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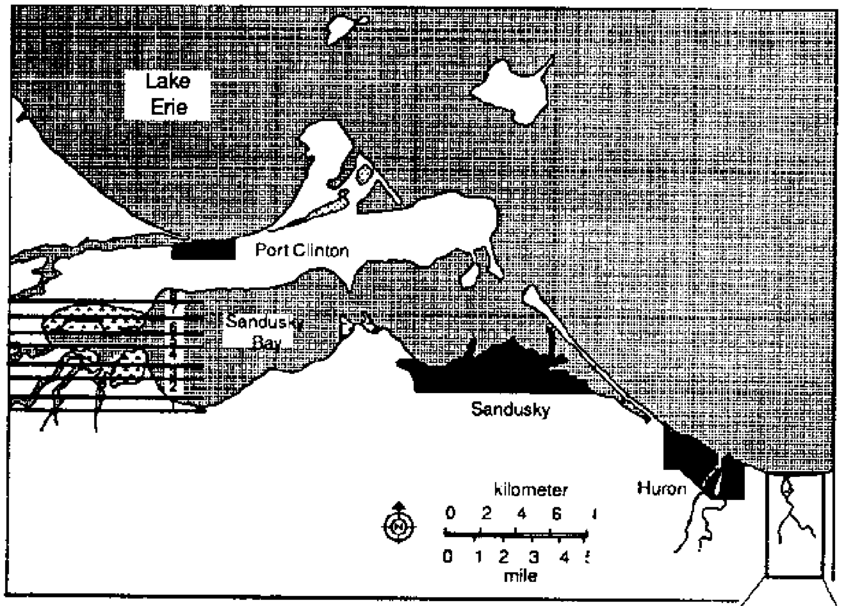
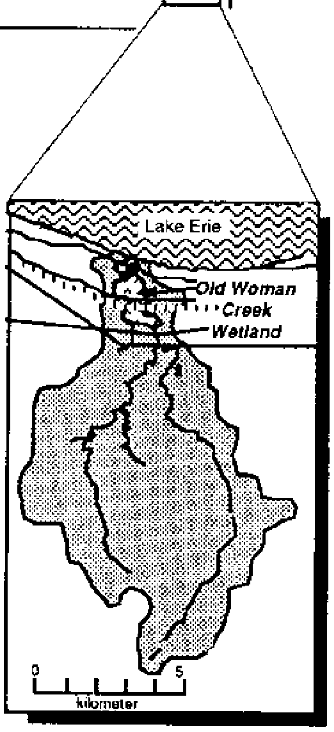
WETLANDS OF OHIO'S COASTAL LAKE ERIE

A Hierarchy of Systems





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October 1989

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Contents

Executive Summary

This technical report presents results of research on ecosystem-level and regional-level studies of the coastal wetlands of western Lake Erie in Ohio. Those studies are presented with several scales of spatial hierarchy (small study plots, whole wetlands, region with many wetlands) and temporal hierarchy (diurnal patterns, seasonal patterns, annual patterns, and geological scale). The overall goals of our research program on Lake Erie, a start of which is reported here, are: 1) to determine if and how these coastal wetlands are serving as buffers between the uplands and Lake Erie, and 2) to estimate what pattern and design of wetlands would be most effective in this buffering capacity. Our study involves ecosystem-level studies at Old Woman Creek National Estuarine Sanctuary (30 ha) in Erie County, Ohio, where processes such as productivity, metabolism, phosphorus cycling, hydrology, and sedimentation are emphasized. Regional-scale studies of wetlands in a 800 km^2 area around Sandusky Bay emphasize water quality, sediment chemistry, and remote sensing of vegetation patterns. Models are used as integrative tools.

Chapter 1 presents an overall picture of the wetlands of this study region. Of the original 4,000 km^2 coastal wetlands in the western Lake Erie basin, only 150 km^2 remain. Many of the remaining wetlands are impounded (diked) and are primarily used for waterfowl management. Forcing functions of the Lake Erie wetlands include short-term water level fluctuations (seiches on Lake Erie), long-term water level fluctuations of the Great Lakes (period of approximately 10 years), shifting shorelines and barrier beaches caused by wind, waves, and sediment dynamics, artificial diking, and water, nutrient, and chemical loadings from upstream watersheds. Present wetlands along Lake Erie, if undiked and opened to overflow from upstream watersheds, could retain only 3.5 to 5 percent of the non-point sources of phosphorus from upstream watersheds.

Chapters 2 through 6 present results of ecosystem-level studies at Old Woman Creek wetland. Chapter 2 investigates diurnal variation of dissolved oxygen in the wetlands in July and October. Diurnal changes of oxygen are from 2 mg/l at dawn to 12-15 mg/l at dusk in July and from 6 to 10 mg/l in October. These data suggest an environment relatively inhospitable to aerobic aquatic life. The diurnal fluctuations suggest an extremely high volumetric productivity although the total depth (<0.3 m) precludes extremely high areal productivity. Average solar efficiencies vary from 0.4% in the summer to 0.3% in the fall. Seasonal patterns of productivity, presented in Chapter 3 and also determined by diurnal patterns of dissolved oxygen, provide an estimate of an annual gross primary productivity in the water column of 3,700 kcal/m^2-yr. Chlorophyll readings and system gross primary productivity have the same general seasonal patterns, but regressions between the two variables for data from all sites and dates is only fair (r=0.15). Changes in planktonic populations throughout the year, each with different chlorophyll ratios, may account for this lack of good correlation.

Net productivity of the dominant macrophyte in the wetland, *Nelumbo lutea*, is estimated from peak biomass harvesting to be 750 kcal/m^2-yr. Because approximately one-third of Old Woman Creek wetland is covered by *Nelumbo*, the overall contribution of macrophytes to the entire wetland is approximately 250 kcal/m^2-yr. Phosphorus concentrations in the *Nelumbo* ranges from 2.2 to 6.1 mg-P/g dry weight and shows an inverse relationship with leaf diameter. Total phosphorus tied up in above-ground biomass of the macrophytes averaged 0.34 g-P/m^2 in the *Nelumbo* communities.

A hydrologic budget is developed for Old Woman Creek wetland for the 7-month period March 1 through September 30, 1988 in Chapter 4. The budget assumed no significant groundwater exchange with the surroundings or Lake Erie relative to other inputs and outflows. Surface inflow is estimated to be 15,200 m^3 while net surface outflow is 13,700 m^3. Contribution from Lake Erie is estimated to be 3,500 m^3. Exchange with Lake Erie occurs only in the spring when the barrier beach is open for 50 days or 23 percent of the study period. This hydrologic budget reflects conditions during extreme drought conditions and flow-thought conditions essentially cease after May for the remainder of the growing season.

Spatial and temporal patterns of phosphorus concentrations in Old Woman Creek wetland are discussed in Chapter 5 and included in an ecosystem model in Chapter 10. Phosphorus often decreases in total, soluble reactive, and total soluble phosphorus from inlet to outlet, but patterns are not consistent. Nutrient budgets are developed in three different ways. A preliminary estimate is obtained from a wetland phosphorus retention model from the literature (Richardson-Nichols model). With an estimated loading rate of 17 to 33 mg-P/m^2-day (determined from other Lake Erie watershed studies), approximately 8 to 13 mg-P/m2-day (39 to 47%) could be expected to be retained by the wetland. Direct field data suggest a loading rate during the March-November study period of only 2.2 mg-P/m^2-day during a severe drought.

A third method of estimating a phosphorus budget for 1988 with an ecosystem simulation model suggests that 30.1 mg-P/m^2-day flows into the wetland and approximately 2.9 mg-P/m^2-day or 10 % is retained in the wetland. This last estimate may be the most realistic because it accounts for a high rate of phosphorus into the wetland during high spring floods. The overall phosphorus budgets cannot be used to conclude that Old Woman Creek wetland is a phosphorus sink as the field data and model calibration are for an unusual drought year. The lower than average phosphorus sedimentation rate determined by the model is a reasonable estimate for a drought year.

A 5-meter sediment core from Old Woman Creek wetland is examined in detail by Reeder in Chapter 6 for chemical stratigraphy and historical sedimentation rates. The core strata indicate three main zones in the sediments: a zone or intermediate organic content reflecting the recent history; a zone of high organic content after the final glacial retreat (5,000 years BP) to approximately 180 years BP; and a zone of very low organic deposits through the glacial events. There was a net sedimentation rate of 0.73 cm/yr in the wetland over the past 180 years, as defined by the appearance of *Ambrosia* sp. in pollen counts. The sedimentation rate translates to an average phosphorus retention rate of 22 mg-P/m^2-day, approximately 10 times that predicted by the model for the 1988 drought year.

Chapters 7 through 9 present preliminary results of regional studies on water levels, water quality, sediment chemistry, and remote sensing. A study of water levels and chemistry of eleven wetlands presented by Robb in Chapter 7 demonstrates preliminary indication of differences between diked (impounded) and undiked wetlands. Water levels drop precipitously in the undiked wetlands but are generally maintained in diked wetlands and in Old Woman Creek wetland with its closed barrier beach. Conductivity, alkalinity, and ortho-phosphate are generally higher in diked wetlands while turbidity and total phosphorus are generally higher in undiked wetlands. Sediment chemistry data of the regional wetlands, examined in Chapter 8, suggest that undiked wetlands have lower organic content. Available phosphorus is highest in sediments from Old Woman Creek wetland and very low in impounded Bay View marshes on Sandusky Bay. Chapter 9 by Roush and others presents results of remote sensing of some of the wetlands of the region and an illustration of typical wetland maps generated from color and color infrared photography. A computerized map analysis by Yi in Chapter 9 suggests that between 1969 and 1983, there was a net loss of 20% of the wetlands in the western reaches of Sandusky Bay.

