OPEN MARSH WATER MANAGEMENT STANDARDS

FOR SALT MARSH MOSQUITO CONTROL

State Mosquito Control Commission
c/o NJ Dept. of Environmental Protection
Office of Mosquito Control Coordination
P.O. Box 400
Trenton, NJ 08625-0400

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Attachments

Introduction

The Office of Mosquito Control Coordination (the Office), within the Division of Fish and Wildlife of the New Jersey Department of Environmental Protection (NJDEP), is the operational arm of the New Jersey State Mosquito Control Commission. The Office administers several state-aid programs to county mosquito control organizations, such as the State Airspray and State Bio-Control Programs. One of the most important programs administered by the Office is the State Equipment-Use Program, which allows counties to lease state-owned equipment to supplement their mosquito control activities. One of the primary equipment needs within the state is for low-ground pressure equipment to perform water management projects, activities regulated by the NJDEP Land Use Regulation Program as well as the United States Army Corps of Engineers (in coastal locations). Water management is the most effective means to control mosquito populations by removing larval habitat – it is a source reduction technique that substantially reduces the need to apply insecticides.

Historically, the most significant problems within the state have been in coastal locations where salt marshes provide large areas of larval habitat for mosquito production. Prior to the implementation of mosquito control measures many of the state's most important recreational and tourist destinations, such as Long Beach Island and Atlantic City, were considered nearly uninhabitable due to the nuisance and potential for disease transmission associated with the large mosquito populations in these areas. In the 1960's and 70's (as a means of reducing mosquito problems as well as restore severely disturbed salt marsh habitat) several organizations within the state – including the NJDEP, Rutgers University, and county mosquito control organizations – developed and refined techniques for Open Marsh Water Management (OMWM). OMWM is a land management practice that restores salt marsh habitat that has been disturbed by human intervention through practices such as parallel grid ditching and salt hay farming to a more natural environ while increasing tidal exchange on the marsh. The practice results in increased habitat for a variety of fauna and effective mosquito control by introducing natural fish predators to feed on larvae. In many locations where OMWM has been performed insecticide use has been rendered unnecessary.

Enclosed within this document is the "Standards for Open Marsh Water Management", five select articles from the Proceedings of the New Jersey Mosquito Control Association, and a list of references. The purpose of this document is to provide a complete description of what OMWM is, what it is not, and what the costs and benefits of its use are. Additional articles on the subject are available from the "Proceedings" of the New Jersey Mosquito Control Association, Inc. Tables of content and how to obtain copies may be found at www.njmosquito.org.

Standards for Open Marsh Water Management (OMWM)

County mosquito commissions, Rutgers University and the New Jersey Division of Fish, Game and Shellfisheries have been perfecting one technique, Open Marsh Water Management (OMWM) for the control of all genera of salt marsh mosquitoes on open tidal marshes for over two decades. Perfection is achieved by continued improvement and evaluation. In order to ensure the finest quality and identify this management technique, certain standards are a necessity. These standards should be included in any riparian or other permit. Improper adherence to these standards would be a violation of the permit and infringement on the quality of the management technique. The following standards shall be utilized and strictly adhered to in any OMWM project:

I. <u>NEED.</u> OMWM will be based entirely on need and utilized on breeding marshes only.

- A. OMWM will be confined to the *Spartina patens* or mixed *S. patens*, short *S. alterniflora* or types of similar vegetation that are irregularly flooded by rains, spring or storm tides. It will not be employed on marshes that are regularly inundated or affected by daily tides such as tall saltmarsh cordgrass (*Spartina alterniflora*), wildrice (*Zizania aquatica*), cattail (*Typha spp.*), arrow arum (*Peltandra virginica*), threesquare (*Scirpus olneyi*) and other types of similar vegetation.
- B. All alterations must directly affect mosquito breeding depressions.
- C. The direction and type of alteration used will depend on the distribution of the mosquito breeding depressions and their proximity to natural ponds and tidal ditches.
- D. An experienced wildlife biologist, mosquito control worker, or both, shall stake out all breeding depressions ahead of the equipment. Depression marking shall be utilized to determine the least amount of alteration needed to eliminate mosquito breeding.
- E. All mosquito or other ditches encountered that are not contributing to breeding mosquitoes will not be cleaned.
- F. When possible, ponds previously altered by mosquito ditches will be restored.

II. <u>ALTERATIONS.</u> Three types of alterations (tidal ditches, ponds and pond radials) will be used.

- A. <u>Tidal Ditches</u>
  1. All tidal ditches will be dug with suitable equipment, preferably with a rotary ditcher.
  2. When mosquito breeding depressions are located adjacent to a tidal, mosquito or other ditch, a tidal ditch alteration will be utilized.
  3. When a tidal ditch is dug near a pond, the spoil should be deposited on the pond side.

4. Attempts should be made to dig tidal ditches to a depth of approximately three feet. Meandering or straight ditches are acceptable.
5. Main tidal ditches are used to provide tidal circulation through large areas. They should be connected to a tidal source on both ends where possible. Their location is determined by the distribution of breeding depressions.
6. Lateral tidal ditches connect breeding depressions to mains, natural tidal ditches or other laterals. Such laterals often dead-end in a breeding depression.
7. All mosquito or other ditches that are breeding will be cleaned.
8. Spoil shall be used whenever possible to fill adjacent mosquito breeding depressions or spread evenly over the marsh to encourage growth of existing vegetation.

B. Pond Radials

1. All mosquito breeding depressions located near a natural or other permanent pond shall be connected to this pond by pond radials. These radials will provide access for fish to devour mosquito in the depressions.
2. All pond radials shall be constructed with suitable equipment, preferably with a rotary ditcher.
3. To prevent drainage of a pond by muskrats or snow geese, all pond radials shall terminate at a sufficient distance from a tidal ditch.

C. Ponds

1. Where large numbers of mosquito breeding depressions are concentrated in a limited area, a pond alteration will be utilized.
2. Pond construction is accomplished by the use of the rotary ditcher, amphibious crane or other suitable equipment.
3. Ponds should be shallow, less than one foot in depth, to promote the best waterfowl, wading and shore bird use.
4. To prevent mosquito breeding during droughts, a reservoir three feet in depth shall be installed within the pond.
5. These reservoirs should provide proper pond access by humans. When large numbers of radials are used, reservoirs are unnecessary.
6. Reservoirs for fish can be ensured in natural ponds that dry out during droughts by construction of three foot ditches with a rotary ditcher or other suitable equipment. These reservoirs will connect all the lowest areas within the pond.
7. Pond spoil should be squashed and leveled without causing depressions. It should be reduced to the lowest possible level to ensure reestablishment of existing vegetation. Spoil shall approximate the level of the existing marsh.

8. Ponds may take the shape of the breeding area or may be squared off to facilitate construction. The shape of a pond or ditch does not appreciably affect wildlife use. Depth, food potential and availability are the main factors that determine wildlife utilization.

III. OBJECTIVES

A. To adequately serve the three major objectives (control mosquitoes, eliminate insecticides and enhance the tidal food web) all three alteration types (tidal ditches, ponds and pond radials) shall be utilized on each section of marsh whenever possible. Diversity provides a better marsh environment, prevents marsh surface breeding by all genera of mosquitoes and enhances both major branches of the tidal food web.

B. Insecticide use is gradually phased out as OMWM progresses to eliminate breeding acreage. When the project is completed, all insecticide use should terminate.

IV. OTHER TECHNIQUES

Impoundments, stop ditches and other types of management techniques are not OMWM.

V. EVALUATION

Mosquito larval dippings, vegetational plots, invertebrate sampling and wildlife censuses are to be conducted on the area treated with OMWM and compared with a control of similar composition.

Attachment A – Articles from the Proceedings of the New Jersey Mosquito Control Association

“The establishment of unified open marsh water management standards in New Jersey”
by Dr. Kenneth W. Bruder, 1980

“*Open marsh water management”*
by Fred Ferrigno and Daniel M. Jobbins, 1968

“Saltmarsh water management for mosquito control”
by Fred Ferrigno, Patrick Slavin, and D. M. Jobbins, 1975

“A cost comparison between open marsh water management and chemical larviciding, utilizing modern mosquito control equipment”
by Richard Candeletti and Thomas M. Candeletti, 1990

“The history and application of Open Marsh Water Management in New Jersey”
by Richard Candeletti, 2007

THE ESTABLISHMENT OF UNIFIED OPEN MARSH WATER MANAGEMENT STANDARDS IN NEW JERSEY

Dr. Kenneth W. Bruder
Office of Mosquito Control Coordination
N.J. Department of Environmental Protection
Trenton, N.J. 08625

As most of you are aware, mosquito control agencies here in New Jersey, as in other States, are required to obtain Army Corps of Engineer permits before commencing any water management work on our salt marshes. A major problem that often confronted the counties in the past, however, was the lengthy delays in the issuance of such permits due to the review process of the federal agencies involved.

This problem may have been eliminated, or at least reduced, here in New Jersey. For through the cooperative efforts of county, state and federal personnel over the past few months, a set of Open Marsh Water Management Standards has been compiled which is acceptable to all concerned agencies.

These standards have been so well accepted, in fact, that the Army Corps of Engineer's Permit Section has already indicated that they will be incorporated in all future permits for marsh management work on New Jersey's open tidal areas. The acceptance, and inclusion of the Open Marsh Water Management Standards in all future permits, will hopefully eliminate any concern the Corps has had in the past regarding inappropriate mosquito control practices on open tidal marsh areas and should help in expediting the issuance of permits to the counties.

It has taken over twenty years to develop the standards that are being discussed today. Ferrigno et al, (1975) listed some nine general standards for Open Marsh Water Management. Of special note is the fact that in the article the authors briefly mention the U.S. Fish and Wildlife Service's interest in having coastal states establish standards for water management for mosquito control so that such standards could be used by the federal government in screening permit applications. This was back in 1975. To my knowledge, New Jersey is the first and only state thus far to adopt such a set of standards dealing with mosquito control on open tidal marshes.

The need to adopt a set of standards covering Open Marsh Water Management became apparent this fall. In November, I was informed by the superintendents of the Cape May and Cumberland County Mosquito Commissions of the fact that the Corps was withholding county permits for Open Marsh Water Management work due to problems that it was having in determining what management techniques were being included under the term Open Marsh Water Management, as it appeared on county application forms.

In response, I scheduled a meeting with representatives from the coastal counties and the state to have them air their views on what should, or should not, be considered as acceptable techniques under Open Marsh Water Management, and to establish a set of standards which would be acceptable to all concerned. In attendance were Judy Hansen, Superintendent of the Cape May County Mosquito Commission; Pat Slavin, Director of the Cumberland County Mosquito Commission; Brian Gooley, the Supermintendent for Burlington County; Fred Lesser and Tom Candeletti from Ocean County; Harry Tillett and Dave Rizzley representing the Atlantic County Mosquito Control Agency; Mr. Fred Ferrigno, Senior Biologist from the New Jersey Division of Fish, Game and Shellfisheries; and Dr. Joseph Shisler, Marsh Management Specialist from the New Jersey Agricultural Experiment Station. As a result of the meeting, a first draft of Open Marsh Water Management Standards was drawn up.

