HYDROLOGY OF TWO TIDAL MARSHES IN NORTH CAROLINA WHERE OPEN-MARSH WATER MANAGEMENT MODIFICATIONS HAVE BEEN IMPLEMENTED

By B.F. Pope

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BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey, WRD
3916 Sunset Ridge Road
Raleigh, North Carolina 27607

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	by	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	0.4047	hectare (ha)

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

HYDROLOGY OF TWO TIDAL MARSHES IN NORTH CAROLINA WHERE OPEN-MARSH WATER MANAGEMENT MODIFICATIONS HAVE BEEN IMPLEMENTED

By B.F. Pope

ABSTRACT

In 1988 and 1989, open-marsh water management modifications were implemented at tidal marshes near West Onslow Beach and Hobucken, North Carolina, as part of a pilot program to evaluate the effectiveness of ditching techniques as a mosquito-control method in open marshes. In 1984, before implementation of the modifications, a study was initiated to allow definition of the effects of those modifications on the hydrology of the marshes.

Water levels in canals near the West Onslow Beach study marsh are controlled by periodic, gravitational tides. Daily maximum tides exceeded the elevation of the upper marsh surface 30 percent of the time before and 18 percent of the time after open-marsh water management. Water levels in canals adjacent to the Hobucken study marsh are primarily controlled by wind-driven tides. Daily maximum tides at this marsh exceeded the upper marsh surface 34 percent of the time before and 24 percent of the time after open-marsh water management.

Natural variation in tidal conditions resulted in varying numbers and duration of floods at the study marshes. Duration analyses indicated that relations between tide levels and marsh surface-water levels were unchanged after modifications.

Ground-water movement through the marshes varies seasonally and is primarily vertical. Withdrawals are by evapotranspiration and recharge is by infiltration. During nongrowing months saturated conditions prevail. Ground-water flow to the marsh interior from the surrounding tidal canals was not detected during these declines. Changes in the natural variation in withdrawals from and recharge to ground water were not indicated by the data collected during this study.

INTRODUCTION

A system of ditching modifications, known collectively as open-marsh water management (OMWM), has been proposed as a method for mosquito population control in tidal marshes of North Carolina. Although new to North Carolina, OMWM has been applied to tidal marshes in several other States along the east coast, including Delaware, Florida, Maryland, and New Jersey. In previous applications, however, there has been little documentation of the hydrology of the marshes where OMWM was implemented (Dale and Hulsman, 1990). Knowledge of hydrologic conditions and interactions in tidal marshes in general is limited. Consequently, in 1984 the U. S. Geological Survey, in cooperation with the Public Health Pest Management Section of the Division of Environmental Health, North Carolina Department of Environment, Health, and Natural Resources, initiated a study to characterize the hydrologic conditions before and after the implementation of OMWM at two tidal marshes in Onslow and Pamlico Counties, North Carolina (figs. 1 and 2).

Background

Saltwater tidal marshes provide an excellent habitat for the breeding and production of several species of mosquitoes, most notably salt marsh mosquitoes *Aedes sollicitans* and *Aedes taeniorhynchus* (U.S. Department of Health and Human Services, 1977). These mosquitoes deposit their eggs in shallow depressions on the surface of the marsh soil. The eggs remain dormant until the marsh is inundated, either by tide or heavy rainfall. The eggs then hatch, and the larvae mature in ponded water that remains in the depressions after the tide has receded and excess water has drained from the higher elevations of the marsh (U.S. Department of Health and Human Services, 1977).

Historically, mosquito control on tidal marshes has been achieved by use of various pesticides, by destruction of breeding habitat, or often, by a combination of these means. Aerial spraying to control adult mosquito populations and larviciding of breeding areas to control immature mosquito populations are the primary means of control through pesticide use. Destruction of habitat has primarily been by draining tidal marshes, using drainage ditches to remove all water from the marsh surface and lower the marsh water table.

Increased knowledge and concern about the use of pesticides has led to constraints on the types and amount of pesticides that may be used to control mosquitoes. In addition, drainage ditching was prevalent at a time when many felt that draining tidal marshes not only controlled mosquito populations but also converted marshlands into more productive land uses. As understanding and knowledge of tidal-marsh ecology increased, the role of tidal marshes as important parts of the global ecosystem was recognized and the practice of draining the whole marsh to control one insect pest began to be questioned. The need to control or manage populations of pest mosquitoes persisted, however. As a result, OMWM methods of mosquito population control that minimized adverse effects on the marsh environment began to evolve in the 1960's (Dale and Hulsman, 1990).

The objective of OMWM is to limit mosquito populations by altering or managing the marsh habitat to make it less suitable for the production of mosquitoes in a manner that does not significantly alter other functions of the marsh environment. The intent of OMWM is to connect isolated depressions on the marsh surface and create habitats for populations of larvivorous fish, thereby reducing the suitability of the marsh environment for mosquito production.

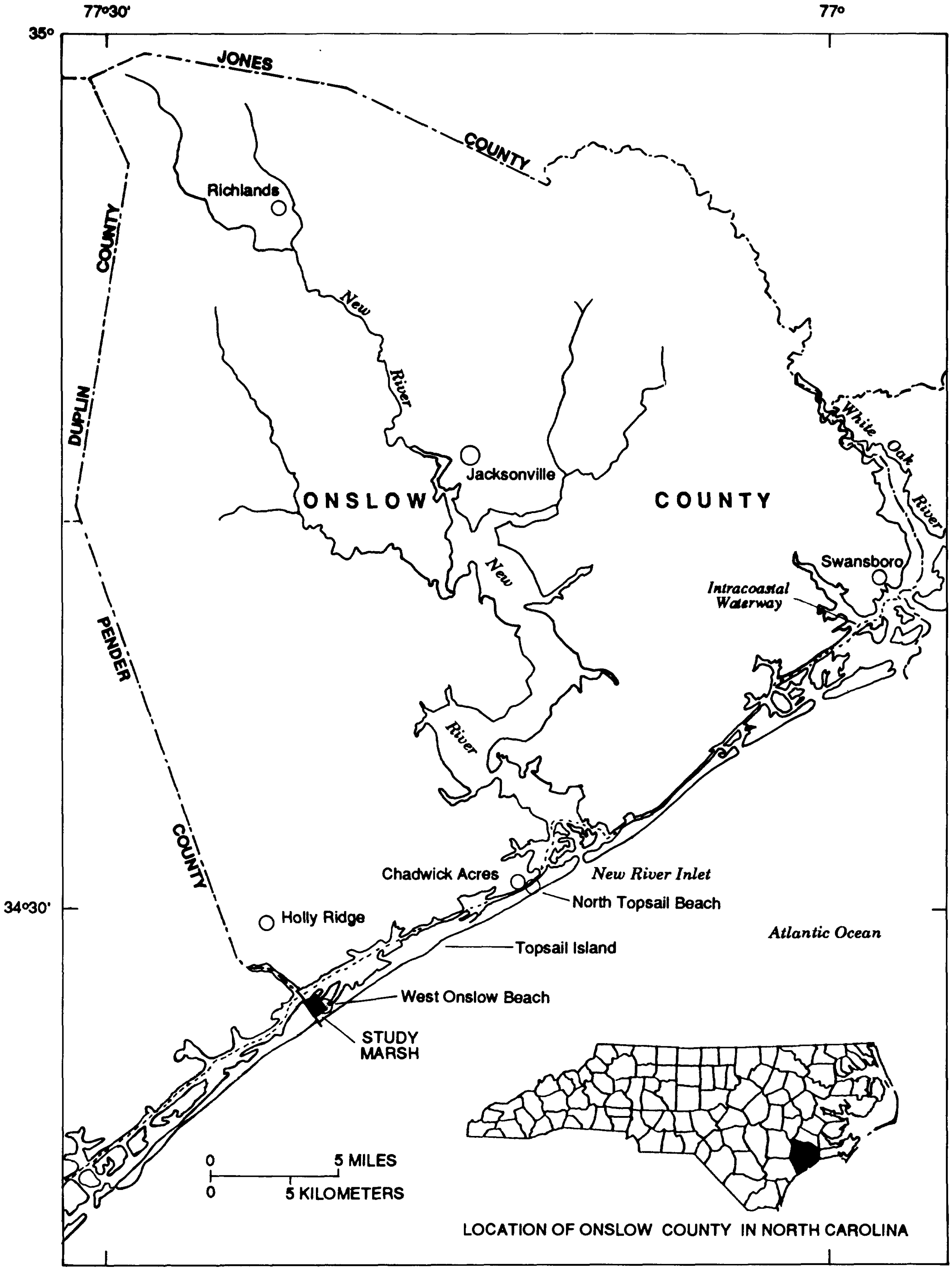

Figure 1.--Location of West Onslow Beach study marsh in Onslow County.

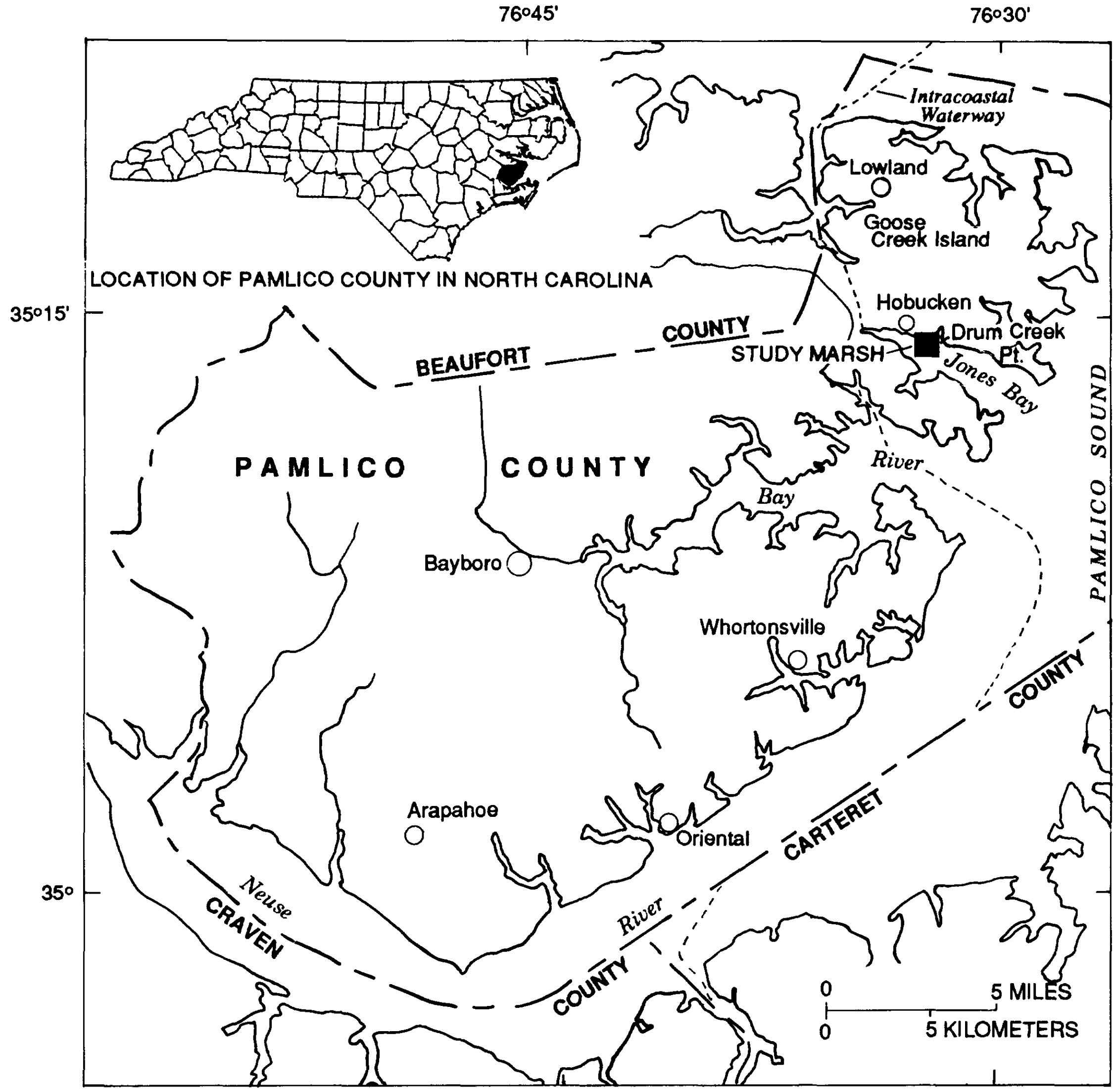

Figure 2.--Location of Hobucken study marsh in Pamlico County.

Dale and Hulsman (1990, p. 296-297) described three types of OMWM systems:

> There are three types of systems, an open one, a semi-open one, and a closed one, which together maintain a dynamic and relatively pest-free environment. The open system consists of tidal ditches, connected to relatively deep tidal outlets which, together with lateral spur ditches, permit daily tidal exchange. This maintains an energy, organism, and nutrient flow between marsh and marine environments. The semi-open system consists of full-depth ditches with a shallow tidal outlet or sill, plus lateral spur ditches to landward of the shallow outlet--this is semi-tidal. The closed system contains shallow pools and deeper reservoirs plus pond radial ditches. There are no tidal outlets, and tidal exchange occurs only during spring or storm tides. This part of the system provides a refuge for predatory fish and other marsh organisms. It does not provide protection for mosquito larvae * * *. From a pest's point of view, there is no place to hide under an OMWM regime. There are fish foraging in the tidal channels, receding tides flush larvae toward the dangers of the estuary, and there are predators in the pools. Not surprisingly, mosquito populations are nonexistent or small.

In practice, aspects of the three types of OMWM (fig. 3) are used separately or combined, as the system is adapted to the specific needs of a particular marsh. A schematic of a semi-tidal outlet, or sill, is also shown in figure 3.

OMWM is intended to reduce mosquito populations in a manner that minimizes undesirable effects on existing functions of tidal marshes (Meredith and others, 1985). Change in marsh vegetation is a key indicator in evaluation of possible undesirable effects of OMWM on related functions of tidal marshes. Marsh vegetation is, in turn, sensitive to changes in the hydrology of the marsh, especially changes in the elevation of the marsh water table. As a result, an important consideration in the evaluation of the hydrology of marshes where OMWM has been implemented is changes in ground-water levels in the marshes.

Purpose and Scope

This report documents hydrologic conditions of the West Onslow and Hobucken tidal marshes before and after the implementation of OMWM. Specific hydrologic characteristics described include (1) tidal conditions in adjacent canals, (2) surface-water conditions on the marshes, including frequency and duration of flooding, and (3) ground-water conditions in the marshes.

The data collection included evaluation of 34 soil cores and construction of 4 recording surface-water gages, 2 recording tide gages, 2 recording precipitation stations, and 30 ground-water level observation wells, 8 of which were equipped with recording instruments. Data were collected from October 1985 through March 1991. This period includes 2 1/2 years before OMWM and 3 years after OMWM at the West Onslow Beach study marsh, and 3 1/2 years before OMWM and 2 years after OMWM at the Hobucken study marsh. Weather observations by the National Oceanic and Atmospheric Administration were also used.

Analysis of the data utilized hydrographs, cumulative frequency diagrams, and water-level profiles. Standard statistical methods were employed.

Acknowledgments

The author gratefully acknowledges assistance with data collection provided by Dr. Alice Anderson of the Public Health Pest Management Section and her staff, as well as by Mitchell Parker, Charles Miracle, and the staff of the Onslow County Mosquito Control Program. The author especially thanks Troy Hefner for agreeing to have the tidal canal gage at the West Onslow Beach marsh study site located on his boat dock; Lionel Yow, agent of the owners of the marsh near West Onslow Beach, for permitting access to the marsh; and James Johnson, owner of the study marsh near Hobucken, for allowing access to that marsh.

PHYSICAL SETTINGS OF STUDY MARSHES

The study areas include a tidal marsh near West Onslow Beach in Onslow County, North Carolina (fig. 1), and a tidal marsh near Hobucken in Pamlico County, North Carolina (fig. 2).