Two modelling approaches are suggested in Chapters 10 and 11 to understand and manage Lake Erie's coastal wetlands. Chapter 10 presents a preliminary ecosystem model of Old Woman Creek wetland. The model is calibrated with some success with 1988 data that illustrate seasonal patterns during the drought. The calibrated model allows calculations of a phosphorus budget (discussed above) and phosphorus sedimentation and resuspension dynamics. Even with recycling, resuspension of phosphorus is necessary in the model to predict productivity experienced during the calibration year.

Yi summarizes possibilities of including cartographic modelling and geographic information systems with dynamic modelling in a descriptive/prescriptive approach toward the development of new approaches to understanding and managing these coastal wetlands.

William J. Mitsch
Columbus, Ohio
October, 1989

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Appreciation is given to the management of Old Woman Creek State Nature Preserve National Estuarine Research Reserve, especially to Gene Wright and Dave Klarer, for allowing and facilitated access to that wetland, even for some of our peculiar sampling hours. We are particularly indebted to Dave Klarer from OWC for providing his lab, his assistance, and his wealth of knowledge about Old Woman Creek. His support was invaluable to all of the students involved in this study. We appreciate the support of Roy Kroll for allowing access to Winous Point wetland and for his interpretation of aerial photography. We also thank other site managers, especially Tom Smith and Larry Davis, who allowed access to their wetlands and assisted with field work. Several students not listed as authors, including the students in our summer and fall 1988 wetland courses, contributed to this research. Finally and most importantly, we appreciate the fine work of the graduate students who were in the trenches performing the research and writing about the results.

1

Wetlands of Coastal Lake Erie in Ohio—A Hierarchy of Systems

William J. Mitsch

Introduction

Wetlands have always been a part of the shoreline of the Laurentian Great Lakes, expanding and retreating with changing water levels, yet always maintaining themselves as ecotones between the uplands and the Lakes. As shorelines were stabilized and the land was drained for agriculture and urban development, these wetlands were mostly destroyed or significantly altered and their buffering capacity was diminished or lost altogether. Herdendorf (1987) estimates that over 4,000 km^2 of extensive coastal marshes and swamps in the western Lake Erie basin have been cleared, drained and filled to the point where only 150 km^2 remain, most artificially diked from open access to Lake Erie while other uncertain estimates are given for wetlands around the Great Lakes (Table 1.1). It could be surmised that had the surrounding wetlands remained intact, the rate of cultural eutrophication of some of the lakes such as Lake Erie may have been much less severe.

Few if any of comprehensive studies have been carried out on Great Lakes coastal wetlands, especially on wetland functioning of these ecosystems. This is particularly apparent when compared with the abundant literature available on coastal salt marshes. Much of what is known about Great Lakes coastal wetlands is included in the proceedings of a "Great Lakes Coastal Wetlands Colloquium" (Prince and D'Itri 1985). The editors of that work conclude that:

> ...in spite of general scientific opinion that wetlands are important to Great Lakes ecosystems, they represent one of the least well understood parts of those systems. Moreover, they are greatly diminished in extent and quality along most moderately settled shorelines. Still, in 1981, around the heavily settled lower Great Lakes (Ontario, Erie, and St. Clair), about 61,480 hectares of coastal wetland remained....

Research Goals

The goals of our research are to use an ecosystem approach to western Lake Erie coastal wetlands 1) to determine if and how these systems are serving as chemical and hydrologic buffers between the upland and Lake Erie, and 2) to determine what types of wetlands, e.g., diked vs. undiked, are the most effective for future wetland design along the Lake. This report represents only the beginning of that effort, as a summary of our work for 1987 through mid-1989. The overall project will answer a number of questions using field measurements, remote sensing, and mathematical models of hydrologic, chemical, and ecological processes of the wetlands and adjoining watershed. These will ultimately answer the following questions about coastal wetlands along Lake Erie: Are these coastal wetlands chemical sinks, sources, or transformers for runoff and stream flow from the upland agricultural watershed? How valuable is their survival and protection to the enhancement of water quality of Lake Erie? What processes within the wetland are most important in the changes that occur? What are the seasonal patterns of nutrient dynamics in the wetland? How do the processes change with changing lake levels and artificial dikes? What happens to the wetland when seiches occur, reversing the normal flow from the wetland to Lake Erie? If the wetland studied proves to be carrying out valuable functions, what are the design criteria for building similar wetlands in other watersheds along the

Table 1.1 Area of coastal wetlands along Laurentian Great Lakes (from Mitsch et al., 1989)

Region	Wetland Area, km^2	Reference
Great Lakes Wetlands (emergent and aquatic beds)		Kroll et al. (1988)
Total	700	
Lake Erie	187	
Lake St. Clair	165	
Lake Ontario	133	
Lake Huron	128	
Lake Michigan	50	
Lake Superior	37	
Western Lake Erie		
Presettlement	4,000	Herdendorf (1987)
Present	150	
Lakes Ontario, Erie, & St. Clair	615	Prince and D'Itri (1985)
Total Great Lakes		
Present	1,209	Herdendorf et al. (1981)
Lake Erie-Lake St. Clair	119	
Coastal Wetlands - Ontario		McCullough (1985)
Presettlement	500	
Present	330	
Lake St. Clair	25	
Lake Ontario	6	
Coastal Wetlands - Ohio		
1979	59	ODNR (1982)
Coastal Wetlands - Michigan		
1979	428	Jaworski et al. (1979)

Great Lakes?

Study Area

Our wetland study area centers on the wetlands in the region of Sandusky Bay on the southwestern shore of Lake Erie in Ohio (Figure 1.1). The area is approximately 60 km wide and is bounded on the east by Old Woman Creek Wetland, approximately 5 km west of Huron, Ohio and on the west by the mouth of Sandusky River and Muddy Creek as they enter Sandusky Bay southwest of Port Clinton, Ohio. We have chosen initially to look at the Lake Erie wetlands in this region on two scales of hierarchy (Figure 1.2). Intensive studies and measurements of ecosystem productivity, nutrient cycling and paleolimnology are being carried out at Old Woman Creek State Nature Preserve and National Estuarine Research Reserve, located adjacent to Lake Erie in Erie County, Ohio. A synoptic assessment of water quality, sediments and productivity, which includes several other marshes along Lake Erie, is included in the study to determine if the intensive studies at Old Woman Creek can be generalized to coastal wetlands along Lake Erie.

Old Woman Creek Wetland

Old Woman Creek State Nature Preserve and National Estuarine Research Reserve is a coastal wetland located adjacent to Lake Erie in Erie County, Ohio (Figure 1.3). The wetland itself is 30 hectares in size and extends about 1 km south of the Lake Erie shoreline (see Klarer 1988, Mitsch 1988a, Mitsch et al. 1989, for site details). It is approximately 0.34 km wide at its widest portion. Depths may reach up to 3.6 meters in the inlet stream channel but for the major portion of its area it is usually less than 0.5 meters deep. Klarer (1988) estimates that the retention time of the wetland varies between 25 hours (at peak flow) and 114 hours (at average flow).The wetland has an outlet to Lake Erie that is often open but which can be closed for extended periods of time by shifting sands in a barrier beach. Rare but dramatic seiches on Lake Erie can reverse the flow, causing lake water to spill into the wetland. Aquatic habitats within the wetland include open water plankton systems and extensive embayment marshes with American lotus (*Nelumbo lutea*). There are also areas with white water lilies (*Nymphaea tuberosa*), spatterdock (*Nuphar advena*), arrow arum (*Peltandra virginica*), and cattails (*Typha angustifolia*), and wooded wetlands in certain shallow areas. The major land use within the watershed (68.6 km^2) is agricultural. Sedimentation in the wetland was estimated to have been 0.76 mm/yr prior to agricultural development in the early 1800s and more than 10 times that (10 mm/yr) at present (Buchanan 1982).Due to its status as a National Estuarine Sanctuary, the marsh remains relatively undisturbed and is frequently used for nature education, recreation, and scientific study. Sanctuary facilities include a visitors' center and an aquatic ecology research laboratory on the site.

Regional Scale Wetlands

We have initially chosen 10 wetland sites in addition to Old Woman Creek for regional studies of water quality, hydroperiod, sediment analysis, and application of remote sensing techniques. These wetlands are shown in Figure 1.4 and are listed in Table 1.2. Six of the wetlands are diked to maintain artificial water levels, primarily to attract waterfowl. These include Winous Point Shooting Club and Ottawa Shooting Club, which are private hunt clubs found in the western extreme of Sandusky Bay. Bay View Marshes are diked wetlands located on the southeast edge of Sandusky Bay near the causeway from Sandusky to Port Clinton. Pickerel Creek Wetland and Willow Point Wetland are undiked marshes found on the south shore of Sandusky Bay, while Plum Brook Wetland and Sheldon Marsh are found in the embayment behind the Cedar Point Amusement Park peninsula.

Forcing Functions of Coastal Lake Erie Wetlands

Lake Erie wetlands have several characteristics that make them unique ecological systems to study and manage. These include: 1) water level fluctuations of the Great Lakes, which vary both seasonally and daily; 2) periodic seiches or "wind tides," which may occur many times a season; and 3) shifting shoreline sediments, moved during storm events, which can dramatically change the hydrologic, chemical, and biological connections between the wetland and the Lake; 4) varying nutrient loading from the upstream watershed; and 5) artificial dikes that surround many of these wetlands to maintain water levels in view of a fluctuating Lake Erie level. All of these patterns have one thing in common — they are important in determining the forcing functions of the wetlands and greatly influence the exchange of geologic and biological materials from upstream watersheds and to and from Lake Erie.