A second meeting was then held on December 14, with the same individuals in attendance, plus Jeff Steen and Frank Cianfrani from the Permit Section of the Army Corps of Engineers in Philadelphia. The standards were further reviewed and additional amendments made. At the meeting, Mr. Steen requested that the revised standards be submitted to the Corps' Office in Philadelphia as quickly as possible, for final approval. This was done in early January. Since then, my office has received several letters from representatives of the Corps of Engineers and the U.S. Fish and Wildlife Service indicating their acceptance of the standards.

I strongly believe that the Open Marsh Water Management Standards, although established primarily for work on New Jersey's open tidal marshes, can be utilized and adopted in other states as well.

At this time, I would like to briefly run through our Standards with you.

<u>STANDARDS FOR OPEN MARSH WATER MANAGEMENT (OMWM)</u>

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I would like to express my appreciation to the superintendents of the county mosquito control commissions, and to Dr. Joseph Shisler and Mr. Fred Ferrigno for their cooperation and input in setting up the standards. I would also like to thank Jeff Steen and Frank Cianfrani from the U.S. Army Corps of Engineers and Mr. Tom Huph from the U.S. Fish and Wildlife Service for their interest and assistance in putting together an acceptable set of standards for Open Marsh Water Management in New Jersey.

REFERENCE CITED:

Ferrigno, F., P.Slavin and D. M. Jobbins. 1975. Saltmarsh water management for mosquito control. Proc. N.J. Mosq. Cont. Assoc. 62:30-38.

OPEN MARSH WATER MANAGEMENT

FRED FERRIGNO, *Biologist, New Jersey Division of Fish and Game, and* DANIEL M. JOBBINS, *Head, Mosquito Investigations, Rutgers University*

Over the past ten years cooperative surveys and projects between the New Jersey Agricultural Experiment Station, New Jersey Division of Fish and Game, Cape May County Mosquito Commission, Cumberland County Mosquito Commission, and the Salem County Mosquito Commission, have made considerable progress toward the goal of developing long-range management plans to reduce the breeding of pestiferous salt marsh mosquitoes while still conserving the fish and wildlife resources of valuable coastal marshes.

Now that the bulk of the survey work has been completed, efforts are being made to develop management techniques. To date, all ecological data collected in the field clearly indicate that specific types of controls are necessary for each major type of wetland. Oftentimes these controls must vary somewhat to suit the various interests encountered. In the three southern counties of Cape May, Cumberland and Salem, the different categories of wetlands where specific management and studies are needed include: (1) open tidal mosquito breeding marshes, (2) diked salt hay meadows, (3) mosquito impoundments, (4) waterfowl impoundments, (5) muskrat impoundments, and (6) upland swamps.

Paper of the Journal Series, New Jersey Agricultural Experiment Station, Rutgers University, New Brunswick, New Jersey.

For the most part, ditching has failed in diked salt hay meadows and the most effective control here at present appears to be one application of endrin granules or two applications of Baytex (Ferrigno and Jobbins, 1965). Investigations will continue on chemical control in this environment. The Riggins Ditch Project, a cooperative endeavor between the U. S. Soil Conservation Service, New Jersey Agricultural Experiment Station, New Jersey Division of Fish and Game, and the Cumberland County Mosquito Commission will be another attempt at water management on diked salt hay meadows.

Water management has been very effective against mosquitoes in impoundments managed for waterfowl. Studies with the U. S. Fish and Wildlife Service and the U. S. Entomology Branch have developed water level management techniques designed to eliminate mosquito breeding and at the same time provide an abundance of waterfowl food plants (Chapman and Ferrigno, 1956) (Ferrigno, 1967).

Pumps, dikes and spillways in mosquito impoundments in Cape May County have been extremely costly and have not eliminated the mosquito problem. The proposed impoundment at Fishing Creek to improve fresh water reserves and outdoor recreation should be studied and the effects of flooding on mosquito production known.

Little work has been accomplished in the muskrat impoundments in Salem County and upland swamps. Various water management techniques should be tried in both of these types of wetlands and the results evaluated from the standpoint of mosquito control and wildlife management.

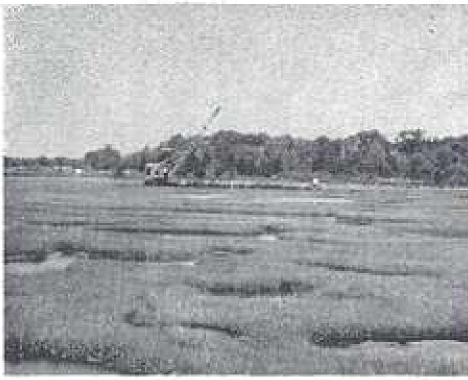
Open marsh water management is the primary concern of this paper and it is designed to control mosquitoes on tidal breeding areas. Since these marshes are part of a very valuable ecosystem involving marshes, creeks, and estuaries, it is imperative that mosquitoes be controlled without serious interruption of the transportation of materials and energy throughout this entire system. This means that the tidal life line of organisms should be maintained free of dikes, obstructions, and chemicals that destroy or disrupt the tremendous network of food chain organisms that eventually end in a very important recreational and food source of man.

In order to accomplish this, quality ditching and water management in an open marsh environment is needed. All harmful effects of previous ditching on tidal marshes was carefully studied and recommendations to the two county commissions were made that would eliminate or reduce these detrimental effects. It was hoped that through quality, instead of quantity, open marsh water management could be so designed that it would promote a longer lasting control of mosquitoes and still be beneficial to the entire ecosystem.

If the diagram of the major types of marshes (Figure 7-Ferrigno, Jobbins, and Shinkle, 1967) is observed, mosquito breeding commences in short salt marsh cordgrass (*Spartina alterniflora*) and reaches a peak in tidal salt hay (*Spartina patens*). Two counties, Cape May and Cumberland, have very representative marshes of these two types. Cape May County has approximately 6,000 acres of tidal salt hay marsh and approximately 40,000 acres of short cordgrass marsh. To determine the effects of open marsh water management on mosquitoes and other marsh organisms in this short cordgrass type, a study area was selected on the state-owned tract, the Seaville Fish and Wildlife Management Area near Seaville, New Jersey. Development work here was accomplished by the Cape May County Mosquito Commission.

The other study area was situated on the Egg Island Fish and Wildlife Management Area, near Dividing Creek, Cumberland County, New Jersey. This county has over 30,000 acres of the tidal salt hay type. The same open marsh water management was used on Egg Island, but the effects of this management on this type tidal salt hay may differ from short cordgrass because the marsh is situated at a higher elevation. The Egg Island Study Area is riddled by thousands of depressions created by large populations of wintering snow geese. It represents some of the heaviest tidal salt marsh *Aedes* breeding ever encountered in South Jersey. Situated over six miles from the upland, dangerous soft mud areas, and so many mosquito-breeding depressions provided unbearable working conditions for a newly formed mosquito commission. The manner in which the Cumberland County Mosquito Commission overcame many difficulties, kept improving their equipment and accomplished every task given them, is deserving of the highest praise.

The major objective of open marsh water management is to eliminate all mosquito breeding from a given acreage of marsh for as long a period of time as possible without adversely affecting or, better yet, improving these marshes for fish, wildlife, and whatever other interest might be involved. In order to obtain complete mosquito control for longer periods of time, every breeding and potential breeding depression has to be located. Then each depression has to be connected to a tidal ditch to allow tidal circulation, or a permanent body of water to insure access for killifish, or buried under the sod. Potential breeding depressions may be defined as the deeper depressions that are not subject to consistent drying out and reflooding which is conducive to heavy mosquito breeding. They will breed during droughts, neap tides, and as the marsh increases its elevation. The reason that short cordgrass marshes produce much fewer mosquitoes than salt hay marshes is because the percentage of potential breeding depressions in regard to actual breeders is much higher. In addi-



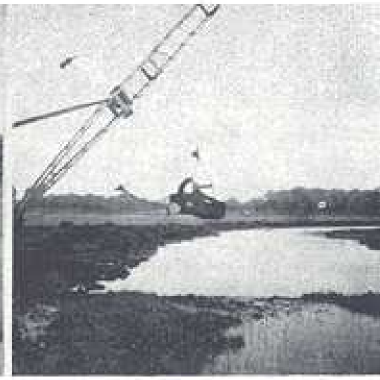


Figure eight pond illustrating numerous depressions (left) and construction (right). Cape May County Mosquito Extermination Commission.

tion, on tidal marshes less mosquitoes are produced during extended wetter periods of rains and high tides because many breeders become potential breeding depressions and do not condition properly. During extended drought periods most of the depressions dry out, condition, and the brood that follows is usually an enormous one.

Various marsh management units were formed and backhoes, draglines, amphibious cranes, trackmasters, and boats were used to accomplish the job. Draglines were especially good for digging ponds and large ditches. Amphibious cranes did a nice job on mains, and heavy tractors with a blade were used to mash down and grade sod piles.

Many ponds were present on both areas. These salt marsh ponds are extremely valuable to wildlife. Yet, there are many depressions along the edges that are subject to alternate drying and reflooding and breed mosquitoes. While eliminating these breeding areas it must be kept in mind that the best type of habitat for fish and wildlife is a diversified one. Permanent water areas should be saved and isolated from the rest of the ditching system. Thereafter, both the tidal and pond environment can be improved upon while eliminating nearby depressions. Once pond areas are isolated, mosquito breeding can be eliminated by the construction of a pond, a deep peripheral channel, or radials, depending on the number and location of depressions.

