustain the mosquito larval predator. Clarke (1938) likened the activity of the fish at the water surface to champagne bubbles. Bodola (1970) later noted that while these created "champagne pools" provided good larval control in the immediate vicinity of the pond, the fish could not penetrate the dense marsh grasses surrounding the pools to reach isolated larval habitat depressions. Cottam (1938) took this idea one step further when he proposed creating permanent ponds with channels radiating outward like spokes of a wheel to allow predatory fish to penetrate into the marsh. These early attempts using selective water management were thought to provide better mosquito control and to be less destructive to the marsh than large scale mechanical drainage.

In New Jersey during the mid-1960's Ferrigno and Jobbins (1966, 1968) coined the term "quality ditching" to describe the use of tidal ditches to selectively connect larval habitat depressions or potholes to a tidal source, as opposed to indiscriminate parallel grid ditching. By selectively connecting the isolated depressions, mosquito control is achieved through tidal circulation of these moist mud depressions required by saltmarsh mosquitoes for oviposition and by providing access for larvivorous fish to areas of the marsh that produce mosquitoes. In areas of multiple depressions, closed ponds were excavated by a drag-line crane sitting on wooden mats, sometimes with radial ditches connecting isolated depressions to the pond. An innovative technique not reported heretofore was to use the excavated spoil material to fill in other depressions to the level of the surrounding marsh and usurping the oviposition sites. This technique of selectively creating ponds and connective tidal ditches was called OMWM. Open marsh water management advocates source reduction of mosquito larval habitat and biological control as a more ecologically sound alternative to indiscriminate mechanical drainage or temporary chemical control. These authors and others (Daiber 1986, Meredith et al. 1985) reported on the multiple objectives of OMWM and how properly installed OMWM systems could be used not only to control mosquitoes, with a concomitant reduction or elimination of insecticides or other temporary measures, but also to enhance fish and wildlife habitat and increase estuarine interactions. A more comprehensive review of OMWM's effects on selected marsh resources is provided in an earlier publication by Wolfe (1996).

Although OMWM, which was developed in New Jersey and the Atlantic coast, has been the most studied in terms of habitat modification for mosquito control, water management is not exclusive to the eastern United States. Similar in design and theory to quality ditching, Resh and Balling (1979) describe the use of shallow "recirculation ditches" in San Francisco marshes to promote tidal circulation and dewater larval habitat. Similarly, Hulsman et al. (1989) describe the use of wide, shallow channels or "runnels" in Australia to promote tidal circulation and drainage of *Oc. vigilax* (Skuse) pools. These techniques provided the necessary control of mosquitoes while having neutral to beneficial impacts on other marsh resources.

## OPEN MARSH WATER MANAGEMENT BASICS

The basic approach using "quality ditching" is to connect larval habitat depressions or potholes to a tidal source (tidal ditch or natural creek) with a 0.6-1.0 m deep channel (Figure 2). As previously stated, this interrupts salt marsh mosquitoes from ovipositing on the moist substrate needed for egg conditioning, plus allowing fish access to these sites to consume any larvae that may be produced. Old grid ditches that are slowly filling in and actually producing mosquitoes themselves are selectively cleaned (as opposed to indiscriminately recleaning all ditches) to restore tidal flow and to serve as a tidal source from which to connect isolated potholes. Occasionally, a "band ditch" is excavated along the wetland/upland interface to allow tidal circulation to that zone which was sometimes distal from a natural tidal creek or river.

