United States
Environmental Protection
Agency

Science Advisory Board

EPA-SAB-EPEC-98-003
January 1998
http://www.epa.gov/sab

EPA

Ecological Impacts And Evaluation Criteria For The Use Of Structures In Marsh Management

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Ecological Impacts And Evaluation Criteria For The Use Of Structures In Marsh Management

Stephanie Sanzone and Anne McElroy, Editors

Marsh Management Subcommittee

Ecological Processes and Effects Committee

EPA Science Advisory Board

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, DC 20460

January 22, 1998

EPA-SAB-EPEC-98-003

Honorable Carol M. Browner
Administrator
U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, DC 20460

Subject: Ecological Impacts and Evaluation Criteria for the Use of Structures in Marsh Management

Dear Ms. Browner:

In 1994, at the request of the Office of Wetlands, Oceans, and Watersheds (OWOW), the Science Advisory Board (SAB) established a Marsh Management Subcommittee to review the state of the science underlying the use of structures to manipulate marsh hydrology. This approach to marsh management, termed Structural Marsh Management (SMM), entails the use of structures such as canal plugs, weirs, tide gates, and levees to manipulate local hydrology in tidal and Great Lakes marshes. The genesis of the request to the SAB was OWOW's interest in assessing the scientific basis for a consistent Agency, and ultimately national, approach to the evaluation of proposed SMM projects, which are currently being implemented most widely in coastal Louisiana under the federal Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA). As part of the CWPPRA process, the various federal and state agencies with a role in the evaluation of proposed restoration projects, including SMM projects, have expressed differing views on the ecological desirability of SMM.

Historically, structural manipulation of marsh hydrology, including impoundment, has been used to enhance habitat for waterfowl and wildlife, provide physical buffers against wave or tidal scouring, control mosquito populations, create nursery habitat for fish and macroinvertebrates, and treat wastewater and storm water. More recently, SMM has been undertaken for the specific purpose of protecting or creating emergent vegetated wetlands in coastal Louisiana, where the rapid rate of deterioration of extensive coastal wetlands and marine encroachment has prompted protective efforts by landowners and public resource agencies.

In the Charge to the Subcommittee, which was developed by OWOW with input from the U.S. Fish and Wildlife Service, the National Marine Fisheries Service, the U.S. Army Corps of Engineers, and the Soil Conservation Service (now the Natural Resources Conservation Service), the Subcommittee was asked to evaluate the impacts of SMM on emergent marsh vegetation, natural marsh-sustaining processes, and fish and wildlife. In addition, the Subcommittee was asked to assess the cumulative impacts of numerous large-scale SMM projects in a region, identify high priority research and monitoring needs, and suggest scientific or technical evaluation criteria that the Agency could use to evaluate proposed SMM projects. To address the Charge, the Subcommittee worked over a two-year period, holding two public meetings, a site visit to coastal Louisiana, a writing session, and several rounds of draft review and revision. The SAB report provides a summary of the state of the science on the ecological consequences of SMM from a national perspective, science based-evaluation criteria for SMM projects, monitoring and research recommendations, and a discussion of SMM issues in various regions of the country.

In agreeing to evaluate the science underlying SMM, the Subcommittee was very aware of the contentious nature of the issue, and the political and management implications of any report on this subject. The Subcommittee recognizes that ecological considerations are not the only factors that must be utilized by the Agency in developing any proposed policy on SMM. The Subcommittee is also aware that consensus among the federal agencies with a role in SMM may be a longer-term goal. Nonetheless, we urge the Agency to consider fully the findings of this report in developing and adopting an Agency policy on SMM.

We would like to emphasize the following Subcommittee conclusions:

a) The collective experience around the country has shown that unintended, unanticipated, and sometimes undesirable effects have resulted from structural management of marsh hydrology.

b) Although marsh management practices have evolved over the years to include more sophisticated structures and management approaches for controlling water levels, there is insufficient information at present to determine whether these new structural approaches are inherently better than those used in the past.

c) SMM projects may be irreversible (e.g., in cases where the marsh has subsided behind levees or spoil banks) and thus imply a perpetual, and often costly, commitment to the management and maintenance of control structures.

d) Past SMM projects have shown that while it is relatively easy to change marsh hydrology, it is much more difficult to control or manage the changes or to predict fully the consequences of proposed modifications.

With these cautionary notes as a backdrop, the Subcommittee urges the Agency to evaluate all proposed SMM projects carefully against the criteria in this report, taking into account the potential impacts of projects from an ecosystem, rather than single-species or single-resource, perspective. Although specific choices regarding SMM should be based on local circumstances, management objectives, and trade-offs; the Subcommittee proposes the following science-based principles for SMM to achieve sustainable wetlands:

a) Wetlands systems that are providing a suite of wetland functions and are self-sustaining should be left undisturbed and not subject to SMM.

b) Only if restoration of hydrology or physical processes is not feasible should SMM be considered as an approach to restore/improve the wetland.

c) The decision of whether or not to use SMM should reflect a firm scientific understanding of the causes of marsh degradation, both in a local and regional context, and should take into account regional differences in marsh dynamics. The Proposed Guidelines for Ecological Risk Assessment (EPA, 1996) should guide the evaluation of risks to the system with and without the proposed SMM.

d) Preference should be given to SMM strategies that restore, to the degree possible, natural wetland processes and functions and provide for at least periodic hydrologic connectivity with surrounding ecosystems.

e) In large part, SMM techniques are experimental and should only be applied with appropriate experimental design, including monitoring of both the managed site and control sites to assess the impacts of the SMM on marsh processes and long-term marsh viability and to determine whether the project is meeting management and design objectives.

In summary, the Subcommittee has attempted to synthesize the large body of scientific literature on the ecological consequences of changing marsh hydrology, including what is known and not known, and to emphasize the development of science-based criteria that should guide evaluation of proposed SMM projects. We hope the report will assist you and the Agency in developing a scientifically based policy for SMM, and we look forward to your reply.

Sincerely,

Dr. Joan M. Daisey, Chair
Executive Committee

Dr. Mark A. Harwell, Chair
Ecological Processes and
Effects Committee

Dr. Anne McElroy, Chair
Marsh Management Subcommittee

Enclosure

NOTICE

This report has been written as part of the activities of the Science Advisory Board, a public advisory group providing extramural scientific information and advice to the Administrator and other officials of the Environmental Protection Agency. The Board is structured to provide balanced, expert assessment of scientific matters related to problems facing the Agency. This report has not been reviewed for approval by the Agency and, hence, the contents of this report do not necessarily represent the views and policies of the Environmental Protection Agency, nor of other agencies in the Executive Branch of the Federal government, nor does mention of trade names or commercial products constitute a recommendation for use.

ABSTRACT

The Marsh Management Subcommittee of the Science Advisory Board's Ecological Processes and Effects Committee reviewed the state of the science for structural marsh management (SMM). The Agency requested this review in support of their plans to develop an interim Agency position on SMM, with a long-term goal of developing a national marsh management policy. The Subcommittee used the term "structural marsh management" to distinguish this fairly narrow set of management approaches from the broader set of practices that are commonly associated with the term marsh management. The Agency's definition for marsh management is "the use of structures (such as canal plugs, weirs, gates, culverts, levees and spoil banks) to manipulate local hydrology in coastal marshes." The Agency specified in the Charge for the Subcommittee to include in its review wetlands influenced by the tide, and lands and waters associated with the Great Lakes.

The Subcommittee found that the collective experience on SMM around the country has shown that unintended, unanticipated, and sometimes undesirable effects have often resulted from structural management of marsh hydrology. The Subcommittee found it difficult to generalize about the ecological impacts of SMM because of differences in the physical environment, status of wetland resources, or management objectives in different wetland areas. The Subcommittee recommends that the application of a marsh management policy should be done at least at the region-specific, ecosystem-specific, or basin-specific level. The Subcommittee urges caution in the adoption or approval of SMM projects in order to avoid counterproductive results on the long-term sustainability of imperiled tidal and Great Lakes wetlands. The Subcommittee also recommends that Agency decisions regarding proposed SMM projects take into account the potential impacts of the project from an ecosystem, rather than single-species or single-resource, perspective.

In addition to providing a summary of the state of the science on the ecological consequences of SMM from a national perspective, the report recommends a number of scientific/technical criteria that should be used to evaluate proposed SMM projects, highlights priority monitoring and research issues, and discusses SMM issues that are relevant in various regions of the country.

Keywords: coastal marshes, hydrology, marsh management, structural marsh management

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Acknowledgments- In addition, other Science Advisory Board Staff Members contributed to the development and/or completion of this report. These include Robert Flaak, who staffed the site visit to Louisiana; Dorothy Clark, who provided meeting support; Roslyn Edson, who provided final edits; and Wanda Fields, who typed the final edits to the report. The subcommittee also thanks the Agency staff, in particular Fran Eargle and the members of the Team for Ecosystem Restoration in the Wetlands Division, for their assistance in gathering and organizing a large number of scientific and policy background documents.

Contents

1. EXECUTIVE SUMMARY

At the request of the Environmental Protection Agency's Office of Wetlands, Oceans and Watersheds, the Ecological Processes and Effects Committee of the Science Advisory Board (SAB) established a Marsh Management Subcommittee (the Subcommittee) to review the state of the science for structural marsh management in support of Agency plans to develop an interim Agency position on SMM, with a long-term goal of developing a national marsh management policy. The Charge to the Subcommittee (Appendix A) defines marsh management as "the use of structures (such as canal plugs, weirs, gates, culverts, levees and spoil banks) to manipulate local hydrology in coastal marshes." The Charge notes further that "marsh management or tidal impoundments for the purpose of this review will include those wetlands influenced by the tide and lands and waters associated with the Great Lakes." The Subcommittee subsequently decided to use the term "structural marsh management" (SMM) to distinguish this fairly narrow set of management approaches from the broader set of practices that are commonly associated with the term marsh management.

Historically, structural manipulation of marsh hydrology, including impoundment, has been used to enhance habitat for waterfowl and wildlife, provide physical buffers against wave or tidal scouring, control mosquito populations, create nursery habitat for fish and macroinvertebrates, and treat wastewater and storm water. More recently, SMM has been undertaken for the specific purpose of protecting or creating emergent vegetated wetlands in coastal Louisiana, where the rapid rate of deterioration of extensive coastal wetlands and marine encroachment has prompted protective efforts by landowners and public resource agencies. In the Charge, the Subcommittee was asked to evaluate the impacts of SMM on emergent marsh vegetation, natural marsh-sustaining processes, and fish and wildlife. In addition, the Subcommittee was asked to assess the cumulative impacts of numerous large-scale SMM projects in a region, identify high priority research and monitoring needs, and suggest scientific or technical criteria that the Agency could use to evaluate proposed SMM projects.

Although most experience with SMM is based on efforts primarily designed to accomplish a purpose other than the protection or creation of emergent vegetated wetlands, the collective experience around the country has shown that unintended, unanticipated, and sometimes undesirable effects have often resulted from structural management of marsh hydrology. Differences in the physical environment, status of wetland resources, and management objectives make it clear that the application of a marsh management policy needs to be at least region-, ecosystem-, or basin-specific. Further, the impact of SMM on marsh-sustaining processes depends on the type of management scheme employed. For these reasons, it is difficult to generalize about the ecological impacts of SMM. However, the interruption of daily, monthly, and seasonal hydrologic cycles as a result of SMM inevitably influences important elements of the ecosystem such as sediment chemical processes, water column chemistry, the distribution and migration of aquatic and semi-aquatic organisms, and material import and export from the marsh.

Because of the substantial uncertainties about the impacts of SMM and because not all SMM projects are reversible, the Subcommittee urges caution in the adoption or approval of SMM projects in order to avoid counterproductive results on the long-term sustainability of imperiled tidal and Great Lakes wetlands. Further, we strongly recommend that Agency decisions regarding proposed SMM projects take into account the potential impacts of the project from an ecosystem, rather than single-species or single-resource, perspective. We recognize that ecological sustainability is not the only consideration in the evaluation of SMM projects. However, insofar as the Agency's goals are to ensure long-term marsh survival and productivity, the Subcommittee proposes five science-based principles with regard to SMM (Figure ES-l).

The Subcommittee's responses to the specific questions in the Charge are summarized below:

a) Does SMM protect or create emergent vegetated wetlands? In regard to this evaluation, consider two conditions in the response: i) areas where net sediment deficit occurs (i.e., soil building does not keep up with relative sea level rise), and ii) areas where there has been extensive human-induced wetlands deterioration.

Figure ES-1 Science-Based Principles for Structural Marsh Management to Achieve Sustainable Wetlands

1) Wetlands systems that are providing a suite of wetland functions and are self-sustaining should be left undisturbed and not subject to SMM.

2) Only if restoration of hydrology or physical processes naturally occurring at the site is not feasible should SMM be considered as an approach to restore/improve the wetland.

3) The decision of whether or not to use SMM should reflect a firm scientific understanding of the causes of marsh degradation, both in a local and regional context, and should take into account regional differences in marsh dynamics. The Agency's Proposed Guidelines for Ecological Risk Assessment (EPA, 1996) should guide the evaluation of risks to the system with and without the proposed SMM.

4) Preference should be given to SMM strategies that restore, to the degree possible, natural wetland processes and functions and provide for at least periodic hydrologic connectivity with surrounding ecosystems.

5) In large part, SMM techniques are experimental and should only be applied with appropriate experimental design, including monitoring of both the managed site and control sites to assess the impacts of the SMM on marsh processes and long-term marsh viability and to determine whether the project is meeting management and design objectives.

The available scientific studies on the efficacy of SMM are highly equivocal. Emergent wetland area has been maintained or increased in some SMM projects, but unchanged or decreased in others, relative to similar unmanaged areas. In salt and brackish marshes in regions undergoing rapid subsidence, SMM generally restricts the supply of mineral sediments needed to accrete soil, does not seem to protect wetlands, and may even hasten their demise. There may be a better case for the application of SMM in protecting tidal freshwater wetlands with highly organic or even floating soils. However, critical scientific appraisals of the effectiveness of SMM in such environments have yet to be performed. (See Section 3.1.)

b) To what extent does SMM impact the physical, biological and/or chemical aspects of natural marsh-sustaining processes? With regard to this evaluation, consider long-term marsh survival and productivity, including accretion of organic and inorganic sediments.

Depending on the extent of intervention, SMM may impact natural marsh-sustaining processes greatly or little at all. If SMM is applied to protect vanishing marshes or restore lost marshes, it must seek to do so by altering the physical, biological, and chemical processes operable. However, it is difficult to manipulate one process deemed necessary for sustaining or restoring a marsh (e.g., current flows or salinity) without also affecting others (e.g., sediment supply, water and sediment chemistry). Therein lie the controversies regarding the long-term effectiveness of SMM. In those cases in which SMM has been successful in protecting or expanding vegetated wetlands, the long-term effectiveness of SMM (and thus sustainability) in the face of geomorphic trends and sea-level rise remains in question. In any case, it is clear that SMM requires a perpetual management commitment to maintain its effectiveness. (See Section 3.1.)

c) What are the impacts of SMM, if any, to estuarine fisheries, waterfowl, and other fish and wildlife? If there are impacts, provide an analysis of the extent of these impacts.