Lake Erie Water Fluctuations and Artificial Dikes

Wetlands along Lake Erie in general, and Old Woman Creek Wetland in particular, are influenced by water level fluctuations of the Great Lakes. The water levels for Lake

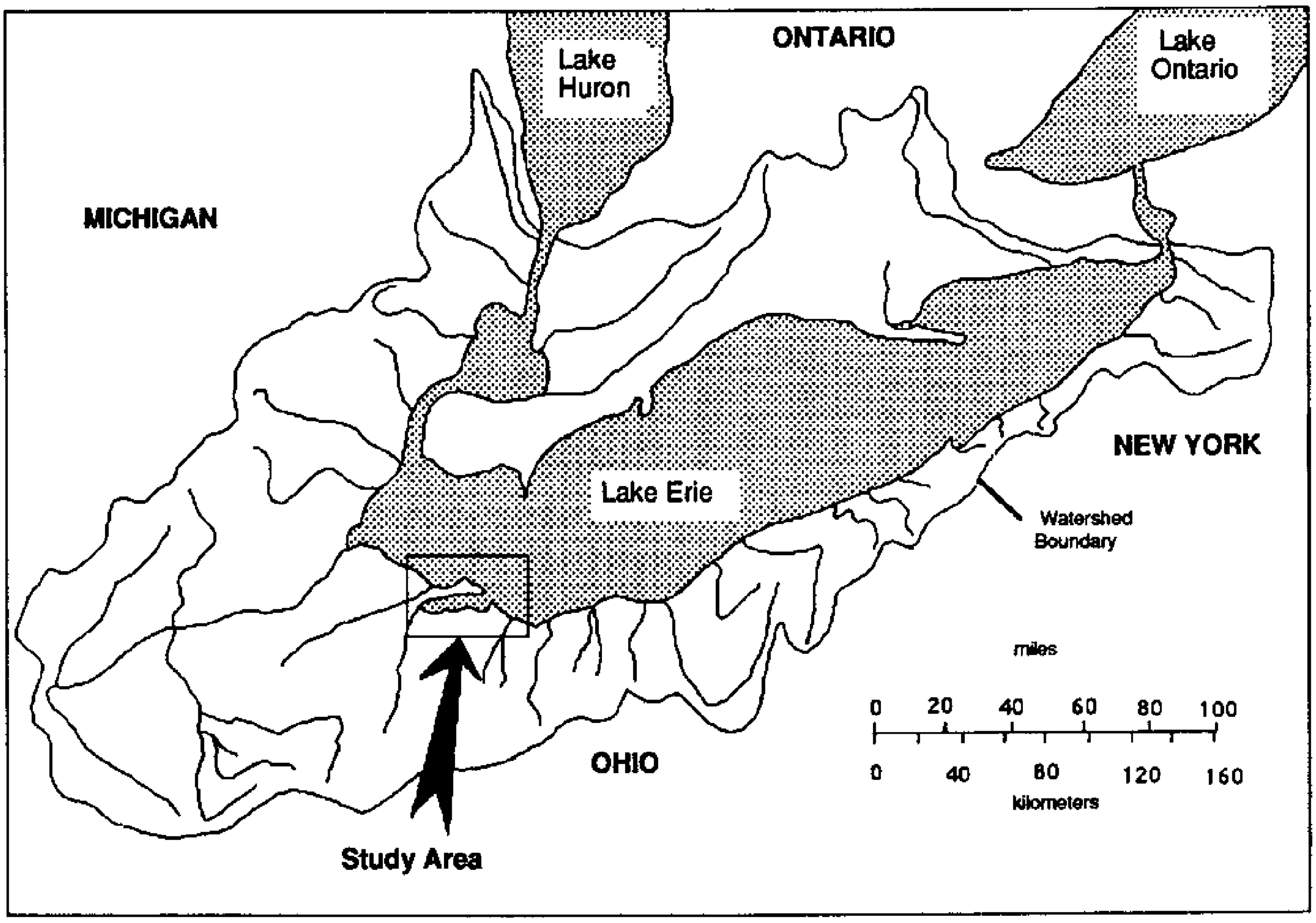

Figure 1.1 Location of general study area in western Lake Erie

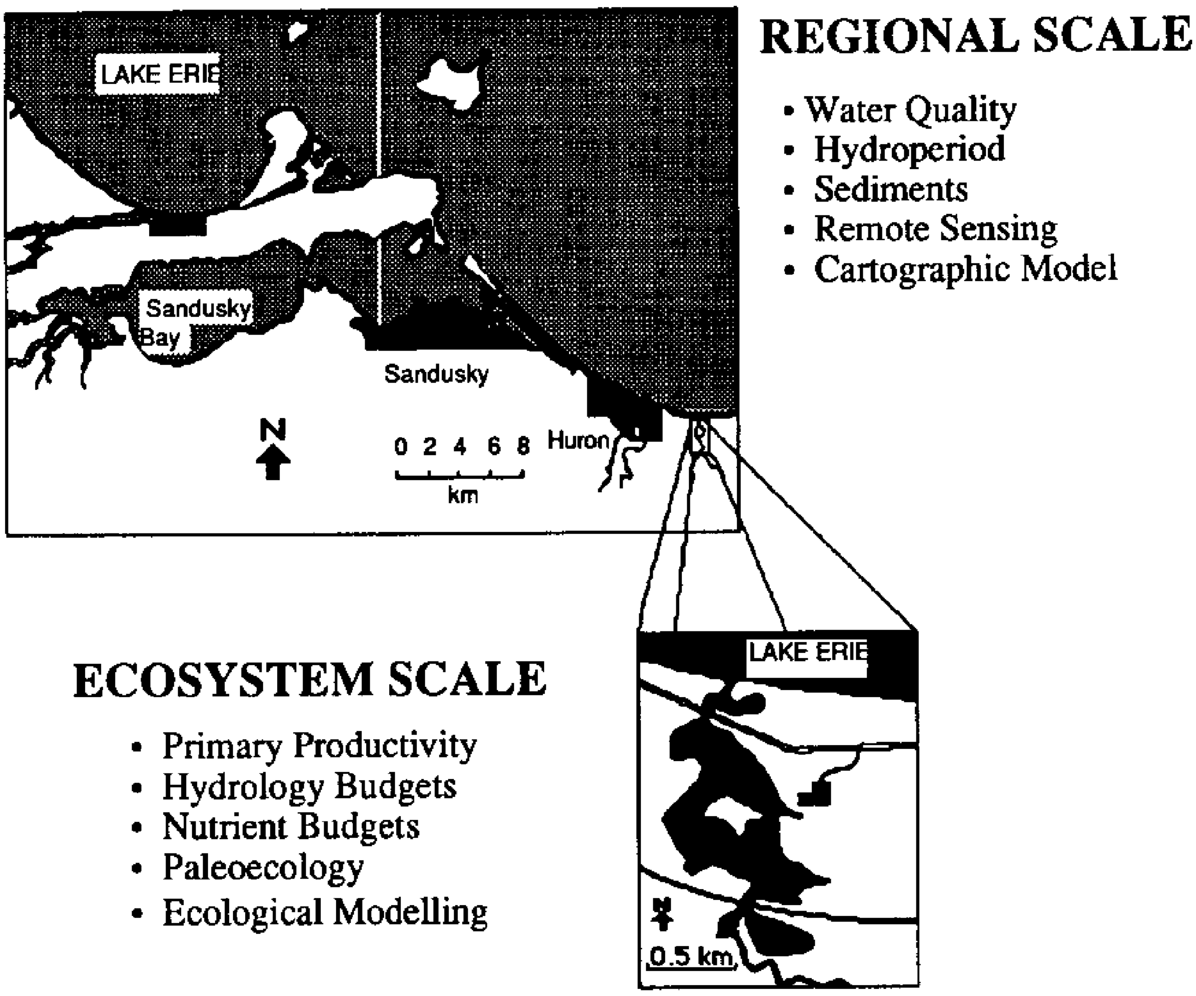

Figure 1.2 Hierarchy of scales used for this research program

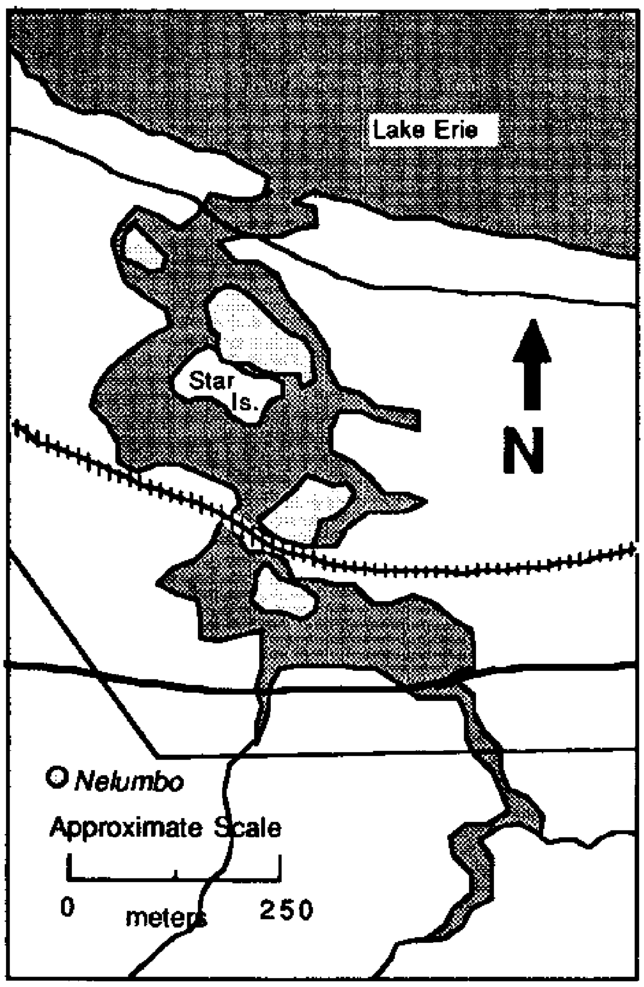

Figure 1.3 Old Woman Creek Wetland, the site of detailed ecosystem-level studies

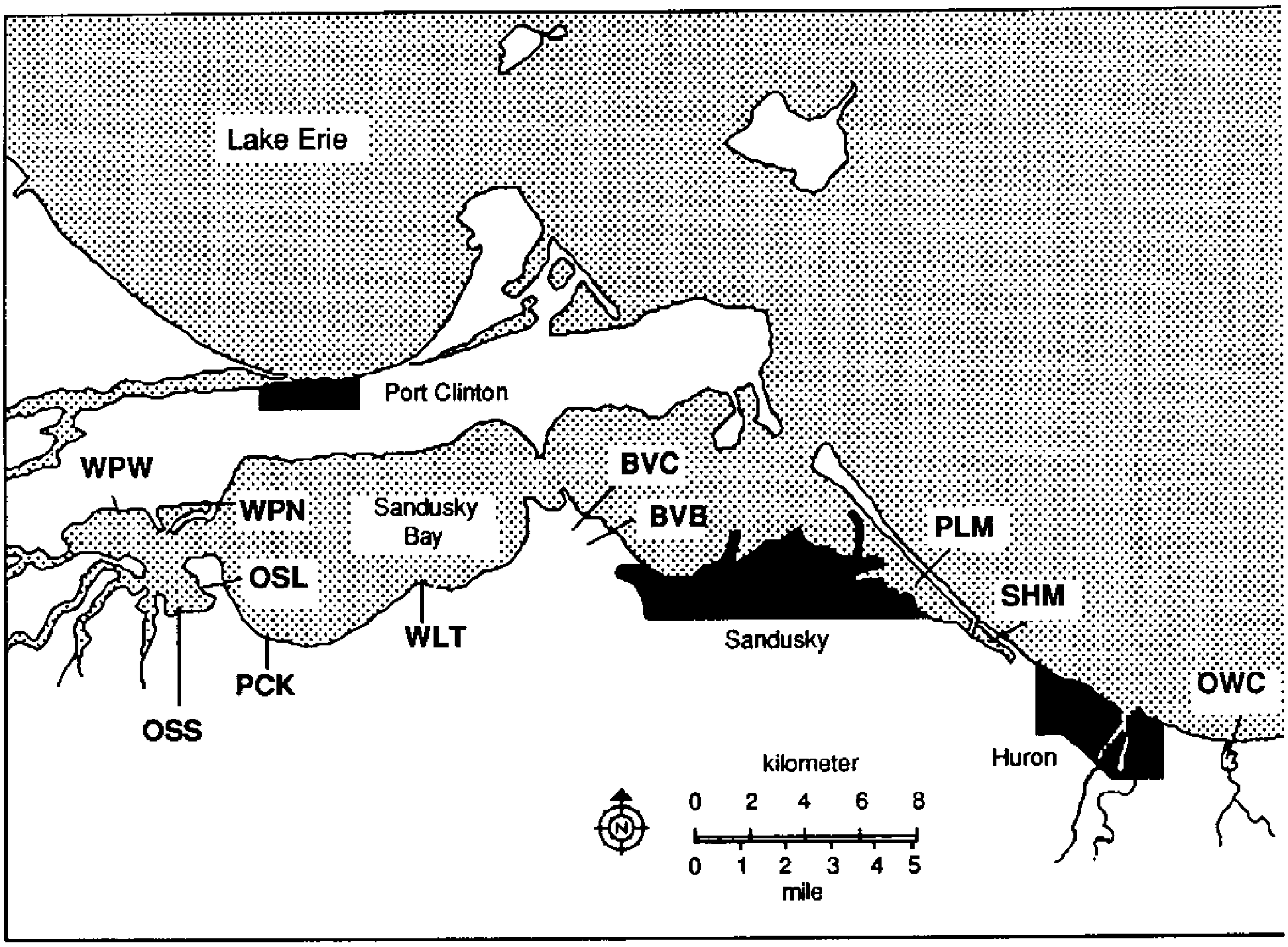

Figure 1.4 Locations of regional scale wetlands around and adjacent to Sandusky Bay

Table 1.2 Diked and undiked wetlands sites used in this study for general studies of water quality, sediments, and hydroperiod

Abbrev.	Wetland	Approximate Area, ha	Ownership
Diked Wetlands			
WPN	Winous Point North Marsh	260	private shooting club
WPW	Winous Point West Marsh	140	private shooting club
OSS	Ottawa Shooting Club - Small Pond Marsh	10	private shooting club
OSL	Ottawa Shooting Club - Big Pond Marsh	120	private shooting club
BVC	Bayview Center Marsh	40	private
BVB	Bayview "B" Marsh	14	private
Undiked Wetlands			
PCK	Pickerel Creek	variable	state-owned wildlife management
WLT	Willow Point Wetland	variable	state-owned fisheries management
SHM	Sheldon Marsh	variable	state nature preserve
PLM	Plum Brook	variable	former industrial site
OWC	Old Woman Creek	30	state nature preserve and national estuarine reserve

Erie over the past 125 years are shown in Figure 1.5. Over this period, there was a difference of about 1.5 meters between low and high water level in Lake Erie. This amplitude and the time are long enough between high and low water levels (period approximately one decade) to significantly affect the structure and function of the coastal wetlands. In presettlement times, high water levels would send the wetlands "inland" while wetlands would extend "lakeward" during low water levels (Figure 1.6). The wetlands are usually in a state of disequilibrium with this fluctuating water level. A given location will vary from a system dominated by emergent vegetation (during shallow water times) to one that is a planktonic or floating leaved aquatic system (during high water level). This fluctuating water level has led to a common practice of marsh management along Lake Erie involving the construction of artificial dikes. Dikes are constructed around wetlands and pumps or flap gates are installed to keep water levels below those of Lake Erie during high water times and to keep the wetland wet (i.e., water level high) during periods of low water level in Lake Erie (Figure 1.7). Because many of the coastal wetlands along Lake Erie are managed for waterfowl, diked wetlands are the most common type of wetland left along southwestern Lake Erie. Our study sites include 6 diked marshes in addition to 5 undiked marshes.