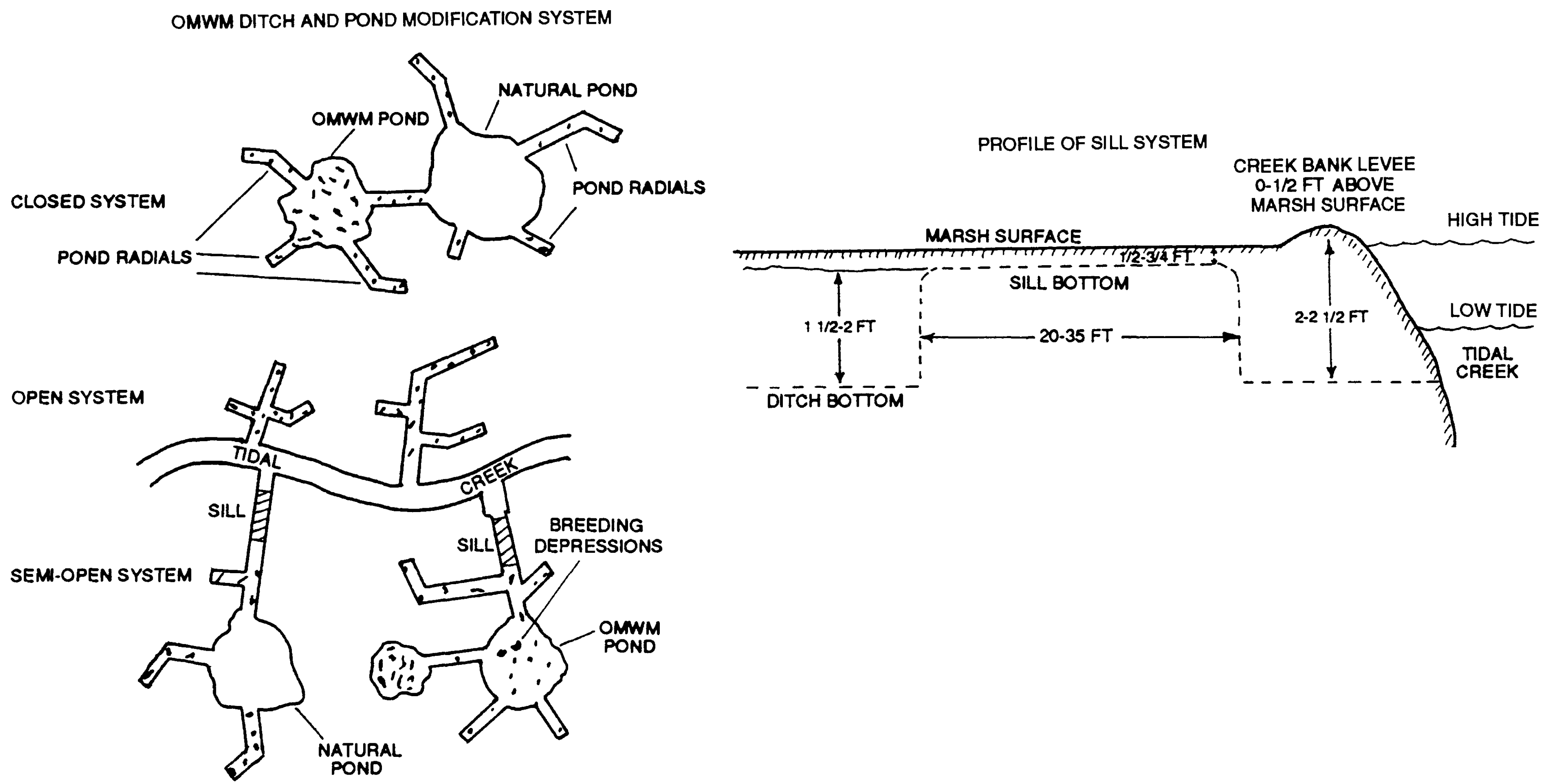

Figure 3.--Idealized open-marsh water management system (OMWM), incorporating aspects of open, semi-open, and closed systems, and profile of a semi-tidal outlet, or sill (modified from Meredith and others, 1985).

Both study marshes are located along the south-central coast of North Carolina and experience similar climatological conditions. Summers are hot, and locally intense thunderstorms are common. Winters are usually mild, with little snowfall. July and August are usually the wettest months. The most significant events are hurricanes, which occur in late summer and early fall, and northeastern storms, which can occur anytime throughout the year. Strong winds from these storms are significant because they can produce abnormally high water levels which, when combined with heavy rainfall that often accompanies these storms, can flood the marshes for periods of several days.

West Onslow Beach Study Marsh

The West Onslow Beach study marsh is on the Intracoastal Waterway side of Topsail Island adjacent to the unincorporated community of West Onslow Beach in southwestern Onslow County (fig. 1). Topsail Island is one of the chain of barrier islands that form the ocean coastline of North Carolina. New River Inlet to the northeast (fig. 1) and Topsail Inlet, which is about 12 miles southwest of West Onslow Beach, separate the island from adjacent barrier islands.

Topsail Island is approximately 22 miles long and 1 mile wide, and is oriented in a southwest to northeast direction. The southeastern shore is a sand beach that slopes gently to the Atlantic Ocean. The northwestern shore is composed of a network of tidal marshes and tidal canals, separated from the mainland by the Intracoastal Waterway. Land elevations on the island range from sea level to 15 ft above sea level. Low-lying areas are beaches on the ocean side of the island and tidal marshes on the landward side of the island. Maritime forests and developed areas occupy areas of higher elevation.

Topsail Island is a growing resort and recreational area with a combined permanent population of 2,481 in three incorporated towns. During the summer, however, seasonal population can expand to as many as 100,000 people (Sharon A. Braswell, Town of North Topsail Beach, written commun., 1991).

The West Onslow Beach study marsh covers approximately 45 acres and is bordered by a tidal canal to the east and south, an area of ponds and canals to the west, and is separated from the Intracoastal Waterway by a narrow strip of upland forest on the northern border (fig. 4). The surface elevation of this marsh is highest near western and southwestern edges of the marsh and slopes gradually to the east and northeast. For the purposes of this report, the upper marsh-surface elevation is 1.0 ft above sea level, and the lower marsh-surface elevation is 0.75 ft above sea level. Although there are many small depressions in the marsh surface, these depressions are generally only a few hundreths of a foot deep. Primary vegetation includes the salt marsh grasses *Spartina alterniflora* and *Distichlis spicata* (Kirby-Smith, 1989).

Soil cores were taken by members of the Department of Geology, East Carolina University, along two transects on the marsh in the spring of 1986 (fig. 4). Analyses of these cores by members of the Department of Geology, East Carolina University, show surface layers of peat, loamy sand, or sand, with large quantities of root masses underlain by sand, sandy loam, or sandy clay loam (fig. 5) (Dr. Alice Anderson, North Carolina Department of Environment, Health, and Natural Resources, written commun., 1989).

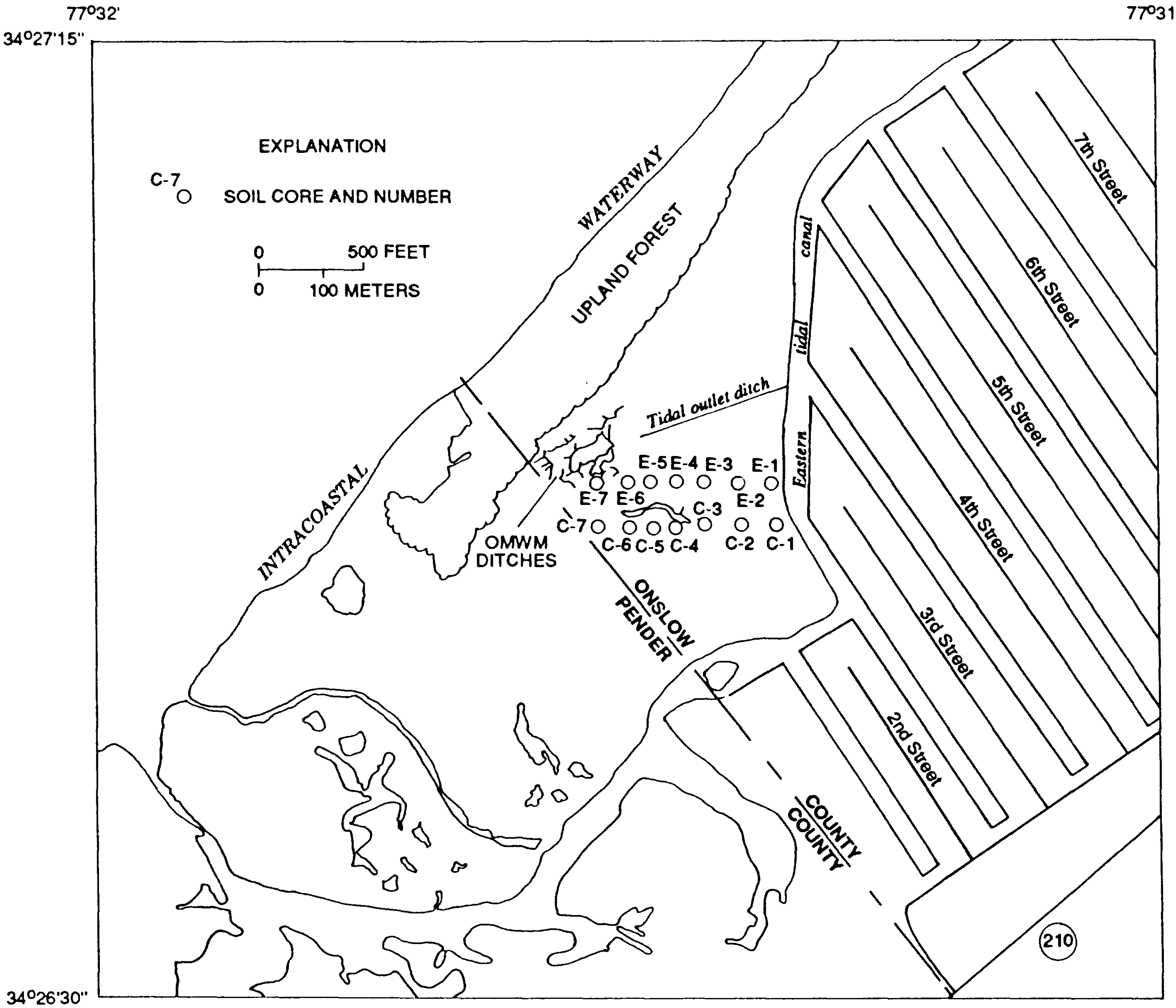

Figure 4.--Open-marsh water management (OMWM) ditches and locations of soil cores at West Onslow Beach study marsh.

At the West Onslow Beach study marsh, a closed OMWM system of ditches and ponds was installed by the Public Health Pest Management Section at the end of March 1988 (fig. 4). The installation of this closed system involved deepening and enlarging existing ponds to incorporate some breeding areas into these ponds and digging radial ditches to connect the remaining breeding areas to the modified ponds. A tracked excavator equipped with a rotary ditching head that spread the spoil in a thin layer excavated the ponds and ditches. The depth of the ditches ranged from 1.5 to 2 ft and the width of the ditches averaged about 1 ft. One semi-tidal outlet was also constructed at this study marsh, but was not part of the main OMWM system. This ditch is about 1.5 ft deep and 1 ft wide with a 6-in. sill about 30 ft

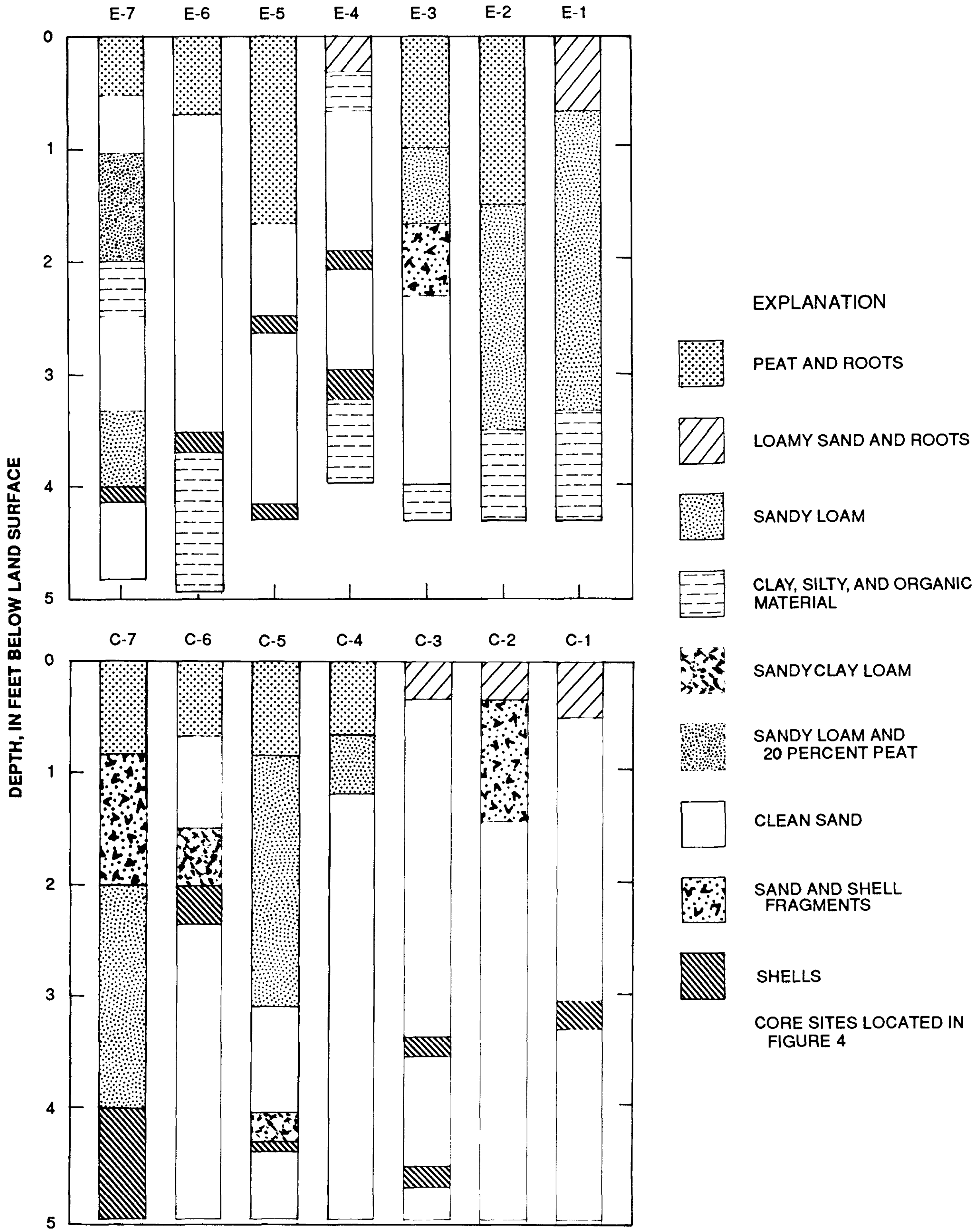

Figure 5.--Soil profile diagrams at West Onslow Beach study marsh.

landward of the canal and ends about 100 ft short of the other OMWM excavations. This outlet ditch serves to increase tidal exchange onto the marsh but, because there is no direct connection to the system, does not drain the system at low tide.

Hobucken Study Marsh

The Hobucken study marsh is on Drum Creek Point, which extends into Jones Bay on the south side of Goose Creek Island near Hobucken, North Carolina (fig. 2). Goose Creek Island is on the tip of the Pamlico peninsula in eastern Pamlico County. Pamlico Sound is to the east and the north, Jones Bay is to the south, and the Intracoastal Waterway and the mainland are to the west (fig. 2). Land elevations on the island range from 0 to 5 ft above sea level. Low-lying areas form tidal marshes, and areas of higher elevations are covered with pine forests and some agricultural fields. Goose Creek Island is sparsely populated; approximately 850 permanent residents live on the island, mostly in the two communities of Hobucken and Lowland (Andy Willis, Pamlico County, oral commun., 1992).

The Hobucken study marsh covers approximately 100 acres and is bordered by the open waters of Jones Bay and Drum Creek to the south and by tidal canals to the east, west, and north. Tidal marshes continue eastward and westward of the tidal canals, and an area of upland pine forest lies to the north of the tidal canals (fig. 6). The surface elevation of the Hobucken study marsh is highest at the northwestern corner of the marsh and slopes gradually to the south-southeast. For the purposes of this report, the upper marsh-surface elevation is 1.5 ft above sea level, and the lower marsh-surface elevation is 1.35 ft above sea level. Although there are many small depressions in the marsh surface, these depressions are generally only a few hundreths of a foot deep. Primary vegetation on this marsh is needlerush, *Juncus roemerianus*, with large patches of the marsh grass *Distichlis spicata* interspersed throughout the marsh (Kirby-Smith, 1989).

Soil cores were taken by members of the Department of Geology, East Carolina University, along two transects on the marsh in the spring of 1986 (fig. 6). Analyses of these cores by members of the Department of Geology, East Carolina University, show surface layers of sandy peat and peaty sand, underlain by organic-stained clayey sands to depths ranging from 1 to 3 ft (fig. 7). Below these initial layers is sandy clay that grades to slightly clayey sand with increasing depth (Dr. Alice Anderson, North Carolina Department of Environment, Health, and Natural Resources, written commun., 1989).