In a wide variety of cases and regions, SMM has been shown negatively to affect estuarine fisheries by creating an artificial separation between the wetland and the estuary or lake, reducing either the access to or escape from the habitat. This impact has been reduced, but not eliminated, by improvements to the design of weirs and gates. In addition, impoundments within the managed marsh may result in degraded water quality (e.g., salinity, temperature, and dissolved oxygen extremes, and mobilization of sulfate), occasionally with drastic results for marsh biota. SMM can enhance the habitat value for waterfowl and other wildlife and has been widely used for that purpose. It is not clear, however, whether SMM results in increases in the regional or continental populations of these resources. On the other hand, wading birds and other organisms that depend on periodic exposure of the marsh surface for effective feeding and prey capture, and endangered birds that nest or feed in specific types of vegetation, may be negatively affected by SMM. (See Section 3.2.)

d) What are the cumulative effects of numerous large-scale SMM projects with respect to emergent vegetation, accretion, fish and wildlife, and other resources?

Collateral and cumulative effects of SMM are poorly understood and virtually unquantified. Potential cumulative effects relate to the reduced water exchange between the managed marsh and adjacent wetlands and waters, altered patterns of sediment transport and deposition, altered movement of nutrients, pollutants, and organisms into and out of the marsh, and the ability to support regional biodiversity and rare or endangered species. Assessment of cumulative effects of SMM should be of central concern in areas where SMM is widely practiced or proposed for expansion. Presently, however, this assessment is based on highly subjective and qualitative approaches, rather than sound data and models. Research in this area should be a high priority for federal and state agencies. (See Section 3.3.)

e) What are the gaps and the highest priorities for research studies related to the effects of SMM projects, and for routine monitoring of such projects?

High priority research areas include: the development and testing of alternative management techniques that maintain the hydrological connections between marshes and coastal ecosystems; improved SMM technologies (e.g., improvements to control structure design and hydrological modeling of marshes); the effects of SMM on marsh morphology and productivity; and the cumulative effects of numerous SMM projects within a watershed or region. The Subcommittee recommends that monitoring be required for SMM projects and suggests parameters that should be measured. Routine monitoring of SMM projects involves characterization of the physical, chemical, and biological attributes of the marsh ecosystem to identify how the projects affect the ecosystem structure and function, and is clearly distinct from compliance monitoring. Monitoring of SMM projects is important because it provides a mechanism for the development of new SMM approaches. (See Section 5.)

f) What scientific or technical criteria should EPA use as part of the basis for case-specific decision-making; or, as an alternative, what approach should EPA take to develop such criteria?

The Subcommittee suggests that the Agency develop both generic national criteria and criteria relevant to specific regions of the country. These criteria should be consistent with the science-based principles discussed above. The Subcommittee has identified a number of scientific and management evaluation criteria that should be used when evaluating proposed SMM projects, including: the historic quality and productivity of the marsh; the current state of the marsh; the suitability of the modifications for the proposed site; the relationship of the proposed project to long-term, regional restoration goals; the ability of the SMM design to cope with extreme weather events; the potential for cumulative impacts; and the ecological impacts were the project to fail or be abandoned. (See Section 4.)

2. Introduction

2.1 Charge to the Subcommittee

At the request of the Office of Water's Office of Wetlands, Oceans and Watersheds, the Ecological Processes and Effects Committee of the Science Advisory Board (SAB) established a Marsh Management Subcommittee (the Subcommittee) to review the state of the science for structural marsh management in support of Agency plans to develop an interim Agency position on SMM, with a long-term goal of developing a national marsh management policy. The Charge to the Subcommittee (Appendix A) defines marsh management as "the use of structures (such as canal plugs, weirs, gates, culverts, levees and spoil banks) to manipulate local hydrology in coastal marshes." The Charge notes further that "marsh management or tidal impoundments for the purpose of this review will include those wetlands influenced by the tide and lands and waters associated with the Great Lakes." The Subcommittee subsequently decided to use the term "structural marsh management" (SMM) to distinguish this fairly narrow set of management approaches from the broader set of practices that are commonly associated with the term marsh management. The Charge included the following specific questions to the Subcommittee:

a) Does SMM protect or create emergent vegetated wetlands? In regard to this evaluation, consider two conditions in the response: i) areas where net sediment deficit occurs (i.e., soil building does not keep up with relative sea level rise), and ii) areas where there has been extensive human-induced wetlands deterioration.

b) To what extent does SMM impact the physical, biological and/or chemical aspects of natural marsh-sustaining processes? With regard to this evaluation, consider long-term marsh survival and productivity, including accretion of organic and inorganic sediments.

c) What are the impacts of SMM, if any, to estuarine fisheries, waterfowl, and other fish and wildlife? If there are impacts, provide an analysis of the extent of these impacts.

d) What are the cumulative effects of numerous large-scale SMM projects with respect to emergent vegetation, accretion, fish and wildlife, and other resources?

e) What are the gaps and the highest priorities for research studies related to the effects of SMM projects, and for routine monitoring of such projects?

f) What scientific or technical criteria should EPA use as part of the basis for case-specific decision-making; or, as an alternative, what approach should EPA take to develop such criteria?

2.2 Scope of the Report

In accepting the request, the SAB agreed to consider the state-of-the-science underlying SMM and to recommend criteria for evaluating the potential ecological effects of marsh management projects in various types of marsh systems and regions of the country. While recognizing that much of the impetus for an Agency policy on SMM arises from concerns in coastal Louisiana, the Subcommittee was constituted to reflect a balance of geographic expertise, and the report is intended to provide guidance that the Agency can apply in marsh ecosystems around the country.

The Subcommittee held public meetings in Washington, DC on July 21 and September 7-8, 1994, to receive comments from federal and state agencies with marsh management responsibilities, as well as from non-governmental organizations and members of the public. A large volume of technical material and public comments was supplied to the Subcommittee as a result of these meetings, including a summary and proceedings from an EPA-sponsored workshop on SMM held in Louisiana in August 1994. In addition, several Subcommittee members visited marsh sites in coastal Louisiana in February 1995 to observe first-hand several marsh management projects underway in that area.

Much has been written on SMM, and the Subcommittee did not attempt to compile an exhaustive summary of all relevant technical studies. Rather, this report includes references to key scientific studies of SMM in various regions of the country. The Subcommittee, focusing on published reports in refereed scientific journals, has attempted to summarize the state-of-the-science as it relates to SMM, including what is known and not known about the ecological impacts of intentional or unintentional changes to marsh hydrology. An overview of SMM issues on the national level (Section 3) is complemented by more detailed discussions of the circumstances and concerns in various regions of the country (Section 6). Recommendations for monitoring and priority research to improve our understanding of the impacts of SMM are also included (Section 5).

A primary focus of this report is on scientific and technical criteria that should guide the assessment of ecological impacts of proposed SMM projects (Section 4). In most cases, SMM has resulted in trade-offs in which certain wetland values have been maintained at the expense of other values. The determination of management objectives is a reflection of societal choices at the national, state, and local levels, rather than a scientific debate, and as such is not the domain of the SAB. However, the selection of management objectives needs to be informed by a scientific assessment of what is feasible and what are the likely trade-offs. The Subcommittee agrees that region-specific characteristics, including the extent, location, connectivity, and condition of wetland resources, as well as differences in local goals and priorities, will affect decisions on where and when to implement SMM. Despite these region-specific factors, however, the Subcommittee has proposed a number of criteria for evaluating the ecological desirability and feasibility of proposed SMM projects (Section 4). These proposed criteria, developed in response to elements (a) through (d) of the Charge to the Subcommittee, are intended to allow the Agency to assess the regional impacts of a proposed SMM project on wetland ecological values and functions. In addition, the report discusses a number of management considerations that the Subcommittee finds are directly related to whether or not a SMM project is likely to achieve its management objectives.

3. State of the Science: The National Perspective

The Charge to the Subcommittee includes a series of questions regarding the impacts of SMM on specific biological, physical or chemical components of marsh ecosystems. In the past, federal and state agencies have often been charged with the protection or management of a particular component of the marsh ecosystem (e.g., the navigable waters, fishery resources, or wildlife species). In some cases this has resulted in different agencies having conflicting goals for the management of wetland areas. Although the Subcommittee has organized the subsequent discussion around the charge questions, we urge the Agency, in concert with the other relevant federal and state agencies, to take an ecosystem, rather than species-specific or single-resource, approach to the management of wetlands that focuses on the sustainability and long-term viability of the resource. Further, the Subcommittee recognizes that regional differences in the physical environment, status of wetland resources, and management objectives, as well as variations in SMM practices around the country, make it difficult to generalize about the ecological impacts of SMM. Much of the present debate over SMM is dominated by concerns over the extensive loss of wetlands in coastal Louisiana. This section, therefore, summarizes the range of ecological responses to SMM that have been observed under a variety of conditions. A description of the specific SMM issues in different coastal regions is contained in Section 6, and highlighted in Figure 1. (see page 8)

3.1 Impacts of SMM on Marsh-Sustaining Processes

Historical objectives for SMM have included enhancement of habitat for waterfowl and wildlife, physical buffers against wave or tidal scouring, mosquito control, creation of nursery habitat for fish and macroinvertebrates, and wastewater and stormwater treatment. More recently, SMM has been undertaken for the specific purpose of protecting or creating emergent vegetated wetlands in coastal Louisiana, where the rapid rate of deterioration of extensive coastal wetlands and marine encroachment has prompted protective efforts by landowners and public resource agencies. SMM may also be used to create inland, nontidal wetlands for wastewater treatment, stormwater/desilting detention basins, and other uses; the application of SMM in this context, however, is outside the scope of this report.

Although most experience with SMM is based on efforts aimed at accomplishing a purpose other than the protection or creation of emergent vegetated wetlands, the collective experience around the country has shown that unintended, unanticipated, and sometimes undesirable effects have often resulted from structural management of marsh hydrology. Differences in the physical environment (e.g., hydrologic and geomorphic conditions), status of wetland resources, and management objectives make it clear that the application of a SMM policy needs to be at least

We urge the Agency, in concert with the other relevant federal and state agencies, to take an ecosystem, rather than species-specific or single-resource, approach to the management of wetlands that focuses on the sustainability and long- term viability of the resource region-, ecosystem-, or basin-specific. Further, the impact of SMM on marsh-sustaining processes depends on the type of management scheme employed. However, a number of general conclusions emerge from the scientific literature regarding the effects of SMM on marsh vegetation and natural marsh-sustaining processes, as well as effects of SMM on fish and wildlife that rely on marshes for food, habitat, and refuge.

Marsh-sustaining processes include hydrology (water level, and fluctuations thereof, water residence times, waves, and currents); plant recruitment, growth, and decay; soil formation (including deposition and erosion of organic and

Figure 1. Regional SMM Issues

Coastal Louisiana

- extensive loss of wetlands caused by subsidence, hydrologic modification, and/or intrusion of saltwater
- high percent of remaining wetlands are under SMM, with more proposed

New England

- previous diking for road and railroad construction has transformed salt marsh to brackish or fresh marshes dominated by exotic species
- management priority is to restore tidal flushing to diked marshes

Mid-Atlantic Coast

- greatest area of wetlands under SMM in the region is in SC and DE
- SMM areas in SC are remnants of rice cultivation prior to the 1900s
- In NJ, DE, MD, and VA, SMM is used to enhance waterfowl habitat
- many states have legal restrictions on reclaiming abandoned and open impoundments

Eastern Florida Coast

- thousands of acres of marsh-mangrove wetlands were impounded for mosquito control in 1950s and 1960s
- regional water management district has begun a concerted effort to reconnect impoundments with the Indian River Lagoon

Great Lakes

- large area of wetlands has been lost to development or drainage for agriculture
- SMM has been used to restore wetlands where protective natural barriers (barrier beaches and sand spits) have eroded

Southern California

- very few coastal wetlands remain, largely as a result of urbanization
- nearly all coastal wetlands have been inadvertently impounded by construction of roadways that act as breached levees

San Francisco Bay/Delta

- 95 percent of San Francisco Bay's tidal wetlands have been converted to agricultural uses, salt ponds, duck clubs, or urban development
- there is growing interest in restoring large areas of diked former marshes by restoring hydrologic connections to the estuary

inorganic matter); nutrient cycling and exchange with other ecosystems; water and soil chemistry (including biogeochemical processes in the soil); and competition and predation. All of these can be altered by structural management of water level.

3.1.1 Marsh Hydrology

SMM is defined as the use of structures to modify marsh hydrology. Since hydrology drives the other physical, chemical, and biological processes in a wetland, it is inevitable that SMM impacts all aspects of wetland function. Hydrologic modification, through active manipulation of water level changes, alters the flux of nutrients and other chemical constituents into and out of the marsh as the amount, frequency, and duration of flooding change (Swenson and Turner, 1987; Boumans and Day, 1994). The modification of daily, monthly, and seasonal hydrologic cycles also influences soil chemical processes and oxidation-reduction (redox) status, water column chemistry, the distribution and migration of aquatic and semi-aquatic organisms, and particulate material import and export from the marsh. In addition, deep water basins or canals created within the marsh act as sediment and detrital traps, contributing to anoxic and eutrophic depressions, and provide habitat for larger estuarine predators that prey on diminutive marsh resident species and juveniles of transient species (Harrington and Harrington, 1982; Rey et al., 1990b).

Despite the fact that hydrology drives all of these marsh-sustaining processes, little is known about the effects of SMM design elements on such basic hydrologic parameters as water level control and water residence time. Careful documentation of the relationship between gate cross section (relative to impounded area) and water level equilibration rates under different water head conditions does not exist, and studies of the effects of gates on water residence time are similarly lacking. Considerable research has gone into documenting the effects of hydrology (water level and water level fluctuation, and flushing/ residence time) on wetland plants; however, without the link between SMM design and hydrology, this information is not helpful for assessing the impacts of SMM. The importance of engineering design considerations in the success or failure of SMM projects is discussed in Section 3.4.

Little is known about the effects of SMM design elements on such basic hydrologic parameters as water level control and water residence time

3.1.2 Marsh Vegetation and Primary Production

Theoretically, SMM can protect or create emergent vegetated wetlands under the right conditions. Natural processes of water flow and inundation, soil formation, and plant growth are responsible for creating existing wetlands. The loss of wetlands is usually associated with a change in those processes, which disrupts the dynamic equilibrium. It may be possible, then, to restore these processes or to manage them in a way that enhances the survival and propagation of wetlands. To do so requires an understanding of marsh ecosystem processes, their interactions, and how structures affect them. At least in the short term, SMM has in some cases succeeded in increasing marsh plant cover, usually following draw-downs of water level, which allows seed germination in previously submerged soils. In wetland areas adjacent to the Great Lakes, for example, SMM has been used to recreate lost natural barriers to wave erosion and has allowed marsh vegetation to become established.