Seiches

Shorter period water level oscillations due to wind action, called seiches, frequently occur on the Great Lakes (Figure 1.8). The coastal wetlands along the lakes are subject to water and chemical exchanges from seiches in much the same way that coastal salt marshes are subjected to tides, although these seiches are not as periodic as semidiurnal coastal tides. Sager et al. (1985), for example, measured 269 seiche events in one year on lower Green Bay on Lake Michigan with a mean amplitude of 19.3 cm and a mean period of 9.9 hours. Their study indicated that coastal marshes may be serving as sinks for total phosphorus and as transformers of nitrogen from dissolved oxidized forms to particulate and reduced forms. Seiches are a common occurrence along Lake Erie, although the contributions of these events to the nutrient budgets and biotic communities of undiked wetlands are not well known. Diked wetlands are generally isolated from the exchanges due to these seiches.

Shifting Sand Bars

For most of the year, the general direction of flow in undiked wetlands is from the wetland to Lake Erie, driven by the difference in elevation between the two bodies of water which can vary with storm events and short-term Lake Erie fluctuations. The difference between the two levels can be exacerbated when the mouth of the stream between the wetland and Lake Erie is closed, a rather frequent event in our Old Woman Creek study site. The wetland then remains closed for a several month period, after which the combination of high water levels in the wetland and a sudden storm event once again opens the wetland to Lake Erie.

Loadings from the Upland Watershed

Undiked wetlands are influenced by runoff from upstream watersheds which are, for the most part, dominated by agricultural use. The 69 km^2 watershed that drains into Old Woman Creek wetland is primarily agricultural, with runoff containing relatively high levels of nutrients (Klarer 1988). An estimated phosphorus loading of 0.5 - 1.0 kg/ha-yr drains into Old Woman Creek (Johnson et al. 1978, IJC 1980, Novotny 1986) resulting in 3,500 to 7,000 kg-P/yr (12 - 23 g-P/m2-yr) discharged to the wetland. This loading rate is a conservative (low) estimate of the contribution of agricultural non-point sources. Many counties in Ohio in the western Lake Erie basin have loading rates of 1.0 to 2.5 kg-P/ha-yr. A study group of Great Lake's pollution called PLUARG (Pollution from Land Use Activities Reference Group) presents a range of 0.1 to 9.1 kg-P/ha-yr (IJC 1980).