At the Hobucken study marsh, a semi-open OMWM system was installed by the Public Health Pest Management Section at the end of March 1989 (fig. 6). Ditches connected isolated breeding areas on the marsh and formed a network of ditches and breeding depressions. The ditches range from 1.5 to 2 ft deep and average about 1 ft wide and were dug using a rotary ditcher that broadcast a spoil slurry over a wide area. Two of these ditches were connected to the northeastern tidal canal (fig. 6). Semi-tidal outlets or sills were constructed in these ditches by reducing the depth of excavation from the full depth of 1.5 ft to about 6 in. beginning at a point 30-40 ft landward of the canal and continuing to a point about 5-10 ft landward, where depth of excavation increased to the full depth of about 1.5 ft (fig. 3). At high tide, water flows over the sills into the ditches, introducing tidal water and predatory fish into the ditches. As the tide recedes, the sills act as long, narrow weirs that

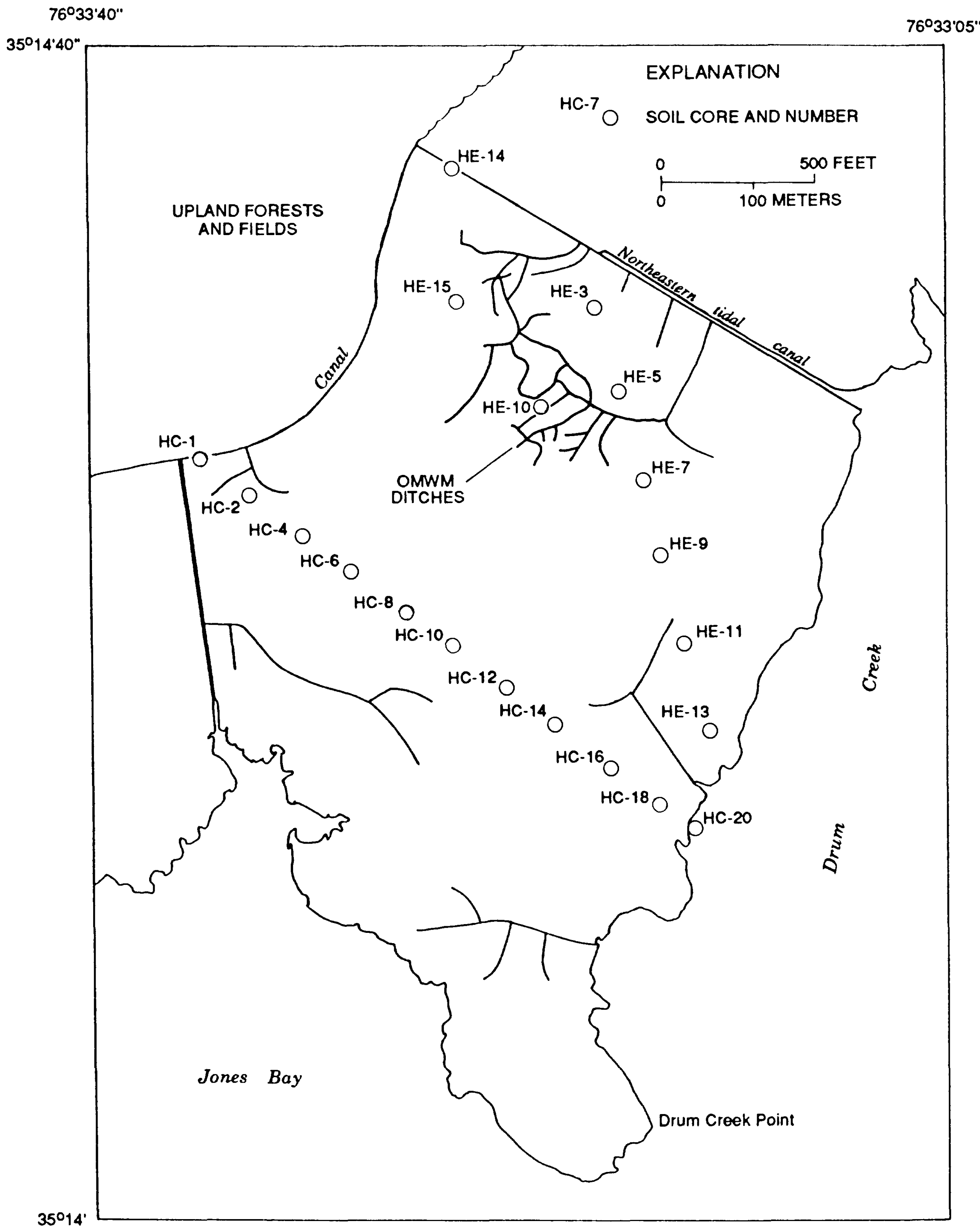

Figure 6.--Open-marsh water management (OMWM) ditches and locations of soil cores at Hobucken study marsh.

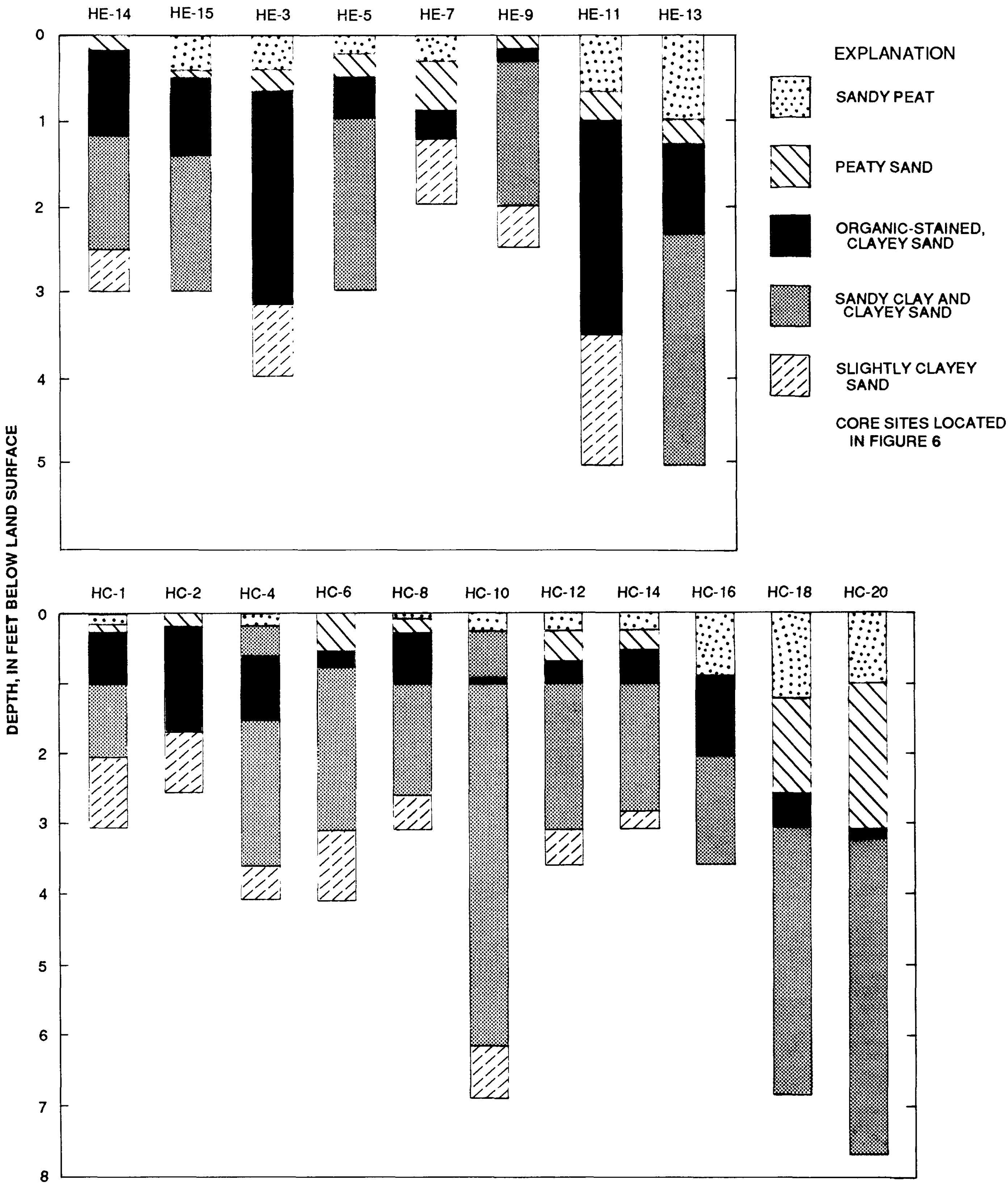

Figure 7.--Soil profile diagrams at Hobucken study marsh.

maintain water levels in the ditches at a fairly constant level. With each successive high tide, tidal water enters the ditch, mixes with the ditch water, and partially flushes the system.

DATA COLLECTION AND ANALYSIS

Data-collection networks established at each study marsh included (1) continuous tide-stage data in adjacent canals, (2) continuous stage data for surface water on the marsh, (3) continuous and periodic ground-water level data, and (4) continuous precipitation data. The following sections describe the data-collection network at each study marsh and the analytical methods used to describe the hydrologic characteristics of the marshes before and after implementation of OMWM.

Data-Collection Networks

Surface-water data collected at the West Onslow Beach study marsh consisted of continuous tide-level records collected from a gage on the eastern tidal canal (fig. 8), and continuous-stage records collected at two marsh surface-water gages, ON-SW1 and ON-SW2. Precipitation data were collected using a continuous-record rain gage. The recording interval of the tide, surface-water, and rain gages was 60 minutes. The lowest reliable stage that could be recorded at ON-SW1 and ON-SW2 was 0.85 ft (the marsh elevation at these two gages was 0.75 ft).

At the West Onslow Beach study marsh, ground-water level data were collected from 18 observation wells numbered as ON-1 to ON-18 (fig. 8). The wells were constructed to depths between 4 and 6 ft to measure the elevation of the marsh water table. Wells ON-1 through ON-12 were installed in August 1985 and form a square-shaped well network 600 ft by 600 ft (fig. 8). Wells ON-13 through ON-18 were added in March 1987 to increase the density of data points near the OMWM ditches. Wells ON-1, ON-3, ON-10, and ON-12 were equipped with analog-digital recorders set to a 60-minute recording interval. Water levels in the remaining observation wells were measured weekly or biweekly by Onslow County Mosquito Control or Public Health Pest Management Section personnel.

Surface-water data collected at the Hobucken study marsh consisted of continuous tide-level record collected from a gage on the northeastern tidal canal (fig. 9), and continuous-stage records collected at two marsh surface-water gages, PA-SW1 and PA-SW2. Precipitation data were collected using a continuous-record rain gage. The recording interval of the tide, surface-water, and rain gages was 60 minutes. The lowest reliable stage that could be recorded at PA-SW1 and PA-SW2 was 1.40 ft (the marsh elevation at these two gages was 1.35 ft).

At the Hobucken study marsh, ground-water data were collected from 12 observation wells numbered as PA-1 to PA-12 (fig. 9). The wells were constructed to depths between 4 and 7 ft to measure the elevation of the marsh water table. Wells PA-1 through PA-12 were installed in August 1984 and form a square-shaped well network about 800 ft by 800 ft. Wells PA-1, PA-3, PA-10, and PA-12 were equipped with analog-digital recorders set to a 60-minute recording interval. Water levels in the remaining wells were measured weekly or biweekly by Public Health Pest Management Section personnel.

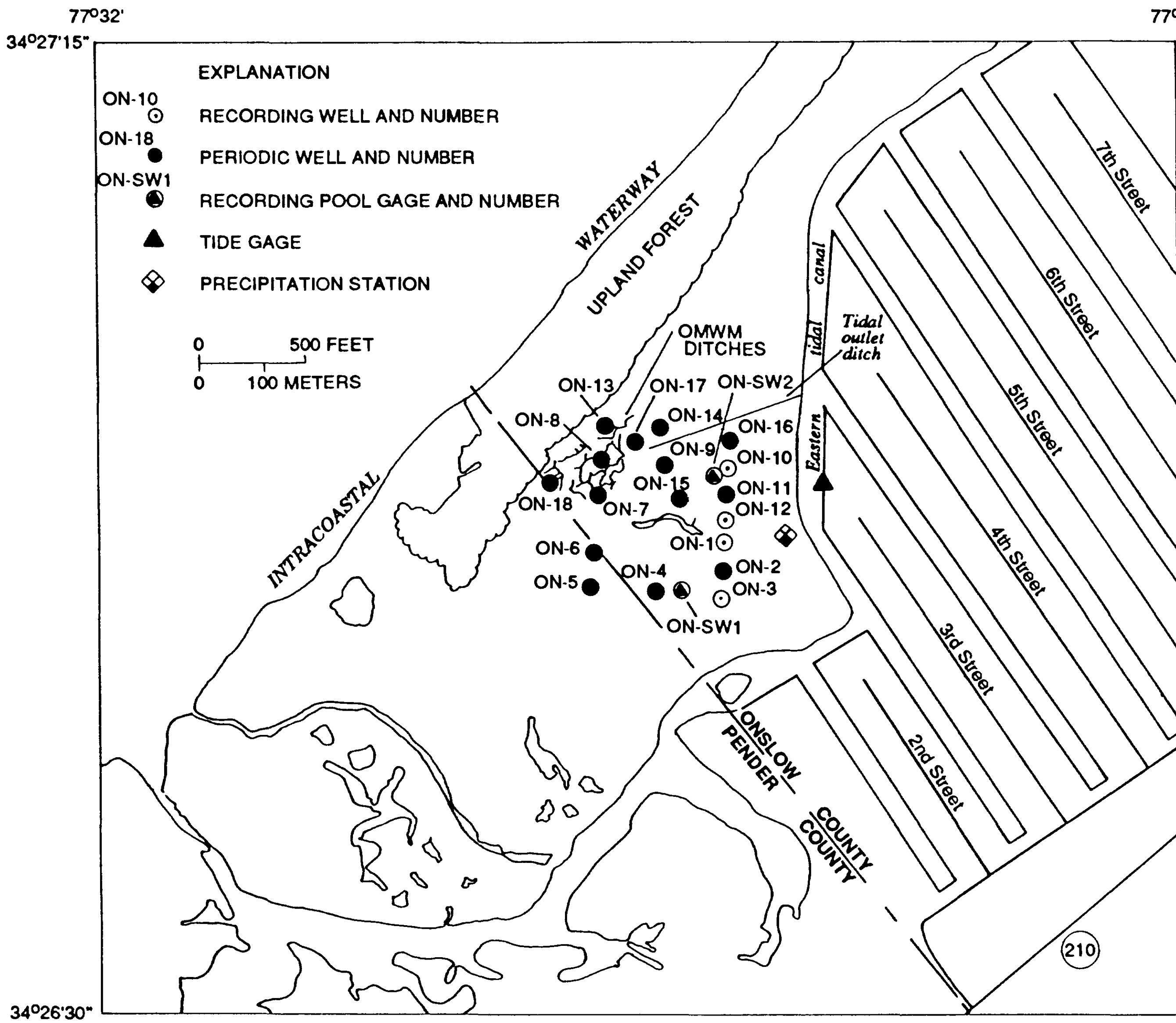

Figure 8.--Data-collection sites and open-marsh water management (OMWM) ditches at West Onslow Beach study marsh.

The data-collection networks at the study marshes were specifically designed for the OMWM systems initially proposed for the study marshes. The design of the OMWM systems was revised prior to actual construction, after most of the data collection had been completed for pre-OMWM conditions. The revised OMWM systems consisted of fewer ditches and covered less area of the marsh than the initially proposed systems. Consequently, the spatial resolution of data collected following implementation of OMWM did not allow full examination of all possible hydrologic changes resulting from OMWM, especially in areas closer than about 10 ft from the OMWM ditches.

Measuring-point elevations for the tide and surface-water gages and for the observation wells at both study sites were established by leveling when the data networks

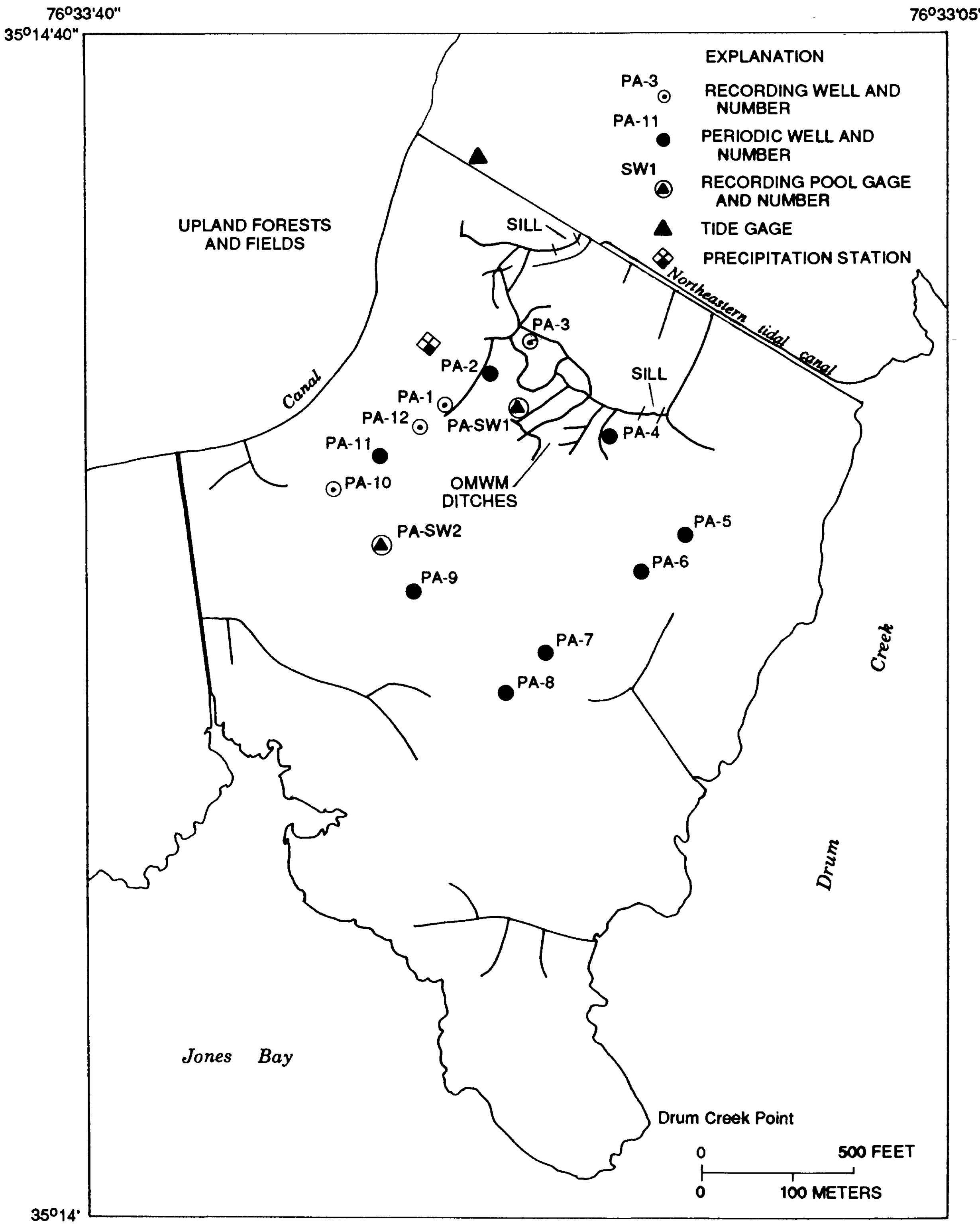

Figure 9.--Data-collection sites and open-marsh water management (OMWM) ditches at Hobucken study marsh.

were installed. These elevations were also checked by leveling when data collection was ended. Although the second leveling procedure indicated some settling of measuring points, in no case was the final measuring point elevation different from the original by more than 0.05 ft. No datum corrections were applied to any of the data.