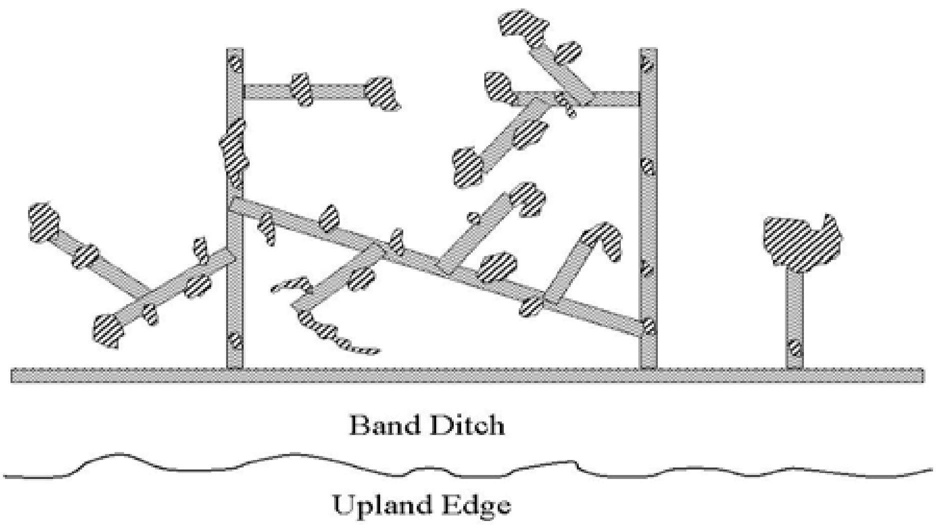


**Figure 2.** Use of quality ditching to eliminate larval habitat depressions (cross-hatched areas. From Ferrigno and Jobbins, 1968).

In areas of multiple depressions between tidal creeks or old grid ditches, ponds and connective ditches can be used (Figure 3). After the potholes are demarcated, a pond is excavated to incorporate the majority of these potholes. If higher marsh areas within the pond boundary are not creating larval habitat, they could be left unexcavated or islands could be created using the excavated material to fill in depressions. Leaving islands reduces the amount of material being excavated, minimizing the impact to the marsh surface as well as being more efficient which, in turn, reduces workload and costs. The remainder of the spoil is used to fill in isolated potholes or spread thinly on the marsh surface to promote revegetation by underlying grasses. If isolated potholes still remain, they can be connected via quality ditching to a tidal ditch or to the newly created pond. A secondary benefit of these ponds is to restore some of the surface water lost by grid ditching and enhance the habitat for a variety of wetland dependent species. These ponds are used by a number of fish and waterbird species and provide neutral to beneficial impacts to these resources (Erwin et al, 1994, Huang 2003).

Open marsh water management became the technique of choice for long-term salt marsh mosquito control. However, some questioned whether OMWM, as practiced in New Jersey, could be used in other parts of the country and achieve similar results, noting such regional differences as marsh soil types, salinities, tidal regimes, and community assemblages. For example, when open tidal ditchesFor example, when open tidal ditches were used in Maryland marshes (Lesser 1982), they noticed a continued net drainage effect (similar to parallel grid ditching) which dewatered the marsh causing changes in marsh vegetation from predominantly salt hay (*S. patens* and *D. spicata*) to marsh shrubs (*I. frutescens*). Daiber (1986) noted that “while the basic OMWM concept remains sound, it appears that modifications to accommodate local situations are in order.”

To counter the net drainage effect caused by open tidal ditches, a shallow, 10-20 cm deep connector or “sill ditch” (Meredith et al. 1985) was introduced to provide restricted tidal exchange from the OMWM system to an open tidal ditch or creek. The sill provides greater tidal exchange than a closed

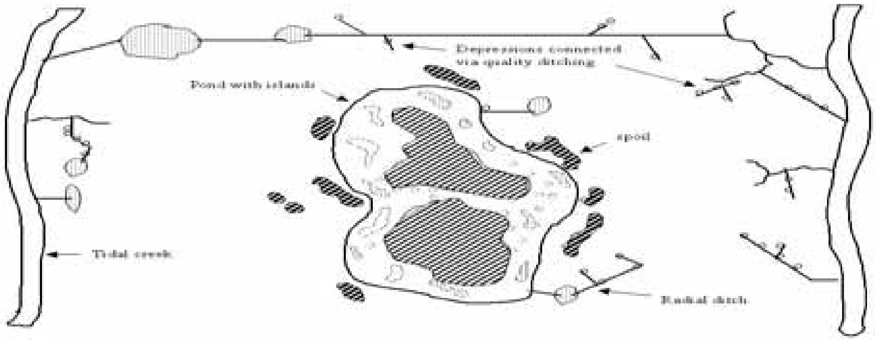


**Figure 3.** Use of OMWM ponds, ditches and excavated spoil to eliminate multiple mosquito-larval habitat depressions (cross-hatched areas) and enhance wildlife habitat (from Ferrigno and Jobbins, 1968).

system on a flooding tide and restricts, due to the depth of the sill, the amount of drainage at ebb tide. At low tide the sill also acts to draw overflow surface water from outside of the pond or ditch system back into the confines of the pond or ditch boundary, minimizing any chance of this shallow sheet water to breed mosquitoes.