To illustrate how mosquito breeding depressions can be adequately taken care of while still providing for wildlife, various examples of section of treated marsh to illustrate various principles can be presented. A considerable number of areas at Seaville were similar to Figure 1. The main's (F) dug in the early 1930's were now a series of holes no longer function-

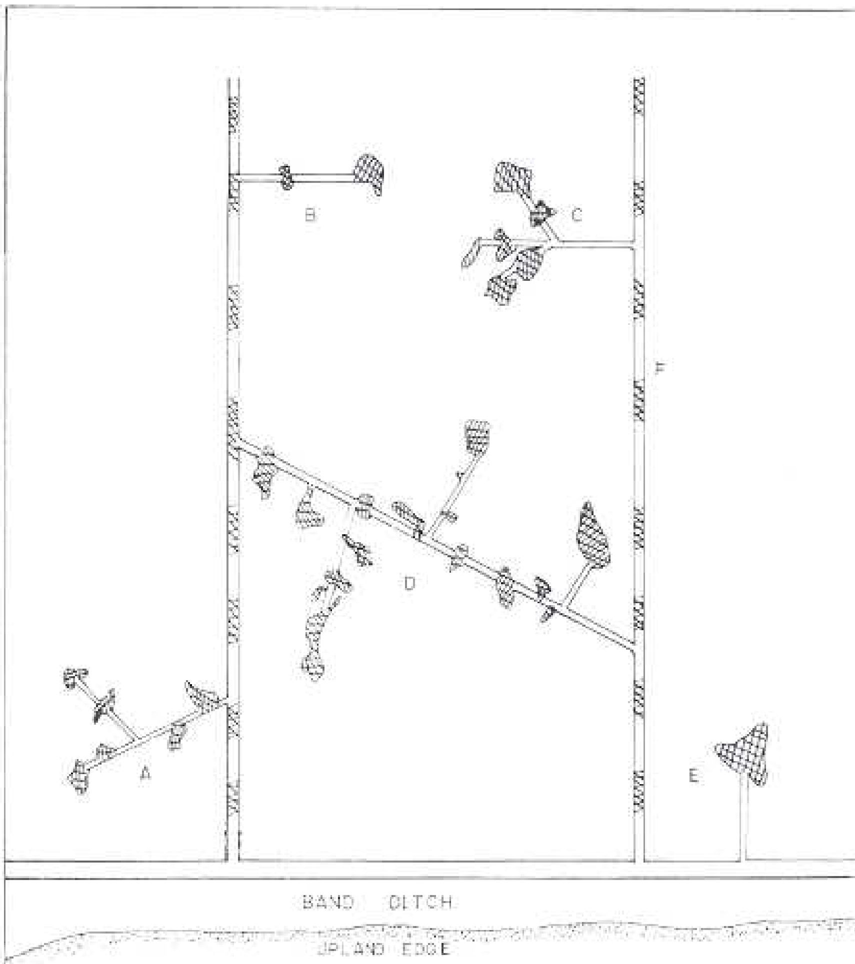


Fig. 1. — Elimination of mosquito breeding depressions by ditching to allow tidal flow. Cross-hatched areas indicate depressions.

ing properly and these ditches had to be cleaned up and replaced with a draglined ditch 3 feet wide and 3½ feet deep. These mains were connected to a band ditch of similar size to improve circulation. Depressions between mains were connected to the nearest ditch. Depending on their pattern, straight laterals (A, B, and E) dendritic ditches (C), long ditches that connnected two mains and radiated short laterals to adjacent holes (D) were used to eliminate mosquito breeding depressions.

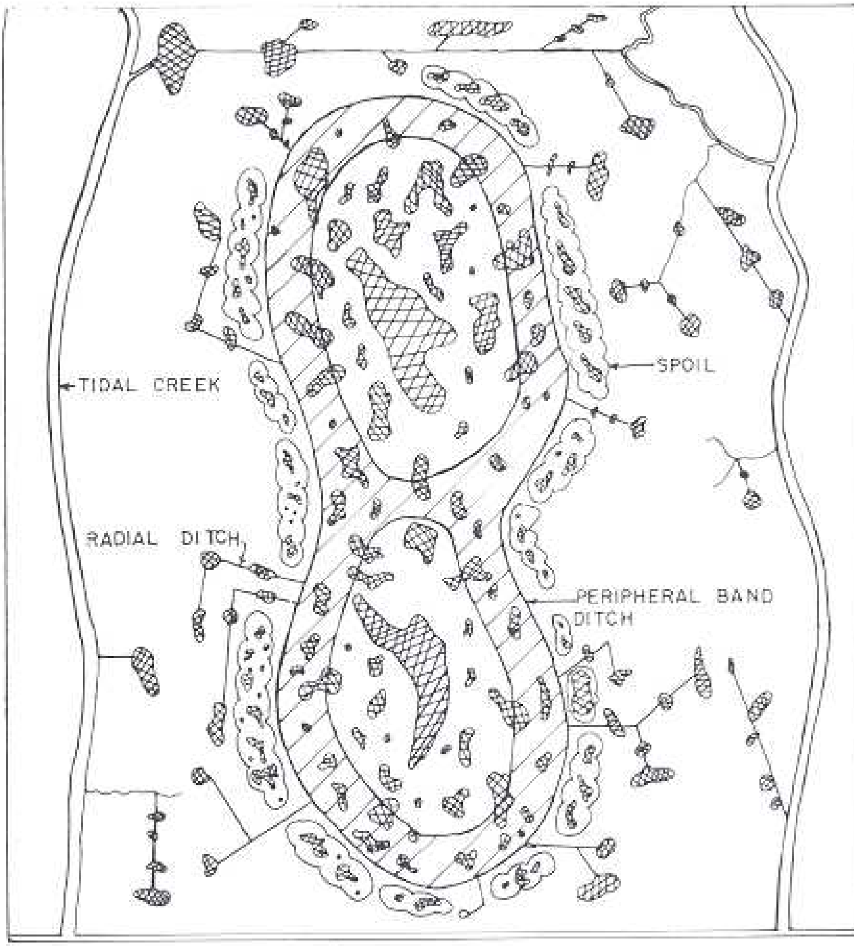


Fig. 2. — Elimination of multiple mosquito breeding depressions and improving wildlife habitat through ponding and ditching. Cross-hatched areas indicate depressions.

In some locations there were so many depressions that it was impossible to ditch them all. Figure 2 illustrates an example of how a multiple depression area was handled by the Cape May County Mosquito Commission. The edges were staked out and the pattern resembled that of a figure eight. A 35- to 40-foot peripheral channel was dug along the edges. The pond itself adequately handled 207 depressions. An additional 86 were buried under the sod and 47 connected to the pond by radials. The rest, about 39 holes, were ditched to tides. Overall, the pond

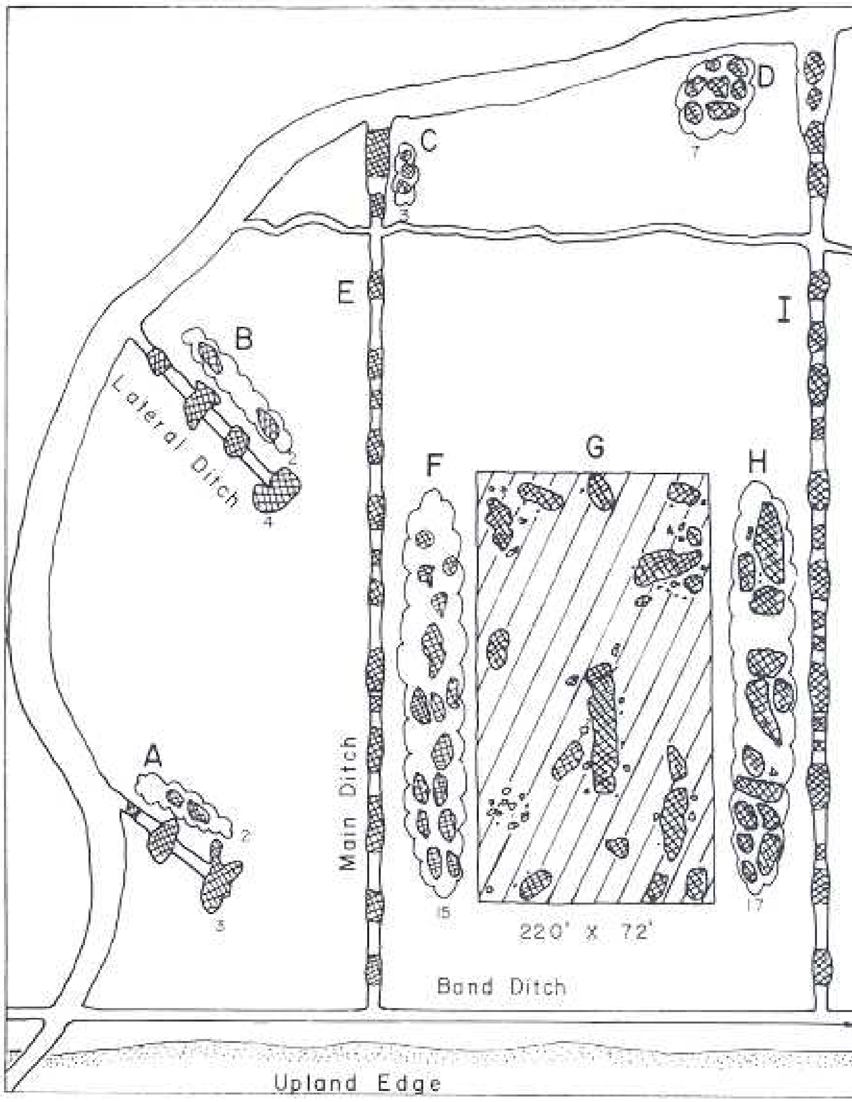
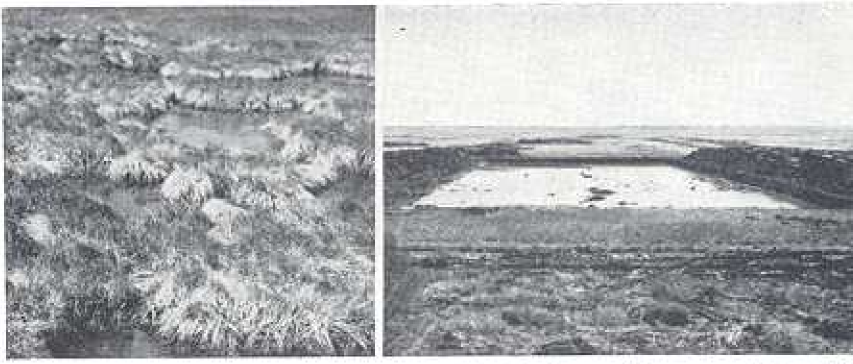


Fig. 3. — Open marsh water management employed on a given section of mosquito breeding marsh.

environment was improved for wildlife by increasing the surface area and it was isolated from the tidal environment. This example and other multiple depression areas were best taken care of by the construction of ponds. The end results are elimination of mosquito breeding, improve-



Multiple depression area (left) eliminated by pond (right). Cape May County Mosquito Extermination Commission.

ment of both the tidal and pond habitat, and additional sites for duck hunting.

In another 40-acre area, depressions were handled in this manner (Figure 3). Those that were bunched in one corner were eliminated by a pond (G). The pond covered 67 depressions, 32 were buried under the sod (F and H) and the rest taken out by laterals to tide water or covered (A, B, C and D).

From the field evaluation of the physical mechanisms involved in open marsh water management, it appears that if development is to be efficient, long lasting, and beneficial to wildlife certain precautions should be taken:

(1). Small ditches were practically useless and did not hold up well. Realizing this, the Cumberland County Mosquito Commission changed all their bucket sizes to greater than 30 inches. It is to be remembered that tidal circulation and not drainage is the controlling breeding factor and circulation prolongs the longevity of a ditch. Therefore, the deeper and wider the ditch the better. Ditches at least three feet deep (I-b) are needed to get some circulation on higher, tidal salt hay marshes like Egg Island and at least two feet deep (I-b) on short cordgrass marshes like Seaville (Figure 4). Deeper ditches are even more efficient and provide better circulation and tidal inundation and last much longer.