Ground-water-level data from the recorder-equipped wells at both sites are available in the U.S. Geological Survey annual data-report series, Water-Resources Data, North Carolina (U.S. Geological Survey, 1984-90). Data for the West Onslow Beach marsh continuous-record observation wells are in the 1986-90 editions, and data for the Hobucken marsh continuous-record observation wells are in the 1984-90 editions.

Analytical Approach

The hydrology of the two study marshes is characterized in this report by description of (1) tidal conditions in canals adjacent to the study marshes, (2) surface-water conditions on the study marshes, and (3) ground-water conditions at the study marshes. Description of each of these characteristics was approached in a similar manner. First, hydrographs of the respective water levels were examined to detect any indicative patterns, unique occurrences, or obvious trends. Several hydrographs are presented in the following sections to illustrate these features. Second, descriptive statistics were computed, either mean or median, or the cumulative relative frequency of occurrence (duration analysis) of water-levels. In the case of surface-water conditions, the cumulative relative frequency of the differences between simultaneous tide and surface-water levels was computed.

HYDROLOGY OF TIDAL MARSHES

Because OMWM is intended to minimize effects on the marsh environment as a whole, the descriptions of the hydrology of the two study marshes in this report focus on the three major aspects of the large-scale hydrologic conditions of the marshes. The following sections describe tidal, surface-water, and ground-water conditions at the study sites before and after the implementation of OMWM as indicated by the data collected during the study and in terms of mechanisms identified by previous researchers.

Tidal Conditions

Tides are the result of several component gravitational forces, known as partial tides, each having a unique amplitude and period. The result of these partial tides is a tide having a period of approximately 12.5 hours from high water to high water. Superimposed upon this primary periodic cycle are lower frequency periodic variations in the amplitude of the tidal fluctuations. These variations arise as the different partial tides move alternatingly in and out of phase with each other, leading to constructive or destructive interference. The maximum tide is known as a spring tide, and the minimum tide is known as a neap tide. This cycle of spring and neap tides has a period of about 14 days. Long-period partial tides create a similar pattern of alternating interference but with a frequency on the order of several months and a variation in amplitude of about one-half foot (Giese and others, 1985, p. 4-5).

Water-level fluctuations can also be caused by the force of wind blowing over open water. The amplitude and frequency of wind-induced water-level fluctuations, commonly called wind tides, vary with wind speed and direction. The frequency and duration of wind tides depend on the frequency of occurrence and duration of prevailing winds. The magnitude of wind tides increases with wind speed and is proportional to the square root of the continuous length of open water, or fetch, that is exposed to wind. Wind tides can increase or decrease the mean elevation of water-level fluctuations, or they can interfere constructively or destructively with gravitational tides, altering the period and amplitude of water-level fluctuations.

The daily tidal range in the eastern tidal canal at the West Onslow Beach study marsh (fig. 8) is typically between 1 and 2 ft. The difference between low neap tide and high spring tide is typically between 2 and 3 ft, but it can be as much as 3.5 ft. The maximum observed tidal elevation during the study period was 2.60 ft above sea level on January 1, 1987, and the minimum observed tidal elevation was 1.63 ft below sea level on January 22, 1990.

The period of tidal fluctuations in the eastern tidal canal is approximately 0.5 day, and the period of the spring-neap tidal cycle is approximately 14 days (fig. 10). The magnitude of these two primary periods of fluctuation and the regular pattern of tidal fluctuations indicate that tidal fluctuations in this canal are primarily due to gravitational partial tides.

Heavy rains, high winds, and varying barometric pressure also contribute to water-level variations. These factors occur irregularly and are more evident in the daily mean tide-level record than in the instantaneous tide-level record (fig. 10). Prolonged winds blowing from offshore are most likely to affect water levels in the canals around the West Onslow Beach study marsh. These winds tend to elevate mean water levels and increase the amplitude of water-level fluctuations without affecting the period of these fluctuations. A more detailed description and further discussion of the factors that contribute to variation in mean tidal levels are given in Giese and others (1985).

The daily tidal range in the northeastern tidal canal at the Hobucken study marsh (fig. 9) is variable, ranging from less than 0.2 ft to as much as 1.5 ft. The water level during low neap tide is typically between 1 and 2 ft lower than during high spring tide, although the difference can be as much as 3.0 ft. The maximum observed tidal elevation during the study period was 3.60 ft above sea level on November 4, 1985, and the minimum observed tidal elevation was 0.16 ft below sea level on November 21, 1989.

The lack of a clearly discernible half-day period of fluctuation and the variability in daily tidal range indicate that wind tide is the most significant component of water-level fluctuations in the canals that border the Hobucken study site, almost always dominating the effects of gravitational tide. This is typical of areas near the Pamlico Sound, which is wide and shallow relative to its width and has limited direct connection to the open ocean (Giese and others, 1985). These factors combine to increase the amplitude of wind tides and decrease the amplitude of gravitational tides. In general, easterly winds tend to elevate water levels in the canals surrounding the Hobucken study site, and winds from the west tend to lower water levels in those canals (Giese and others, 1985). During periods of strong, sustained winds, the wind-induced component of water-level variation masks the gravitational component completely, and water levels in the canal remain elevated or reduced for periods of several days depending on the wind direction (fig. 11).

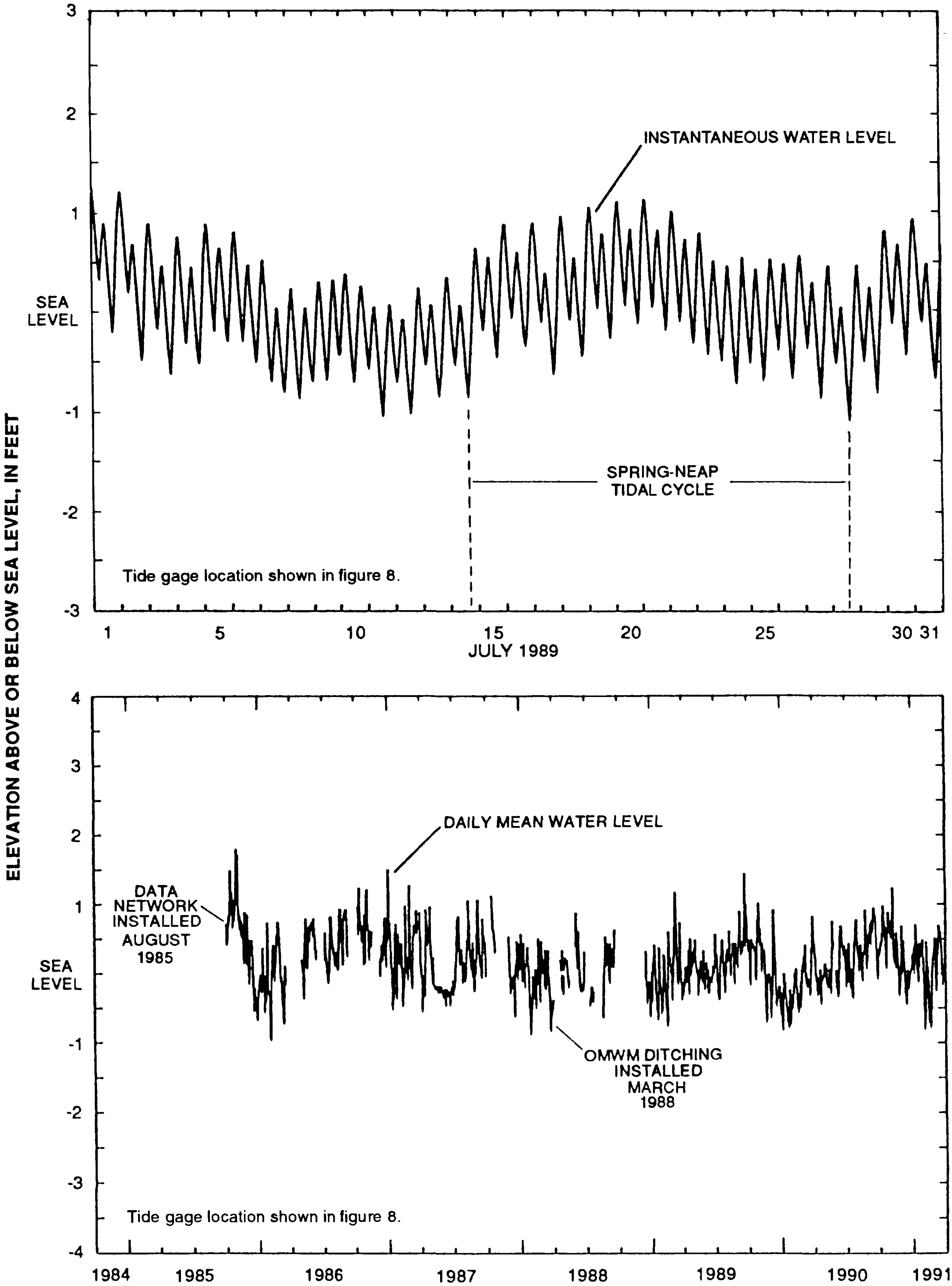

Figure 10.--Tidal levels in the eastern tidal canal at West Onslow Beach study marsh.

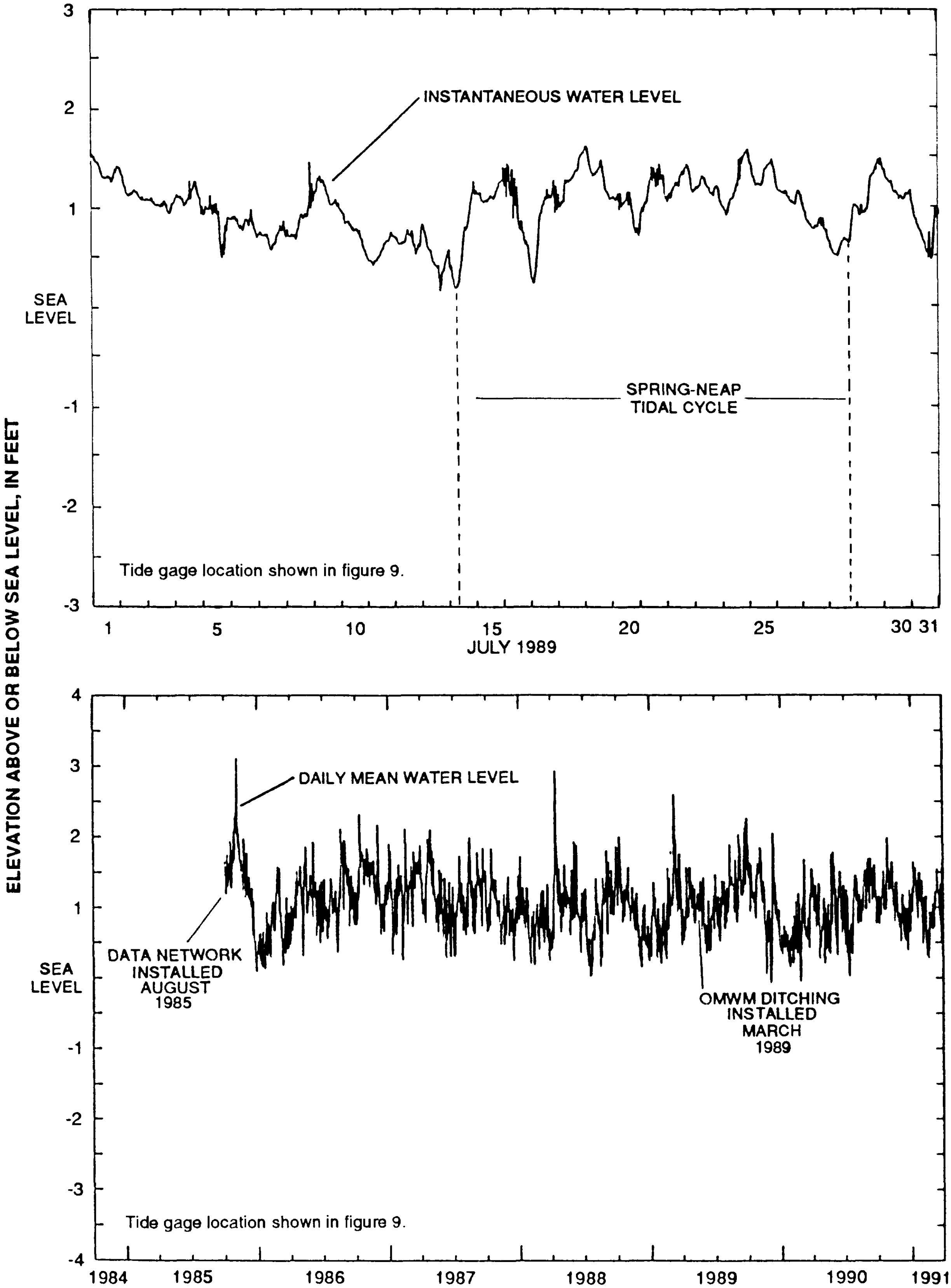

Figure 11.--Tidal levels in the northeastern tidal canal at Hobucken study marsh.

Water-level fluctuations in the canals bordering the Hobucken study marsh are less regular than those in the canals near the West Onslow Beach study marsh (figs. 10 and 11). However, a spring and neap tide cycle can be seen in instantaneous water-level record. In addition, the long-term patterns of tidal-level fluctuation at the two study marshes are similar. The effects of long-period partial tides, weather patterns, and localized storms, can be seen in the daily mean tidal levels at both sites.

Tidal conditions in the canals adjacent to the study marshes can be characterized by the cumulative relative frequency of occurrence, or duration, of tide levels within the range of fluctuations at each canal. In addition to characterizing tidal fluctuations in the canals near the study marshes, the percentage of time that tide levels exceed the elevation of the marsh surfaces indicates the potential for flooding of the study marshes. Cumulative relative frequency distributions were computed for daily mean tide levels and for daily maximum tide levels in the canals near the study marshes (figs. 12 and 13).

Daily mean tides in the eastern tidal canal adjacent to the West Onslow Beach study marsh were generally higher before OMWM was implemented than after OMWM. The median daily mean tide was 0.20 ft above sea level before OMWM and 0.08 ft above sea level after OMWM. During the period before OMWM, the daily mean tide exceeded 1.00 ft above sea level, the elevation of the upper marsh surface, less than 5 percent of the time. After OMWM, the daily mean tide was greater than 1.00 ft above sea level less than 1 percent of the time (fig. 12).

The median daily maximum tide in the eastern tidal canal was about 0.70 ft above sea level during the entire period of the study; there was no significant difference in this statistic before and after implementation of OMWM. The daily maximum tide was greater than 1.00 ft above sea level 30 percent of the time before OMWM was implemented and about 18 percent of the time after OMWM was implemented (fig. 12).

Daily mean tides in the northeastern tidal canal adjacent to the Hobucken study marsh were also higher before OMWM was implemented at that marsh than during the period after OMWM was implemented. The median daily mean tide was 1.07 ft above sea level for the period before OMWM and 1.01 ft above sea level for the period after OMWM was implemented. The daily mean tide was greater than 1.50 ft above sea level, elevation of the upper marsh surface, about 19 percent of the time during the period before OMWM and 10 percent of the time during the period after OMWM was implemented (fig. 13).