SMM often results in shifts in species composition and diversity of plant communities

Similarly, marsh plant coverage may be increased by drawdowns in impounded marshes at Rockefeller State Wildlife Refuge in coastal Louisiana. However, there are few scientific studies comparing the long-term effects of SMM relative to unmanaged reference sites, and the effectiveness of SMM in protecting or creating emergent marsh over the long term has not been well documented.

Historical comparisons of areas in coastal Louisiana structurally managed for waterfowl habitat with similar reference areas have demonstrated that water level control has frequently not protected or restored emergent vegetated wetlands (although it may result in a proliferation of submerged aquatic vegetation) and in a number of cases has accelerated the loss of emergent wetlands. For example, in one such study, an evaluation of 16 managed sites in Louisiana showed that water level management was effective at increasing marsh acreage at fewer than half of the sites (Cahoon and Groat, 1990). In a somewhat similar environment (e.g., relatively rapid subsidence, small tidal range, and limited sediment supply), the hydrologic barrier caused by a roadway across the marsh has unwittingly contributed to the rapid breakup of marshes at the Blackwater Wildlife Refuge on the Chesapeake Bay (Stevenson et al., 1985). Furthermore, in systems that receive little freshwater input (e.g., in southern California), impoundment of wetlands can lead to hypersaline conditions and massive diebacks of the most sensitive halophyte plant species (Ibarra Obando, 1990, 1993; Ibarra Obando and Poumian-Tapia, 1991; Zedler et al., 1992).

Phragmites encroaching on salt marsh at Rough **Meadow Sanctuary near Plum Island Sound, Massachusetts**

Photo by FL Buchsbaum

Most experience, however, is based on SMM efforts aimed at accomplishing a primary purpose other than the protection or creation of emergent vegetated wetlands. Thus, it should not be expected that these efforts also protected or created emergent wetlands. Recent marsh management techniques have improved in sophistication, and active management of water levels may improve the ability to create emergent vegetated marsh. Although it is not clear why some projects succeed in growing marsh plants, at least in the short term, while others do not, the ability to draw down water levels, especially in the spring to stimulate seed germination and growth of perennial species, seems to be one of the more important factors (Keddy et al., 1989; Leek, 1989; van der Valk and Pederson, 1989). The implications of this and other ecological management objectives for the design of SMM structures are discussed in Section 3.4.

The Subcommittee notes, however, that the presence of emergent vegetation should not be the sole measure of marsh productivity and sustainability. Where the primary management goal is implicitly or explicitly the maximization of waterfowl or shorebird use, this often requires the maintenance of open water or mudflats as well as vegetated areas. In areas with existing emergent marsh, SMM often results in shifts in species composition and diversity of plant communities in response to altered salinity, water level, and flooding regime (frequency and duration) (Chabreck and Junkin, 1989; Turner et al., 1989; Cahoon and Groat, 1990; Reed, 1995). In some areas, invasion by aggressive, exotic plant species has been observed following implementation of SMM (e.g., Roman et al., 1984). Monospecific stands of these aggressive species are generally considered of less value to wildlife than the more diverse natural marsh community.

In addition to shifts in marsh plant species composition, changes in flooding regime that favor growth of emergent vegetation may affect overall primary productivity. Prolonged inundation affects periphyton and epibenthic algal and bacterial communities, as does shading by vascular plant canopies. Scientific studies indicate that for some wetland systems these algal mats may be more important as food sources for wetland fauna than many wetland vascular plants (Rey et al., 1990c; Browder et al., 1994).

3.1.3 Sedimentation and Soil Formation

In natural systems, the long-term viability of a marsh requires that inputs of inorganic and organic sediments be sufficient to offset substrate compaction, erosion, and relative sea-level rise. If marsh elevation is not maintained, marsh vegetation is inundated and drowned. SMM may interrupt the supply of inorganic sediment from the watershed or the ocean. If the decline in inorganic sediment supply is not offset by an increase in accretion of organic material, subsidence within the managed area will result. In San Francisco Bay, for example, managed marsh areas typically have subsided about four feet behind levees constructed to protect the areas from storm surge flooding or for waterfowl management. In a managed system, water levels can be manipulated to compensate for subsidence, but at the cost of continued intervention. Without adequate soil formation, this effort is ultimately a losing battle. Conversely, in areas with a net sediment surplus, loss of tidal flushing can result in elevation of the marsh surface and conversion to upland, terrestrial habitat, either as a result of accumulation of organic detritus (e.g., mangrove forest litter in Florida impoundments; Rey et al., 1990c) or from increased supply of sediments from the watershed as a result of urbanization (e.g., in southern California). In summary, the impact of SMM on marsh sediment accretion depends on the nature of the sediment supply to the marsh in question.

3.1.4 Water and Soil Chemistry

Both water column and sediment chemistry change in response to changes in hydrologic cycles, principally by changing the salinity and

Impoundment tends to increase the range of environmental extremes in a marsh (e.g., salinity, temperature, and dissolved oxygen)

oxidation-reduction (redox) status of sediments and processes controlling organic carbon decomposition. Redox cycles change because of changes in the exposure of the marsh sediments to the atmosphere. Thus, depending on the management scheme, SMM has been shown to lower redox potentials in some instances and result in more oxidized soils in others (Cahoon and Groat, 1990); this change in redox potential has implications for the cycling of H_2S and NH, (e.g., Carlson et al, 1983; Nickerson and Thibodeau, 1985). The redox state at any given time will control the mobility of many metals, plant nutrients, toxic organics, and sediment. SMM strategies that drain marshes and create dry ground will increase the redox potential and foster the more oxidized conditions that in turn lead to: release into the water column of metals generally bound to sulfides in anaerobic sediments; increased oxidation of organic matter that binds organics and metals and helps to hold fine grain sediments together; and release of plant nutrients (nitrogen and phosphorus) into the water column, which can give rise to excess growth of algae in adjacent waters. SMM practices that change water levels to submerge land will lower the redox potential and lead to binding and concentration of metal sulfides in the sediments, increased denitrification, and accumulation of organic material and some nutrients. Aside from redox changes, water level manipulation can also change sediment accumulation rates, thereby affecting the availability of those materials that bind to sediments (e.g., metals and toxic organics).

Water control structures may affect water quality, e.g., by changing water residence times and deposition of organic and inorganic matter.

Photo by R. Flaak

With regard to water quality, impoundment tends to increase the range of environmental extremes in a marsh (e.g., salinity, temperature, and dissolved oxygen). Reduced or no tidal flushing in the managed marsh may increase deposition of organic matter, inducing algal blooms and subsequent low levels of dissolved oxygen or anoxic conditions in the water column. Changes in wetland water quality resulting from impoundment construction or management may require mediation mechanisms to prevent mortality of indigenous flora and fauna. As an example, natural low-energy hydrological conditions at impounded mangrove forest sites may be augmented seasonally during low water quality periods by pumping large volumes of open estuarine waters through the impoundment and out of bottom water release structures to the open estuary (Rey et al., 1990a).

3.2 Impacts of SMM on Fish and Wildlife

To varying degrees, SMM creates an artificial separation between the open water body (estuary or lake) and wetland, thus interfering directly or indirectly with transport and migration of organisms. Direct interference occurs with aquatic organisms that ride water currents passively or migrate actively into or out of the marsh for feeding, habitatrefugia, or spawning. Indirect interference occurs with terrestrial and avian organisms that feed on the marsh surface when it is exposed at low tide but cannot feed when the marsh is flooded (e.g., certain insects, wading birds, reptiles, and certain mammals) (Lewis et al., 1985; Gilmore, 1987). Fish and wildlife are sensitive to changes in marsh hydrology, sedimentation, and water chemistry as well.

3.2.1 Migratory and Anadromous Fish

Structural marsh management of tidal and Great Lakes wetlands has generally had a negative impact on migratory fishery resources, i.e., those resources based on species that use the wetland-shallow water complex for spawning or as a nursery and then leave this environment to open water as they mature. This impact appears largely to be the result of restrictions of access to the managed marsh, which is the means of seeding the nursery with larvae, postlarvae, or juveniles. Loss of access to spawning, refuge, and foraging habitat, as well as changes in the availability of preferred forage organisms, has detrimental effects on a number of fish, shrimp, and crab species (Harrington and Harrington, 1982; Gilmore et al., 1982a; Rey et al., 1990b; Rogers et al., 1992; Rogers et al., 1994; Herke et al., 1992; Herke et al., 1996). While those animals recruited into the managed marsh may actually do quite well, they are less likely to escape at the appropriate time in their development and join the fishery or breeding stocks. Further, since use of diked wetlands as fisheries habitat is generally restricted to species that enter as larvae passing through screens, fish and invertebrate species diversity in pump-controlled diked wetlands may be considerably lower than in undiked systems (Johnson, 1989; Navarro and Johnson, 1992).

Another concern is the blockage of anadromous fish runs by dams, dikes, and culverts, which has been a major source of decline of these fish, one of which, the short-nosed sturgeon, is on the federal endangered species list. Although large dams on major rivers are generally upstream of coastal marshes, the tidal portions of

A great egret *(Casmerodius albus)* in diked wetland along the shore of western Lake Erie. Photo by D. Wilcox

An alternative approach called Open Marsh Water Management (OMWM), which may have greater benefits for shorebirds and wildlife, has been employed in a number of New England and mid-Atlantic states

many rivers and streams are impacted by culverts, dikes, and tidegates, all of which may impede the passage of fish. Various modifications in water control structures or flow management schemes have been used to reduce the effects of this “ingress-egress” problem, including slotted weirs and specially designed culverts and gates (Rogers et al., 1994). However, these modified structures are not used in many instances, and there is general consensus that some detrimental effects are unavoidable.

As mentioned in Section 3.1.4, impoundments within the managed marsh may also result in degraded water quality (e.g., salinity, temperature, and dissolved oxygen extremes, mobilization of sulfate), occasionally with drastic results for marsh biota (DeVoe and Baughman, 1986; Portnoy, 1991; Greene and Van Handel, 1992).

Open Marsh Water Management site at Cranes Beach near Essex, Massachusetts.
Photo by Northeast Massachusetts Mosquito Control and Wetlands Management District

There is a conundrum here, though, in that if deteriorating marsh is not protected or restored, the wetland habitat needed to sustain these fishery resources may be lost altogether. Thus, in some cases it may be necessary to make some concessions regarding reduced value for fisheries over the short-term, if this will ensure the sustainability of the habitat over the long term. This would require that adequate fish passages be included in the project design. However, the concern remains that intensely managed wetland systems may not be sustainable, i.e. able to be maintained independently.

3.2.2 Waterfowl/Wading Birds

SMM certainly can be applied in a way that enhances the value and attractiveness of the habitat for waterfowl. Typically, this result is achieved by the promotion of conditions for growth of certain submerged,aquatic vegetation or emergent plants that provide food resources (Chabreck, 1976; Chabreck and Junkin, 1989). It is less clear that these benefits extend to waterfowl populations, however, or whether they merely serve to concentrate existing populations. Migratory waterfowl populations could be controlled by birth, mortality, or growth in areas other than the habitat in question, e.g., at inland nesting sites or subtropical overwintering sites. In addition, while wetlands managed for waterfowl provide wintering habitat for migratory species, it is not clear how these wetlands compare in value with natural tidal marsh or waterfowl habitat in non-tidal areas. Similarly, existing salt ponds and seasonal wetlands in agricultural areas provide good bird feeding and resting areas, but a systematic comparison of their habitat values relative to those of natural marsh plain ponds and natural seasonal wetlands is lacking.

Waterfowl benefit from impoundments when the relative amount of open water in a marsh system is increased (Weller, 1988). Effects on waders (e.g., herons and egrets) and shorebirds are variable, depending on the depth of the impoundment. Deeper impoundments or steep bank impoundments and mosquito ditches may not provide the shallow water and muddy shores waders need for foraging areas. The long-term benefit to waterfowl of diked systems is problematic, since these systems evolve to *Phrugmires*- dominated marshes along much of the east coast, thought to be of lower habitat value to waterfowl. Hence a diked marsh requires continued, intensive management to maintain its value to waterfowl.

In recent years, an alternative approach called Open Marsh Water Management (OMWM), which may have greater benefits for shorebirds and wildlife, has been employed in a number of New England and mid-Atlantic states. OMWM is a method of mosquito control with two overall goals: controlling salt marsh mosquitoes and maintaining the productivity of marshes for wildlife. In the past, salt pannes, small pools on the marsh surface that are often important feeding areas for birds, had been drained in the name of mosquito control. OMWM retains and deepens these pannes to serve as reservoirs for small fish that then reach mosquito breeding areas through a system of shallow canals dug into the marsh surface and consume mosquito larvae. In the mid-Atlantic states where OMWM was first developed, several-acre ponds were dug to serve as fish reservoirs. In New England in recent years, OMWM has also been used as a way to restore salt pannes. Further knowledge of the salt panne functions would help to determine if this trade-off has net benefits for wildlife.

3.2.3 Other Wildlife

Impacts of SMM on wildlife, including various terrestrial and aquatic invertebrates (crustaceans, insects, mollusks, and polychaetes), reptiles, songbirds, raptors, and mammals, may be great if major changes in the plant community or hydrology take place with impounding (e.g., Gilmore and Snedaker, 1993). Many indigenous wetland invertebrates (e.g., fiddler crabs) require periodic exposure to the atmosphere and may drown if kept inundated for several days. In addition, resident crustaceans or fish populations that require intertidal substrate exposure to the atmosphere as part of their life cycle can be eliminated under SMM scenarios (Provost, 1967; 1977; Rey et al., 1990c; Taylor, 1990). Effective feeding behavior and prey capture by wading birds and many wetland reptiles are often dependent on periodic marsh surface exposure which does not occur in flooded impoundments (Kushlan, 1986; Bancroft et al., 1994; Ogden, 1994). The same may be true of mammalian species that feed in coastal wetlands (e.g., raccoons, otters, and bobcats). Further, vegetative shifts resulting from SMM can eliminate habitat for endangered birds that have specific nesting and feeding requirements (e.g., light-footed clapper rail). The extinction of the dusky seaside sparrow was caused in part by the elimination of indigenous vegetative habitat due to marsh impoundment within the Merritt Island Wildlife Refuge in Florida (Kale, 1981; Walters, 1992). On the other hand, lengthy drawdowns of diked marshes may completely eliminate less mobile, wholly aquatic organisms, including some that are endangered or of commercial value.