(2). Mains should be connected on both ends to tidal ditches or band ditches. Band ditches are recommended along roads, railroad beds, and upland with the sod placed on the road or upland side at irregular intervals. Band and main ditches should be as straight as possible (Figure 5). Straight ditches (B) have the main current velocity going straight down

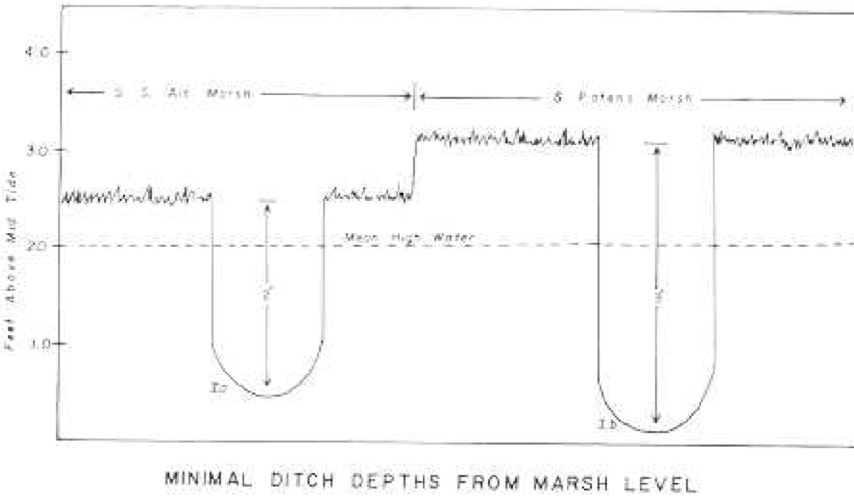


Fig. 4. — Relationships between major vegetational zones and depth of mosquito ditches.

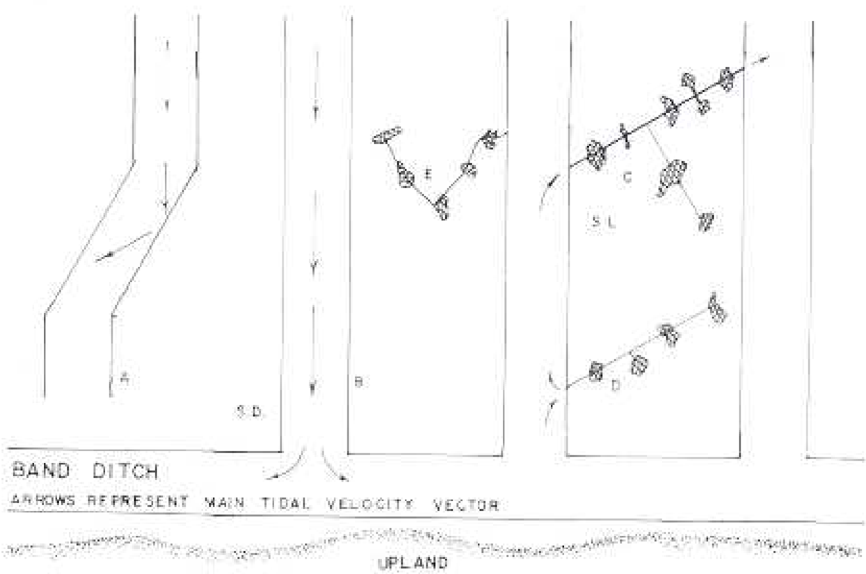
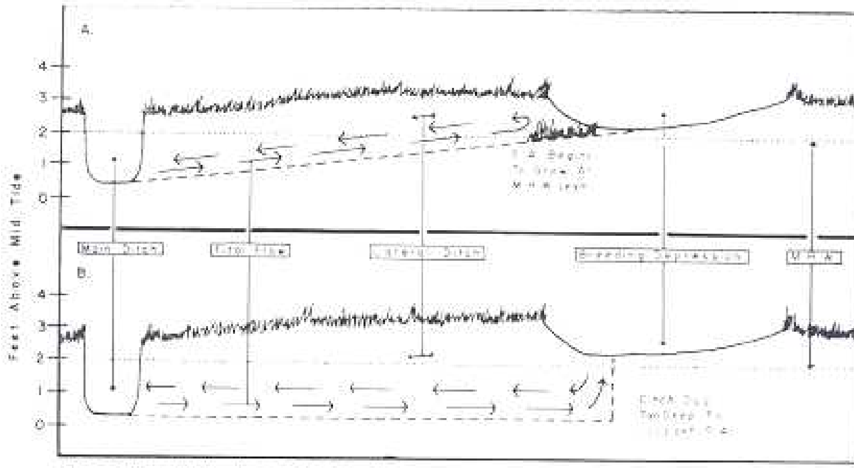


Fig. 5. — Comparative ditching methods to improve tidal circulation, eliminate breeding depressions and increase ditch longevity. Cross-hatching indicates depressions.



SIDE-CUT VIEW OF LATERAL DITCH CONNECTING THE DEPRESSION WITH THE MAIN DITCH

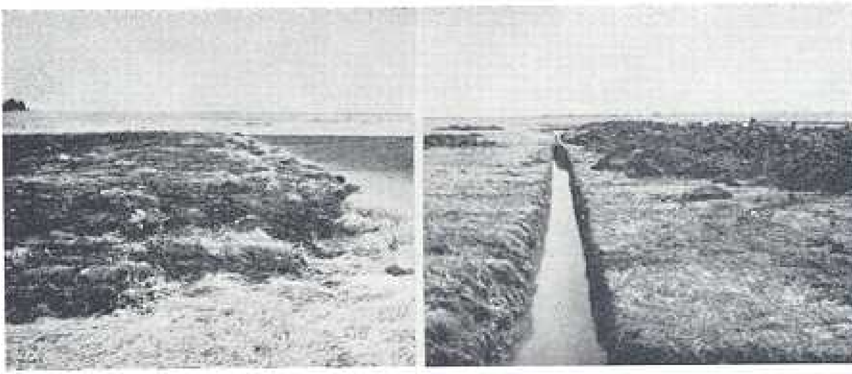
Fig. 6. — Proper deep ditching technique vs. improper grading technique.

the middle of the ditch. If there is a bend in the ditch (A), the main velocity vector hits the sides and there is considerable erosion and deposition that reduces the longevity of the ditch.

(3). Even laterals connecting holes that are straight last longer than crooked ones. Laterals connected on both ends (C) function for greater periods than dead-end ones (D). It is to be remembered that tidal water carries silt in suspension. When the velocity of the current slows, the silt drops out of suspension. Because of resistance the period of silt deposition is much greater in dead-end ditches.

(4). One common mistake is to try to drain depressions by a ditch with a gradual decrease in elevation (Figure 6). Such graded ditches will become re-vegetated. The depression itself will again be isolated from the tidal flow and subjected to irregular flooding by rains and storm tides, a condition conducive to mosquito breeding. Ditches cut in deep to the lowest part of the depressions provide the necessary tidal fluctuation and control mosquitoes for a much longer period of time.

(5). The sod itself is also important. Some commissions deposit the spoil in piles, others alternate from one side of the ditch to the other after 100 to 300 feet are deposited on one side. To provide the least interference of water moving over the surface of the marsh, breaks in the sod are needed and it should be mashed down or graded. The most serious mosquito breeding encountered as a result of improper sod piling was that of a right-hand operator who always placed the sod on the right side of



Graded sod (left) contrasted to ungraded spoil (right). Sod not properly disposed of is unsightly, leads to poor mosquito control and wildlife management.

the ditch. This resulted in complete sections of marsh being diked off from tidal flow causing the entire area to breed mosquitoes.

(6). Piles of sod will form pockets, holding temporary water and breeding mosquitoes. Grading sod is time consuming but it eliminates the possibility of creating new breeding areas. In addition, graded sod will not fall back into the ditches, thus reducing maintenance and other additional costs. Sod not properly disposed of leaves an unsightly appearance. It is hardly noticed on a marsh where it has been properly knocked down or graded. Proper sod handling, therefore, is important in preventing the introduction of undesirable plants, improves the appearance of the marsh, is good mosquito control as well as wildlife management.

The effects of open marsh water management on mosquitoes and other marsh organisms is being evaluated and will be reported in future publications. Briefly, the results on Egg Island exhibit a thorough job on treated marsh for over a 3-year period. On this study area, it has been roughly estimated that between 40 to 60 million mosquitoes were produced per acre last year. This means that for every 1,000 acres completed the production of 40 to 60 billion mosquitoes will be eliminated annually for as long as the ditching is effective. Insecticide applications were eliminated which reduced chemical costs and protected wildlife.

Waterfowl utilization immediately after ditching is not too favorable. But as soon as algae and submergent aquatics volunteered in the ponds, utilization increased. Fiddlers and snails appeared to be more abundant where tidal inundation was restored. Birds that subsist on these organisms were also in greater numbers.

Overall open marsh water management may be the answer toward making real progress in controlling mosquitoes on open valuable tidal marshes, while still considering other interests. The authors are thankful for the splendid work and cooperation of the Cape May and Cumberland County Mosquito Commissions. Many thanks also to M. Schuler, L. G. MacNamara, G. N. Alpaugh, P. D. McLain, B. B. Pepper and L. Hagmann for their support and guidance.

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SALTMARSH WATER MANAGEMENT FOR MOSQUITO CONTROL

Fred Ferrigno[1], Patrick Slavin[2] and D. M. Jobbins[3]

Present saltmarsh management in New Jersey has progressed from years of cooperative endeavors between mosquito control and conservation agencies. Although the management has been perfected in New Jersey, the overall direction is oriented by ecological association of the major type of coastal wetlands. This ecological approach is practical and sound and can be applied to similar types along the Atlantic coast. All coastal states have enclosed or tidal marshes. From Florida to Nova Scotia, improved management of these wetlands would benefit mosquito control and wildlife management. Enclosed marshes or impoundments are managed either for agriculture, wildlife or mosquito control. Water manipulation in privately owned agricultural impoundments are conducive to the production of salt hay and other crops. Under these conditions the resulting heavy saltmarsh *Aedes* breeding is largely controlled by insecticides. Larvicides, such as Abate® granules, are applied during early instars when large broods are present.

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The ultimate solution for enclosed marshes is for the state to purchase them from willing sellers and then subject them to proper water level management or restore them to tides. Research is continuing on both of these management techniques, water level management and tidal restoration. They require special reporting, and, because of the time element, management of the open tidal marsh will be the primary consideration of this report. With the involvement of marine fisheries and other interests, there is a demand for a technique that maintains the open character of the tidal marsh.