The median daily maximum tide in the northeastern tidal canal was less than 0.1 ft higher during the period before OMWM was implemented than during the period after OMWM. During the period before OMWM, the maximum daily tide was greater than 1.50 ft above sea level about 34 percent of the time. The maximum daily tide exceeded 1.50 ft above sea level about 24 percent of the time during the period after OMWM was implemented at the Hobucken study marsh (fig. 13). Natural variation in these tidal conditions is independent of OMWM.

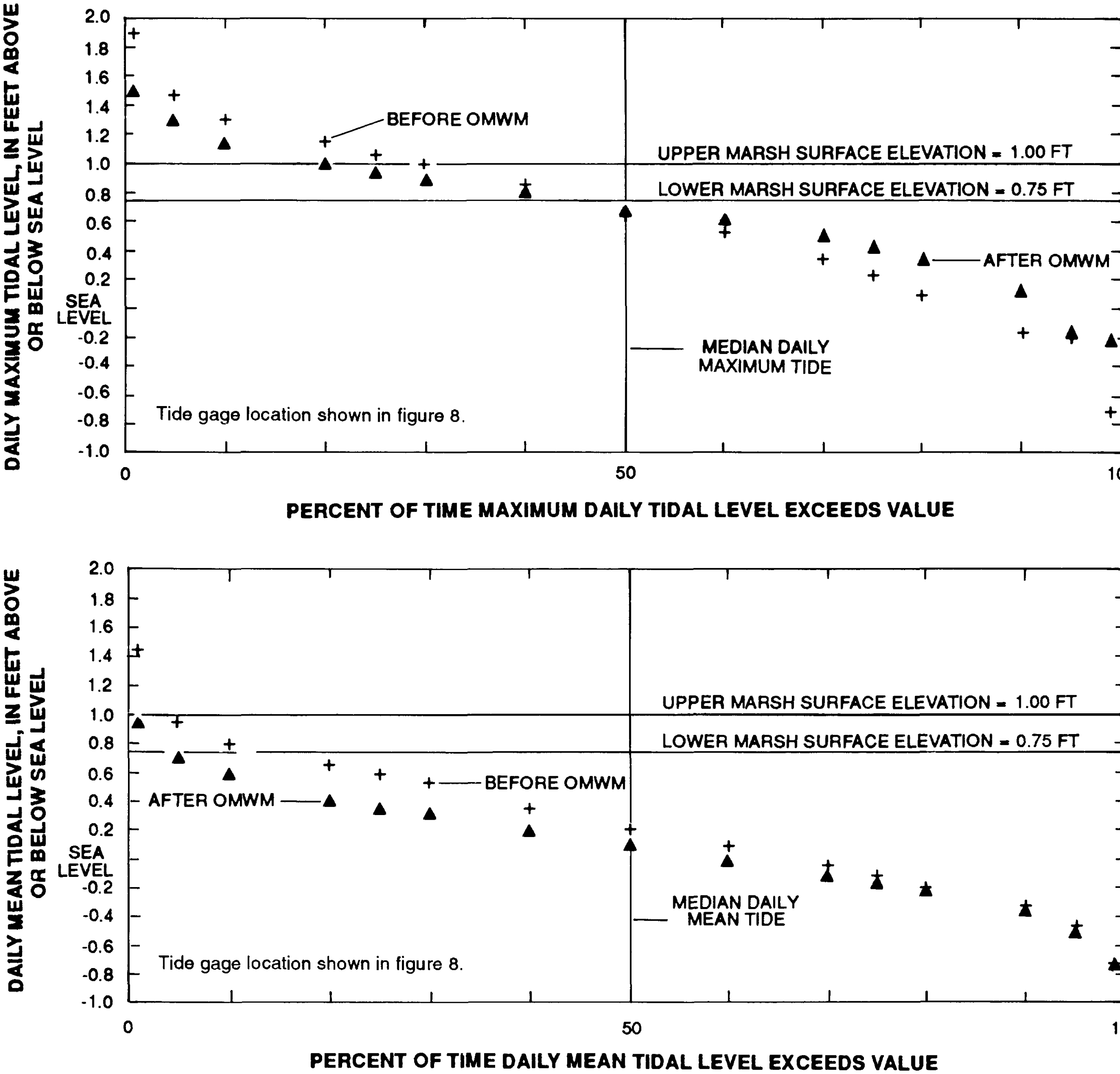

Figure 12.--Cumulative relative frequency of occurrence of daily tidal levels in the eastern tidal canal at the West Onslow Beach study marsh before and after open-marsh water management (OMWM), 1985-91.

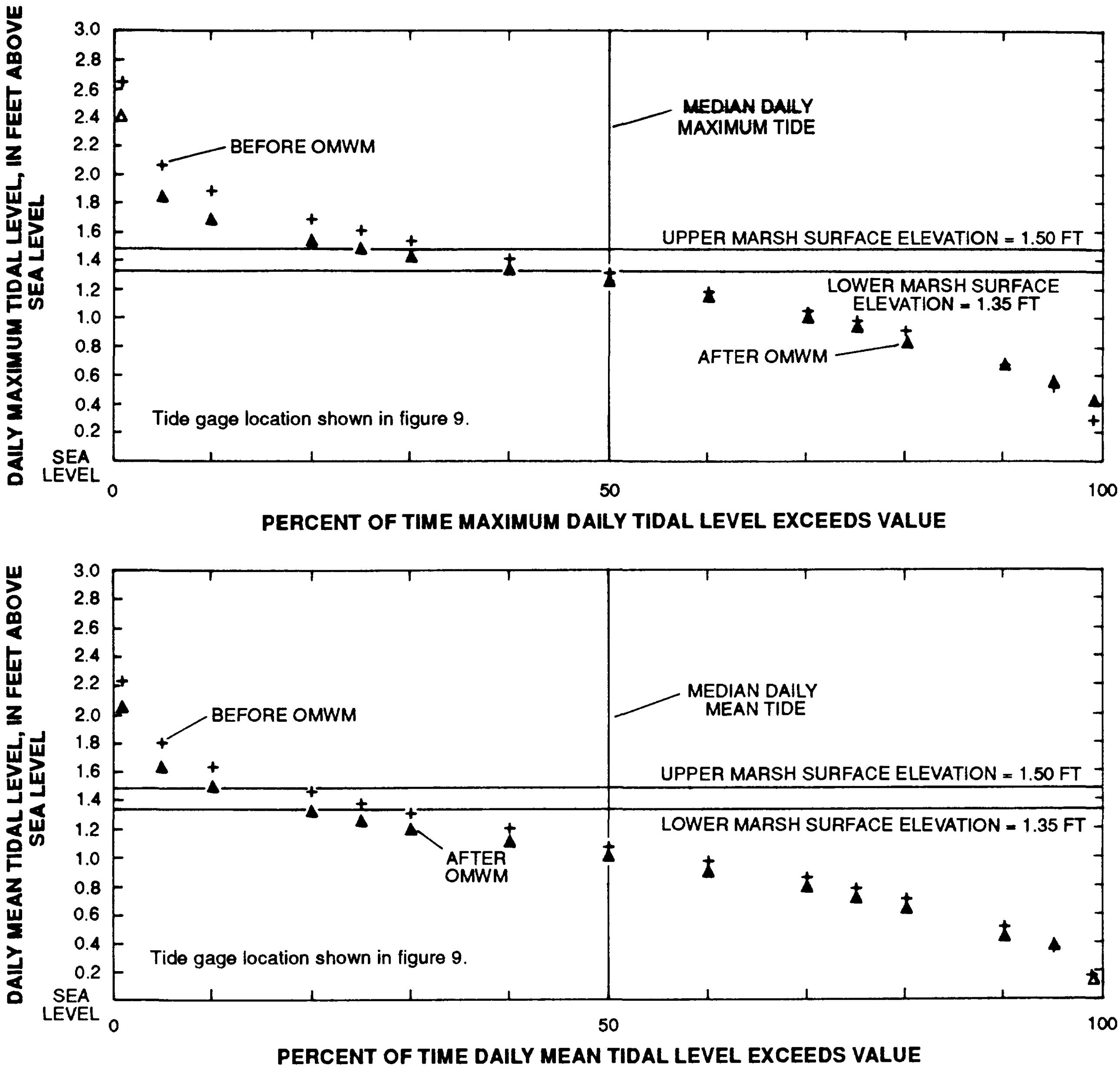

Figure 13.--Cumulative relative frequency of occurrence of daily tidal levels in the northeastern tidal canal at the Hobucken study marsh before and after open-marsh water management (OMWM), 1985-91.

Surface-Water Conditions

Rising tides are the primary source of surface water on the study marshes, although heavy rainfall can add to the depth of surface water on the marshes. Hurricanes, tropical storms, and northeastern storms combine high winds and heavy rainfall and are the cause of extremely high surface-water levels on the study marshes.

Records from the marsh surface-water gages, tide gages, and rainfall gages provide examples of extreme flooding due to the combination of high tides and rainfall. For example, during late October and early November of 1985 these conditions prevailed at both marshes (fig. 14). The West Onslow Beach study marsh was flooded to a depth of 1.25 ft, while the Hobucken study marsh was flooded to a depth of more than 2.0 ft. Similar conditions occurred again in September 1989 at the study marshes after OMWM (fig. 15), causing the West Onslow Beach site to be flooded again to a depth of about 1.25 ft, and the Hobucken site to be flooded to a depth of more than 1.75 ft.

Surface water on both study marshes varies in depth and spatial extent. The marsh surfaces have slight topographic gradient and are irregular, containing many small, shallow depressions that trap water. At both marsh sites, the surfaces are covered by thick vegetation that obstructs flow. If tidal levels do not exceed the highest surface elevation of the marsh, water movement across the marsh will be slow and may not submerge all of the marsh before tidal levels recede.

Flooding of the marsh is total submergence of the marsh by tide or rain water. Water above the highest surface elevation is removed from the marsh primarily by surface drainage. After tidal levels recede, some water will remain on the marsh surface in many small depressions, and some water will be retarded from draining by the thick vegetative cover on the marsh. Water thus retained is removed from the marsh surface by evaporation and infiltration.

Records from gage ON-SW2 at West Onslow Beach study marsh (fig. 8) and gage PA-SW1 at Hobucken study marsh (fig. 9) were used to determine the total number and duration of floods at the study marshes (table 1) before and after the implementation of OMWM. Surface-water levels that remained above the marsh surface for more than a half day were counted as a flood. Flood durations were calculated to the nearest half day.

At the West Onslow Beach study marsh, the mean number of floods per year was 24 for the period before OMWM and 21 for the period after OMWM. At the Hobucken study marsh, the mean number of floods per year was 25 for the period before OMWM and 16 for the period after OMWM. At the West Onslow Beach study marsh, the mean duration of floods was 2.6 days for the period before OMWM and 1.8 days for the period after OMWM. At the Hobucken study marsh, mean duration of floods was 3.5 days for the period before OMWM and 3.8 days for the period after OMWM.

The number of floods per year at both marshes varied over the period of the study depending on the climatic factors that influenced tidal fluctuations and the distribution of rainfall. The mean duration of floods at the Hobucken study marsh was generally longer than at the West Onslow Beach study marsh (table 1).

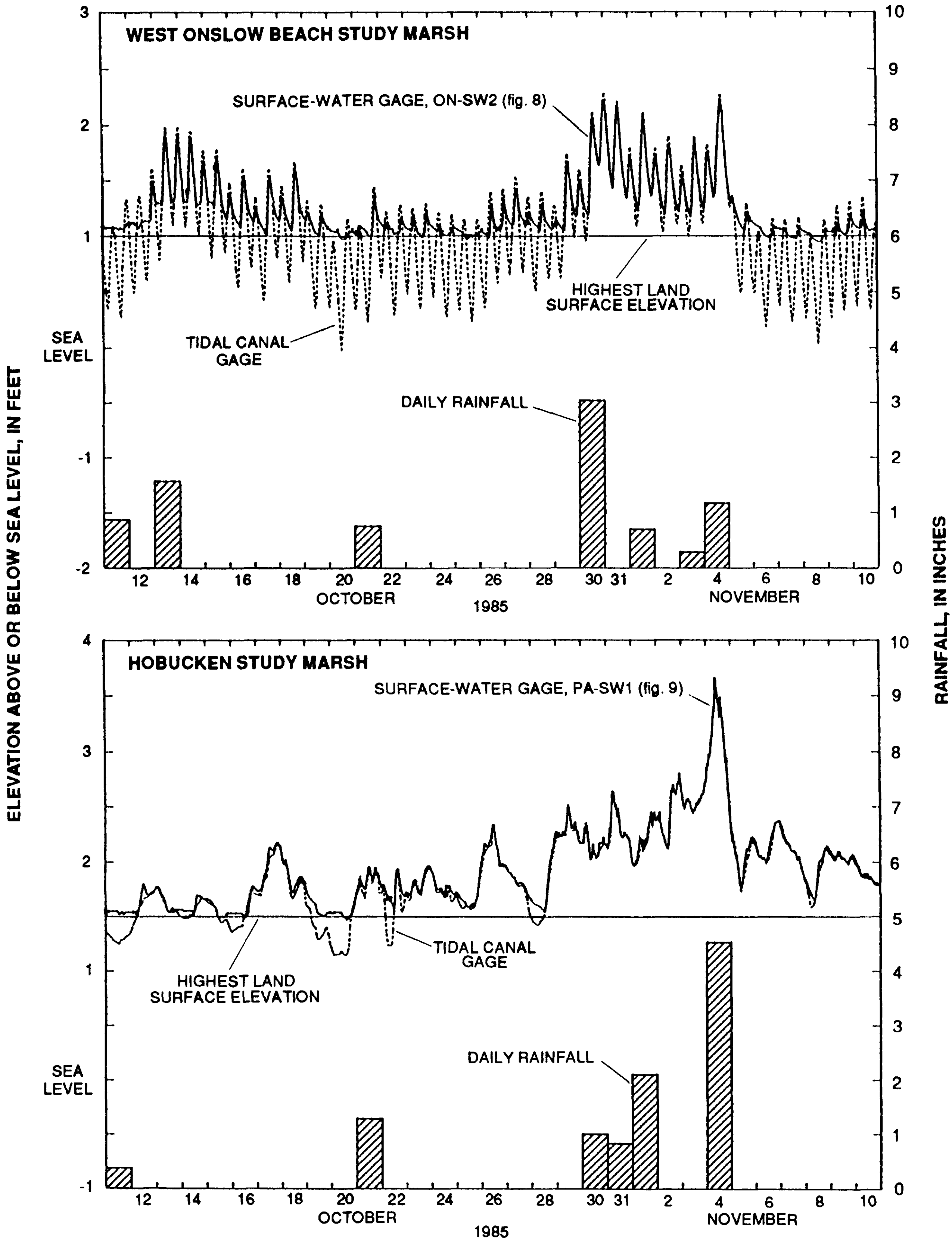

Figure 14.--Extreme flooding conditions at the study marshes before implementation of open-marsh water management, October-November 1985.

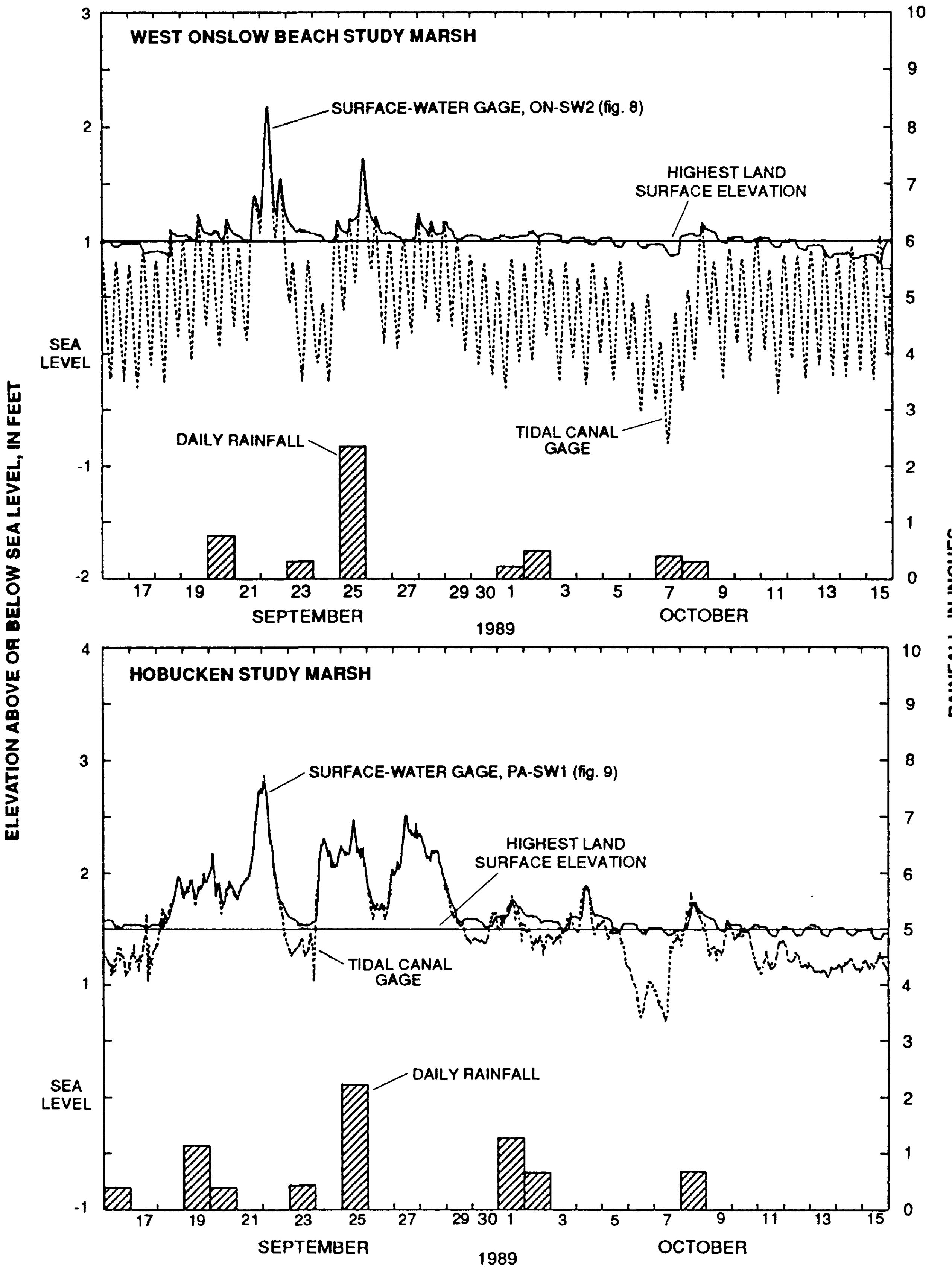

Figure 15.--Extreme flooding conditions at the study marshes after implementation of open-marsh water management, September-October 1989.