Ecosystem Models

Ecosystem models of wetlands can be used to guide field research efforts, to identify gaps in data, to investigate ecosystem behavior, and ultimately to aid in the management and possible design of Great Lakes coastal wetlands. In our research, models, whether conceptual, quantitative, or simulation, are always guiding our work. Modelling will aid in the management of the Great Lakes by demonstrating the temporal patterns of wetlands productivity and nutrient exchange that occur with different hydrologic conditions, watershed uses, and lake levels changes. Our approach uses a hierarchy of models, ranging from watershed approaches to an ecosystem level approach that emphasizes ecosystem processes (Mitsch 1988a). Figure 1.9 illustrates an overall chemical and hydrologic budget for a Lake Erie wetland. Note the role that dikes have on exchanges from upstream watersheds and from Lake Erie itself. On the other hand, the exchange of chemicals and water between Lake Erie and an open wetland can be complicated by water level fluctuations and seiches on the Lake. Figure 1.10 shows a model with details of some of the processes in a wetland which contribute to its nutrient retention capability. Plant uptake, both by plankton and macrophytes, sedimentation, and resuspen-

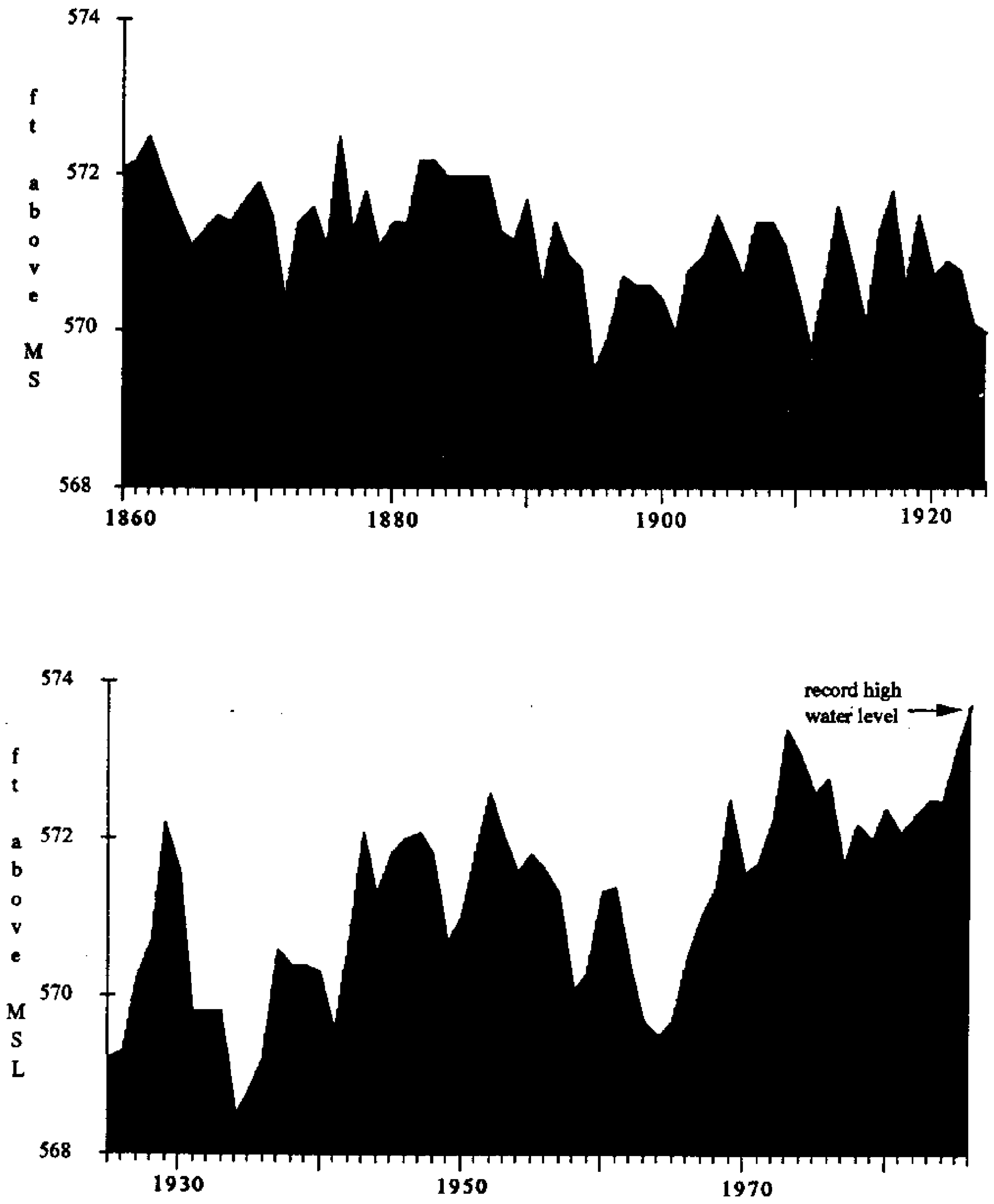

Figure 1.5 Water level fluctuations in Lake Erie from 1860 to 1986

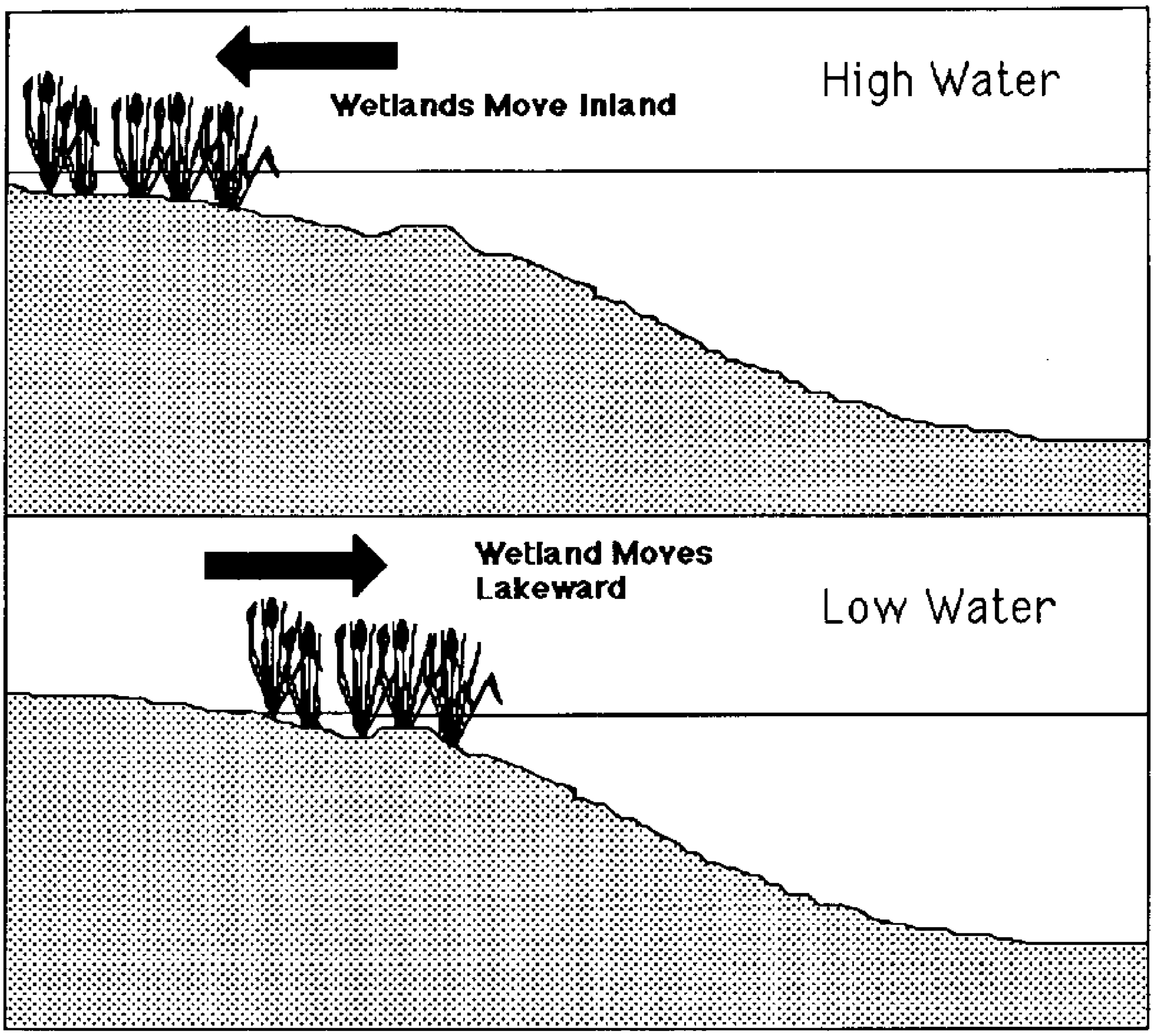

Figure 1.6 Lake Erie wetlands during presettlement times during high and low water conditions