Open Marsh Water Management (OMWM)

OMWM is a cooperative endeavor by mosquito control and conservation agencies to perfect a quality water management technique for the mosquito breeding areas of the open tidal marsh. By continually improving on quality through trial and evaluation, the technique is becoming extremely effective in controlling mosquitoes and, at the same time, enhancing tidal marsh resources. Most of the work has been accomplished by three county mosquito commissions, Ocean, Cape May and Cumberland. They work in cooperation with the New Jersey Division of Fish, Game and Shellfisheries and the Entomology Department at Rutgers. A considerable number of these projects are funded by the State Mosquito Control Commission. Evaluation was funded by federal aid to wildlife, P. R. Project W-53-R.

A Cumberland County management crew under the direction of Edward Smith and Patrick Slavin deserves considerable credit for perfecting the technique (Figure 1). In 1966, this unit tackled one of their major problem areas, 5,000-acre Egg Island area, six miles from the upland and riddled with mosquito-breeding depressions created by snow geese. The first year they almost terminated activities when their two backhoes were repeatedly almost lost in the mud. Somehow they endured the hardships and continued annually to improve on methods, equipment and effects. They gradually progressed to their present status of treating over 1,000 acres in a single summer. This Egg Island project has been an outstanding marsh management accomplishment. It has controlled mosquitoes on over 5,000 acres of saltmarsh. It has freed over 16,000 acres of marsh and a large portion of Delaware Bay from insecticide contamination. There were beneficial vegetational changes, increases in food chain organisms and wildlife use.

OMWM is confined to that marsh area that is slightly below to slightly above spring tide line. In New Jersey, it is closely correlated with the salt-meadow cordgrass (*Spartina patens*) and mixed *S. patens*-short saltmarsh cordgrass (*Spartina alterniflora*) types. It is in these major type areas, where irregular flooding from rains and storm and spring tides occurs, that OMWM is being tried, evaluated and perfected. The reed (*Phragmites*

Fig. 1 Edward Smith directs the management crew of the Cumberland County Mosquito Extermination Commission at the Egg Island Project, 1966-74.

communis) zone, well above the spring tide line, also breeds mosquitoes. However, because of the dense vegetation, equipment used in OMWM would not be effective in this zone. Major types that are regularly flooded or kept moist by daily tides such as tall saltmarsh cordgrass (*S. alterniflora*), threesquare (*Scirpus olneyi*), wildrice (*Zizania aquatica*), cattail (*Typha* spp.) and arrow arum (*Peltrandra virginica*) will not produce mosquitoes, and management practices here should be avoided. Most of these types do occur in the other Atlantic coastal states. Sometimes they are replaced by other major types such as the rushes or cutgrasses. Each state is aware of mosquito productive and non-productive types and their relation to mean high water and spring tide lines.

Sod Disposal

Proper sod disposal is essential to quality and is correlated with the ditching machine. Even though some sod can eventually provide nesting cover for certain birds, overall improper sod disposal can create breeding areas, is unsightly, brings in undesirable vegetation, interferes with water movement over the marsh and can adversely affect marsh organisms. Original attempts to squash, grade or disperse sod were time-consuming and expensive. Today, most of the sod disposal problems associated with ditching have been solved by the new amphibious rotary ditcher (Figure 2). This mosquito controller's dream machine, consisting of marsh buggy and mud slinger, has speed and maneuverability, requires little operating and protects the environment. It can do the work of several backhoes and amphibious cranes and do it better. Within a year, virtually no visible signs of spoil exist. The thin layer of spoil on the side of the ditch becomes revegetated quickly. In time it is hoped that all commissions plagued with saltmarsh mosquito breeding will convert to the rotary ditcher.

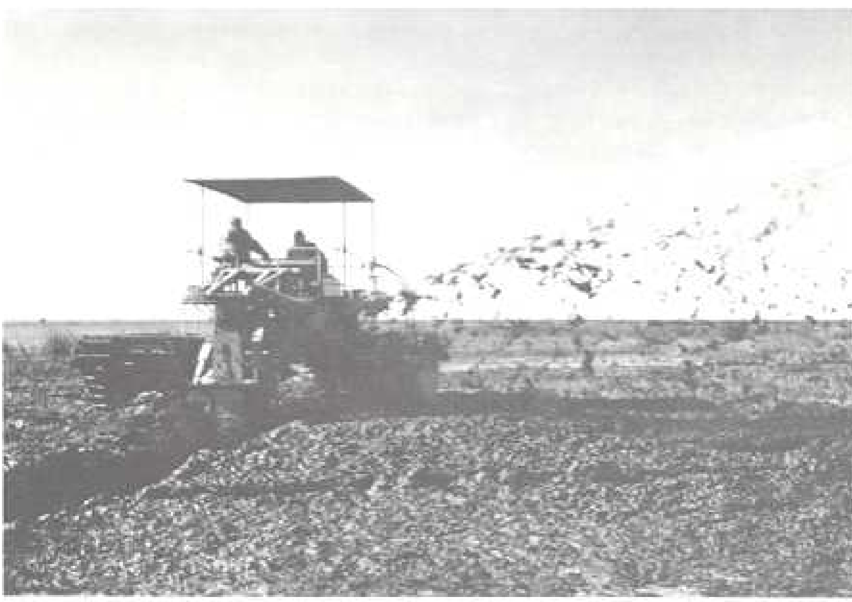

Fig. 2 Most of the problems associated with improper sod disposal have been eliminated by this new amphibious rotary ditcher.

Pond construction is presently accomplished by the amphibious crane. Sod should be graded without creating new depressions. Proper handling of the sod and new equipment still require refinement. A machine like the rotary ditcher that could remove a swath of six feet or more at a depth of six inches would be an enormous asset to the management unit. Ponds may take the shape of the breeding area or may be squared off to facilitate construction by the equipment operator. Pond depths of six inches to one foot promote best waterfowl usage. Deeper sections or edges should be installed to insure survival of killifish during periods of drought.

Objectives

There are three major objectives for OMWM. It must:

1. Control mosquitoes.
2. Eliminate insecticides.
3. Enhance the tidal food web.

Mosquito control in the first objective must be thorough enough and involve all genera in order to adequately serve the second objective of phasing out insecticides. Enhancing the tidal food web (Figure 3), which serves important food and other sources of man and wildlife, is essential for support from other agencies. In this web there are two major branches. One branch goes to the permanent pond with all its associated food chains. The other is the tidal branch were abundance and availability of organisms depends on the tidal life line. To encourage support from all important resource agencies concerned with tidal marshes, OMWM is designed to improve both the permanent pond and the tidal branches of the tidal food web.

Techniques

There are three basic alterations used in OMWM: tidal ditches, ponds and pond radials. Most of the time the alteration selected depends on the distribution of breeding depressions and their proximity to tidal ditches or natural ponds. Sometimes, when water surface is lacking, ponds should be encouraged. When numerous natural ponds are present, pond radials and ditches are preferred.

To illustrate how OMWM actually works, a comparison is made of the two techniques, grid ditching and OMWM on the same piece of marsh (Figure 4). On the right half, grid ditching was previously employed. Engineering principles were utilized. The tidal ditches were cleaned, grids were established and water hydraulics and circulation were excellent. However, even with the use of these engineering principles, the three major objectives were not adequately served. The grids did a fine job of removing surface water and during some floodings stranded larvae in depressions. During periods of excessive flooding, most depressions not connected by grids had sufficient water for mosquitoes to complete their life cycles. Because only a few depressions were directly connected, the percent control was low. Insecticides had to be used and they were easily carried to the tidal ditches by the grid system. The tidal branch of the food web was improved. Tall *S. alterniflora* volunteered along the grid ditch edges, along with fiddlers, snails, mussels and other organisms. However, the permanent pond

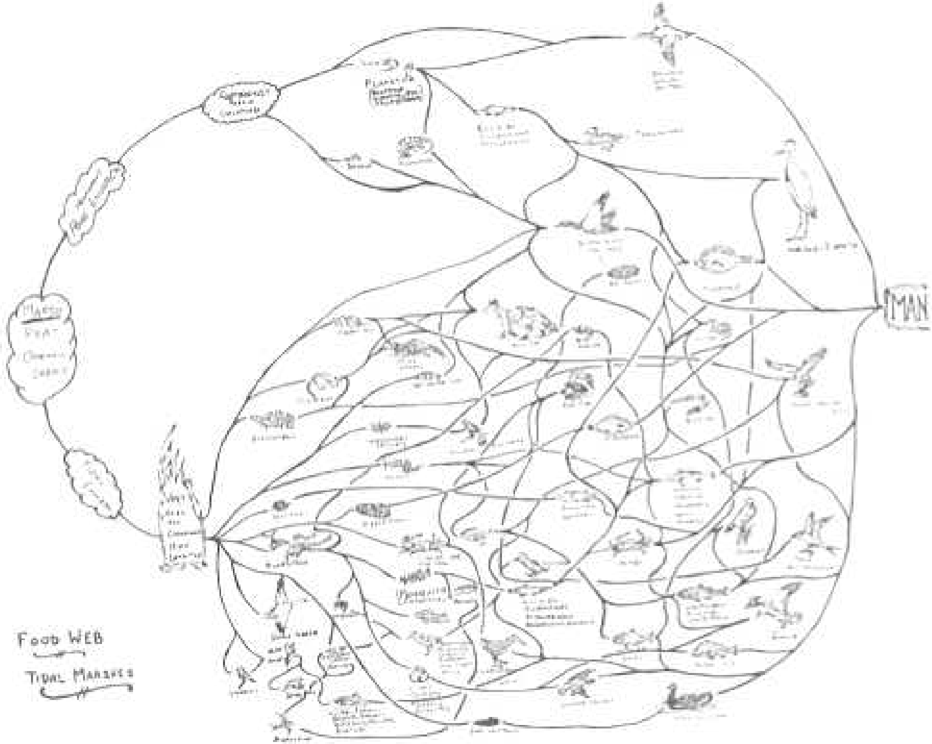

Fig. 3 Open marsh water management enhances both the permanent pond and tidal branches of the tidal food web.

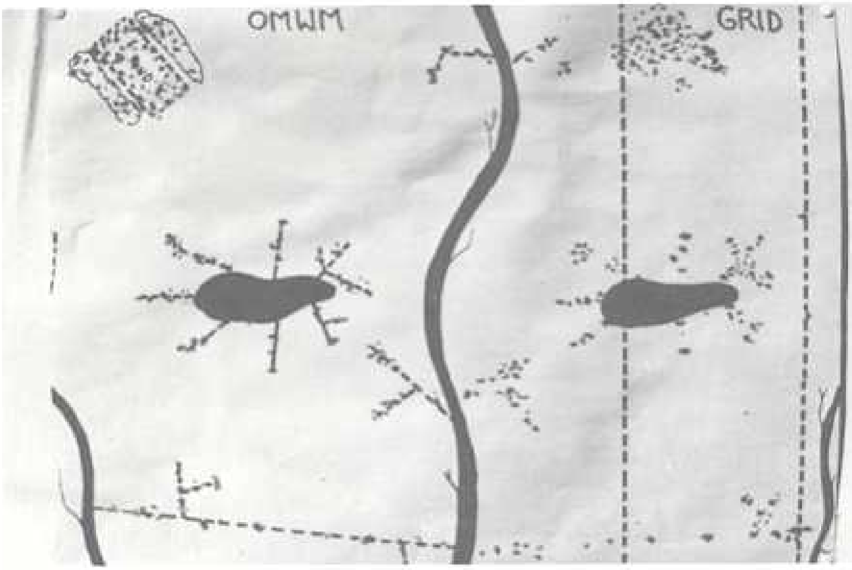

Fig. 4 A comparison of two management techniques, OMWM and grid ditching, on the same portion of marsh with a similar distribution of mosquito-breeding depressions.

branch was adversely affected by drainage of the natural pond. This resulted in complaints from waterfowl hunters and other interests concerned with this branch of the tidal food web.