Table 1. --*Number and duration of floods before and after open-marsh water management modifications at West Onslow Beach and Hobucken study marshes, October 1985 through March 1991*

[OMWM, open-marsh water management; na, not applicable]

Before OMWM			After OMWM		
Period of record	Number of floods	Average duration (days)	Period of record	Number of floods	Average duration (days)
West Onslow Beach study marsh					
October 1985-March 1986	11	2.7	April 1988-March 1989	17	2.3
April 1986-March 1987	37	1.9	April 1989-March 1990	18	1.5
April 1987-March 1988	12	3.2	April 1990-March 1991	28	1.7
Total	60	na		63	na
Mean per year	24	2.6		21	1.8
Hobucken study march					
October 1985-March 1986	16	4.4	April 1989-March 1990	13	4.9
April 1986-March 1987	33	3.6	April 1990-March 1991	20	2.6
April 1987-March 1988	21	2.9			
April 1988-March 1989	19	3.2			
Total	89	na		33	na
Mean per year	25	3.5		16	3.8

The number and duration of floods at the study marshes are primarily dependent on tidal fluctuations in the canals adjacent to the study marshes. A measure of this relation is the difference in daily maximum tide and surface-water levels. This difference was computed at each marsh as daily maximum tide minus the daily maximum surface-water level. Only days were computed when the daily maximum tide and the daily maximum surface-water levels were above the threshold elevation for each marsh. The cumulative relative frequency distribution, or duration curve, of these differences was then determined (figs. 16 and 17).

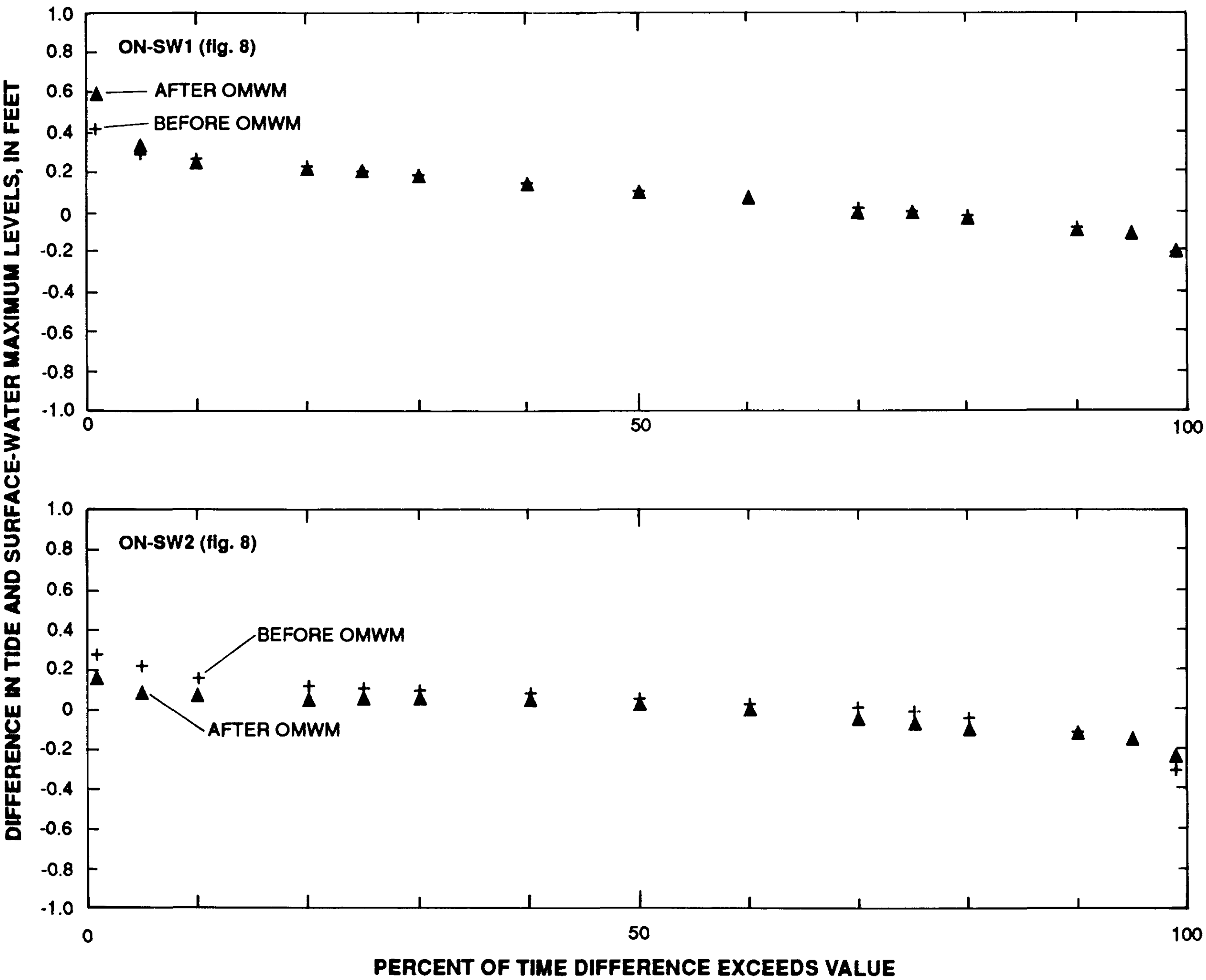

Figure 16.--Cumulative relative frequency of differences between maximum tide and surface-water levels at the West Onslow Beach study marsh before and after open-marsh water management (OMWM), 1985-91.

At the West Onslow Beach study marsh, the duration curves of differences between daily maximum tide and daily maximum surface-water level at ON-SW1 are nearly identical for the periods before and after OMWM was implemented. At ON-SW2, however, the duration curves differ slightly (fig. 16). This difference, although slight, may be due to the construction of the semi-tidal outlet ditch near the OMWM system of ditches. This cannot be positively determined without further investigation of the drainage patterns on this marsh.

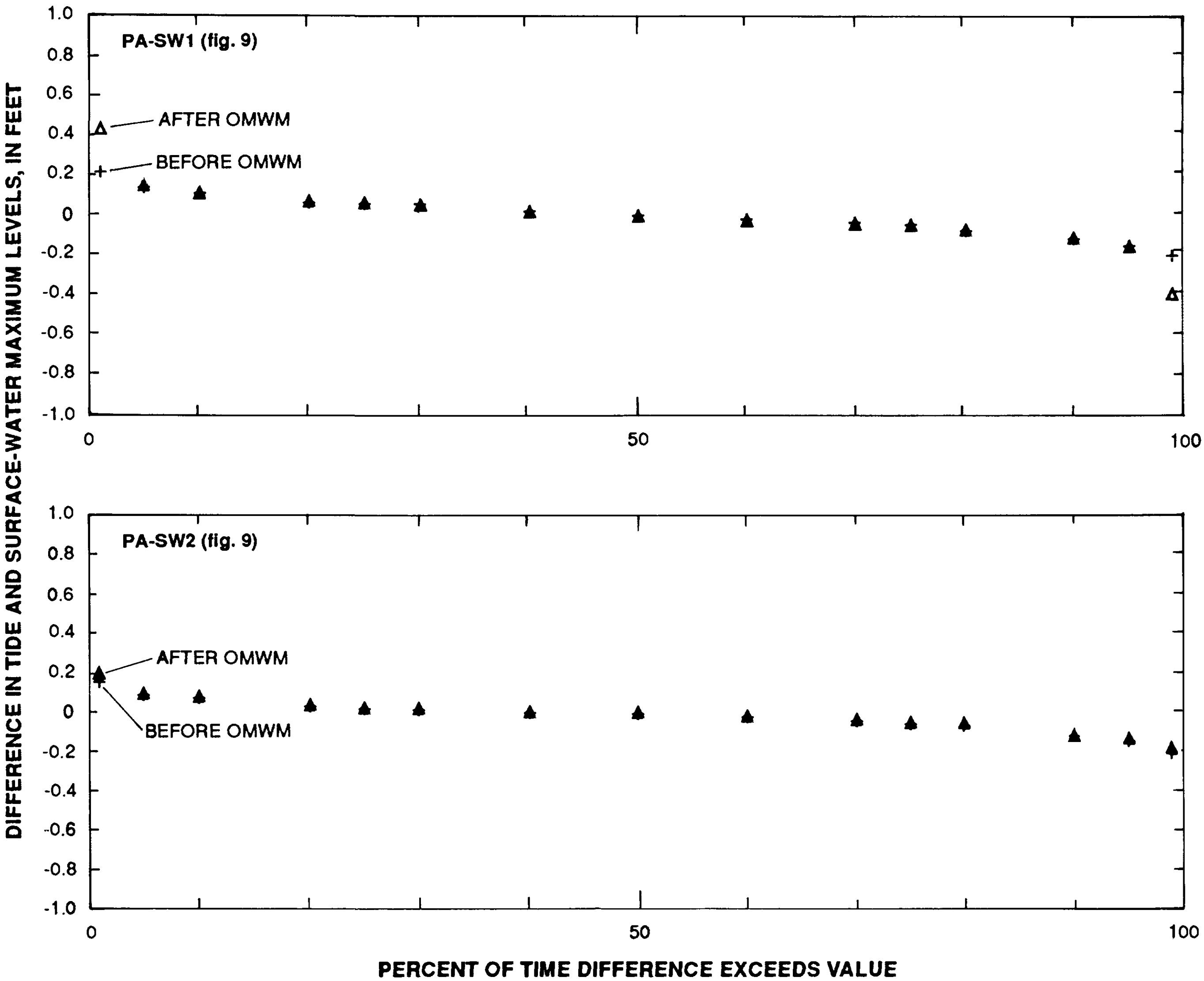

Figure 17.--Cumulative relative frequency of differences between maximum tide and surface-water levels at the Hobucken study marsh before and after open-marsh water management (OMWM), 1985-91.

At the Hobucken study marsh, the duration curves of the differences between maximum daily tide and surface-water levels are nearly identical at both PA-SW1 and PA-SW2 (fig. 17). These results and that at West Onslow Beach ON-SW1 indicate that although surface-water conditions varied during the study at both study marshes, the relation between maximum tide and surface-water levels did not.

Ground-Water Conditions

Recharge to ground water at the study marshes occurs throughout the year primarily by infiltration during periods of inundation, flooding, and precipitation. Discharge from ground water is primarily by evapotranspiration and root uptake by marsh vegetation, which are at a maximum during the growing season. For the purposes of this study, the growing season is defined as the period between the last spring freeze and the first fall freeze. Temperature data from nearby National Oceanic and Atmospheric Administration weather stations were used to determine beginning and ending dates for each year's growing season (National Oceanic and Atmospheric Administration, 1985-91).

Hydrographs of water levels in the observation wells at each study marsh show the general seasonal pattern of ground-water declines during the growing seasons and more frequent periods of saturated conditions during the nongrowing seasons (fig. 18). Inundations and floods, indicated by water-levels greater than marsh-surface elevation, occur throughout the year. Ground-water declines during the growing season are attributed to evapotranspiration and root uptake by marsh vegetation. During the nongrowing season, evapotranspiration is minimal, and saturated conditions often prevail with ground-water levels at or close to marsh surface between frequent inundations and floods. The lack of significant ground-water declines during the nongrowing season confirms that evapotranspiration is the major ground-water discharge mechanism operating in the marshes. However, ground-water declines occur during the nongrowing season (fig. 18) probably as a result of short periods of warm temperatures during winter that cause significant evaporation and stimulate growth in some perennial marsh vegetation.

During the growing season, ground-water levels decline continuously until the marsh surface is inundated again and recharge by infiltration occurs. Diurnal tidal fluctuations do not appreciably influence the rate of ground-water-level decline (figs. 19 and 20), which is an indication of the absence of significant horizontal ground-water flow in the marsh system.

Ground-water response to recharge is rapid (figs. 19 and 20). Infiltration begins as soon as water is available at the marsh surface and continues until the soil is saturated or until the available water is exhausted. When the ground-water level reaches marsh surface, the soil is by definition saturated, and additional infiltration is limited by the rate of ground-water discharge by evapotranspiration and root uptake.

Data collected at both marshes during this study indicate results similar to those of other researchers who have studied aspects of the hydrology of tidal marshes. Harvey and others (1987) determined that significant horizontal ground-water flow in a marsh in response to tidal fluctuations is limited to within approximately 15 meters of the creek or canal bank. Hemond and Fifield (1982) modeled flow patterns in the interior of an extensive marsh and determined that vertical movement is the dominant mechanism of ground-water movement in the marsh interior beyond the limit of the creek-bank effect. Similar conclusions were reached by Yelverton and Hackney (1986) in their study of ground-water flow in a tidal marsh on the North Carolina coast. Dacey and Howes (1984) showed that evapotranspiration and root uptake are the dominant mechanism for ground-water withdrawals on tidal marshes in South Carolina and Massachusetts.

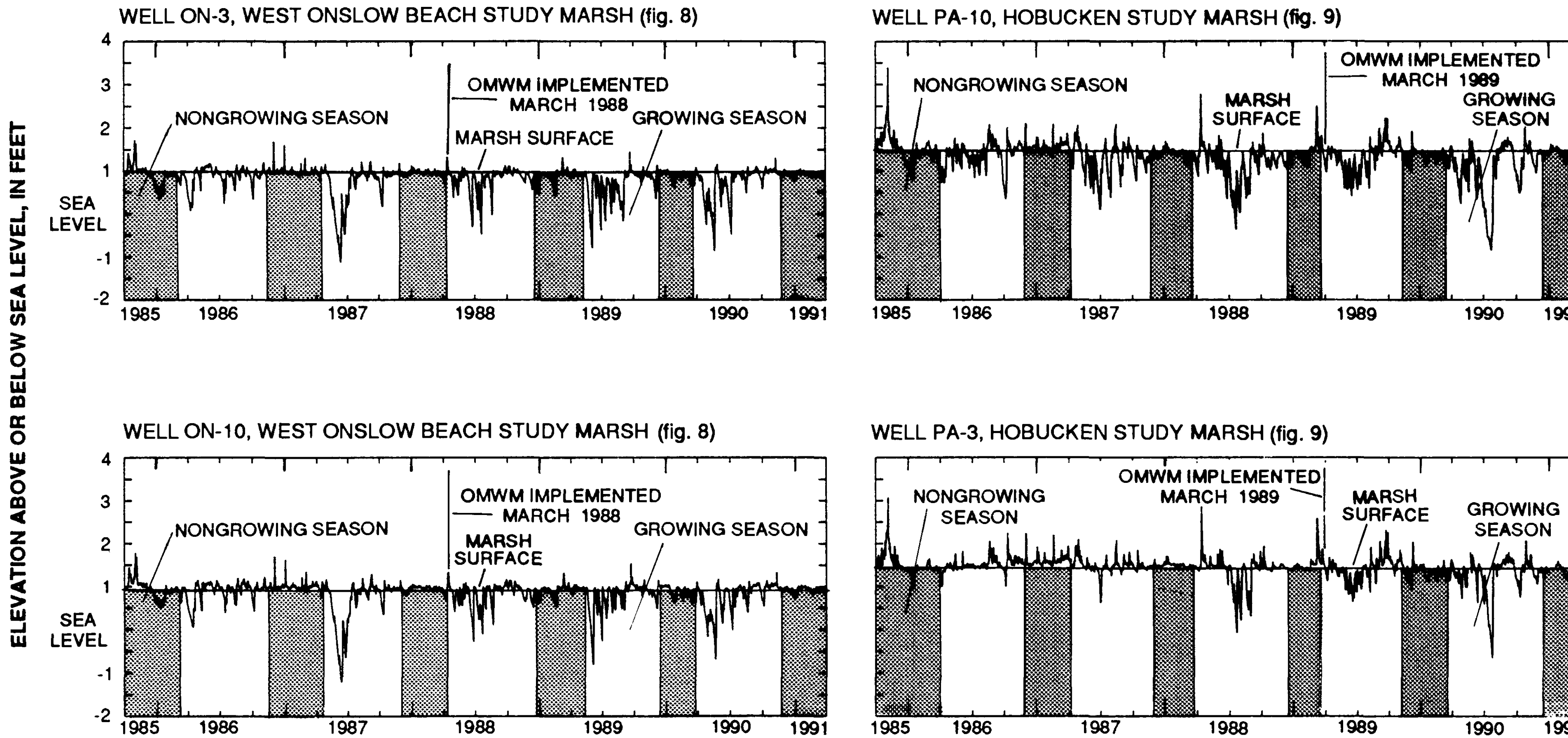

Figure 18.--Daily mean water levels in selected recording observation wells at West Onslow Beach and Hobucken study marshes.