Figure 4 demonstrates the use of the sill to connect the OMWM system to a tidal source. A full-depth (75-120 cm) ditch is excavated through the natural creek side levee and serves as a sedimentation trap. The sill is then excavated behind the levee through firm marsh and connects to the OMWM system. The bottom of the sill is essentially flat but may have a gentle taper towards the tidal source to prevent scouring and the creation of a plunge pool at the mouth of the sill which could undercut and eventually erode the sill. The potential for erosion is dependent on the soil substrate and the tidal energy in the creek or ditch.

The length of the sill is dependent on the soil substrate. A minimum length of 15 m is recommended in firm, mineralogic soils, while a minimum of 30 m is recommended for use in more peaty, organic soil where burrowing by muskrats or scouring by tidal energy is more of a concern. The depth of the sill is very important and highly dependent on the tidal amplitude. In marshes where the tidal amplitude is small (0.3-1.0 m) the sill should be shallower to avoid excess drainage. In high amplitude marshes (>1 m) a greater depth sill can be used. Note that the shallower the depth of the sill, the more likely it will be to fill in and potentially compromise the longevity of the sill system.

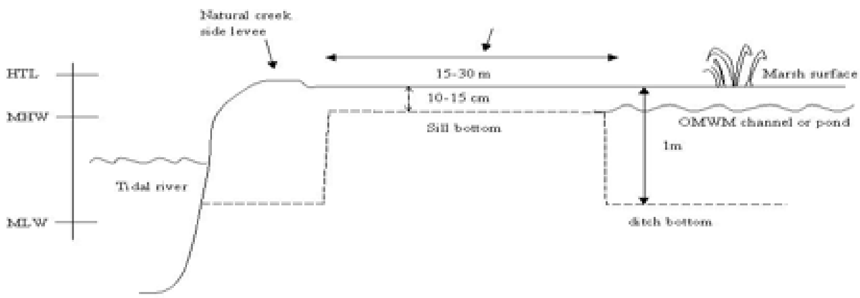


**Figure 4.** Side view of a sill (restricted tidal) connecting an OMWM system with a tidal creek.

## GETTING STARTED AND DESIGN CONSIDERATIONS

As with any integrated pest management program, a good OMWM program begins with surveillance and identification of mosquito larval habitat sites. A good place to start is with inspection and larviciding records and local knowledge of larval habitat areas by mosquito control personnel. Aerial maps (e.g., color infrared, orthoquad) of the marsh in question should be reviewed to identify potential mosquito habitat such as high marsh areas dominated by salt hay grasses which may only get inundated during spring tide events or heavy rainfall. Ground reconnaissance is essential to locate all potholes and oviposition sites in a given locale. These sites are then demarcated with stakes or flags and mapped using global positioning system units or other technique.

At this point the designer should step back and view the array of flags and then design the most efficient system that will "connect the dots" or potholes. Remember that some holes can be filled with excavated spoil, if allowed by permit, and that areas that are not active sites can be left as islands if a pond is designed. Bear in mind that there is no one way to design a system and that other goals (e.g., larger ponds for enhanced habitat) can be integrated into the design. Post-excavation monitoring of at least 1 year is recommended to determine 1) if mosquito control was achieved, 2) that no new depressions were created by equipment or improper placement of spoil during construction (which would have to be revisited and corrected), 3) if muskrats or tidal scouring had impacted the system, and 4) if other resources (e.g., fish, birds, vegetation recovery) are responding favorably. The designer should also keep in mind such factors as the juxtaposition of tidal sources for a water source or potential for burrowing and drainage by muskrats, the volume of spoil that will be generated and the efficient use or disposal of that spoil (filling in potholes or old grid ditches, spreading thinly on the marsh surface, pushing or hauling to upland), any limitations of the equipment (e.g., ground pressure, reach of the excavator), ease and efficiency of installation while designing a system that makes sense to the equipment operators.