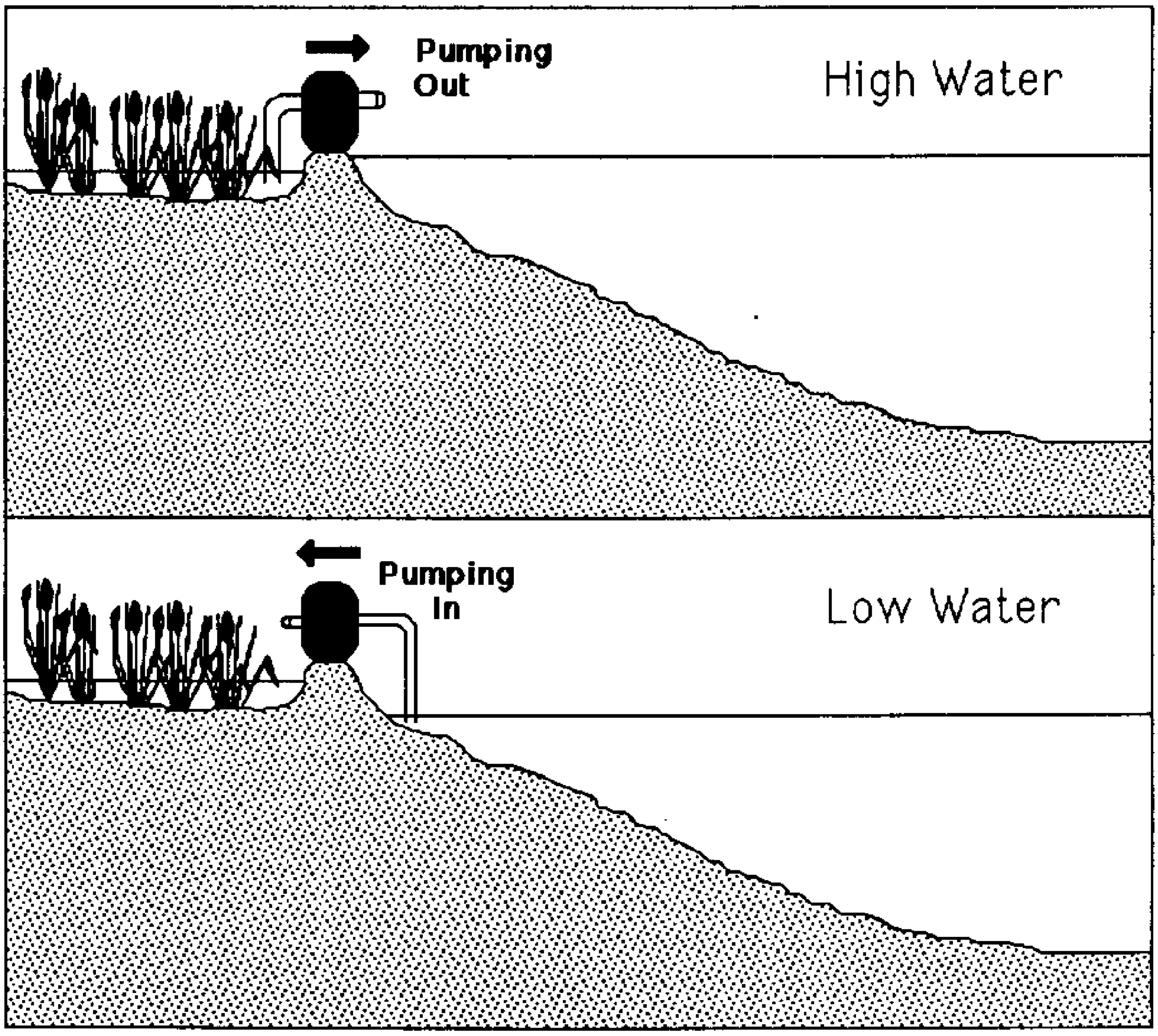

Figure 1.7 Lake Erie diked wetlands as managed for high and low water conditions with dikes and pumps

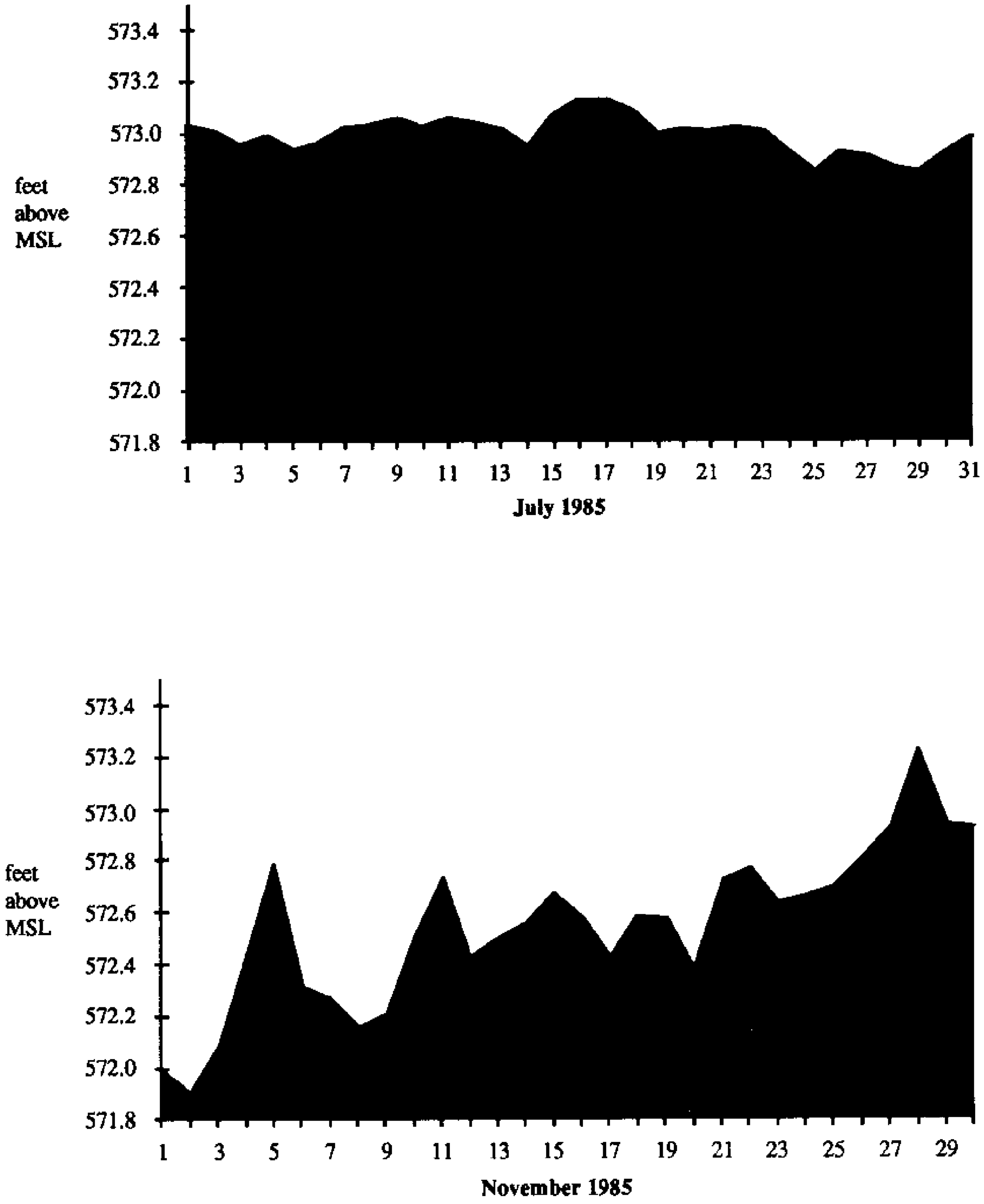

Figure 1.8 Daily water level fluctuations in Lake Erie for July and November 1985 at Cleveland, Ohio

sion are probably the most significant processes involved in the wetland retaining and releasing phosphorus.

Actual and Potential Role of Wetlands in Western Lake Erie

Our continued studies will demonstrate the usefulness of coastal wetlands as buffer zones between the uplands and the Great Lakes. Preliminary calculations suggest that the existing wetlands along western Lake Erie are retaining approximately 75 to 100 metric tons/yr (Mitsch et al. 1989). To put that possible retention in perspective, it should be noted that non-point phosphorus loading to western Lake Erie was estimated to be about 2,100 metric tons/yr for 1978-80 (Yaksich et al. 1982). This suggests that the remaining wetlands are currently retaining about 3.5 to 5 percent of the non-point source loading to the Lake. If we determine that these coastal wetlands are truly sinks for nutrients, it may be possible to suggest the construction of wetlands along the Great Lakes to take advantage of that function. For example, a program to develop 1000 km^2 of wetlands in the western Lake Erie shoreline and watershed (one fourth of the extent of presettlement wetlands) could conceivably lead to a 24 to 33 percent reduction in non-point loading of phosphorus to the western basin. Economic valuation of coastal wetlands will be more feasible as a result of these kinds of studies, as we expect to demonstrate the long-term as well as short-term value of wetlands. We would like to continue studies such as this one to provide design criteria and cause for ecological engineers to protect wetlands along the Great Lakes for their assimilative capacity in the landscape.