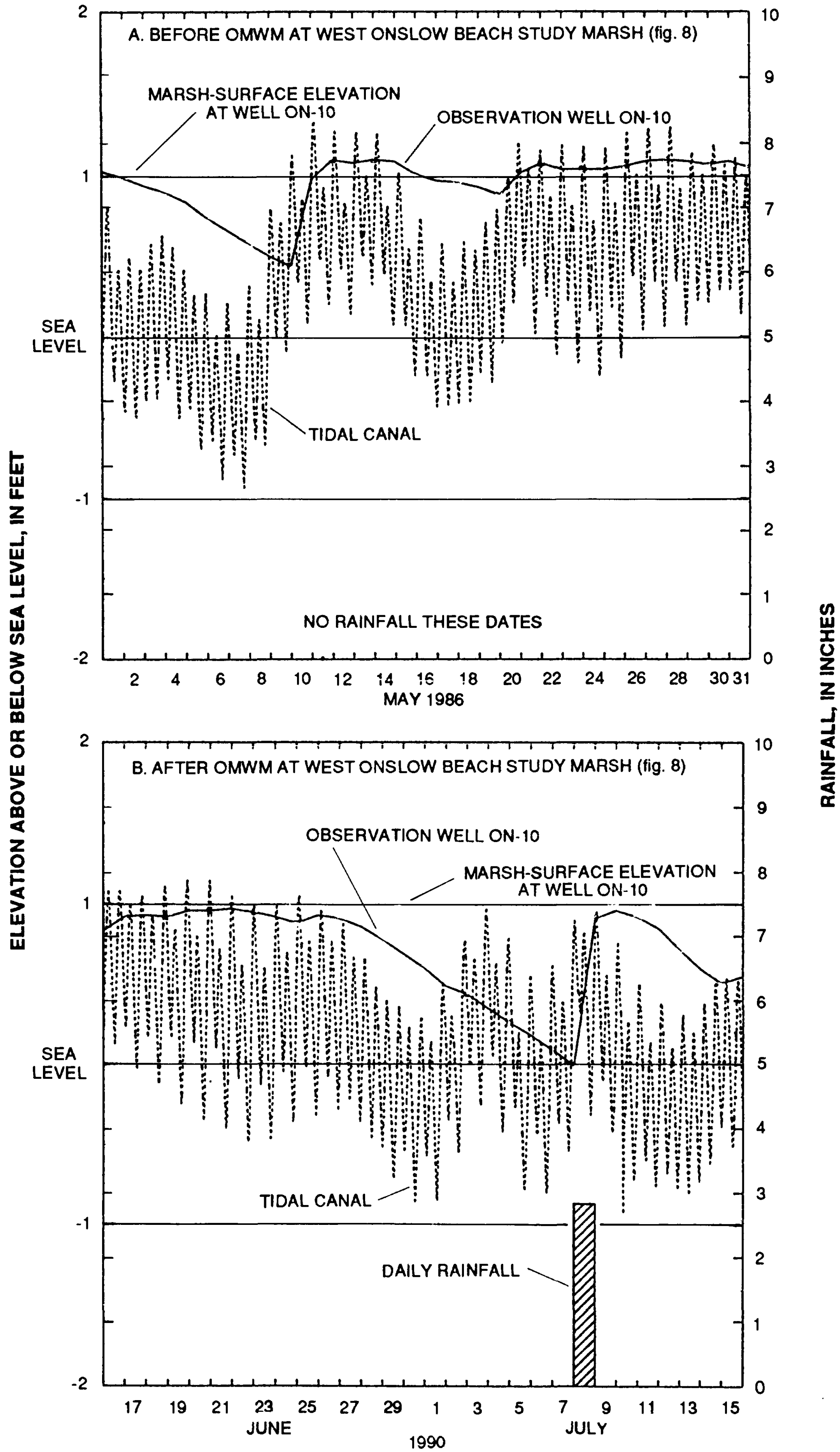

Figure 19.--Response of ground-water levels to recharge by tides and rainfall at West Onslow Beach study marsh (A) before and (B) after open-marsh water management (OMWM) modifications.

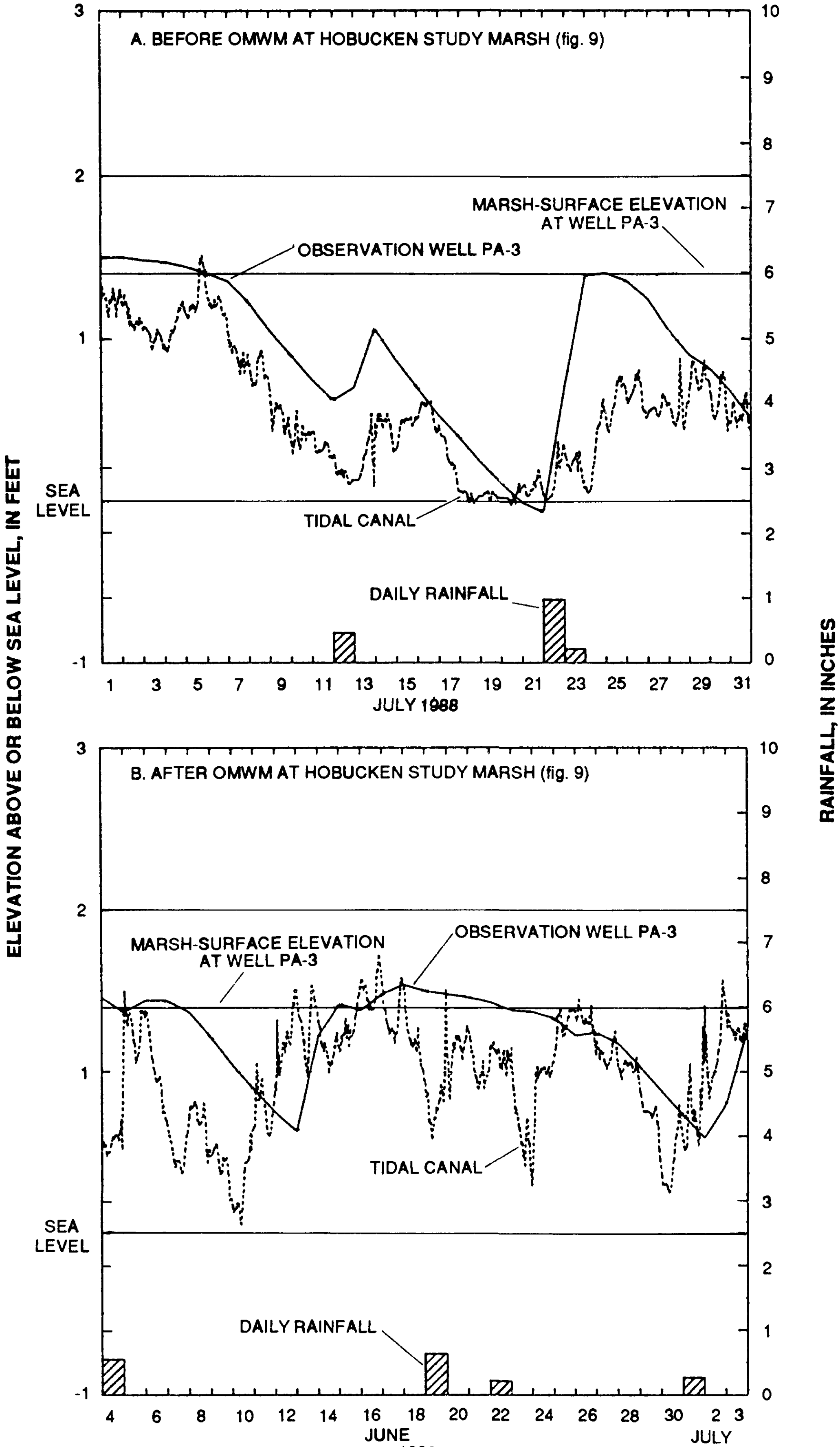

Figure 20.--Response of ground-water levels to recharge by tides and rainfall at Hobucken study marsh (A) before and (B) after open-marsh water management (OMWM) modifications.

Except for declines observed during the growing season, ground-water levels at both study marshes were typically at or near marsh surface during the study period. At the West Onslow Beach study marsh, the ground-water level declined as much as 1.27 ft below sea level in well ON-10. At the Hobucken study marsh, the ground-water level was as low as 1.80 ft below sea level in well PA-11. Water levels equal to or greater than the marsh-surface elevation occurred as much as 70 percent of the time in wells at the West Onslow Beach study marsh and as much as 80 percent of the time in the Hobucken study marsh wells (figs. 21 and 22).

Cumulative relative frequency distributions of daily mean ground-water levels are similar before and after the implementation of OMWM at both study marshes (figs. 21 and 22). In general, these cumulative frequency distributions indicate that low ground-water levels occurred slightly more frequently after OMWM was implemented than before.

Simultaneous ground-water-level measurements during growing periods before and after implementation of OMWM modifications at both study marshes indicate that ground-water gradients were less than 0.10 inch per foot between wells. At the West Onslow Beach study marsh, pre- and post-OMWM water-level profiles show similar ground-water gradients across the marsh; the profiles are virtually flat with little variation in gradient between wells (fig. 23). For the Hobucken study marsh, profiles show slightly greater variations of gradient between wells (fig. 24), likely caused by greater local variations in recharge and discharge conditions at the wells. Overall, these small head gradients confirm that there is little horizontal ground-water flow at the study marshes and that vertical flow dominates in response to recharge and discharge.

Any effect of the OMWM ditching would be seen in water-level responses in wells closest to the ditches (Harvey and others, 1987). At the West Onslow Beach study marsh, wells ON-7 and ON-8 are approximately 10 ft from OMWM ditches (fig. 8), but ground-water-level profiles for conditions before and after OMWM show no apparent change in water levels in these wells relative to water levels in other wells on that marsh (fig. 23). At the Hobucken study marsh, however, water-level profiles indicate a slight lowering of water levels only in well PA-3 after OMWM (fig. 24). Wells PA-1 and PA3 are about 10 ft from OMWM ditches.

Cumulative relative frequency distributions of differences between daily mean water levels in wells PA-1, PA-3, and PA-10 were computed as an additional test of possible influence of the OMWM modifications on ground-water levels. Well PA-10 is more than 200 ft from the nearest OMWM ditch, and its water levels should not be influenced by the ditching. These distributions indicate a reduced frequency of occurrence of negative differences between water levels in wells PA-1 and PA-10 and water levels in well PA-3 for the period after OMWM (fig. 25). The cumulative frequency distribution of the differences between water-levels in well PA-10 and water levels in well PA-1, however, did not change after OMWM was implemented (fig. 25) indicating that relative changes in ground-water levels are limited to the area between well PA-1 and PA-3. Additional data and study are needed to quantify these changes further and to determine if these changes can be attributed to OMWM modifications or to variations in the recharge and discharge conditions near the wells.

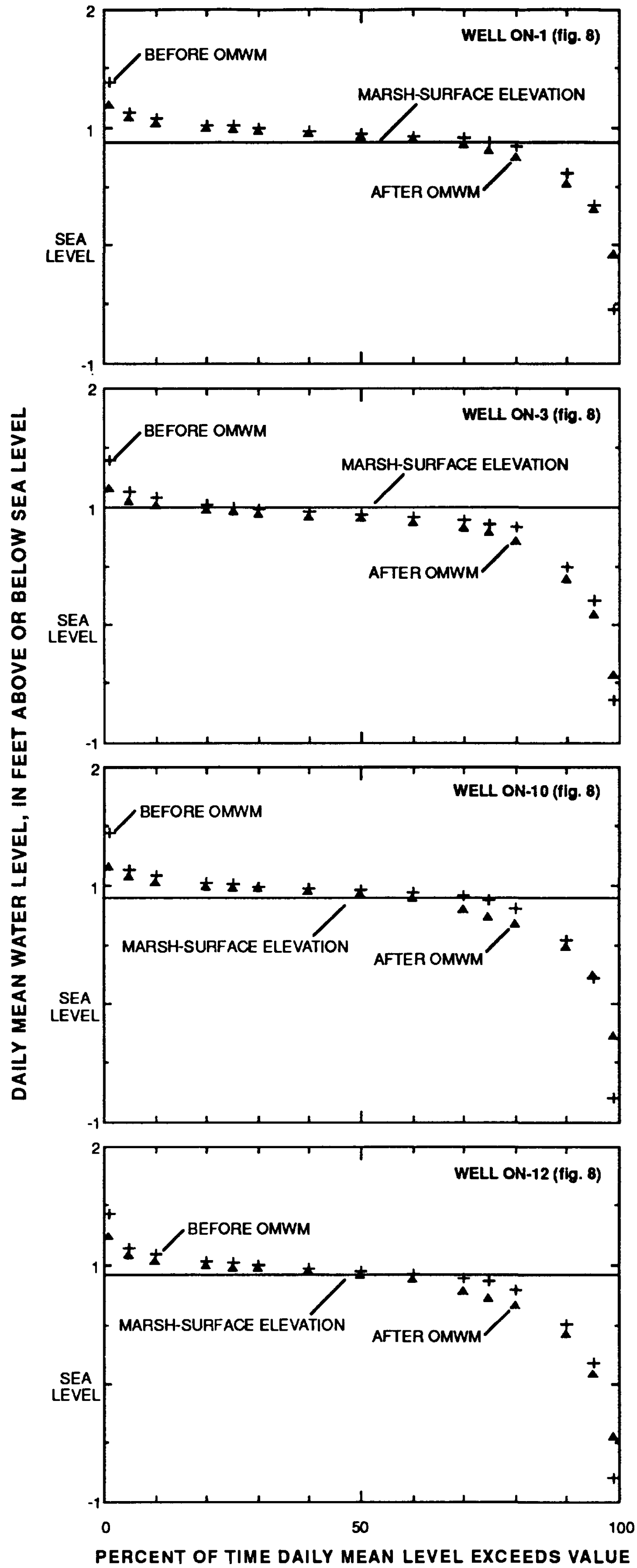

Figure 21.--Cumulative relative frequency of occurrence of water levels in recording observation wells at West Onslow Beach study marsh before and after open-marsh water management (OMWM), 1985-91.

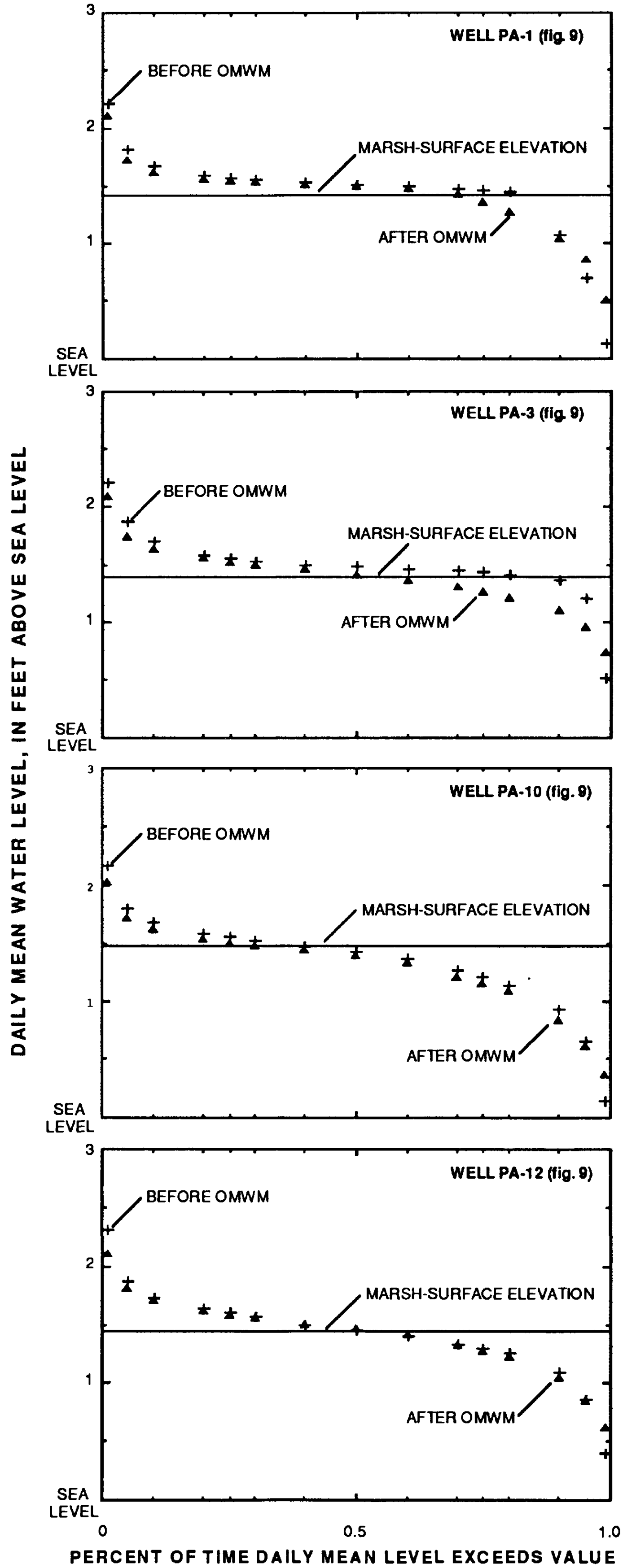

Figure 22.--Cumulative relative frequency of occurrence of water levels in recording observation wells at Hobucken study marsh before and after open-marsh water management (OMWM), 1985-91.