The question of cumulative effects of SMM is particularly relevant in coastal Louisiana, where great increases in SMM are proposed

3.3 Cumulative Impacts of SMM

While many assessments of SMM focus on induced changes within the managed area (e.g., changes to plant and animal species composition and diversity, marsh productivity, and marsh surface elevation), SMM may have implications far beyond the confines of the project area. It is of critical importance to understand the effects of the site-specific SMM on surrounding environments and the interactive effects of numerous SMM projects within the same hydrological unit (watershed, estuary, lagoon, or embayment) (Gosselink and Lee, 1989). Assessment of such collateral and cumulative effects is particularly critical in regions in which SMM has been extensively applied. In documentation supplied to the Subcommittee, Good (1994) estimated that 15.8% of the coastal wetlands of South Carolina, 13.1% of those in California, and 11.6% of those in Louisiana were under various types of SMM. SMM is even more extensive in particular estuaries or hydrological units. For example, 75% of the salt marshes adjacent to the Indian River Lagoon (Florida) were impounded for mosquito control during the 1950s and 1960s and in some hydrological basins of coastal Louisiana, e.g., the Calcasieu-Sabine Basin, the majority of marshes are under SMM.

The question of cumulative effects of SMM is particularly relevant in coastal Louisiana, where great increases in SMM are proposed by landowners and as part of restoration efforts under the Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA). In a draft Environmental Impact Statement on marsh management, the New Orleans District of the U.S. Army Corps of Engineers (1995) estimated that while previously issued permits for marsh management (1977 to 1995) encompass nearly half a million acres, candidate CWPPRA marsh management and hydrological restoration projects (which may involve erecting barriers to flow, but are not generally intended to control water level) could add an additional half-million acres to the total.

Cumulative effects of SMM have received little study and have been identified as an important knowledge gap (Cahoon and Groat, 1990). Although there are no careful studies of the consequences of large areas of impoundments on hydrology in Louisiana, elsewhere the effects are dramatic. When the great marshes in New England were diked in the last century, the harbors filled with sediments as a result of the decrease in tidal prism (Gosselink et al., 1974). In San Francisco Bay, tidal sloughs were silted in after adjacent marsh plains were diked off for agriculture, salt ponds, or duck-hunting clubs (Coats et al., 1989).

Potential collateral or cumulative effects of SMM projects include the following:

a) SMM reduces the volume and/or frequency of water exchange resulting from tidal action or wind forcing (seiches) between the managed marsh, adjacent wetlands, and coastal water bodies. Thus, water-level fluctuations and currents may be affected in adjacent unmanaged marshes or more broadly in the estuary, lagoon, or embayment. Additional SMM projects in the same hydrologic system would further affect water-level fluctuations and flow. In the microtidal, shallow lagoons of the Gulf Coast and Florida, where SMM is most widely applied, placing extensive wetlands under SMM could affect the tidal prism and, thus, the currents, salinity, and tidal exchange of materials and organisms. Even if the tidal prism is not affected, tidal amplitude and exchanges may be increased in other unmanaged marshes (Cahoon and Groat, 1990).

b) In addition to reducing the tidal influx of sediments into the managed area, SMM may alter patterns of sediment transport and deposition elsewhere. If many management areas are implemented in a region, much of the freshwater and sediment entering the upper reaches of the water body may flow past the managed marshes, thus altering the flushing rates and sediment distribution within the region (Cahoon and Groat, 1990). Also, if tidal flows are increased outside of the managed areas, greater resuspension of bottom sediments and bank erosion may result.

c) Water quality, including nutrient flux, may be affected beyond the managed marshes as well as within them. The nutrient- and pollutant-trapping capacity of the wetlands may be reduced. Waters depressed in dissolved oxygen may be released from semi-impounded areas. Conversely, oxygen-demanding organic matter may be trapped in the managed areas, and organic loading to surface waters could be reduced.

d) Where migration of fish and crustaceans between ocean and estuarine habitats and coastal wetlands is decreased by SMM, multiple SMM projects that significantly reduce the available marsh habitat within an estuary or lagoon will impact the overall fisheries productivity of that ecosystem.

e) The numbers of certain types of wildlife, including waterfowl, may be increased in a particular tract of marsh under SMM. While often cited as a beneficial effect of SMM, it is unclear whether this increase represents actual increases in the populations of these species within the region, or whether it merely reflects aggregation to a preferred habitat.

f) Biodiversity and the conservation of rare or endangered resources may be affected as the proportion of marshes under SMM increases in a region.

In addition to these environmental and natural resource concerns, there are additional socioeconomic concerns-beyond the scope of the Subcommittee's assessment-relative to cumulative impacts of SMM. These include interference with access via navigable waterways, ownership and use of the living resources impounded by SMM, and riparian rights.

The cumulative effects of SMM should be of central concern in areas where SMM is widely practiced or is proposed for expansion, yet they are poorly understood, much less quantified. It is therefore troubling to see plans being developed for expansive, adjacent, or interlinked SMM (e.g., some CWPPRA projects: Gagliano, 1994) based on highly subjective and qualitative reasoning, rather than sound scientific data and models.

3.4 Engineering Design Issues

A key element of SMM is the correct design of drainage structures to manage key hydrologic processes. Strategies for controlling water levels in the managed marsh fall into two categories: those that rely on gravity drainage and those that utilize pumps. Passive control structures range from fixed crest weirs (which are seldom used anymore) to a range of types of variable crest weirs with and without culverts (see, for example, Broussard, 1988; Clark and Hartman, 1990). Since hydrologic processes are the major driving force in wetlands, the design characteristics of

In many cases, SMM control structures do not provide adequate rates of drawdown to meet ecological management objectives

SMM projects to control these processes, particularly with respect to capacity of the damage system, are critical to project success. In the absence of powered pumps, successful drawdown requires a natural gravity head and appropriate structures that can be manipulated to

Examples of two water control structures in use in coastal Louisiana.

Photos by R. Flaak

take advantage of notoriously fickle weather and tide conditions to maintain the required water gradient (e.g., north winds associated with the passage of cold fronts build up a temporary head differential that can allow drainage of an impounded marsh). However, in impounded areas where vertical accretion does not keep pace with relative sea level rise, the gradient from the impoundment into adjacent waters is slowly lost, reducing and then eliminating the effectiveness of gravity drainage over time.

Several formulae are used to calculate the appropriate cross-sectional area of water control gates in a managed marsh (considering such factors as marsh area, the desired range of managed water levels and culvert cross-sectional area) (Broussard, 1988; Louisiana Department of Natural Resources and Soil Conservation Service, 1988; Clark and Hartman, 1990). In many cases, however, SMM control structures built using these formulae do not provide adequate rates of drawdown to meet ecological management objectives. For example, a drawdown to enhance seed germination, a common feature of many marsh management plans, often requires water level reductions of a foot or more in a short time. Even if much of the impounded area is marsh, thus reducing the volume of water to be drained compared to open water ponds, the calculated drawdown period using standard formulae may be as long as three weeks. In addition, it is imperative to be able to drain an area rapidly after storm surges that introduce saline water into low salinity areas. Even assuming that weather conditions allow maintenance of the necessary hydrologic head, a three-week drawdown period is long enough to kill all salt-intolerant vegetation. In contrast, water levels in open, unmanaged Gulf Coast marshes can drop one to two feet in 24 to 48 hours when a high pressure weather system with north winds moves through the area (a common occurrence).

In one of the few studies to relate drawdown effectiveness to drainage capacity, Hess et al. (1989) documented response to attempted drawdowns in 10 managed areas in coastal Louisiana, ranging from 19 to 639 acres in size. They reported successful drawdowns (dried pond bottoms within the impoundment) in 6 out of 12 years, depending largely on weather conditions. They found that the larger semi-impoundments drained more slowly than small ones, even though the control gates number and size had been designed for the larger area. For example, a 47 acre impoundment could be completely dewatered in two days of exceptionally low tides. Under the same tidal conditions, however, only 2 to 4 inches of water could be drained off the larger semi-impoundments. Despite the enhanced drainage capacity of these semi-impoundments, averaging 215% larger than the National Resources Conservation Service guidelines, the authors found gravity drainage in the larger semi-impoundments to be only adequate.

In summary, the Subcommittee recommends that much more attention be given to hydraulic and hydrologic design criteria for SMM projects, especially to the quantitative drainage capacity under different weather conditions. In general, drainage capacity should always be oversized in SMM projects since it is easy to stop down a culvert but impossible to increase its capacity beyond the construction size. The Subcommittee notes, however, that project success requires not only adequate engineering design, but competent construction, as well as maintenance and management over the life of the project.

4. Evaluation Criteria

4.1 Science-Based Principles

Before discussing the criteria that might be employed to evaluate any specific SMM proposal, the Subcommittee wishes to provide an overall framework and set of principles that should guide the ecological evaluation of SMM projects generally. For purposes of discussion, we have grouped wetlands into three categories: a) wetland systems that are already functioning in some self-sustaining manner; b) wetland systems that have been compromised to the point where they are significantly degraded or are not self-sustaining; and c) wetland systems being created as part of mitigation for loss of wetlands elsewhere. Although the focus of the Charge to the Subcommittee is on assessing the performance, rationale, and criteria for converting existing tidal systems to managed systems, the general principles and evaluation criteria in the report offer significant guidance for choices on strategies for wetlands management, restoration, and conservation, including alternative restoration strategies for large areas of diked former tidal wetlands that are now becoming available for restoration.

Because of the subs tan tial uncertain ties in the impacts of SMM, caution is warranted in the adoption or approval of SMM projects

The lesson from past SMM projects is that while it is relatively easy to change marsh hydrology, it is much more difficult to control or manage the changes or to predict fully the consequences of proposed modifications. Further, not all marsh management projects are reversible; i.e., it may not be possible to return a marsh to pre-SMM conditions simply by removing marsh management structures if, for example, subsidence has occurred. A failed or abandoned SMM project can create conditions that prevent the subsequent evolution of a marsh (e.g., where levees have failed, creating large open water areas exposed to strong wave action). Because of the substantial uncertainties in the impacts of SMM, caution is warranted in the adoption or approval of SMM projects in order to avoid counterproductive results on the long-term ecological sustainability of imperiled tidal and Great Lakes wetlands. In situations where SMM is deemed necessary, proposed projects should be carefully designed and evaluated to ensure that they will accomplish the desired results. The Subcommittee proposes five science-based principles with regard to SMM (see Figure 2).

4.2 Scientific/Technical Criteria

From an ecological viewpoint, changes to a wetland ecosystem, i.e., the presence of an ecosystem that is different from what existed previously, does not necessarily mean that the wetland is “degraded” or of lower ecological value. However, the decision to manage a wetland for specific characteristics inherently reflects a societal judgment regarding the desired state for the wetland. The scientific criteria in this section are designed to allow consideration of the full suite of current, as well as possible future, ecological functions of a marsh for which SMM is proposed.

Although the Subcommittee is impressed with the need to consider large-scale manipulations of wetlands in some circumstances, we believe that adequate technical information does not exist to create a general policy delineating where and when specific modifications should be applied. Obviously, the scale of marsh management projects varies from region to region, with the scale often being dictated by the size of the remaining marshes. Similarly, the potential for cumulative impacts depends largely on the extent of previous modifications to wetland resources in a region and the nature and scope of proposed future projects. Therefore, the Agency may wish to develop two general groups of criteria, the first group to include generic criteria that will have relevance to all wetland ecosystems in the nation and the second group to include criteria specific to certain regions. These criteria should be based on a thorough review of national and regional wetland ecosystem literature and should be reviewed by experts from various parts of the country to determine which criteria are significant and valid for specific regions. However, the Subcommittee recommends that, at a minimum, the following questions should be addressed prior to implementation of any SMM project:

a) **What is the current ecological status of the marsh?**

An assessment should be provided that will indicate the historic significance and present state of the marsh ecosystem. Is the present marsh functioning to provide selected ecological and societal values? Is the marsh presently dysfunctional with regard to selected ecological values? Does the proposal involve restoration or

In situations where SMM is deemed necessary, proposed projects should be carefully designed and evaluated to ensure that they will accomplish the desired results.

Figure 2. Science-Based Principles for Structural Marsh Management to Achieve Sustainable Wetlands

1) Wetlands systems that are providing a suite of wetland functions and are self-sustaining should be left undisturbed and not subject to SMM.

2) Only if restoration of hydrology or physical processes naturally occurring at the site is not feasible should SMM be considered as an approach to restore/improve the wetland.

3) The decision of whether or not to use SMM should reflect a firm scientific understanding of the causes of marsh degradation, both in a local and regional context, and should take into account regional differences in marsh dynamics. The Agency's Proposed Guidelines for Ecological Risk Assessment (EPA, 1996) should guide the evaluation of risks to the system with and without the proposed SMh4.

4) Preference should be given to SMM strategies that restore, to the degree possible, natural wetland processes and functions and provide for at least periodic hydrologic connectivity with surrounding ecosystems.

5) In large part, SMM techniques are experimental and should only be applied with appropriate experimental design, including monitoring of both the managed site and control sites to assess the impacts of the SMM on marsh processes and long-term marsh viability and to determine whether the project is meeting management and design objectives.

reestablishment of a degraded or destroyed marsh? In its present condition, is the marsh at-risk for future viability because of: insufficient sediment, excess sediment, inadequate tidal flooding, excess tidal flooding, exotic organism expansion, changing salinity, or degradation of water quality?

As the wetland ecosystem is largely controlled by hydrologic processes, wetland ecosystem function will change with impoundment. Therefore, proposals to manage a wetland impoundment or to create an impoundment in a wetland should document the functions being provided by the existing wetland, as well as the new functional role of the wetland once impounded or manipulated.

b) **Does the SMM proposal have clearly defined spatial and temporal dimensions that are appropriate for the management objective?**

What are the physical boundaries of the management proposal? How is the subject marsh related to associated ecosystems? What is the viability and ecological status of abutting systems/properties? How long will it take to construct management structures? How long will they be maintained? To what degree will the project require continual input of human resources, materials, or energy? What is the proposed time-line for management activity (i.e., the useful life of the structure)?