Wetland permit conditions may also limit the extent or creativity of the OMWM design. Just as there is no one set of OMWM guidelines that can be used on all marshes, there are no consistent state or regional regulations or interpretations from wetland regulatory agencies when working in tidal wetlands. Therefore, a particular design or use of OMWM (e.g., ponds, new ditches), while allowed in one state or region of the country, may be limited or not allowed in other states. Because of this, the creation of an OMWM review or steering committee is recommended to review and provide comment on OMWM plans. This allows input up front from outside agencies (Environmental Protection Agency, United States Army Corps of Engineers, United States Fish and Wildlife Serve, National Oceanic and Atmospheric Administration, state tidal wetland regulatory and fish and wildlife agencies, local conservation groups) that would otherwise review the permit application. This also fosters cooperation, coordination with other wetland initiatives and could identify potential sources of funding and technical support.

Figure 5 shows the use of open, semi-tidal (sill), and closed OMWM systems (from Meredith et al. 1985). A natural tidal creek is shown running through a salt marsh with a characteristic low marsh *S. alterniflora* zone (ALT) near the creek and a higher salt hay zone (HAY) distal to the creek. There is a natural salt pond in the HAY zone. Multiple Mosquito larval habitats have also been identified primarily in the HAY zone. For simplicity, no grid ditches are shown here. Using OMWM, simple, open tidal ditches (i.e., "quality ditching") are used to connect the potholes directly to the tidal creek. Smaller closed ponds with pond radials are created in the HAY zone to incorporate areas of multiple epressions. A larger pond system with islands and radials is created in larger areas of multiple depressions. The large pond is connected to the tidal source by a sill ditch. The natural pond can also be used as a permanent water source from which radial ditches can connect isolated potholes. A deeper sump could also be excavated to ensure adequate fish habitat. Note the optional muskrat barrier that can be used if the OMWM system is threatened by their presence. Sheets of marine plywood can be pushed (by excavator bucket) or rat wire can be buried in soft, organic soils to deter muskrat burrowing that could drain the newly created OMWM system. Although not noted in this schematic but discussed in the Delaware guidelines, remember that potholes can

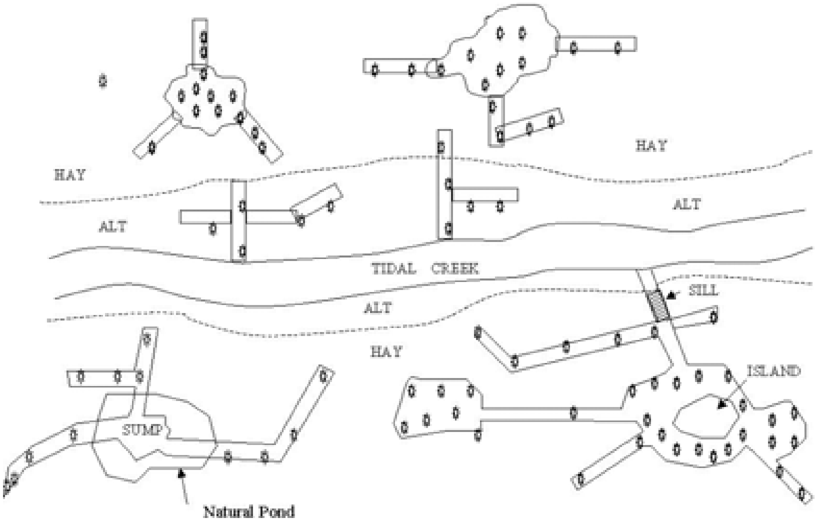


**Figure 5.** Use of open, closed, and sill (restricted tidal) systems in OMWM design. Circles indicate mosquito larval habitat depressions (from Meredith et al, 1985).

also be filled with excavated spoil to reduce the amount of excavation needed. Also, some of the old grid ditches can also be plugged and incorporated into the design.