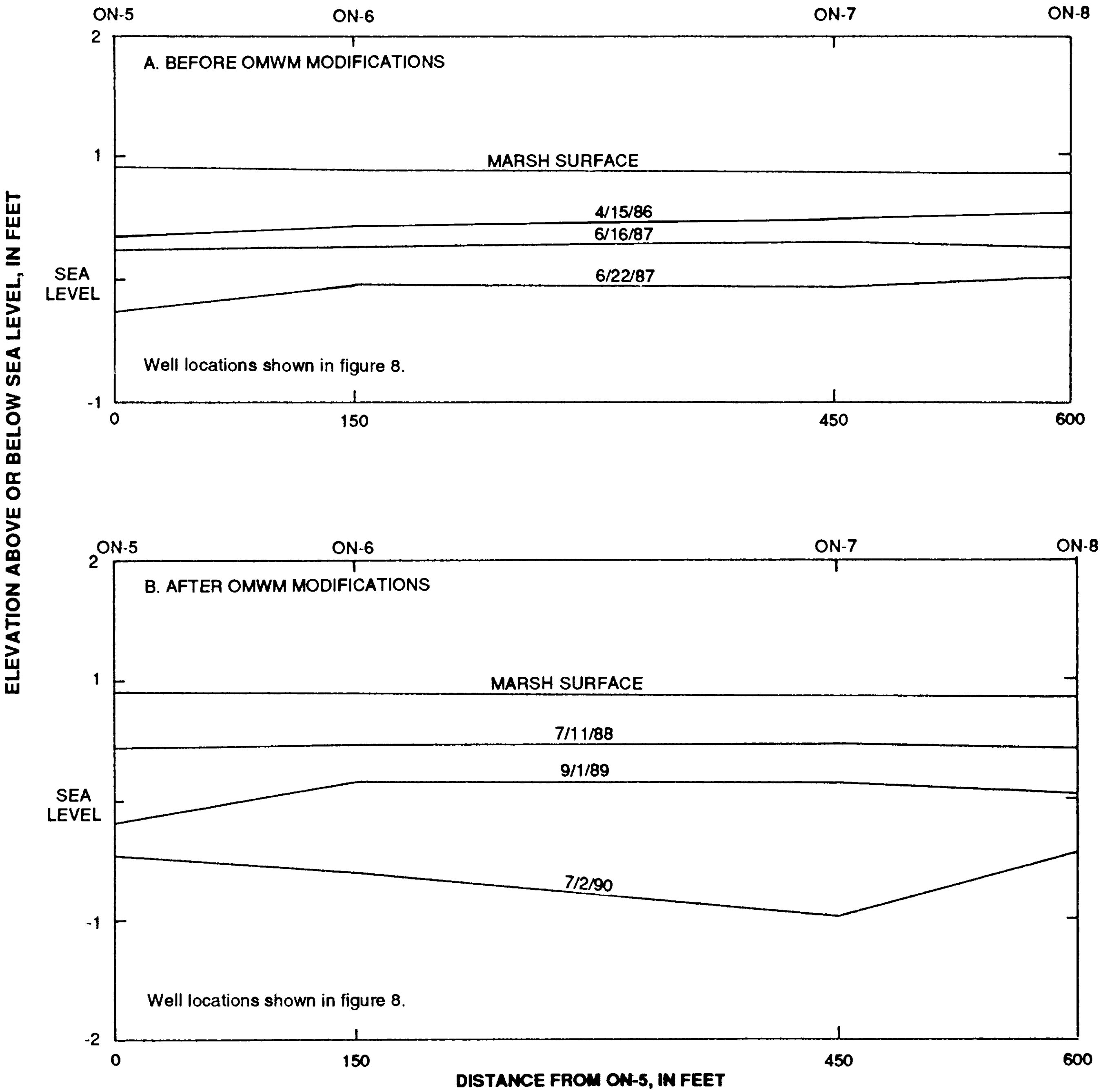

Figure 23.--Water-level profiles at West Onslow Beach study marsh during selected growing periods (A) before and (B) after open-marsh water management (OMWM) modifications.

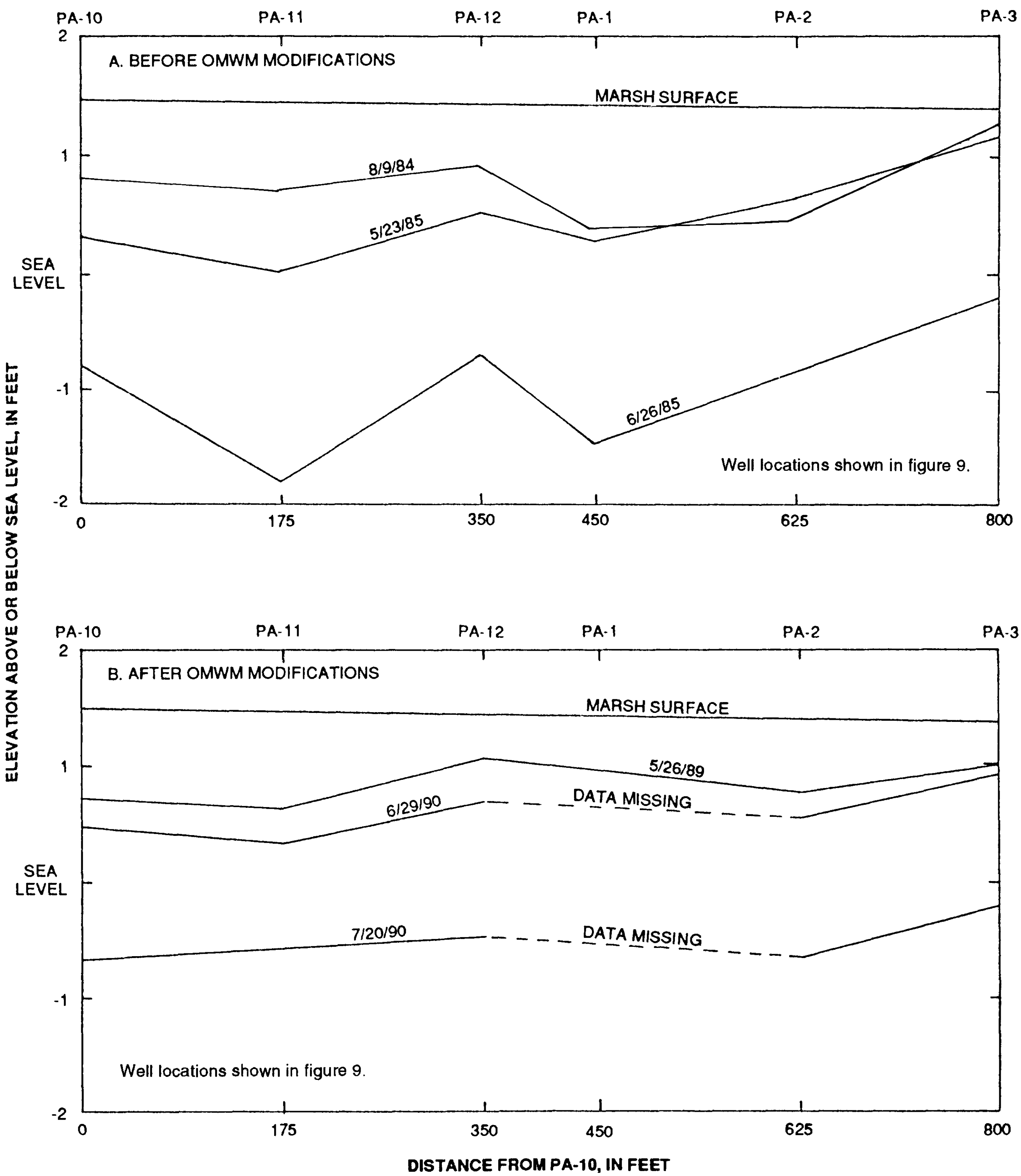

Figure 24.--Water-level profiles at Hobucken study marsh during selected growing periods (A) before and (B) after open-marsh water management (OMWM) modifications.

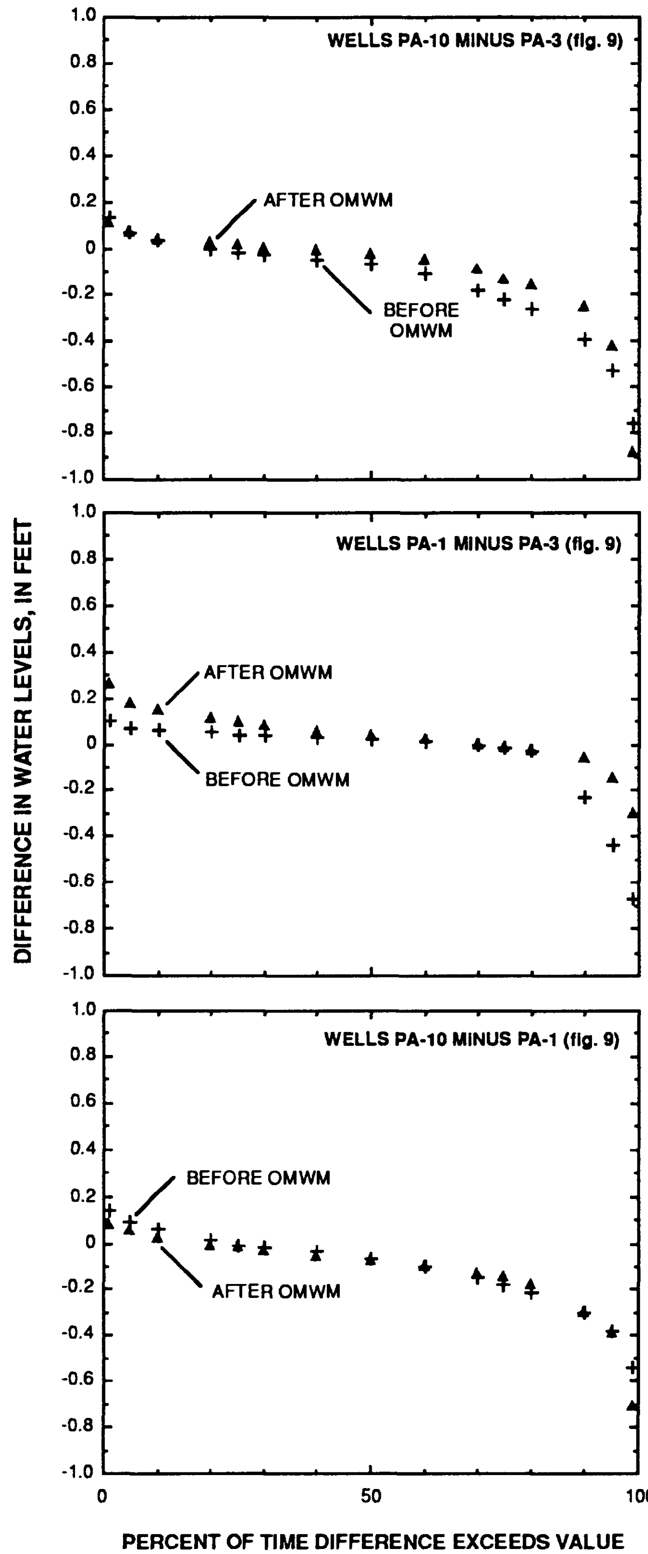

Figure 25.--Cumulative relative frequency distributions of differences in observation well water levels for conditions before and after open-marsh water management (OMWM) at the Hobucken study marsh, 1985-91.

SUMMARY AND CONCLUSIONS

In March 1988 and March 1989, open-marsh water management (OMWM) was implemented on a tidal marsh near West Onslow Beach and a tidal marsh near Hobucken, North Carolina. The purpose of OMWM was to alter the marsh environment to make it less suitable for mosquito production without significantly altering the hydrology and other functions of the marsh.

The West Onslow Beach study marsh covers about 45 acres on the shoreward side of a barrier island and is bordered by tidal canals and the Intracoastal Waterway. The upper marsh-surface elevation is about 1 ft above sea level. At this marsh, a closed system of OMWM ditches was constructed along with a single semi-tidal outlet that is not part of the main OMWM system. The Hobucken study marsh borders Jones Bay and Drum Creek, along the western Pamlico Sound estuary, and is about 100 acres in extent. The upper marsh surface is about 1.5 ft above sea level. At the Hobucken marsh, a semi-open OMWM system of ditches was installed with shallow sill connections to tidal canals.

Tidal, surface-water, ground-water, and precipitation data were collected at 38 sites at these study marshes from August 1985 through March 1991. The data were used to characterize the hydrology of the marshes before and after OMWM practices were implemented.

Water-level fluctuations in the canals surrounding the West Onslow Beach study marsh are caused primarily by gravitational tides. During the study period, tidal levels ranged between 2.60 ft above sea level and 1.63 ft below sea level. Typical daily tidal range was between 1 and 2 ft. In the canals surrounding the Hobucken study marsh, water-level fluctuations are dominated by wind tides. During the study period, tidal levels ranged between 3.60 ft above sea level and 0.16 ft below sea level. The daily tidal range at the Hobucken marsh is dependent on wind speed and direction and typically was less than 0.2 to more than 1.5 ft during the study.

Duration analysis of tidal levels at the study marshes indicate that daily maximum tides greater than the elevation of the upper marsh surface at the West Onslow Beach study marsh occurred about 30 percent of the time before OMWM was implemented and about 18 percent of the time after OMWM. At the Hobucken study marsh, analyses indicated daily maximum tides exceeded the upper marsh surface 34 percent of the time before and 24 percent of the time after OMWM was implemented. Natural variation in tidal conditions is independent of OMWM.

Surface water on the study marshes is characterized as inundations or floods, depending on whether the marsh is partly or completely submerged by rising tide and(or) rainfall. At the West Onslow Beach study marsh, the mean number of floods per year and their mean duration were 24 and 2.6 days, respectively, before OMWM; after OMWM the respective mean values were 21 and 1.8 days. At the Hobucken study marsh, the mean number of floods per year and mean duration of flooding were 25 and 3.5 days before OMWM and 16 and 3.8 days after implementation of OMWM. Inundation and flooding of the West Onslow Beach study marsh occurs more regularly and is generally of shorter duration than at the Hobucken study marsh. Natural variation in tidal patterns resulted in similar variations in number and duration of inundations at both marshes. Analysis of the differences between daily maximum tides and daily maximum surface-water levels indicate that although surface-water conditions varied at both study marshes, the relation between maximum tide and surface-water levels did not vary.

Recharge to ground water in the study marshes occurs primarily by infiltration of surface water and precipitation. Discharge of ground water is primarily through evapotranspiration and root uptake by marsh vegetation. Recharge takes place, or the potential for recharge is present, throughout the year, but discharge is at a maximum during the growing season. The primary response to recharge and discharge is through the vertical flow of ground water.

During the study period, ground-water levels ranged from the marsh surface to 1.27 ft below sea level at the West Onslow Beach study marsh and from the marsh surface to 1.80 ft below sea level at the Hobucken marsh. Water levels in observation wells were equal to or greater than the marsh surface 70 percent of the time at the West Onslow Beach study marsh and 80 percent of the time at the Hobucken study marsh.

Selected profiles of ground-water levels during growing seasons indicated that gradients between wells were no more than 0.10 inch per foot during the study. At the West Onslow Beach study marsh, profiles showed no changes in relative elevations of ground-water levels between wells after implementation of OMWM. However, after OMWM at the Hobucken marsh, a slight lowering of water levels was observed in one well about 10 ft from an OMWM ditch. This was confirmed by duration analysis of differences in daily mean ground-water levels among several wells at the site. Further investigation is needed to quantify this change and to determine if it can be attributed to OMWM or if it is largely due to variation in recharge and discharge conditions near the well in question.

The hydrology of the tidal marshes near West Onslow Beach and Hobucken is complex and involves interactions between tidal levels, surface water on the marsh, and ground water. All of these components vary naturally; therefore, the net effect of the interaction between them is one of constant flux. In this environment, the relatively shallow ditches that were installed to implement OMWM create only localized disturbances in the ground-water levels in the marshes and only slight changes in tidal flow into the marshes, which are dominated by natural variations.

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