In structural management of marsh systems, the spatial and temporal scales of change, both those of the natural background on which the plan is imposed and those that are part of the management plan, need to be characterized and considered in the formation of alternatives. Change is a natural part of the evolution of natural systems, and restoration or management proposals that seek to return to conditions in some past time may not be feasible or sensible. This is especially true in wetland systems that have been the sites of previous, unsuccessful management efforts. Land uses (e.g., development) surrounding the wetlands may also limit what can be done.

c) **Has the SMM proposal considered relevant site characteristics, including hydrology, geomorphology, ecology, and meteorology?**

Are the management proposals consistent with available regional, local, or site-specific hydrologic models? Data should be evaluated on site characteristics, including: natural hydrologic conditions (tidal periodicity/amplitude, riverine flow), historical vegetative community, quantitative assessment of indigenous tidal marsh aquatic fauna, substrate characteristics, background water quality data, and interactions with adjacent ecosystems. Paleoecological studies and seed bank studies may also be useful to characterize past and potential plant communities to guide managers in decisions on management and restoration of vegetation. The goal should be to determine how the original natural wetland at a site developed and functioned; this information should then be related to natural and anthropogenic changes in the region that might determine how many of the original wetland functions and site characteristics can still be restored.

d) **Is the SMM proposal ecosystem-based?**

SMM projects should be evaluated in the context of ecosystem management; i.e., is the proposal in conformance with or in conflict with long-term regional, estuary-wide, or larger ecosystem restoration strategies? Is holistic consideration given to the structure and function of the ecosystem. What is the successional status of the marsh? Does the proposal seek to “hold the marsh in a certain successional stage (often a reality when upland development no longer allows natural marsh migration)? What is the impact of the proposal on species composition, food web structure, energy flow, and nutrient cycling? What impacts on physical and ecological processes are expected or possible, both within and adjacent to the managed site?

e) **Does the SMM proposal provide flexibility to adapt to changing environmental conditions?**

Marsh ecosystems are dynamic systems subject to predictable and stochastic perturbations. Is the SMM proposal flexible? Can it be readily altered/modified to accommodate changes related to natural or anthropogenic forces?

f) **Does the SMM proposal provide for monitoring?**

Monitoring of relevant and quantifiable parameters is essential to evaluate success in reaching the goals of the project, to evaluate impacts on other components of the system and/or on surrounding ecosystems, and to provide the technical basis for future modifications. Although the elements of an appropriate monitoring program will depend on the particular system being studied, suggested minimum requirements are outlined in Section 5.

g) **Does the SMM proposal, in concert with other human-induced or naturally occurring events, result in a cumulative adverse impact at a larger (regional) scale?**

As discussed in Section 3.3, the cumulative impact of multiple marsh management proposals or other co-occurring human projects in a given locale must be evaluated. This assessment should take into account region-specific factors such as the extent and condition of the marshes and the combined acreage of marsh currently under (or proposed for) SMM.

h) **Does the engineering design for the project provide adequate drainage capacity under different weather conditions expected at the site?**

As discussed in Section 3.4, the design criteria for the control structure(s) should be evaluated to determine whether the system will allow adequate water level control, including rates of drawdown required to meet ecological management objectives.

i) **What will be the physical and ecological impacts of management failure, either structural, mechanical, or operational?**

Structural failures (including those resulting from extreme storm events, such as storm surges and river floods) typically include levee subsidence or undermining of control structures, mechanical failure can include debris obstruction of culverts or tidegates, and operational failures can include erroneous weir settings or lack of scheduled maintenance.

4.3 Management Considerations

Studies evaluating the factors that contribute to the success or failure of SMM projects (see, for example, Cahoon and Groat, 1990; Josselyn et al., 1993; Holderman, 1994) indicate the importance of evaluating a number of management aspects of a proposed project. Although the establishment of management and implementation requirements for SMM projects is a policy decision, these management issues have a direct impact on the ecological consequences of SMM projects. Therefore, the Subcommittee recommends that, in addition to assessing the potential environmental impacts of a proposed SMM project design, the Agency consider the following:

a) Does the project include a clearly defined set of goals and criteria for judging the success or failure of the management approach?

b) Is there a management plan for the project that explains the design rationale, documents the baseline conditions, establishes performance criteria, identifies expected operation and maintenance, and identifies responsible and interested parties?

c) Is there a management system in place with an agency or other entity with the authority, expertise, staffing, and funding to implement the plan for the lifetime of the project?

d) Is there evidence that the proposed management regime will achieve its objectives based on past experience?

e) If the proposed management is experimental in nature, what is the experimental design, what hypotheses are to be tested, and how will the project test them?

f) Are there alternate locations that are better suited for restoring natural physical processes or achieving the proposed objectives (e.g., can the management objectives be achieved by conversion of upland sites presently outside the area of potential tidal influence)?

g) Does the proposal include contingency plans to modify the design or discontinue structural management in the event that desired results are not being achieved, or the cost of maintaining the levee/control structure system becomes too great in the face of relative sea level rise? What will be the impacts of decommissioning?

5. Monitoring and Research Priorities

SMM projects should include a monitoring plan that will provide data with which to assess the impacts of the project on marsh processes and long- term viability, to determine whether the project is meeting management and design objectives, and to provide guidance for improving the design of future SMM projects.

Very few studies have systematically looked at the effects of SMM relative to unmanaged reference marshes, not only on vegetative growth, but on other marsh functions, and over a l0- to 20-year time frame. Thus, there is a general lack of scientific documentation that the structural approaches used in the past have achieved sustainable improvements in marshes. Although marsh management practices have evolved over the years to include more sophisticated structures and management approaches for controlling marsh water levels, at present there is insufficient information to determine whether these new structural approaches are inherently better than those used in the past.

Given these uncertainties, proposed SMM projects should be considered carefully using the science-based evaluation criteria in the previous section. In addition, SMM projects should include a monitoring plan that will provide data with which to assess the impacts of the project on marsh processes and long-term viability, to determine whether the project is meeting management and design objectives, and to provide guidance for improving the design of future SMM projects. Monitoring prior to construction of SMM could provide temporal response measures. Routine monitoring of SMM projects should evaluate marsh biota (e.g., see PERL, 1990), as well as physical processes and contaminants. In many cases, very little is known of the quality of inflowing waters or resident sediments. Thus, monitoring efforts should include stream gauges just upstream of managed wetlands. In addition, remote recorders are recommended for monitoring of salinity, oxygen, and temperature, with proper safeguards to minimize vandalism.

Although parameters to be measured will depend in part on the particular system being managed, the monitoring plan should include, at a minimum: a) monitoring of water level and flow, salinity, dissolved oxygen, temperature, and nutrients; b) cover and composition of emergent and submergent vegetation; c) soil accretion rates (organic and inorganic) and land elevation changes; d) system productivity (although this parameter may be unrealistic in monitoring of small sites); and e) fish and wildlife utilization of the marsh. Monitoring should also include fecal coliform bacteria and toxic contaminants on a case-by-case basis in areas where such pollutants are suspected (e.g., in urban lagoons). Data for these parameters should be compared with similar data obtained in non-managed marsh areas in the ecoregion. Absent this information, monitoring data should also be collected in non-managed areas.

The highest priority for research is to develop alternative SMM techniques that maintain the hydrologic connections between marshes and coastal ecosystems, while meeting objectives such as restoring and protecting coastal marsh vegetation, providing wildlife habitat, and controlling mosquito populations. Long-term (multi-annual, decade-long) multi-disciplinary comparative studies of impounded and unimpounded coastal wetlands will allow predicted successional changes to be studied and documented, and management approaches to be refined. Previously impounded marshes offer tremendous opportunities for interdisciplinary study of the effects of hydrologic manipulation compared simultaneously with natural systems. To this end, efforts should be made to obtain past, present, and continuing aerial photographs of study sites at the largest scale affordable.

In order to improve our understanding of the impacts of SMM, the following specific research areas should be addressed by the Agency, in concert with other federal and state agencies and research institutions:

Highest Priority Research Areas

Marsh Hydrology

Control structures: assess the effects of impoundment control structure size and design on marsh hydrology (e.g., water level, flux, and water residence time) and develop ecological criteria to judge design and performance of control structures.

Hydrologic models: develop and/or improve hydrologic models of marshes to improve prediction of conditions (including salinity) within the managed marsh under different closure and freshwater inflow regimes.

Management technology/engineering: develop and test new technologies applicable to active marsh management (e.g., environmental sensors, flow regulators, and control structure design to allow ingress/egress of organisms that utilize the marsh).

Marsh morphology: assess the effects of SMM on marsh morphology within the managed area (e.g., changes to tidal channel geometry, tidal creek density, edge/marsh ratios, and creek length/area).

Ecosystem Management

Productivity: examine the effects of SMM on marsh productivity, including the effect of flooding on plant growth and the relative importance of different types of primary producers (e.g., vascular plants, periphyton, cyanobacterial or algal mats, and phytoplankton).

Cumulative effects: assess the effects of multiple SMM projects within a single hydrologic unit such as an estuary or watershed, including impacts on circulation patterns, flows, and geomorphology of streams, water bottoms, and marshes.

Other Priority Research Areas

Sediment/Soil Geochemistry

Marsh soil formation: assess the effects of SMM on mineral versus organic sedimentation rates and net accretion rates.

Geochemistry: assess the effects of SMM on soil geochemistry, especially of drawdowns (e.g., oxidation rates, oxidation-reduction potentials, and related soil chemistry).

Marsh Vegetation and Fauna

Exotic species: evaluate the occurrence and role of exotic plants and animals in managed marshes, factors affecting their distribution, and their effects on native biota.

Wildlife Support: assess the relative role of managed vs. unmanaged marsh in the support of wildlife species and the preservation of regional biodiversity.

6. Regional Experiences with SMM

Evaluation of proposed SMM projects and the identification of priority research questions must be informed by the particular regional characteristics of the wetland resource

The Subcommittee has attempted to summarize the ecological impacts of previous SMM and to propose a consistent set of evaluation criteria for proposed SMM projects that could be applied from a national perspective. We recognize, however, that SMM practices and objectives vary in different parts of the country. Moreover, the nature of the wetland resource-its condition, extent, geomorphology, and dominant biota-and the extent to which it has been modified by human activities vary from region to region. For these reasons, both the evaluation of proposed SMM projects and the identification of priority research questions must be informed by the particular regional characteristics of the wetland resource to be managed and a historical perspective on how and why the resource has been altered. This section, although not all-inclusive, provides a sample of the differing marsh management issues in a number of coastal regions of the United States.

6.1 Louisiana Coastal Wetlands

6.1.1 Resource Status

Approximately **40%** of U.S. coastal wetlands are found in Louisiana. From the **1930s** to 1990, the coastal zone of Louisiana lost an estimated 3950 square kilometers (1526 square miles) of wetlands. This loss constituted about 80% of the total national coastal wetland loss (Boesch et al., 1994). Wetland loss rates in the Louisiana coastal zone for the period 1983 to 1990 have been estimated at 66 km^2/yr (Dunbar et al., 1992), representing a serious threat to the wetland resource.

The loss of emergent wetlands in coastal Louisiana is the result of a complex set of circumstances, among which is the rapid subsidence of the coast, leading to submergence of marshes and intrusion of marine (salt) water. A comprehensive assessment of factors contributing to wetland loss in the region, and possible

Several members of the SAB Marsh Management Subcommittee examine a water control structure during a site visit to coastal Louisiana.

Photo by R. Flaak

The most extensive wetland areas under SMM exist in coastal Louisiana

to wetland loss in the region, and possible management responses, was recently published (Boesch et al., 1994). Submergence results from the net imbalance of aggrading processes (mineral sedimentation and in-place organic production) compared to subsidence. The subsidence rate, itself, can be addressed in some instances where it can be shown that factors such as local faulting and subsurface withdrawals are contributing to the submergence. The primary focus of management solutions, however, should be on ways to increase marsh surface accretion. In areas where mineral sediments are in short supply, water level manipulation has been used and advocated to increase marsh plant expansion and growth, thereby increasing organic production to balance subsidence.

Cumulative effects of SMM are a particular concern in coastal Louisiana because of the extent of wetland loss occurring and the scale of existing and proposed SMM schemes (e.g., Cahoon and Groat, 1990; Day et al., 1990; Gagliano, 1994, Fig. 7,8). In some coastal basins, half of the remaining coastal wetlands are currently under SMM. In addition, the area permitted for marsh management in Louisiana seriously underestimates the total area affected by impoundment since there is-strong interaction with the extensive dredged canal-spoil bank system in the coastal marshes. The hydrology of entire coastal basins has been extensively replumbed by multiple actions, including ditches that drain and channelize adjacent uplands (Gosselink et al., 1979), navigation and oil well access canals and their associated spoil banks, and marsh management projects. These have changed flow directions, channelized flows that were historically over-marsh flows, and replaced natural shallow, sinuous channels with deep straight ones (Gosselink, 1984). In the isolated managed areas, water levels are stabilized, with fewer but longer flood events and fewer but longer unflooded events. There are no detailed studies of the consequences of large areas of impoundments on hydrology in Louisiana.

6.1.2 Management Objectives

The most extensive wetland areas under SMM exist in coastal Louisiana. The current focus of SMM in that area primarily is to stem the loss of emergent marsh by slowing erosion of marsh sediments, increasing production of organic sediments, and increasing the area1 extent of marsh grass. The results of SMM in Louisiana in terms of the effects on marsh loss and salinity intrusion have been mixed, however, and not yet well documented (Reed, 1994). Historical comparisons of areas structurally managed for waterfowl habitat with similar reference areas have shown that: 1) water level control has generally not protected or restored emergent vegetated wetlands (although it may result in a proliferation of submerged aquatic vegetation) and in a number of cases has accelerated the loss of emergent wetlands; 2) the effect of SMM on salinity is variable, but in most cases the change is not ecologically significant (i.e., does not affect the composition of the biota or significantly affect geochemical processes); and 3) soil aggradation is less in managed than in unmanaged areas (Turner et al., 1989; Cahoon and Groat, 1990; Reed, 1992; Boumans and Day, 1994). Some reports, on the other hand, have reported success not only in protecting wetlands, but also in promoting expansion of emergent wetlands (Chabreck, 1994; Klett and Paille, 1994). In general, these reports are less well documented and are often promotional rather than analytical.

The clearest cases for vegetative expansion have been in low salinity regions of the Chenier Plain of Louisiana (Cameron-Creole, Rockefeller Wildlife Refuge) where long-duration drawdowns have been used to allow emergent plants to extend coverage. However, it is unclear whether the expanded wetlands survive re-inundation.

In some areas, notably the Mermentau basin, which is operated as a large freshwater lake for rice irrigation, the U.S. Army Corps of Engineers is increasingly unable to meet its target water level elevations, apparently because the head differential across the control structures no longer exists with sufficient frequency (Gosselink et al., 1979). Thus, the most effective management areas employ pumps to move water. Examples in the Rockefeller Wildlife Refuge show that under these circumstances a vigorous carpet of marsh grass can be maintained indefinitely. There are no data, however, to show whether or not the marsh substrate has accreted in these impoundments.

There is growing consensus within the technical community in Louisiana that “active marsh management which involves water-level control structures and drawdowns is primarily considered for implementation in highly organic marshes in which hydrologic alterations have adversely impacted what was historically a naturally fresh, low-energy environment” (SMM Workshop, August 1994). In these marshes, organic accretion processes have the most potential to benefit wetlands. Many of the marshes in coastal Louisiana (perhaps 250,000 acres) are floating, their mats entirely organic, and expansion from the edge of existing mats has been documented in impoundments (O’Neil, 1949; Sasser, 1994). In brackish and saline marshes, the need for mineral sediment input for healthy marsh vegetation growth and substrate accretion (e.g., Nyman et al., 1990) mitigates against long-term success of structural management projects, which curtail mineral sediment input (Cahoon and Turner, 1989; Taylor et al., 1989; Reed, 1992; Boumans and Day, 1994).