## POND CONSTRUCTION

Figure 6 shows a cross section of a typical OMWM pond with a connector or sill ditch attached. As stated earlier, the shape of the pond is determined by the distribution of clustered mosquito larval sites. Therefore, ponds should be designed with curvilinear edges instead of more geometric patterns which incorporate the depressions to provide more edge habitat and appear more natural. Open marsh water management ponds should be constructed with shallow edges and bottom contours that taper downwards from approximately 15-45 cm (mean depth 30 cm). Experience in New Jersey has shown that, in certain marshes, the edges of ponds with a uniform 30 cm depth will slough and, over time, create similar tapered, shallow edges (R. Candeletti, pers. com.). This average depth is consistent (at least in New England) with depths of natural salt marsh pools (Adamowicz and Roman, in prep). This shallow design serves two functions.  First, from an ecological standpoint, the shallow edges create greater foraging habitat for shorebirds and dabbling ducks and allows sunlight penetration to the bottom to encourage the growth of submerged aquatic vegetation such as widgeongrass (*Ruppia maritime* L.). The second function is much more simplistic; a shallow, tapered bottom generates much less spoil that has to be disposed of than a deeper pond (0.6-1.0 m) with straight sides.

Depending on the size of the pond, at least one sump (1.0 m deep, min. 4 m²) should be excavated in the pond. Between flooding events, (which in some regions may be several weeks in the summer) the pond will naturally draw down through evapotranspiration and expose the shallow edges. This also warms the water resulting in a reduced dissolved oxygen content which was shown to contribute to fish kills in Maryland OMWM ponds (Lesser 1982). The deeper sump, although not consistent with Adamowicz and Roman's observations, provides an area of cooler water, richer in dissolved oxygen for the fish to retreat and ensures that the necessary biological control agent is maintained. The deeper habitat also provides harborage for fish from piscivorous predators such as herons and egrets.

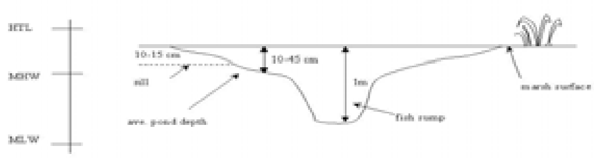


**Figure 6.** Cross-section of an OMWM pond showing shallow, tapered edges and a deeper fish reservoir.

If permit conditions allow the spreading of spoil on the marsh surface (vs. removing to upland), it is important not to surround the perimeter of the pond with spoil but allow sections of the natural marsh around the pond to remain uncovered. This is especially important when constructing closed ponds. Surrounding the pond with spoil could create an artificial elevational increase and allow fewer flooding tides to crest this berm and reach the pond.

## DITCH PLUGS

A brief discussion about ditch plugs is in order here. The length of the ditch plug is dependent on the soil substrate, but Meredith et al. (1985) recommends a minimum length of 8 m in firm, mineralogic soils and 15 m in organic soils. When constructing ponds, the old grid ditches serve as ideal disposal sites if they are not directly needed to convey water to the system. This results in less spoil spread on the marsh surface and also breaks up the parallel grid ditch pattern. If there is concern over the conversion or loss of salt marsh vegetation to creation of open water, bear in mind the plugged ditch will revegetate creating new saltmarsh and could conceivably result in a “no net loss” of marsh. Spoil material used for the plug should be placed in the ditch and packed down or run over with the excavator or bulldozer. Because of air pockets and exposed decomposing organic matter, the plug will settle slightly over time. It is important not to leave the top of the plug at the same elevation as the adjacent marsh surface. If this occurs, the plug will settle below the marsh surface and flooding tides will scour away the top and sides of the plug, eventually resulting in system failure. The top of the plug should be rounded and slightly higher than the marsh, similar to a mushroom cap (Figure 7). The edges of the top of the plug should taper down and over the edge of the adjacent marsh. This will create a firm, long-lasting ditch plug. In soft soils or high-energy tidal systems, marine plywood can be used in the ditch to contain the plug material or to deter muskrat burrowing. Normally within 1-2 growing seasons, the ditch plug is revegetated with natural marsh vegetation. As an added measure to facilitate quicker revegetation, the plug can be top-dressed with a layer of marsh peat and vegetation that has been separated and stockpiled during pond construction.