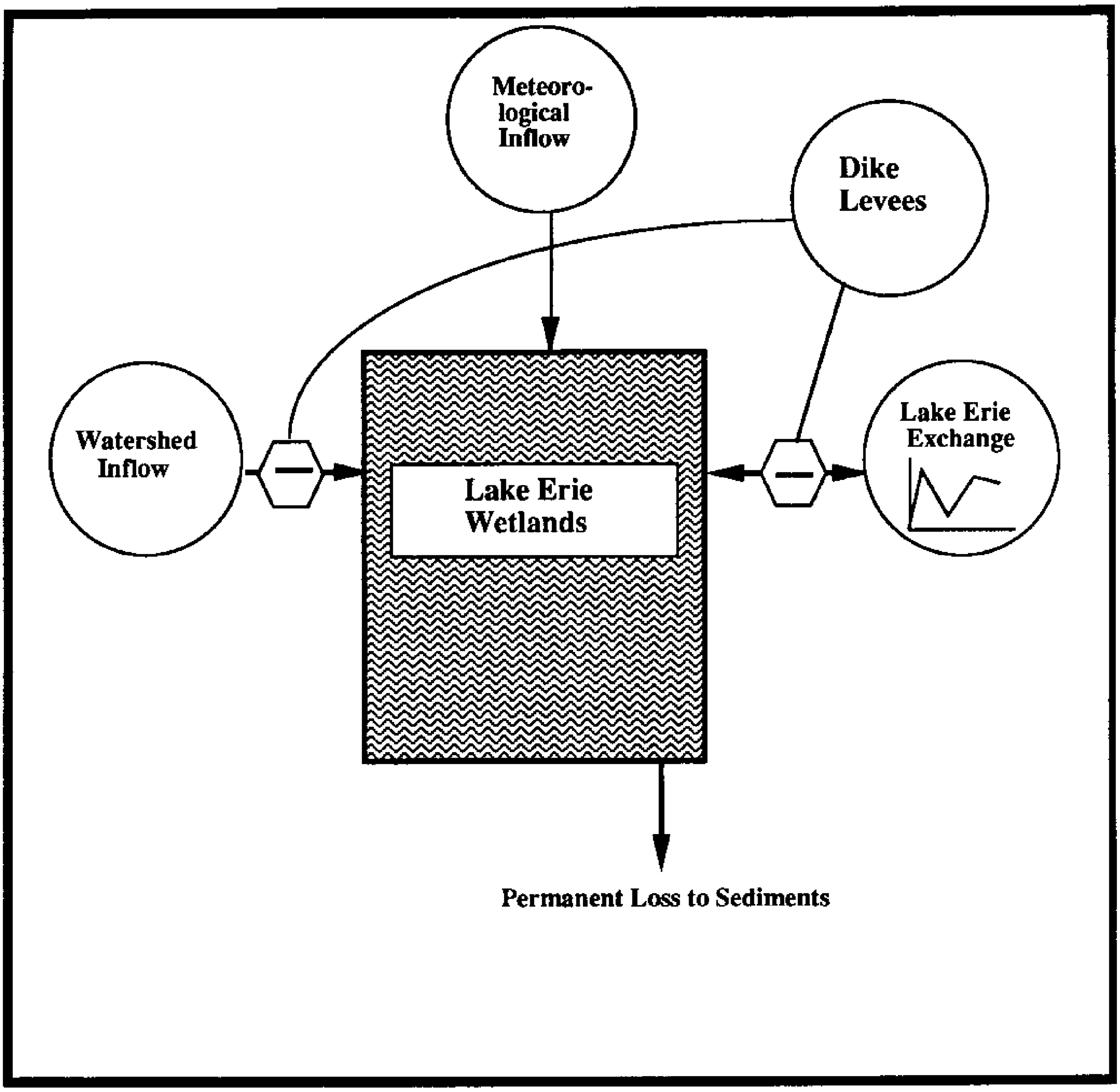

Figure 1.9 Generalized "black-box" model of Lake Erie coastal wetland with role of dikes illustrated

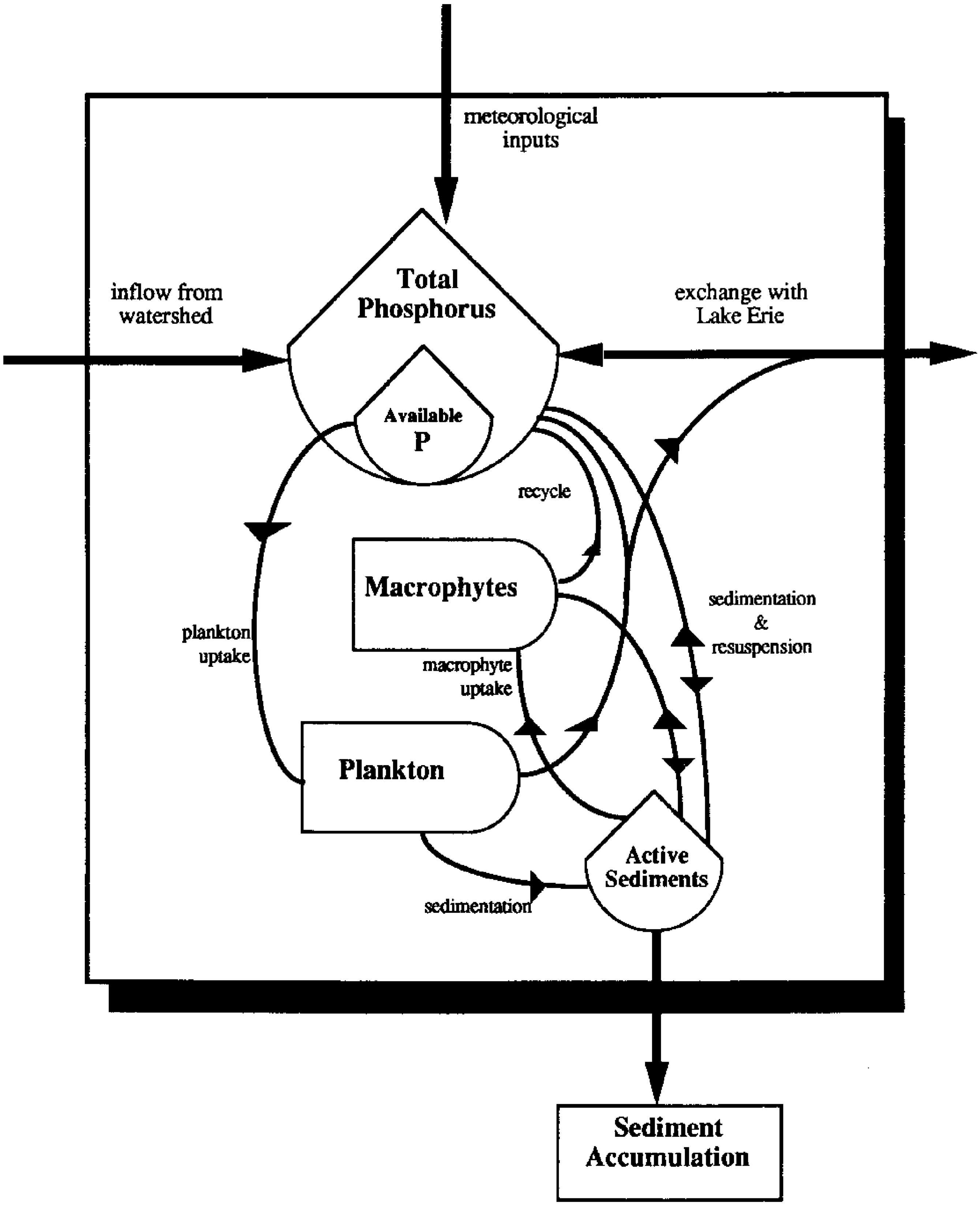

Figure 1.10 Detail of nutrient exchange in typical Lake Erie coastal wetland

Part I. Ecosystem Studies

Old Woman Creek Wetland

2

Diurnal Patterns of Dissolved Oxygen in a Freshwater Coastal Wetland

William J. Mitsch
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Introduction

The rise and fall of dissolved oxygen in an aquatic system reflects that system's metabolism. Diel patterns of oxygen have been used to determine the overall primary productivity and respiration of several different coastal and inland systems (e.g., Odum and Hoskin 1958, Mitsch and Kaltenborn 1980). Some have suggested that this method for measuring productivity is superior to the use of enclosures for either carbon-14 or light-dark bottle methods (Kemp et al. 1986). Shallow plankton-dominated wetlands such as the Old Woman Creek Wetland near Lake Erie are ideal systems in which to measure the diurnal patterns of oxygen and to use those patterns to estimate productivity. The shallow nature of the wetland limits the euphotic zone to a narrow depth of high chlorophyll and dramatic oxygen swings. The warm water temperatures in the summer season further enhance biochemical activity. Furthermore, the calm waters of the shallow wetland usually do not have high rates of oxygen diffusion. Measurement of the diurnal patterns of water chemistry parameters such as dissolved oxygen and temperature are important to predict the habitat value of the wetland for aquatic organisms and the redox reactions.

We report here on the results of two full diurnal measurements of dissolved oxygen in Old Woman Creek Wetland, one in July and the other in October. These diurnal measurements are then used to illustrate the spatial patterns of metabolism in the water column of Old Woman Creek. Chapter 3 gives more details of water column and macrophyte productivity.

Methods

Full dissolved oxygen diurnal patterns with Winkler titration were measured on two occasions: July 11-12, 1988 and October 8-9, 1988. Dissolved oxygen was determined by the azide modification of the Winkler method (APHA, 1985) for 8 stations in Old Woman Creek Wetland (and one site in Lake Erie along the shoreline) as shown in Figure 2.1. Samples were taken just below the surface with a van Dorn sample bottle and water was siphoned into 300 ml BOD bottles. Replicate samples were taken at each station. Temperature was also recorded at the same time with a temperature probe or thermometer. Gross primary productivity and respiration are calculated from rates of change of the dissolved oxygen with nighttime readings giving an estimate of the hourly rate of respiration and day time changes reflecting both gross primary productivity and day time respiration. Oxygen data were entered onto a computer spreadsheet to calculate overall metabolism. Oxygen rates were converted to kilocalorie rates by a multiplication of 3.6. Corrections for oxygen diffusion was assumed to not be necessary based on the diffusion dome measurements described in the next chapter. Solar radiation was recorded with an Eppley black and white pyranometer installed at the sanctuary headquarters.