6.2 New England Salt Marshes

6.2.1 Resource Status

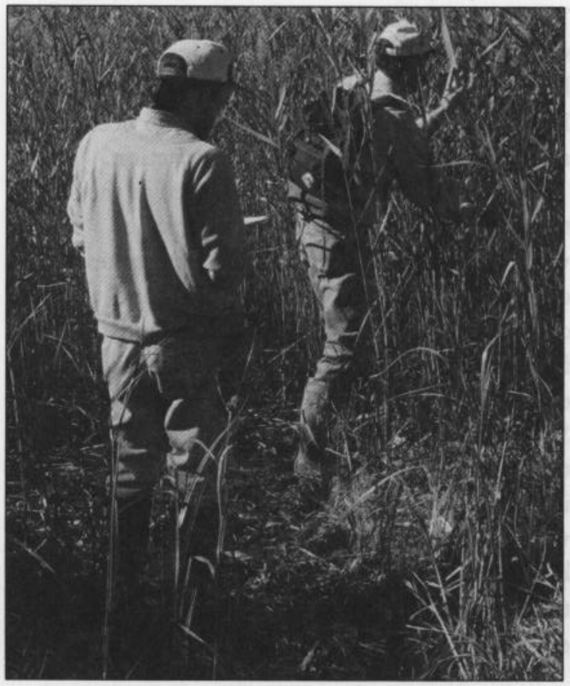
Although SMM is not currently practiced on a large scale in New England, salt marshes have been diked in the past to limit tidal flushing and reduce salinity in marsh areas in order to create brackish or freshwater habitat for waterfowl, provide flood control, and create conditions that would favor *Spartina patens* over *Spartina alterniflora. (S. patens* is the preferred species for salt marsh hay, which is still harvested from some New England salt marshes for livestock fodder). These dikes typically had a tide gate that would shut at high tide, but allow drainage of water at low tide, so that impoundments did not develop. Inadvertent diking of marshes has also occurred as a result of road and railroad construction.

This past SMM has often resulted in the transformation of well-functioning saline wetlands to brackish or freshwater marshes dominated by exotic alien emergents and considered degraded in terms of wetlands functions (Roman et al., 1984). There are regional effects, such as widespread replacement of *Spartina* by the freshwater exotic *Phragmites*, but they occur in individual marshes based on individual hydrologic conditions. As of yet, no widespread declines of any salt marsh species have been definitively attributed to such transformations through monitoring or research efforts. Based on circumstantial evidence, however, there is a widely held belief in the region that the replacement of salt marsh vegetation by *Phragmites* has resulted in the loss of habitat for marsh birds, such as rails, shorebirds, herons, bitterns, and sharp-tailed sparrows, since these species are rarely observed within the dense monocultures of *Phagmites.*

SMM in New England has had negative impacts on migratory fish. These may be attributed to outright blockage-e.g., blockage of fish runs by water control structures, which has been a major source of decline in New England of anadromous species such as alewives, blueback herring, shad, rainbow smelt, sturgeon, and Atlantic salmon (Reback and DiCarlo, 1972)-but also to lowered dissolved oxygen and possibly the mobilization of sulfate (Portnoy et al., 1987). Studies on the Herring River, an estuarine river of Cape Cod National Seashore that was diked and a tide gate installed, have documented changes in water quality parameters, accretion of peat, geochemistry of sulfur and other elements, and the species composition of primary producers (Portnoy et al., 1987; Portnoy, 1991). The area behind the tide gate now has reduced tidal flushing and lowered salinities. It has experienced subsidence, periods of hypoxia and anoxia during summer, and mobilization of iron and sulfate. When the salt marsh peat is exposed to air, it decomposes more rapidly, leading to higher biochemical oxygen demand when the area is reflushed during storm events (Portnoy, 1991). Pyrite oxidation increases dissolved sulfate concentrations, reducing pH to nearly 4 in some instances (Portnoy et al., 1987). These conditions have resulted in periodic fish kills and are likely affecting local recruitment of alewives and blueback herring. In addition, a die-off of American eels in the diked Herring River basin has been attributed to low pH from sulfuric acid formation when sulfate in marsh peat is alternately exposed to the air and inundated with fresh water (Portnoy et al., 1987).

Restoring natural tidal flushing is now a major priority of salt marsh managers in much of New England

The subsidence of peat in tidally restricted areas has made it unlikely that simply restoring the tidal flushing alone will bring back a *Spartina* marsh in all cases (Roman et al., 1984; Portnoy, et al., 1987). In New England, marshes receive inorganic sediments from both the ocean and the rivers, although the extent of these inputs is probably less than in other parts of the country. Winter storms may be a major source of sediment from the ocean, and spring floods are a major source of sediment from land; tide gates affect this balance. Marsh accretion that enables marsh to keep up with rising sea level is dependent both on primary production and the input of inorganic sediment, although the extent to which inorganic



Researchers study *Phragmites* stands near Plum Island Sound, Massachusetts

Photo by R. Buchbaum

sediments provide essential constituents, such as metals that complex sulfate and therefore enhance primary production, is an open question.

6.2.2 Management Objectives

Restoring natural tidal flushing is now a major priority of salt marsh managers in much of New England because *Phragmites*- dominated marshes are considered of less functional value and therefore degraded compared to the natural marshes (Roman et al., 1984), although there is little scientific documentation of this in East Coast marshes other than the obvious loss of plant diversity. Roman et al. (1984) estimate that 10 percent of Connecticut marshes are "threatened" by tidal restriction. Removal of tidal restrictions results in a rapid reduction of brackish species and a return of the natural salt marsh species within a few years (Sinicrope et al., 1990; Peck et al., 1994). In the Parker River National Wildlife Refuge in northern Massachusetts, impoundments that were created in former salt marsh habitats to create black duck breeding habitat are now plagued by two exotic emergents, *Phragmites australis* and *Lythrum salicaria,* to the point where the impoundments are currently being managed with herbicides, prescribed burning, and water level manipulations. Despite the general interest in restoring salt marshes in much of New England, wetlands regulations in Massachusetts require that a thorough analysis of wetlands functions in impounded marshes be carried out before any restoration activity is allowed to proceed.

In the future, managing marshes in relation to sea-level rise is something that may need to be addressed in New England, particularly since upland buffers are often developed, leaving no place for marshes to migrate naturally. The merits of structural management of hydrology have been debated in relation to one proposal in Saugus, Massachusetts, but no SMM has been implemented. The major current effort in New England is to restore degraded marshes by restoring their natural hydrology and salinity levels.

In recent years, Open Marsh Water Management (OMWM) systems have been implemented in New England (Hruby et al., 1985). This method of mosquito control relies on maintaining some open water to act as reservoirs for mosquito-eating fish (primarily the mummichog, *Fundulus heteroclitus,* in New England) and a system of radial canals that allow the fish access to mosquito breeding areas. OMWM systems in New England, which are small-scale (e.g., typically less than one acre), have little impact on vegetation, and a clear preference for these areas by shorebirds has not been demonstrated (Brush et al., 1986). Habitat use by birds is more closely related to the relative amount of open water on a marsh than to

Table 1. Estimated area of coastal wetlands under SMM in eastern coastal states and the relationship of managed wetlands to total coastal wetlands (after Good, 1994)

State	coastal Wetlands (acres)	Extent of SMM (acres)	Percent Managed
NJ	779,038	1,500	0.2
DE	197,904	15,000	7.6
MD	215,631	5,000	2.3
VA	176,605	4,000	2.3
NC	2,417,636	5,155	0.2
SC	444,847	70,425	15.8
GA	718,770	7,988	1.1

In South Carolina, most "managed" marshes are in impoundments that had been under cultivation for rice prior to the early 1900s.

whether an area is an OMWM or control marsh. However, the creation of additional habitat and access to the marsh surface for the mummichog is beneficial because this small fish has a vital role in the ecology of New England marshes and estuaries, being one of the major transfer agents of marsh productivity from the marsh surface to higher trophic levels.

6.3 East Coast Coastal Marshes

6.3.1 Resource Status

SMM has been practiced in East Coast marshes (New Jersey through Georgia) for a variety of purposes. These include enhanced habitat for waterfowl, mosquito control, and agriculture. Only recently has protection or enhancement of the vegetated wetland itself been an objective. Table 1 presents estimates of the total acreage of coastal wetlands in which there is structural management of water level and relates these estimates to the total acreage of coastal wetlands. The total area of "managed" wetlands is small compared to that in coastal Louisiana (388,000 acres) and comprises a significant fraction of the coastal wetlands only in South Carolina and Delaware.

In South Carolina, most "managed" marshes are in impoundments that had been under cultivation for rice prior to the early 1900s. These impoundments range from those in which tidal exchange with the surrounding estuarine waters is totally cut off, to those that are more or less freely open to the estuary, and to those in which exchange and water level are managed for some specified purpose. Such impoundments have been studied in some depth (DeVoe and Baughman, 1986). On the positive side, they provide habitat for migratory waterfowl and other wildlife species, while there may be negative effects on estuarine-dependent fish and shellfish populations and on water quality, particularly if tidal exchange is limited.

The situation in Delaware differs in that water level control in marshes has been pursued originally for the purposes of mosquito control and waterfowl habitat enhancement rather than agriculture. Many mid-Atlantic marshes, including those in New Jersey, Maryland, and Delaware, have been subjected to parallel grid ditching for mosquito control. This activity has had the effect of dewatering marsh ponds and pannes, resulting in undesirable vegetation changes and often not producing the desired effect of mosquito reduction (Meredith, 1994). To promote source reduction of mosquitoes in order to reduce the application of pesticides, the use of Open Marsh Water Management (OMWM) is increasing in the region.

The areas of managed marshes listed in New Jersey, Delaware, Maryland, and Virginia consist mostly of impoundments for waterfowl enhancement. These managed marshes have been little studied in terms of the effects of impoundments on marsh loss, sediment accretion, or fish and shellfish utilization. They are viewed by wildlife biologists as important habitat for wading birds and some endangered species (e.g., black-necked stilt) and are favored sites for birdwatchers (Josh Standt, Maryland Department of Natural Resources, personal communication). Marshes in parts of the Chesapeake Bay are undergoing rapid rates of loss much like those of coastal Louisiana. For example, the Blackwater Wildlife Refuge has lost over 7,000 acres since the 1940s (Glenn Carowan, US Fish and Wildlife Service, personal communication). This region, like coastal Louisiana, is characterized by a small tidal range and relatively high subsidence rates, and both areas exhibit break up of marshes from within as a result of a deficiency in soil accumulation compared to relative sea-level rise (Stevenson et al., 1985). Marshes that have been unwittingly impounded by a road crossing Blackwater marshes seem to have accelerated rates of marsh loss.

6.3.2 Management Objectives

In general, there are no plans to increase greatly the area of coastal marshes under SMM in Atlantic states, and a number of states have legal and regulatory restrictions on reclaiming abandoned and open impoundments. Rather, managers seem concerned that EPA policies will restrict them from repairing and modifying existing structures. In South Carolina, for example, the emphasis is on repairing and improving the management of actively managed impoundments rather than attempts to impound or otherwise control water levels in unimpounded wetlands. In that regard, DeVoe and Baughman (1986) pointed out the need for better manipulation of water exchange between impoundments and adjacent natural wetlands. In general, SMM is not being pursued for the purposes of creating or preserving tidal wetlands.

There is also some interest in applying water level management in marshes that have become dysfunctional as a result of human activities (for example, portions of the Blackwater Wildlife Refuge and marshes dewatered by mosquito ditching). Managers profess to be committed to “ecosystem management” of wetlands, which is meant to embody multipurpose management with the sustainability of the habitat as a central goal. Delaware officials speak of their Integrated Marsh Management approach, which combines OMWM, local eradication of the plant pest *Phragmites*, and restoration of dysfunctional impoundments.

6.4 Eastern Florida Marshes

6.4.1 Resource Status

Marshes along the east coast of Florida exhibit varying mixtures of vegetation, from dense mangrove forest, to a mixture of mangrove and marsh grass species, to predominantly marsh grass meadows and ponds. These marsh/mangrove ecosystems have been altered by previous efforts to impound the marsh. For example, thousands of acres of marsh/mangrove vegetation were inundated and drowned with impoundment construction along the Indian River Lagoon on the east coast of Florida during the 1950s and 1960s as water level heights were not controlled to allow plant community survival (Harrington and Harrington, 1982; Gilmore et al., 1982a). Where vegetation was not eliminated, impoundment often induced successional changes from low salt marsh grasses to mangrove forests. Submerged seagrass meadows grew in impoundments where salterns and salt marshes once thrived. Subsequent control of water levels, i.e., lower water levels during impoundment closure and inundation periods, has permitted marsh/mangrove regrowth, and extensive mangrove forests have developed (basin forest) (Rey et al., 1990a, 1990c; Gilmore and Snedaker, 1993). However, long-term successional changes from herbaceous marsh/saltern systems to mangrove forest communities through the influence of both impoundment management and regional sea level rise are predicted.

Long-term survival of indigenous marsh/ mangrove biota under impoundment may be

The major management objective of the SWIM plan is to rehabilitate the ecological function of impounded wetlands without compromising mosquito control

threatened by high detrital deposition from mangrove forest litter production and reduced detrital transport from the system. Lower levels of biological and hydrological transport of organic materials from impounded marsh and mangrove forest ecosystems will tend to increase organic and inorganic material accretion.

Impacts of impoundment on indigenous marsh/mangrove fish and crustacean species (e.g., snook, tarpon, striped mullet, red and black drum, shrimp, and blue crab) have resulted either from direct death of mangrove or salt marsh grasses following prolonged impoundment flooding, limited access to passive/active migration, or loss of feeding sites or preferred food organisms (Harrington and Harrington, 1982; Gilmore et al., 1982a, 1982b; Lewis et al., 1985; Gilmore, 1987). Cumulative fish and wildlife impacts from standing water associated with impounding marsh and mangrove forest communities are directly associated with vegetative and hydrological changes. Sediment and organic material accretion, tidal water column reduction, and water quality declines associated with eutrophication in subtropical/tropical climates cause available aquatic habitat to decline in quality and quantity. Only those aquatic organisms adapted to eutrophic, anoxic conditions will survive (Peterson and Gilmore, 1991). It is likely, therefore, that without major anthropogenic energy subsidies, species diversity will decline in impounded mangrove forest aquatic communities, with periodic mass mortalities of sensitive aquatic organisms. This successional scenario has already been documented at various locations in Indian River Lagoon impounded wetlands (Greene and Van Handel, 1992).