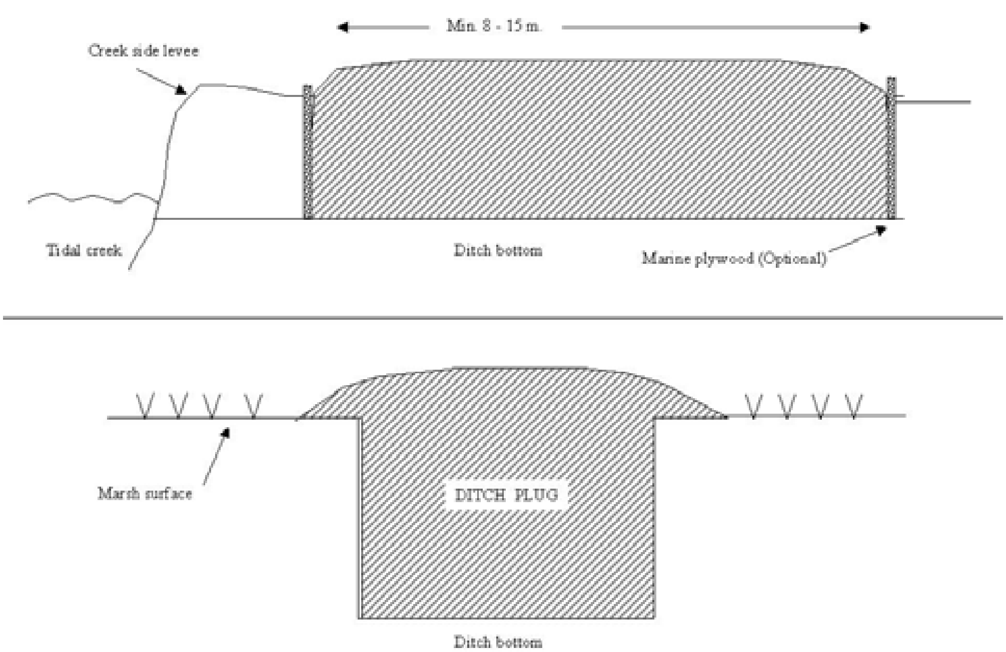


**Figure 7.** Cross-section and longitudinal view of a ditch plug used to restore marsh hydrology.

## A QUESTION OF SEMANTICS

As mentioned earlier, the primary goal of OMWM is to provide long-term source reduction and biological control of mosquitoes with a secondary benefit of enhancing habitat for marsh dependent organisms and increasing estuarine interactions. The term OMWM has often been misused, however, to describe a number of wetland modifications. Although it may be just a question of semantics, OMWM by itself should not be confused with more traditional wetland restoration initiatives such as dredge fill removal, breaching of impoundment dikes, installing larger culverts, or self-regulating tide gates for tidal flow restoration, managing water levels in impoundments for mosquito control or rotational impoundment management (Carslon 1986), creation or enhancement of wetland wildlife habitat in non-mosquito-producing areas, or invasive vegetation control (e.g., *Phragmites*). Some of the differences in these techniques may be subtle, but it is important to differentiate OMWM from other specific forms of wetland modification for regulatory purposes and to help formulate more universal nomenclature and standards in the expanding practice of wetland restoration and management.

The Connecticut Department of Environmental Protection recognizes OMWM in its original intent as a source reduction technique for mosquito control, but realizes it can be used to augment a larger IMM program (Meredith et al 1985, Wolfe and Capotosto 1998) or modified to enhance one or more functions such as waterbird use (Whitman 1995). Integrated marsh management utilizes the most appropriate techniques used in wetland management in a holistic fashion to achieve multiple objectives so that individual projects are not working contradictory to each other and that projects that can potentially compliment each other do so. Ideally, IMM should not only include the physical manipulations of the habitat but also an educational component including research and long term monitoring. This is an important parameter needed to convey your specific plans to permitting agencies and others, to coordinate with other wetland initiatives, to obtain technical, supportive and financial assistance, and to expand the knowledge base of wetland management.