In the same marsh were subjected to OMWM (left half of Figure 4), all three alterations would have been used. The technique does not require any engineering know-how, just an experienced marsh management unit, some knowledge of marsh ecology and a lot of common sense. Together a wildlife biologist and an entomologist would stake out depressions and would agree to the following alterations. In one area where there is a linear distribution of breeding depressions a main ditch would be dug. The main is connected on both sides to increase longevity and circulation. Some depressions were filled by the rotary ditcher; others were connected by short laterals. The rest of the breeders near tidal ditches were subjected to tidal inundation by laterals shaped according to their distribution. No alterations were wasted in non-breeding areas, as is the case with grid ditching. Pond laterals were used to link depressions to the natural and provide access to killifish (Figure 5). Where numerous depressions were present, a pond was constructed. Adjacent breeders were covered and the spoil graded.

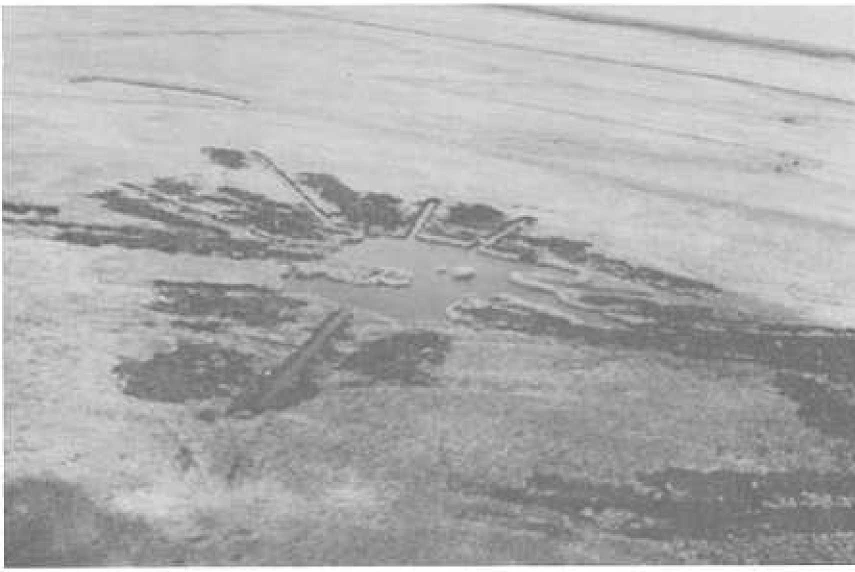

Fig. 5 Pond radials are constructed to provide access for killifish in natural ponds to surrounding mosquito-breeding depressions.

Regardless of weather or flood conditions, OMWM adequately serves all three objectives. The combination of radials and ditches removes surface water adequately. All depressions are either filled or connected to a pond or tidal ditch. Daily tidal inundation and permanent pond access eliminate nearly 100 percent of the mosquito breeding. With mosquitoes controlled, insecticide use is terminated and annual savings of insecticide costs are expected over a forty-year period. Both the tidal (mains and laterals) and the permanent pond (pond radials and ponds) branches of the tidal web are enhanced, resulting in support from concerned agencies.

Present Needs

With the increased interest in protecting valuable marshes, it is essential that mosquito control put its best foot forward and obtain support from the resource agencies involved. In the interest of quality, the U.S. Fish and Wildlife Service has requested standards for water management from various states that could be used to improve quality and screen projects. These standards would also identify a management technique and its effects. Then environmental impact statement, riparian or other permit applications could be submitted to obtain blanket coverage for the technique over a large area. If approved, time-consuming and costly procedures would not be necessary every time the same technique is used. The standards submitted for OMWM, based on years of progress to the present quality, are:

1. OMWM must be confined to the *S. patens* or mixed *S. patens*-short *S. alterniflora* or types of similar elevation that are irregularly flooded by rains or spring or storm tides. It should never be employed on types that do not breed mosquitoes or are regularly inundated or affected by daily tides such as tall saltmarsh cordgrass, wildrice, cattail, arrow arum or three-square.

2. All alterations directly affect mosquito breeding depressions. The three basic alterations include ditches, ponds and pond radials.

3. The type of alteration used will depend on the distribution of breeding depressions, their proximity to natural ponds and tidal ditches and the overall character of the marsh.

4. Both an entomologist and a wildlife biologist are involved in the planning and staking of alterations prior to construction.

5. The amphibious rotary ditcher is used for digging ditches and radials and the amphibious crane for ponds. Impoundments and ditch plugs are not used in this particular management technique. All tidal ditches and pond radials should be cut with the rotary ditcher twice to insure the proper depth for tidal circulation or a reservoir for killifish.

6. The rotary ditcher eliminates sod disposal problems associated with ditches. Spoil from ponds should be graded to the lowest possible level without creating depressions. Shallow ponds with deep edges cut with the rotary ditcher would reduce the amount of spoil considerably.

7. All mosquito or other ditches encountered that are not breeding mosquitoes will not be cleaned or altered in any manner.

8. Proper evaluation is important. Mosquito larval dippings, vegetational mil-acre plots, invertabrate square meter sampling and wildlife censuses are recommended.

9. Insecticide use is gradually phased out as OMWM progresses to eliminate breeding acreage. When the project is completed, all insecticide use is terminated.

A COST COMPARISON BETWEEN OPEN MARSH WATER MANAGEMENT AND CHEMICAL LARVICIDING, UTILIZING MODERN MOSQUITO CONTROL EQUIPMENT

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INTRODUCTION

The Ocean County Mosquito Commission was established in 1915 and has been performing, what is now called integrated pest management, since that time. Some of the earliest records on file indicate that hand ditching actually began on the saltmarsh in 1907, some eight years before the Commission was officially established. Hand ditching continued for quite some time at a rate fluctuating around $0.01 per foot. Early attempts at chemical control were admirable, but futile. Since most chemical control was adjacent to the then existing roads, the large and expansive salt marshes were virtually unsprayed.

COSTS ASSOCIATED WITH LARVICIDING IN OCEAN COUNTY

The eventual utilization of fixed winged aircraft for chemical control afforded the first practical approach to chemical control of the saltmarsh mosquito. Ultimately, the helicopter became Ocean County's primary vehicle for the application of larvicides on the saltmarsh. With its ability to carry both chemical and inspector, as well as land on the marsh, the helicopter enabled immediate inspection and larviciding of mosquito breeding areas. Formerly, limited inspections were either made from a truck or boat, and large blocks of marsh were sprayed, most of which were breeding mosquitoes, but some of which were not.

The original helicopters used were *Bell 47G4A* piston engined machines leased from a private contractor. The spray gear was owned and maintained by Ocean County. Eventually the costs and reliability of leased helicopters were questioned and turbine powered ships were considered for purchase due largely to their increased reliability and safety records. After considering the cost of purchasing and maintaining the ship and their spray gear as well as providing money for the additional insurances and pilots' salaries, owning proved more cost effective than the previous leasing policy. In the fall of 1983, bids were sent out for the purchase of two factory reconditioned turbine powered helicopters complete with larviciding gear.

In May of 1984, two *Bell Jet Rangers* with Simplex spray systems were delivered. Along with the increased safety factors of a turbine engine, many other fringe benefits were discovered. No longer were helicopters leaving the loading areas at or near their maximum lifting capacities. Furthermore, we were able to carry even more pesticide, matching and even exceeding the increased maximum flight time per fuel load of the larger ships. Since less time was spent ferrying back and forth for fuel and chemical, a larger percentage of time was spent inspecting and spraying. This in turn reduced the cost per acre for larviciding.

For the purpose of a current cost evaluation of aerial larviciding versus Open Marsh Water Management at the Ocean County Mosquito Commission, only the latest equipment and techniques have been studied. The cost of these items or services are not merely representative, but are actual costs derived from budget expenditures over the past few years. The Jet Rangers and Simplex spray gear were put into service in 1984, and figures have been analyzed over the past six years to yield a long-term average.

Certain larviciding costs are more or less fixed and only vary to a small degree. Pilots' and inspectors' salaries increase, but usually within a predictable range. The same can be said for helicopter costs per hour and repairs per season. Insurance is costly, but doesn't vary the cost per acre significantly. Administrative costs also increase yearly but are fairly stable. Interestingly enough, the price per unit of fuel and pesticide rise and fall each year, as vendors adjust their prices to the varying market.

The factor which has the most effect on the cost per acre for larviciding is the amount of acreage treated per year. Helicopter inspections of larval breeding habitat are a continual process in Ocean County's salt marsh mosquito control program. In a dry year, a larger percentage of time is spent inspecting instead of spraying. However, the cost of operating the helicopters are still incurred. When the limited sprays of a dry season are totaled at the end of the year, the cumulative acreage sprayed is small. The costs of running the inspection and treatment program that year are spread over a small acreage, and the cost per acre can be extremely high. Conversely, when many acres are sprayed during a wet year, the cost per acre to larvicide can drop severely.

In the six-year period during which the Jet Rangers have been operated, the lightest spray year was 1986. During that year, only 39,898 acres were sprayed, costing an average of $10.57 per acre to larvicide. The past summer of 1989 was the heaviest spray year to date and 75,971 acres were sprayed at an average cost of $6.53 per acre. However, the long-term average for larviciding over the six-year period is $7.74 per acre. In reviewing the cost of our spray program over the past years, we have managed to keep the cost per acre relatively constant. This fact has helped to further justify the decision to purchase rather than continue to lease helicopters.

COSTS ASSOCIATED WITH OPEN MARSH WATER MANAGEMENT IN OCEAN COUNTY

Just as changes were made in our aerial larviciding program, water management has also evolved over the years. Hand ditching became obsolete as various types of heavy equipment and water management techniques were developed. For the longest time, bulldozers and backhoes were used to make ditches. Eventually amphibious draglines replaced them due largely to their increased speed of operation and superior floatation capabilities. Draglines could also be used to construct other large structures such as ponds, impoundment dikes, and stop-ditch plugs. However, many of the procedures also required the use of a bulldozer to level spoil, a process which increased the cost and duration of the projects.