Marsh and mangrove forest aquatic species that require summer tidal variations in order to complete their life history, reproduction, or effective feeding will eventually be eliminated from impounded wetlands. Those indigenous species showing population declines and sensitivity to impounding are the marsh killifish *(Fundulus confluentus:* Gilmore, 1987), rivulus *(Rivulus marmoratus:* Taylor, 1988), and various species of fiddler crabs (Uca spp.). Other species that require shallow mud, algal and salt flats with salt marsh grasses for breeding and/or feeding will also decline in numbers as the mangrove forest canopy shades out these photophilic vegetative species. Species impacted by this plant community succession include the sheepshead minnow *(Cyprinodon variegatus)* and palaemonid shrimp *(Palaemonetes* spp.), as well as the various wading birds (e.g., white ibis, snowy egret, wood stork, and roseate spoonbill) that prey on these species in open waters and shallow flats (Gilmore, 1987). Reptilian, avian, and mammalian species that are adapted to open herbaceous marsh systems will decline as mangrove forest systems succeed. The dusky seaside sparrow, now extinct, was significantly reduced in number because of the vegetational changes and succession induced by wetland impoundment (Kale, 1981; Walters, 1992).

6.4.2 Management Objectives

A variety of state and federal agencies have participated in the review, permitting, and implementation of wetland management plans for the east coast of Florida over the past 25 years. In 1982, the Governor formed the Subcommittee on Managed Marshes to advise state and federal permitting agencies on technical wetland management issues. Most recently, two of the regional water management districts (St. Johns

River and South Florida) have taken the lead in the development of a management plan for the Indian River Lagoon as part of the State's Surface Water Improvement and Management (SWIM) Program. The basic goal of the wetland portion of the SWIM plan is "to attain and maintain a functioning macrophyte-based ecosystem which supports endangered and threatened species, fisheries and wildlife" (Steward et al., 1994). The major management objective of the SWIM plan is to rehabilitate the ecological function of impounded wetlands without compromising mosquito control, either by breaching impoundment dikes and using open marsh management (for northern temperate wetlands) or by the use of numerous gated culverts that can be opened seasonally to tidal influence (for the southern marshes dominated by mangrove forests). The seasonal change in hydrology and water management is called Rotational Impoundment Management (RIM).

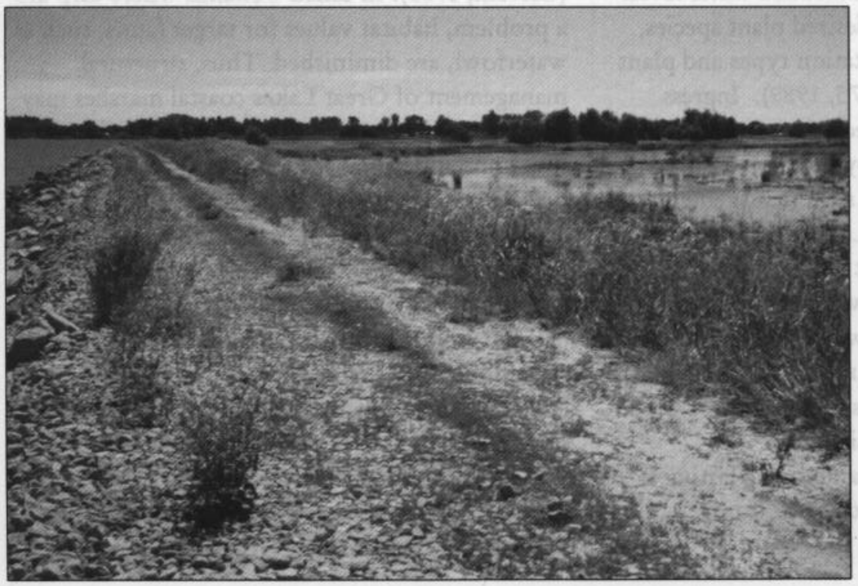
Other important management objectives in the SWIM plan are the preservation of existing marshes, principally through land acquisition, and the creation of wetlands where feasible. Wetland creation is often controversial and will require understanding of the association of wetland function with geomorphology, hydrology, and other site characteristics.

6.5 Great Lakes Marshes

6.5.1 Resource Status

Including the connecting channels and islands, the Great Lakes have 10,900 miles of shoreline. Over 1300 individual wetlands cover an area of more than 470 square miles. A large area of wetland has been lost to development and drainage for agriculture, especially in certain regions, and many existing wetlands have been degraded by human activities (Wilcox, 1995). Although few wetlands could be considered pristine, a number of those in Lake Superior and northern Lakes Huron and Michigan appear to be less degraded

Biological communities in diked Great Lakes wetlands have been altered by isolation from the lakes



Diked wetlands along the shore of western Lake Erie managed by periodic drawdowns.

Photo by D. Wilcox

Very few coastal wetlands remain in southern California, largely as a result of urbanization

than those of Lakes Erie and Ontario. SMM is practiced at a few locations in Lakes Superior, Michigan, Huron, and Ontario. It is widely practiced on the Canadian side of Lake St. Clair and the U.S. side of Lake Erie.

In the past, dike construction was a common response to the degradation of wetlands that occurred when protective barrier beaches and sand spits were eroded and not rebuilt because of an inadequate supply of sediments in the littoral drift. Such lack of sediment supply is generally caused by armoring of the shoreline to protect property from erosion. In addition, revetments and wetland dike structures are less capable of absorbing wave energy during storms and thus transfer this energy downshore where its effect on unprotected beaches, sand spits, or wetlands is magnified.

Biological communities in diked Great Lakes wetlands have been altered by isolation from the lakes. Reduced active transport of plant seeds and propagules into a diked wetland, in concert with the restricted amplitude of controlled water levels and active management for desired plant species, reduces the diversity of vegetation types and plant species richness (Stuckey, 1975, 1989). Ingress and egress of fauna are limited to organisms that can fly or traverse the dike by land. Many of these fauna can benefit from such management (Kroll and Meeks, 1985; McLaughlin and Harris, 1990), and since management efforts are generally directed toward developing waterfowl food or habitat, waterfowl almost always receive benefits. However, exclusion of certain fauna that may be important parts of food webs, either as prey or predators, can further alter biological communities. These effects can be long-lasting if hydrologic connection with the lake is not restored.

Use of diked wetlands as fisheries habitat in the Great Lakes is generally restricted to species that enter as larvae passing through screens when pumps or culverts are used to fill the wetlands (Navarro and Johnson, 1992). As a result, fish species diversity in diked wetlands is considerably lower than in undiked systems (Johnson, 1989); many of the more than 40 species of Great Lakes fish that require wetland habitat in one or more life-history stages (Johnson, 1989; Jude and Pappas, 1992) are excluded; and overall populations of certain species, such as northern pike, may be greatly reduced because of lack of access to wetland spawning areas (Herdendorf, 1987). Common carp that enter diked wetlands as larvae grow to adult size and cannot return to open waters of the lake in mid to late summer as they typically do. While feeding, these large carp can uproot or destroy wetland plants, and they stir up sediments and create turbidity problems that further reduce the ability of plants to thrive (Crivelli, 1983). In diked wetlands where carp are a problem, habitat values for target fauna, such as waterfowl, are diminished. Thus, structural management of Great Lakes coastal marshes may allow for enhancement of certain wetland functions and values for a limited period of time, but the overall wetland ecosystem can be severely compromised by this practice as it is currently conducted.

Numerous large-scale marsh management projects in one region, such as along the Ohio shoreline of Lake Erie, can have cumulative effects of endangering or eliminating populations of certain fish species that require access to wetlands, reducing the overall diversity of wetland plant species and fauna1 organisms that depend on lost plants, and reducing or altering sediment supplies in the littoral drift of the lake.

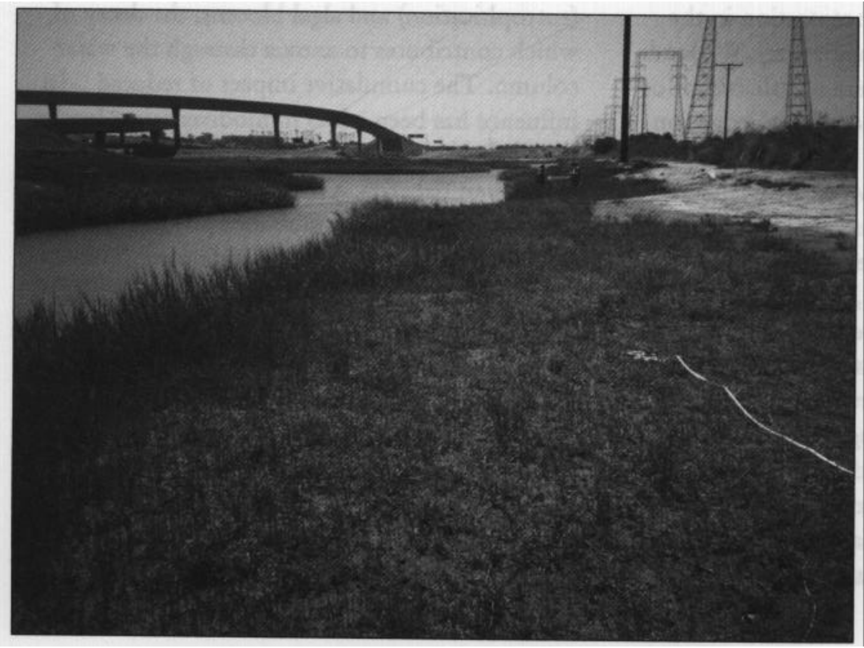
6.5.2 Management Objectives

SMM has been shown to be successful as a restoration technique to create and protect emergent vegetation in coastal areas around the Great Lakes. However, the species composition and diversity of the plant communities can differ from pre-management conditions, with a noted increase in non-indigenous plants, and other ecosystem values are nearly always compromised (Lowden, 1969; Stuckey, 1975, 1989; Kroll and Meeks, 1985; Bartolotta, 1989; Harris et al., 1991). As practiced in the Great Lakes, structural management consists of constructing dikes around wetlands or isolating an embayment wetland from the lake by placing a dike across the mouth of the bay. Water-level control is thus attained and used to create drawdown conditions that stimulate growth of emergent plants from the seed bank. Under most circumstances, hydrologic connection with the lake is not restored. Because water levels in the Great Lakes vary widely on scales of centuries, decades, years, seasons, and hours (seiches), wetland managers find it difficult to restore emergent vegetation in wetlands that have been degraded by other human activities. Given an adequate span of time, natural lake-level cycles would result in low-water years with drawdown conditions that would stimulate the seed bank. However, since these time scales generally do not match management goals, SMM has been chosen as an alternative.

6.6 Southern California Coastal Marshes

6.6.1 Resource Status

Very few coastal wetlands remain in southern California, largely as a result of urbanization. In San Diego County, for example, 85 percent of the historical tidal salt marsh is gone (Macdonald,



This photo of a constructed (mitigation) marsh in San Diego Bay shows the kinds of structures that affect many of the region's wetlands. A freeway on the left blocks access to fresh water inflows. An abandoned railroad and power lines on the right block access to tidal flows. Tidal influx is limited to flows through a flood control channel, which is seen on the horizon; the levee of the flood control channel has a notch that allows tidal inflows, although a shallow wier (submerged except at low tide) impairs drainage. Photo by J. Zedler

Because of drastic losses of all types of wetlands in California, there is now competition for different wetland restoration goals in diked former tidal marshes, such as waterfowl habitat or seasonal wetlands

1990). The coastal watersheds are characterized by highly erodible soils, steep slopes, and ample disturbance associated with urbanization. All of southern California's coastal wetlands receive some unnatural freshwater inflows, as the region imports water from northern California and from the Colorado River. Some of this water makes its way into coastal streams through irrigation runoff or other means. Virtually every coastal wetland has a roadway crossing it; most have three (Coast Highway, Santa Fe Railroad, and Interstate Freeway 5). These structures act as breached levees-they have cut off tidal channels, although a single bridge allows some tidal flow. The result of these "levees" is reduced tidal action and increased sedimentation, both at the ocean inlet (from long shore transport) and from the watershed (entrained sediments).

The effect of this inadvertent impounding of tidal wetlands has been to increase the range of environmental extremes (e.g., water and soil salinity, dissolved oxygen concentration in the water column, and water temperature). Wetlands become hypersaline when there is little runoff or brackish if there is excess inflow from irrigation runoff or other stream flows (e.g., reservoir discharge; raw sewage from Mexico to Tijuana Estuary). Hypersahne soils, as high as 100 ppt interstitial soil water, have developed in some locations (Zedler et al., 1992), causing massive diebacks in the more sensitive halophyte populations. Hyposaline soils (e.g., those under 20 ppt) allow invasions by brackish marsh vegetation (e.g., Typha domingensis, *Scirpus californicus)* which shades and out-competes the native salt marsh plants. Three species are most tolerant of these conditions, and one of them *(Salicornia virginica)* becomes the dominant of impounded wetlands. In watersheds with high runoff from urban or agricultural uses (e.g., San Elijo Lagoon), the water levels may become too high to support emergent vegetation. A comparison of 26 wetlands in southern California shows that the wetlands that are most often fully tidal support up to 19 native halophytes, while the least frequently tidal systems retain as few as 3 (PERL, 1990). While some impoundment may lead to increased vascular plant productivity (Zedler et al., 1980), algal mats are rare beneath these canopies, and total primary productivity may not be enhanced.

In addition to impacting marsh vegetation, salinity, temperature, and dissolved oxygen extremes stress fish and invertebrates, causing heavy mortality. Lack of tidal flushing eliminates habitat for endangered birds that have specific nesting and feeding requirements (e.g., light-footed clapper rail, Belding's Savannah sparrow) and allows the accumulation of nutrients (eutrophication) and algal blooms, the decay of which contributes to anoxia through the water column. The cumulative impact of reduced tidal influence has been a loss in biodiversity, a loss in productivity of sport and commercial fisheries, a loss in bait fisheries, a loss in recreational clamming, and various nuisance problems (e.g., algal blooms, odors, midges, and mosquitoes) (Zedler at al., 1992; Nordby and Zedler, 1991; Zedler, 1996b).

6.6.2 Management Objectives

Because very few coastal wetlands remain, the primary focus of marsh management activities in southern California has been on marsh protection, restoration, and creation. These efforts have been greatly hampered by the lack of a regional plan for wetland management, including identification of sites that need to be restored and sites that might serve mitigation needs (Zedler, 1996a). Most projects merely "remodel" existing wetlands, rather than creating new wetlands from upland. Mitigation projects are undertaken piecemeal, often without regard for the hydrologic suitability of the site. For example, Southern California Edison is required to "substantially restore" 150 acres of wetland with an emphasis on fish production to mitigate losses to coastal fisheries caused by the San Onofre Nuclear Generating Station. The site chosen for this project, San Dieguito Lagoon, cannot be made fully tidal without continual maintenance of the ocean mouth. Since closure is detrimental to fish populations (Nordby and Zedler, 1991; Zedler, 1996b), the project has a low likelihood of achieving its mandate.