Figure 8 is an example of how OMWM can be in integrated into a more comprehensive IMM plan (from Wolfe *in* Majumdar et al. 1998). In this example, a parallel grid ditch has drained a large, natural pool or panne. This site may or may not be a mosquito problem; however, the shallow water habitat for numerous birds and fish has been lost. Upon inspection, numerous depressions were identified in the marsh surrounding the pool. To correct this, an OMWM pond is excavated to incorporate multiple depressions and tie it into the natural pool. This increases the surface area 30-50% of the pool alone

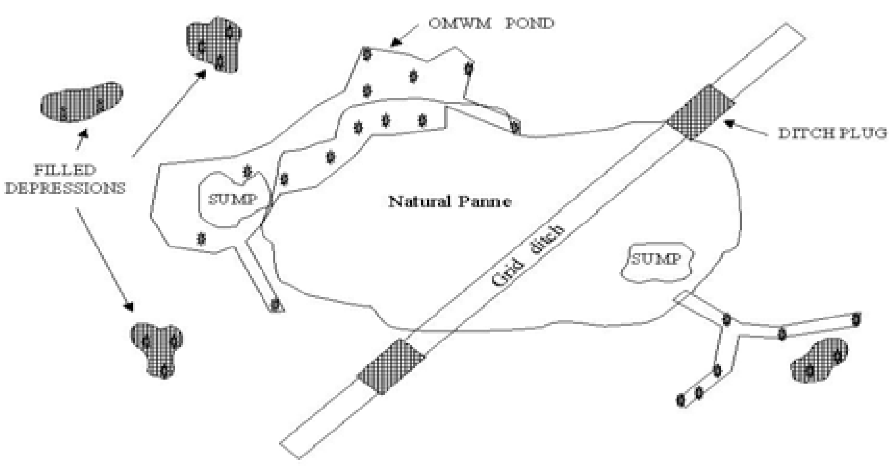


**Figure 8.** Schematic of an IMM system using OMWM to eliminate mosquito production and enhance wildlife habitat and ditch plugs to restore a drained natural pond (from Wofe, in Majunder et al. 1998).

increasing and enhancing the value for fish and wildlife. Radial ditches connect isolated depressions with the natural pool. Deeper sumps are created in the OMWM pond and the natural pool as fish reservoirs. Finally, spoil material is used to fill in isolated mosquito larval habitat potholes and the old grid ditch, thus restoring hydrology to the drained pool.

## CONCLUSION

As the literature indicates, OMWM is an environmentally focused, effective tool that can provide long term, cost effective saltmarsh mosquito control using source reduction and biological control with neutral to beneficial impacts to other wetland resources. There is a concomitant reduction or elimination of pesticide use, and although OMWM projects are more costly to initiate, the long-term economic savings over the continued use of pesticides are significant. There is no one way to design an OMWM system; hence, guidelines have been produced as an aid to implementing OMWM. The designs are based on the extent and distribution of the patchy mosaic of mosquito-producing potholes on any given marsh. Also, the designs are as varied as those who design them and two different people could have two different, yet effective, OMWM system designs. Open marsh water management can be as minimal in design as its original intent of quality ditching ("connecting the dots") to a tidal source or used as a component of a larger IMM program to achieve multiple objectives.

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# ALTERNATIVE FISH SPECIES FOR USE IN MANMADE CONTAINERS

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An effective method of mosquito control to prevent the emergence of adult mosquitoes in areas of permanent standing water is the use of larvae eating fish. In New Jersey, two notable species stocked in mosquito breeding habitats are *Gambusia affinis* Baird & Girard, the Western mosquito fish, and fathead minnows, *Pimephales promelas* Rafinesque. This study was a follow up to a study conducted in 2003 (Musa 2004) using goldfish, *Carassius auratus* (L.) recommended by a pet store that raised questions regarding their use.

During the spring and summer of the 2004 the Warren County Mosquito Commission conducted a comparison study of alternative fish species used in stocking the of natural and man made environments. The goal was to determine which fish would be suited for use in man made structures like ornamental ponds that may or may not be filtered or aerated and was complimented by field studies conducted with *G. affinis* and fathead minnows in natural breeding sites in Warren County.

The study began on May 19, 2004 and ran through September 1, 2004. On May 19, four 75.1 blue water filled tubs were used as habitats for the fish. The tubs were placed next to each other in a line against a building and numbered one through four (Figure 1). Five days later, the first mosquito eggs were noted around the rims of all four tubs. It rained that night; the first larvae were noticed the next morning. Everyday from then until the end of the study in September new eggs were observed in each bucket.

From May 25 to May 28 visual counts yielded 3-10 first instar larvae in each tub. Three days later the counts increased to about 10-15 larvae per tub. Because of rain during this period the counts consisted of a mixture of newly hatched first instar larvae to more advanced second instar larvae.