The late 1960's and 1970's saw the concurrent development and refinement of Open Marsh Water Management and the Amphibious Rotary Ditcher. Today, the rotary bucket machines are the backbone of water management in Ocean County. Presently, three rotary bucket machines are operated in the Open Marsh Water Management program. The oldest machine is a 1977 *Quality Industries* Rotary Ditcher which consists of a pontoon mounted person carrier that is diesel powered and hydraulically controlled. A rotary bucket is mounted on the end of a backhoe arm at the rear of the machine.

An identical pair of 1987 *Quality Industries* Amphibious Rotary Excavators are also used for Open Marsh Water Management and are considered state-of-the-art machines for Ocean County. They consist of *John Deere 490D* excavators mounted on amphibious pontoons. Rotary buckets are attached to the end of the excavator arms and are powered by independent 125 HP diesel engines. Although all rotary buckets can dig and disperse spoil, these machines can spread material further and more evenly than their counterparts. The cab and arm rotate 360° which eliminates much of the turning required of the machine. This reduces wear on the tracks and helps prevent premature track failure.

Some small bulldozers and excavators are occasionally used for water management in Ocean County, but such projects are infrequent. For the purpose of this cost comparison, only the three amphibious rotary machines are being considered. Since these machines were delivered in July of 1987, only 2½ years have been used for the comparison. As with the helicopter analysis, the actual cost of water management has been derived from previous budget expenditures. The figures are based on actual cost for completed projects in Ocean County performing Open Marsh Water Management.

Once again, some of the costs are more or less fixed. The operators/marsh specialist's salary increases yearly, but at a somewhat predictable rate. Equipment purchase cost, parts, and insurance fees also increase at similar rates. Fuel and lubricant rates rise and fall as different vendors bid for contracts. Administrative costs increase yearly, usually in proportion to salaries. The change to more elaborate machinery over the years has increased the cost of water management per acre. Since we have always owned and maintained our own water management equipment, as opposed to using a contractor, no large economical change to lower cost was possible as was the case with our helicopter purchases.

In addition to the increase of water management costs, other variables were also noted. The newer and more elaborate machines allowed water management in areas formerly considered too difficult to manage. Previous activities centered around the construction of tidal laterals or pond radials to known breeding potholes. Management areas were selected largely due to their mosquito breeding history, but to a smaller extent, the site selection was influenced by our abilities to work in the area.

With the present amphibious rotary equipment, we can now work in areas which former machines were unable to cross. Large ponds can be constructed where laterals and radials were not sufficient. Much of the spoils from the ponds are used to fill adjacent breeding potholes while the evenly distributed spoil material doesn't require further grading. However, the increased time spent in each acre means that fewer acres can be managed each year. Presently, each machine can manage approximately 150 acres per year if operated daily with little or no time lost due to repairs or inclement weather. Whenever more time is required per acre or time is lost for maintenance or weather, the cost to manage an acre per year increases.

These cost comparison figures are updated annually and used to evaluate the cost effectiveness of water management projects. In the past, the various projects have paid for themselves in 5 to 10 years. A present Open Marsh Water Management project on 155 acres is being funded by the N.J. State Mosquito Control Commission. The area is typically sprayed 8 times a year at the long-term average cost of $7.74 per acre. The cost of larviciding the project site last year was therefore:

8 applications/year X 155 acres/application = 1,240 acres/year

and

1,240 acres/year x $7.74/acre = $9,597.60/year

Assuming an 8% compounded interest, the cost to larvicide over 5 years was:

$9,597.60 x $5.87* = $56,337.91

*Compound amount factors for uniform series at fixed interest rates versus time (see Grant and Ireson 1970) or

Assuming an 8% compounded interest, the cost to larvicide over 10 years was:

$9,597.60 x $14.49* = $139,069.22

At a cost of $444.23 per acre, water management of 155 acres will cost $68,855.65. As can be seen from the 5- and 10-year cost predictions of larviciding, water management will reach a break-even point near the beginning of the seventh year. By the end of the tenth year, continued larviciding costs would have exceeded water management cost by $70,213.57. Many of the older Open Marsh Water Management projects are now more than 20 years old and functioning well. Since these systems will be virtually permanent, the savings viewed over larger periods of time become staggering. The cost difference after 15 years is approximately $190,000.00, at 20 years it is $370,000.00, and at 25 years it is $630,000.00

Table 1. Compounded interest over time

Years	8%	10%	12%	15%	20%
5	5.87	6.10	6.35	6.74	7.44
10	14.49	15.94	17.55	20.30	25.96
15	27.25	31.77	37.28	47.58	72.03
20	45.76	57.28	72.05	102.44	186.89
25	73.11	98.35	133.33	212.79	471.98
30	113.28	164.49	241.33	434.74	1181.88

CONCLUSIONS

Based on the cost effectiveness of Open Marsh Water Management, the Ocean County Mosquito Commission has a long-term commitment to the program. Most of the involved regulatory agencies seem to favor Open Marsh Water Management at the moment. This sentiment is largely derived from water management studies generated at mosquito control commissions around the state. Aerial larviciding will continue as a short-term control measure. With nearly 29,000 acres of saltmarsh in the county, managed at a rate of 150 acres per machine each year, the need to discontinue larviciding will probably never occur. Over the years, the integrated pest management approach, involving both larviciding and water management, has always proven to be the best method.

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THE HISTORY AND APPLICATION OF OPEN MARSH WATER MANAGEMENT IN NEW JERSEY

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Open marsh water management (OMWM) is the physical alteration of a specific mosquito-producing salt marsh accomplished at or below the marsh surface in order to eliminate the emergence of all species of mosquitoes without the use of chemicals, while either stabilizing or enhancing the tidal food chain. This technique is a key part of an integrated pest management (IPM) plan. Most coastal mosquito control organizations (MCOs) in New Jersey can effectively use this as a method to permanently eliminate salt marsh mosquito production.

The description of this technique might not be easily understood at first glance. The physical alteration of a specific larval habitat means, generally, that low ground pressure equipment is used to physically change the known characteristics of a stagnant piece of marsh that has been identified, or has characteristics known to be identified as mosquito habitat. Areas that do not produce mosquitoes are not candidates for OMWM. It is important to note that OMWM has been developed with mosquito control as the primary goal. While other benefits such as improvements and enhancements to the salt marsh systems are important, OMWM should not be implemented without the presence of mosquito larvae.

Modifications occur at or below the marsh surface. Ponds and radials may be constructed as well as some tidal ditches. Elevated structures that are significantly above the normal marsh elevation, however, would would impair tidal flow, ultimately causing a vegetation change. These structures are not consistent with OMWM guidelines and should not be constructed. Examples of these would be impoundment dikes and stop-ditch plugs. Excavated spoil resulting from pond and ditch construction may be used in marsh mitigation practices if available methods employed minimize changes in marsh elevation. Maintenance of flora type, such as *Spartina patens* and *Spartina alterniflora*, and discouragement of the introduction of woody vegetation ,such as *Iva frutescens* and *Bacharis halimifolia*, is desired.

The main objective of OMWM is to prevent the emergence of all species of adult mosquitoes without the use of chemicals. It is possible (when performing mosquito surveillance) to find larval development in such minimal amounts of water that the emergence to the adult stage is unlikely to occur prior to the disappearance (i.e. evaporation) of the water. When this appears to be the case, OMWM would usually not be required since it's not the presence of mosquito larvae or pupae that is problematic but rather the emergence of the adult mosquito that causes nuisance and disease potential.

Conversely, it is important when performing OMWM to address the entire mosquito habitat so that chemical applications are no longer required. An OMWM project that requires continued chemical applications is usually not considered to have been successful. The performance of OMWM coupled with continued chemical applications should only be entertained under extenuating circumstances. This often occurs as a result of a less than an optimal compromise with a landowner, which ultimately produces lower populations of adult mosquitoes but never gets rid of them entirely.

As previously stated, the main objective of OMWM is to control the emergence of mosquitoes. Fortunately, it is not significantly more difficult or costly to maintain, stabilize or even enhance the environment while performing OMWM. For instance, decades of salt hay farming in the past have removed biomass required for marshes to continue to grow. These practices have introduced acres and acres of tire ruts that hold water and prevent salt marsh grasses from growing. This persistent water results in numerous broods of mosquitoes each season. The spoil material generated from the closed (non-tidal) OMWM ponds is used to level the more remote potholes and low areas, resulting in the regrowth of the salt marsh grasses adjacent to the ponds. Prior to management, the same marsh depressions that triggered larval mosquito production would also trap many species of killifish. The ensuing drying cycle would then kill these fish by the millions. After the application of OMWM, the stagnant water areas that cause fish mortality no longer exist as they have either been incorporated into a pond or have been regenerated into a viable marsh. The fish entering a managed site will ensure survivability by retreating to either a permanent pond or tidal water as the flood water recedes. Fish mortality due to desiccation in such a stagnant, unmanaged marsh goes from nearly 100% pre-management to 0% post-management. These are a few of the possible positive benefits of OMWM; more will be described in the description of pond construction.

The design, application, and success of OMWM come from the knowledge of the mosquito life cycle. In New Jersey, as in many of the surrounding states, the salt marsh mosquito, *Aedes sollicitans*, is by far the predominant mosquito species on the salt marsh. It is not only a tremendous nuisance, but it is a vector of a highly virulent strain of encephalitis. Unlike many other female mosquitoes that can lay their eggs on the water surface, this species can only lay eggs on the damp surface of a pothole. The permanent ponds created during OMWM replace these potholes, and consequently deny the mosquito of its oviposition (egg laying) sites.

All mosquito species are vulnerable during the aquatic phase of their life cycle as they progress through four larval instars and then pupate. During this time period, which can be as short as four or five days, many things may occur which will interrupt their life cycle and cause their demise. Primary among these would be the introduction of appropriate pesticides, the disappearance of the water, or the presence of predacious fish. It is the last two that form the basis of OMWM. The elimination of an oviposition site can be as simple as connecting mosquito producing depressions to a tidal source or by filling such sites with marsh materials excavated as a result of the OMWM operations. In the tidal ditch scenario, mosquito control can occur not only by exposing previously stagnant water to tidal influence, but also by introducing native predacious fish. However, tidal ditching can de-water a marsh and is not generally considered the best way to perform OMWM. Pond radials, which are ditches from existing ponds, can accomplish the same result without draining the marsh. Also, by creating ponds in the more densely clustered pothole areas, permanent water areas are created and their construction serves many ecologically useful purposes. The first step is to identify a stagnant, drying and flooding habitat that is known to be conducive to mosquito production and to transform it into a closed (non-tidal) pond, upon which the salt marsh mosquito can no longer deposit eggs. The pond also serves as habitat for predacious fish, which will feed upon any mosquito larvae. The spoil generated from the pond can be used to fill in adjacent potholes, thereby eliminating stagnant water and encouraging regrowth of the managed marsh.