6.7 San Francisco Bay/Delta Wetlands

6.7.1 Resource Status

Ninety-five percent of San Francisco Bay's 550,000 acres of tidal wetlands has been converted to agricultural uses, salt ponds, duck clubs, or urban development. Since 1965, further conversion of tidal wetlands in the salinity-influenced portion of the estuary has been prevented by legislation. In the freshwater tidal area (the Delta), all but a few isolated remnants of tidal marsh have been converted to agricultural land. Large-scale elimination of fresh and brackish tidal marshes has significantly changed the food web in the estuary. Elimination of tidal marshes has also removed a major sediment sink, resulting in greater sediment recirculation and higher turbidity in the estuary. Vulnerability of SMM sites to catastrophic failure in the event of earthquakes and floods can significantly increase tidal prism and estuarine hydrodynamics.

Tubb's Island Managed Wetlands, San Pablo Bay National Wildlife Refuge, Sonoma County, California.
Photo by Phillip Williams and Associates, Ltd.

6.7.2 Management Objectives

Within the last decade there has been growing interest in restoring large areas of former San Francisco Bay/Delta wetlands, with substantial land acquisitions now underway. In the Delta region, a key impetus for wetland restoration is the protection of freshwater diversions from salinity intrusion caused by tidal inundation of subsided reclaimed land, as well as restoring fishery habitat. In Suisun Marsh, the brackish zone of the estuary, the main concern is the long-term future of 40,000 acres of private wetlands managed for waterfowl habitat in the face of increased saltwater intrusion and deteriorating levees. In San Pablo Bay, up to 20,000 acres of former salt ponds and agricultural land are being purchased by a mix of state, federal, and local nonprofit organizations for restoration as wetlands. In the South Bay, up to 40,000 acres of salt ponds may eventually become available for restoration as wetlands.

One of the most important resource management issues in the region is the attempt to ameliorate the impacts on the estuary of water diversions. EPA is presently engaged in setting flow standards to maintain the ecosystem based on its present day functioning. Because of the loss of most of the tidal wetlands connected to the estuary, only about 10 to 20% of organic carbon input to the estuary comes from marshes compared to 50% generated in the water column by phytoplankton (Jassby et al., 1992). With full tidal as opposed to managed wetland restoration, there is a significant potential for increasing inputs of organic carbon, which is a measure of the source of food for phytoplankton and other biota in the estuarine food web.

As proposals for large-scale restoration projects have matured, an important controversy over wetland restoration strategy has emerged. Because of drastic losses of all types of wetlands in California, there is now competition for different wetland restoration goals in diked former tidal marshes, such as waterfowl habitat or seasonal wetlands. An example of this controversy concerned the recently constructed 300-acre Sonoma Baylands tidal restoration project, where 56 acres of seasonal wetland existed in the hayfields on a site that was formerly a tidal wetland. The U.S. Fish and Wildlife Service argued that mitigation was required for the loss of the seasonal wetland upon restoration of tidal influence. Maintenance of existing “accidental” wetland values on potential tidal restoration areas, such as salt ponds or poorly drained fields, implicitly requires a commitment to a structural marsh management system. This is because the hydrology and geomorphology sustaining these accidental transient wetlands are artificial creations of the former management practices and must be maintained indefinitely to preserve the new status quo.

7. Summary and Conclusions

Although most experience with SMM is based on efforts primarily designed to accomplish a purpose other than the protection or creation of emergent vegetated wetlands, the collective experience around the country has shown that unintended, unanticipated, and sometimes undesirable effects have often resulted from structural management of marsh hydrology. Differences in the physical environment, status of wetland resources, and management objectives make it clear that the application of a marsh management policy needs to be at least region-, ecosystem-, or basin-specific. Further, the impact of SMM on marsh-sustaining processes depends on the type of management scheme employed. For these reasons, it is difficult to generalize about the ecological impacts of SMM. However, the interruption of daily, monthly, and seasonal hydrologic cycles as a result of SMM inevitably influences important elements of the ecosystem such as sediment chemical processes, water column chemistry, the distribution and migration of aquatic and semi-aquatic organisms, and material import and export from the marsh.

Because of the substantial uncertainties about the impacts of SMM and because not all SMM projects are reversible, the Subcommittee urges caution in the adoption or approval of SMM projects in order to avoid counterproductive results on the long-term sustainability of imperiled tidal and Great Lakes wetlands. Further, we strongly recommend that Agency decisions regarding proposed SMM projects take into account the potential impacts of the project from an ecosystem, rather than single-species or single-resource, perspective. All proposed SMM projects should be carefully evaluated in the context of the science-based principles and evaluation criteria described in this report. SMM projects implemented following this careful evaluation should include environmental monitoring to assess the impacts of the project on marsh processes and long-term viability, to determine whether the project is meeting management and design objectives, and to provide guidance for improving the design of future SMM projects. In addition, the Subcommittee has identified priority research questions that should be addressed by the Agency, in concert with other federal and state agencies and research institutions, in order to improve our understanding of the effects of SMM on various ecosystem processes and functions.

The Subcommittee's responses to the specific questions in the Charge are summarized below:

a) **Does SMM protect or create emergent vegetated wetlands? In regard to this evaluation, consider two conditions in the response: i) areas where net sediment deficit occurs (i.e., soil building does not keep up with relative sea level rise), and ii) areas where there has been extensive human-induced wetlands**

deterioration.

The available scientific studies on the efficacy of SMM are highly equivocal. Emergent wetland area has been maintained or increased in some SMM projects, but unchanged or decreased in others, relative to similar unmanaged areas. In salt and brackish marshes in regions undergoing rapid subsidence, SMM generally restricts the supply of mineral sediments needed to accrete soil, does not seem to protect wetlands, and may even hasten their demise. There may be a better case for the application of SMM in protecting tidal freshwater wetlands with highly organic or even floating soils. However, critical scientific appraisals of the effectiveness of SMM in such environments have yet to be performed. (See Section 3.1.)

b) **To what extent does SMM impact the physical, biological and/or chemical aspects of natural marsh-sustaining processes? With regard to this evaluation, consider long-term marsh survival and productivity, including accretion of organic and inorganic sediments.**

Depending on the extent of invasiveness, SMM may impact natural marsh-sustaining processes greatly or little at all. If SMM is applied to protect vanishing marshes or restore lost marshes, it must seek to do so by altering the physical, biological, and chemical processes operable. However, it is difficult to manipulate one process deemed necessary for sustaining or restoring a marsh (e.g., current flows or salinity) without also affecting others (e.g., sediment supply, water and sediment chemistry). Therein lie the controversies regarding the long-term effectiveness of SMM. In those cases in which SMM has been successful in protecting or expanding vegetated wetlands, the long-term effectiveness of SMM (and thus sustainability) in the face of geomorphic trends and sea-level rise remains in question. In any case, it is clear that SMM requires a perpetual management commitment to maintain effectiveness. (See Section 3.1.)

c) **What are the impacts of SMM, if any, to estuarine fisheries, waterfowl, and other fish and wildlife? If there are impacts, provide an analysis of the extent of these impacts.**

In a wide variety of cases and regions, SMM has been shown negatively to affect estuarine fisheries by creating an artificial separation between the wetland and the estuary or lake, reducing either the access to or escape from the habitat. This impact has been reduced, but not eliminated, by improvements to the design of weirs and gates. In addition, impoundments within the managed marsh may result in degraded water quality (e.g., salinity, temperature, and dissolved oxygen extremes, and mobilization of sulfate), occasionally with drastic results for marsh biota. SMM can enhance the habitat value for waterfowl and other wildlife and has been widely used for that purpose. It is not clear, however, whether SMM results in increases in the regional or continental populations of these resources. On the other hand, wading birds and other organisms that depend on periodic exposure of the marsh surface for effective feeding and prey capture, and endangered birds that nest or feed in specific types of vegetation, may be negatively affected by SMM. (See Section 3.2.)

d) **What are the cumulative effects of numerous large-scale SMM projects with respect to emergent vegetation, accretion, fish and wildlife, and other resources?**

Collateral and cumulative effects of SMM are poorly understood and virtually unquantified. Potential cumulative effects relate to the reduced water exchange between the managed marsh and adjacent wetlands and waters, altered patterns of sediment transport and deposition, altered movement of nutrients, pollutants, and organisms into and out of the marsh, and the ability to support regional biodiversity and rare or endangered species. Assessment of cumulative effects of SMM should be of central concern in areas where SMM is widely practiced or proposed for expansion. Presently, however, this assessment is based on highly subjective and qualitative approaches, rather than sound data and models. Research in this area should be a high priority for federal and state agencies. (See Section 3.3.)

e) **What are the gaps and the highest priorities for research studies related to the effects of SMM projects, and for routine monitoring of such projects?**

High priority research areas include: the development and testing of alternative management techniques that maintain the hydrological connections between marshes and coastal ecosystems; improved SMM technologies (e.g., improvements to control structure design and hydrological modeling of marshes); the effects of SMM on marsh morphology and productivity; and the cumulative effects of numerous SMM projects within a watershed or region. The Subcommittee recommends that monitoring be required for SMM projects and suggests parameters that should be measured. (See Section 5.)

f) **What scientific or technical criteria should EPA use as part of the basis for case-specific decision-making; or, as an alternative, what approach should EPA take to develop such criteria?**

The Subcommittee suggests that the Agency develop both generic national criteria and criteria relevant to specific regions of the country. These criteria should be consistent with the science-based principles discussed above. The Subcommittee has identified a number of scientific and management evaluation criteria that should be used when evaluating proposed SMM projects, including: the historic quality and productivity of the marsh; the current state of the marsh; the suitability of the modifications for the proposed site; the relationship of the proposed project to long-term, regional restoration goals; the ability of the SMM design to cope with extreme weather events; the potential for cumulative impacts; and the ecological impacts were the project to fail or be abandoned. (See Section 4.)

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Appendix A: Charge to the Subcommittee

Science Advisory Board Proposed Project

Subject: Marsh Management Practices

Requesting Organization: Office of Water, Assistant Administrator for Office of Water

Operational/Program Contact: Fran Eargle, Wetlands Division

Background:

Marsh management generally refers to practices that selectively modify attributes, individually or in combination, to induce hydrologic changes in a marsh. Marsh management is held to be a viable restoration technology in coastal areas where erosion and subsidence is a critical resource problem. However, the environmental merits of implementing these practices, as well as the potential cumulative and secondary impacts of these projects, are widely debated among the scientific community. In addition, there is often debate about whether a particular project design will yield environmental benefits or cause environmental harm. These practices are regulated under Section 404 of the Clean Water Act because they typically involve the discharge of dredged and fill material into waters of the U.S. Federal funding of these marsh management projects under the Coastal Wetlands, Planning, Protection and Restoration Act (CWPPRA, P.L. 101-646) has also recently been a very contentious issue. To make informed permit and funding decisions, EPA needs clarification on the underlying science regarding marsh management.

Because of the contentious nature of marsh management, permit decisions are often subjected to delays, especially if these permits are elevated to Headquarters. For example, within the last year this issue has been problematic in coastal Louisiana, where three 404(q) elevations regarding marsh management have been initiated, one by EPA and two by National Marine Fisheries Service (NMFS). In addition, federal funding of marsh management projects under CWPPRA has been challenged by some Agencies. This has resulted in polarized federal agency positions and deadlock in reaching consensus on restoration strategies to restore coastal Louisiana wetlands, which continue to be lost at a rate of approximately 25 square miles per year.

To address these concerns, an EPA position on marsh management (as an interim step to establish a uniform Federal policy) is desired to clarify what is and what is not acceptable to EPA. This would expedite the permit review process and define EPA's position regarding federal funding of marsh management projects, consistent with the best available science. This would be consistent with the Administration's Wetlands Plan which established a position that the Federal government be efficient, flexible and fair in conducting the wetlands regulatory program. The Administration's Plan also provides, as one of its basic principles, that wetlands policy should be based on the best available science. The Administration supports the reduction of the impact of regulation on the public, while meeting the objectives of wetlands protection in a technically sound manner. Recently, Federal agencies (Fish and Wildlife Service and NMFS) developed individual agency positions on marsh management. For a long term goal, EPA will seek to work with other Federal agencies to establish a unified Federal policy to reduce confusion and provide federal consistency. However, we believe that a scientific review of this issue is critical to the development of an environmentally sound policy.

In developing a position on marsh management in Region 6, a briefing document was prepared that provides a compilation of literature, and summarizes a status of the science in regard to marsh management practices entitled, "Marsh Management in Coastal Louisiana: impact on vegetation, accretion, and fisheries productivity." In addition, we are seeking assistance from the SAB to assist the Office of Water to identify scenarios for differentiating sound marsh practices from environmentally damaging practices, and to develop criteria for scientific evaluation of marsh management practices.

Charge:

Marsh management is defined as the use of structures (such as canal plugs, weirs, gates, culverts, levees and spoil banks) to manipulate local hydrology in coastal marshes. Marsh management or tidal impoundments for the purpose of this review will include those wetlands influenced by the tide and lands and waters associated with the Great Lakes. As a general rule, the purpose of structural marsh management projects is to at least partially isolate a marsh from natural or altered hydrologic processes, thereby partly or totally impounding a discrete parcel of wetland acreage. This may be done for objectives such as: wetlands protection, enhancement or restoration; aquaculture; mariculture; agriculture; waterfowl hunting and management; enhancement of wildlife and/or local fisheries; and/or protection of property rights. Considering the range of both differences and similarities that exist between marsh types the Office of Water is requesting the Science Advisory Board to perform a review of marsh management practices to assist the Agency in answering the following questions:

1. Does structural marsh management protect or create emergent vegetated wetlands? In regard to this evaluation, consider two conditions in the response 1) areas where net sediment deficit occurs (i.e. sea level rise) and 2) in areas where there has been extensive human-induced wetlands deterioration.

2. To what extent does structural marsh management impact the physical, biological and/or chemical aspects of natural marsh-sustaining processes? With regard to this evaluation, consider long-term marsh survival and productivity, including accretion of organic and inorganic sediments.

3. What are the impacts of marsh management, if any, to estuarine fisheries, waterfowl, and other fish and wildlife? If there are impacts, provide an analysis of the extent of these impacts.

4. What are the cumulative effects of numerous large-scale marsh management projects with respect to emergent vegetation, accretion, fish and wildlife, and other resources?

5. What are the gaps and the highest priorities for research studies related to the effects of structural marsh management projects, and for routine monitoring of such projects?

6. What scientific or technical criteria should EPA use as part of the basis for case-specific decision-making; or, as an alternative, what approach should EPA take to develop such criteria?

Committee: Ecological Processes and Effects Committee

Schedule: July 1994

Prepared By: Fran Eargle