The developments that led to the technique of OMWM can be traced back to the late 1800s as people began to more fully understand their environment. After it was discovered that "wrigglers" in the salt marsh potholes were mosquito larvae, attempts were made to eliminate the habitat. Basic tools such as sod saws, shovels and spades were employed to drain these potholes by connecting them with small ditches. This method was extremely labor intensive, but workers soon realized that the marsh plugs that were removed to create the ditch could be utilized to fill in other potholes, thereby reducing their work. By directly addressing the mosquito producing habitat, the fundamentals of OMWM were born. It can be argued that perhaps one of the major setbacks in the management of salt marshes in the name of mosquito control occurred during the Great Depression. One theory was that a tidal ditch located close enough to a pothole would drain that pothole during low tide because of the porous nature of the marsh substrate. State and federal programs were then devised during the depression years that employed large numbers of individuals to create parallel ditches on the salt marsh at roughly one hundred foot intervals.

These ditches were engineered to be perfectly straight, only intercepting mosquito productive depressions by accident and similarly draining closed (non-tidal) ponds, pans and semi-flooded marshes. The whole process tended to needlessly dry out the marshes, introduce unwanted vegetation, and span across many acres that did not produce mosquitoes. Presently, most of the salt marshes in New Jersey have been grid or parallel-ditched. The subsurface drainage that was thought to occur never achieved lasting success, and the depressions between the parallel tidal ditches continued to produce mosquitoes. This engineering technique was generally viewed as a failure, particularly in contrast to the prior biological approach, which directly addressed specific mosquito habitat. It was not until the end of these programs of engineered parallel ditches that the local mosquito control agencies resumed the former biological control method. Once again, only mosquito habitats were addressed and nonproductive ones were left alone. By this time, however, the technology in the field of heavy equipment had advanced to a degree that allowed other options to become available.

Mosquito control experts began to evaluate the reasons that certain marshes were nonproductive for mosquitoes. Most of the larger ponds were permanently flooded, had deeper areas to ensure mosquito fish survivability during droughts, and had aquatic vegetation that provided nutrients to the pond as well as cover for the fish. These ponds could then be reproduced in mosquito productive areas that had larger concentrations of closely spaced depressions. The spoil material removed from this pond construction could be used to fill adjacent depressions, and pond radials could be used to connect more remote depressions to the ponds. Tidal laterals would then not be as necessary unless located near a tidal source. The use of a tidal ditch in this instance may be preferred since the use of a pond radial near a tidal source could breach and drain a non-tidal pond.

For years, this technique was discussed and employed in New Jersey by the various mosquito control agencies that had salt marsh mosquito problems. Management schemes and equipment choices were refined until a very workable scenario came into practice. Most of this refinement occurred during the late 1960s and 1970s through the efforts of Mr. Fred Ferigno (New Jersey Department of Environmental Protection's Division of Fish, Game and Shellfisheries), Mr. Daniel Jobbins (New Jersey Agricultural Experiment State at Rutgers University), and many individuals at the local mosquito control agencies.

By the late 1970s, Mr. Ferigno had drafted a short, accurate and concise document entitled, "Standards for Open Marsh Water Management." Several meetings were held by the involved agencies which were used to discuss and solidify this document. These are the same standards that were adopted just prior to 1980 and have been followed in New Jersey since their development. A copy of these standards is included with every permit application request as a foundation for the management scheme. A more detailed description as well as the standards themselves can be found in the Proceedings of the Sixty-Seventh Annual Meeting of the New Jersey Mosquito Control Association, Inc. (1980).

Currently, OMWM is most frequently accomplished through the use of rather large amphibious rotary excavators. Many of these have two diesel powered engines, one to perform the usual excavator functions and a second to provide power directly to the rotary ditcher bucket. This ensures that ample power is constantly provided to the ditcher bucket, enabling it to create a wet slurry of spoil materials that is spread thinly and evenly at great distances from the excavation site. Some of the newest machines can distribute the spoil material nearly one hundred feet from its origin. This not only spreads the spoil thinner, but also allows more remote depressions to be filled without additional alterations.

Present day OMWM techniques and equipment can address problem salt marshes that were formerly considered too difficult or too costly to manage. Some areas, such as former salt hay sites, have been so devastated by human impact that only these machines can be used there. With a low ground pressure of approximately 2 pounds per square inch, they can traverse the marsh areas with less disruption than a person walking over it. Much of the marsh has only minimal root mass to provide stable footing, but the wide footprint of these pontooned machines allows them to operate without further destruction. Ponds can be created in the most devastated areas, and the spoils can reach the extreme edges to provide for the resultant revegetation.

In actual practice, there are three techniques commonly used to accomplish OMWM. The first is the tidal ditch. This is used in instances where a depression is connected to a tidal source through the construction of a ditch. Ditches are typically three feet deep. This technique is usually used when the pothole is in close proximity to the tidal source; however, it is often possible to fill this depression rather than create a ditch. This can cause fewer disturbances to the marsh and be less management intensive. With all of the marsh de-watering that parallel ditching has caused, tidal ditching is currently used to a much lesser degree and usually when there is not another preferable option.

Second, the use of the pond radial is often a preferable solution to the management of a depression. In this instance, a ditch from a permanent pond to the depression will eliminate the stagnant water state of the depression and allow predacious mosquito fish to migrate from the pond to the depression. The pond radial and the depression both then become extensions of the pond.

The third technique used in OMWM is the construction of the permanent pond. Some of the more shallow ponds that exist on the marsh are non-permanent and can often be identified by the lack of aquatic vegetation within them. The lack of vegetation is due to the same drying and re-flooding that causes larval mosquito production. By creating deep water habitat within such ponds, the permanent water promotes the growth of aquatic vegetation, ensures killifish survival and eliminates mosquito production.

New pond construction is often the required method when many mosquito producing depressions are clustered close together. In this technique, the pond is created within the area of the maximum mosquito depressions but situated in a manner that allows the spoils to be distributed to the more remote depressions. Simply digging out a pond would generate excessive amounts of spoil. The distribution of this spoil would then become a problem regarding changes to the vegetation composition. For example, the higher elevation that results would promote the growth of woody vegetation and block tidal water flow. In order to create ponds of appropriate size, several methods have been developed to minimize the amounts of spoil generated from construction. One such method is to leave sections of marsh within the pond to form islands. Depressions on these islands can be filled, but their overall elevation must match that of the surrounding marsh. One or more islands can be made depending upon the size of the pond. By leaving these islands within the pond, spoil materials are reduced. Generally, the depth of the water around the islands is three feet, thereby creating a fish reservoir to protect the fish during droughts. Many areas in the pond may only be six to twelve inches deep. These can often be created around the outer edge of the pond, much like a submerged and sloped sidewalk just within the pond's perimeter. This also reduces the amount of spoil generated, while at the same time incorporates the depressions into the pond and adds more water surface in the process. The various water depths promote wading bird feeding and encourage the growth of aquatic vegetation. Killifish that enter the pond almost immediately after construction depend on the development of this vegetation.

When the project is complete, mosquito control is accomplished without the use of pesticides. Typically, few new tidal ditches are created in favor of more ponds and radials. This keeps more water on the marsh. Waterfowl are offered islands as nesting or resting habitat and wading birds are provided shallow water in which to feed. The aquatic vegetation provides nutrients and cover for killifish. The elimination of stagnant water effectively reduces mosquito production to zero and eliminates killifish mortality.

Pond construction, however, is usually the most extreme technique, but serves as the most beneficial in certain areas. Since much work is done and larger amounts of materials are moved, the time it takes for these areas to respond in certain ways is increased over simple tidal or pond radial ditching. Mosquito control is immediate and the presence of killifish soon follows. The re-vegetation will begin at the first growth spurt after construction, but can take several years to complete. Factors contributing to this delay can include the presence or absence of grass prior to construction, the amount of spoil required to fill the adjacent areas or depressions up to grade, and the amount of sand present in the excavated material. Sand can slow the vegetative process significantly since it is low in organic content. Also, and less visible, is the time required for pond maturation. A newly constructed pond is very porous and may not hold as high of a water level as it will when it matures, particularly if a sand substrate was encountered during excavation. Over time, however, it will become more identical to a natural pond as aquatic vegetation and other normally occurring marsh debris allows the pond bottom to seal. A common mistake is to try to evaluate the OMWM sites prior to their maturity. Even though the marsh grasses may have matured, this is does not necessarily mean the pond has.

Another management tool that can be used in conjunction with OMWM is ditch plug construction. Many rotary excavator buckets have the ability to move various amounts of material while not spinning. The ditch plugs can be used to plug ponds that were drained during prior ditching attempts, such as parallel ditching, or to plug a ditch that would otherwise drain a pond that is being constructed. The remainder of the ditch can then be incorporated into the pond. If it were not, it would most likely become another mosquito production site.

There are several ways which one may judge the success of an OMWM project. Adult mosquito populations, measured by landing rates and light trap data can be compared before and after management. However, adult mosquitoes from remote larval habitat make this comparison less than useful. Some of the most helpful forms of evaluation come from larval dip data and aerial spray data both pre and post management. Composite treatment maps, which illustrate sequential and repeated applications of insecticide to specific sites, are often the most visual and impressive indicators. An agency that prepares this kind of map has many years of data showing annual pre-management frequency of treatment. In many cases aerial treatments of larvicides exceed ten per year. Post management maps usually show an immediate drop to zero treatments per year in the completed sites.

Many non-target studies have been accomplished that document the failure of OMWM to impact the flora and fauna of the salt marsh. Most can be found in the past copies of these proceedings. Some were done in the earliest days of OMWM, most notably by Dr. Joseph Shisler of the New Jersey State Agricultural Experiment Station at Rutgers University, where he studied pre and post data on vegetation, fish and invertebrates. Dr. Kenneth Able, also of Rutgers University, studied fish diversity in managed versus natural sites. The common meadow vole populations pre and post management were studied for up to five years after management by Michael Romanowski of the Ocean County Mosquito Commission. As previously noted, the most common mis take made when analyzing OMWM projects is that the data is often collected before the systems have had a chance to fully mature. The failure to study the complete life history of a newly constructed salt marsh pond, however, is often due to loss of adequate resources dedicated to the mission.

A presentation by this author was also published in the NJMCA Proceedings evaluating the cost effectiveness of OMWM. Although the cost of OMWM is more expensive than larviciding in the first year, by the seventh or eighth year, the costs reach equilibrium. However, since many older OMWM projects are now showing thirty years of longevity without requiring larvicides, the cost savings becomes quite substantial.

When reviewing the ojectives of OMWM, it appears that the desired goals are being met. Not only is it cost effective, but it has a long life span that controls mosquitoes without the use of pesticides while stabilizing or enhancing the tidal food chain. For most, it affords a very viable option, particularly when considering the alternative of continued pesticide applications.

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Attachment B – Open Marsh Water Management References

Open Marsh Water Management References

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