Results

Figures 2.2 and 2.3 summarize gross primary productivity and P/R ratio estimates for the 8 sampling stations in Old Woman Creek. All of the oxygen and temperature readings for Old Woman Creek wetland for the July and October

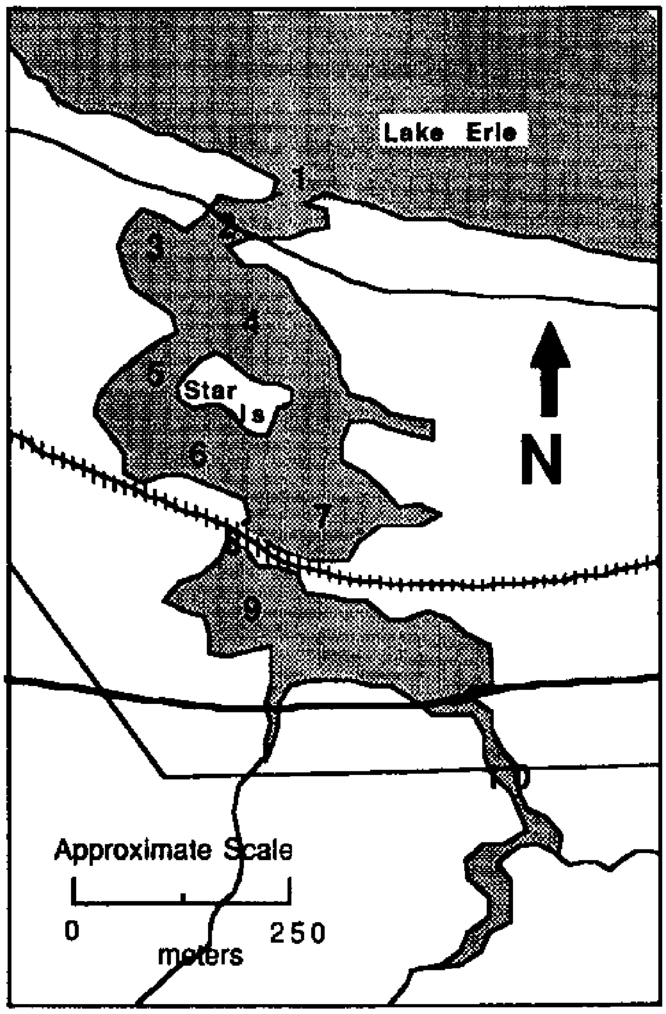


Figure 2.1 Sampling stations for diurnal oxygen measurements in Old Woman Creek Wetland

sampling periods are shown in Tables 2.1 and 2.2 and Figures 2.4 through 2.19. The July diurnal period was approximately 33 hours long, but the last 24 hours were used in calculations of productivity.

Oxygen Concentrations

The July oxygen data display a dramatic change in oxygen over a twenty four hour period. Readings ranged from 2 mg/l at 6 AM to peaks of 12–15 mg/l at dusk. Water temperatures generally were quite warm at 24 to 29°C. In contrast, the dissolved oxygen in Old Woman Creek in early October was less dramatic and generally ranged from 6 to 10 mg/l with a temperature range of 6 to 14°C. Dissolved oxygen during July was clearly supersaturated in late afternoon and clearly undersaturated at dawn, while it remained much closer to saturation during the October readings.

The oxygen readings, by themselves, demonstrate an inhospitable environment in Old Woman Creek wetland for aquatic life. Carp (*Cyprinus carpio*) is a dominant aquatic animal in this wetland, and that species is well known for its adaptations to poorly oxygenated conditions. It would be unwise to think that a shallow, highly productive wetland like Old Woman Creek could ever support a wide diversity of fish with the significant oxygen swings and high temperatures observed here. The data also illustrate the importance of recording the time of oxygen readings in this wetland as it can change from 2 to 14 mg/l in one day. A casual observation during an early afternoon would suggest that the dissolved oxygen is adequate for aquatic life, but an early morning reading would show exactly the opposite.

Gross Primary Productivity

Old Woman Creek, at the water depths prevalent during this study year, is primarily a plankton-dominated system. Plankton productivity in July data ranged from 15 to 57 kcal/m^2-day or an average of 30 kcal/m^2-day for all sites. The October data result in productivity calculations of 2 to 19 kcal/m^2-day with an average of 8 kcal/m^2-day for all sites (Figure 2.2).

P/R Ratios

P/R ratios for the wetland stations for July and October are given in Figure 2.3. The July data suggest an excess of production over respiration at six of the eight sites although, interestingly, there was greater respiration than production at the two sites in the upstream reaches of the wetland (Stations 8 and 9). The low P/R ratio for Station 8 is understandable as it is a flowing station under the railroad bridge. Station 9 has high amounts of detritus and decaying woody vegetation that may make it more heterotrophic. All sites except one in October have P/R ratios less than 1.0. As solar energy and temperatures decrease rapidly in October, the system shifts to one of catabolism and lower productivities.

Solar Efficiency

Traces of solar radiation for the two periods of measurement, as measured by a pyranometer at Old Woman Creek, are shown in Figures 2.20 and 2.21. Integration of the July solar graph for the same 24 hours as used in the diurnal oxygen calculations yielded a total solar radiation estimate of 6,910 kcal/m^2-day, while the October readings yielded an estimate of 2,602 kcal/m^2-day. The average gross primary productivity of 30 kcal/m^2-day in July yields an efficiency of 0.4 %. The average gross primary productivity of 8 kcal/m^2-day in October results in an efficiency of 0.3%. These productivities are significant for planktonic systems and are comparable to those of productive wetlands in flow-through conditions (Mitsch and Gosselink 1986) or highly eutrophic lakes.

Acknowledgments

We appreciate the field support of the students in the senior author's *Wetland Ecology and Management* course during these diurnal measurements. David Klarer made the Old Woman Creek laboratories available and provided the solar radiation data.

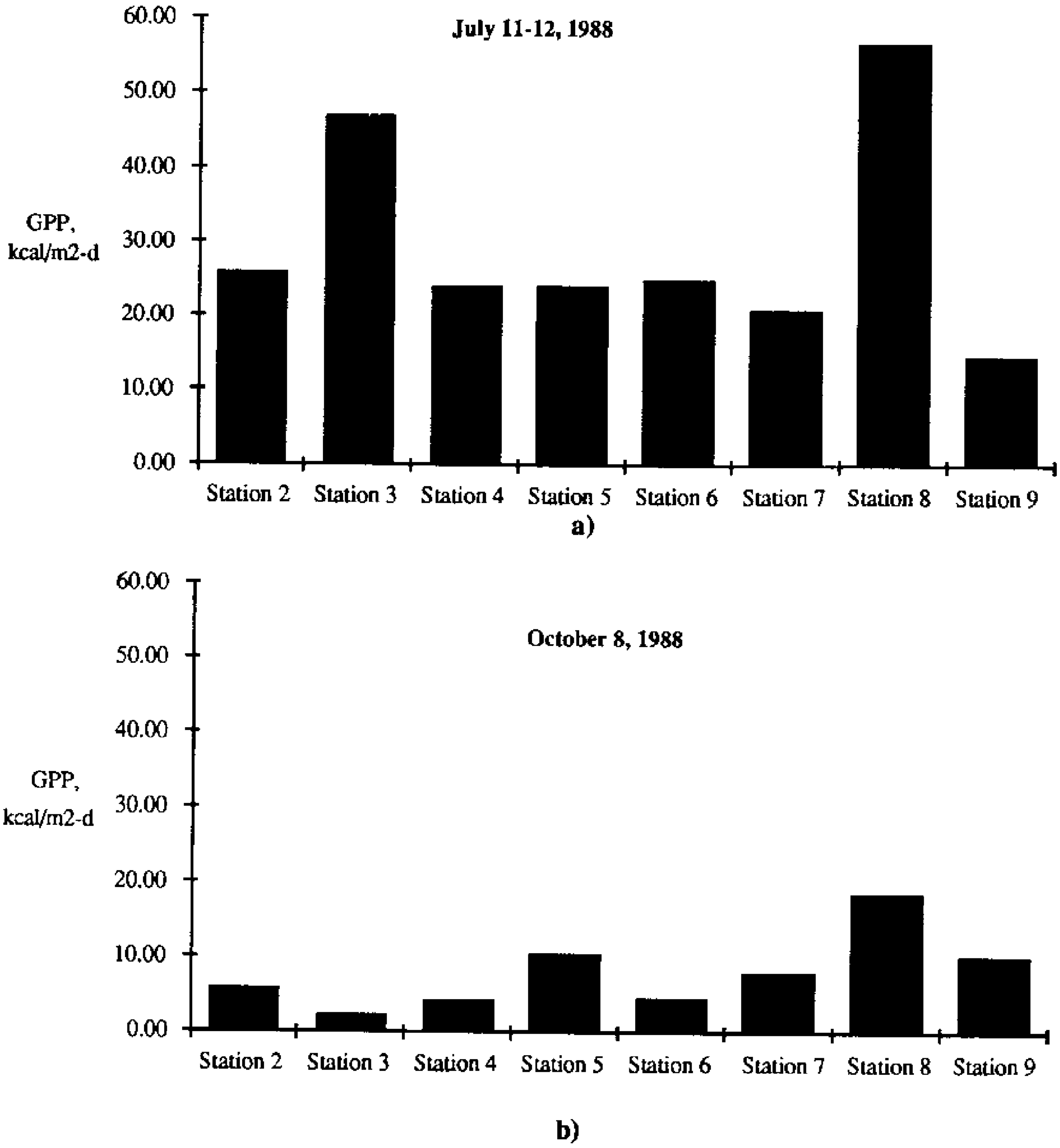


Figure 2.2 Summary of gross primary productivity (GPP) measurements for Old Woman Creek sampling stations for a) July 11-12, 1988, and b) October 8–9, 1988

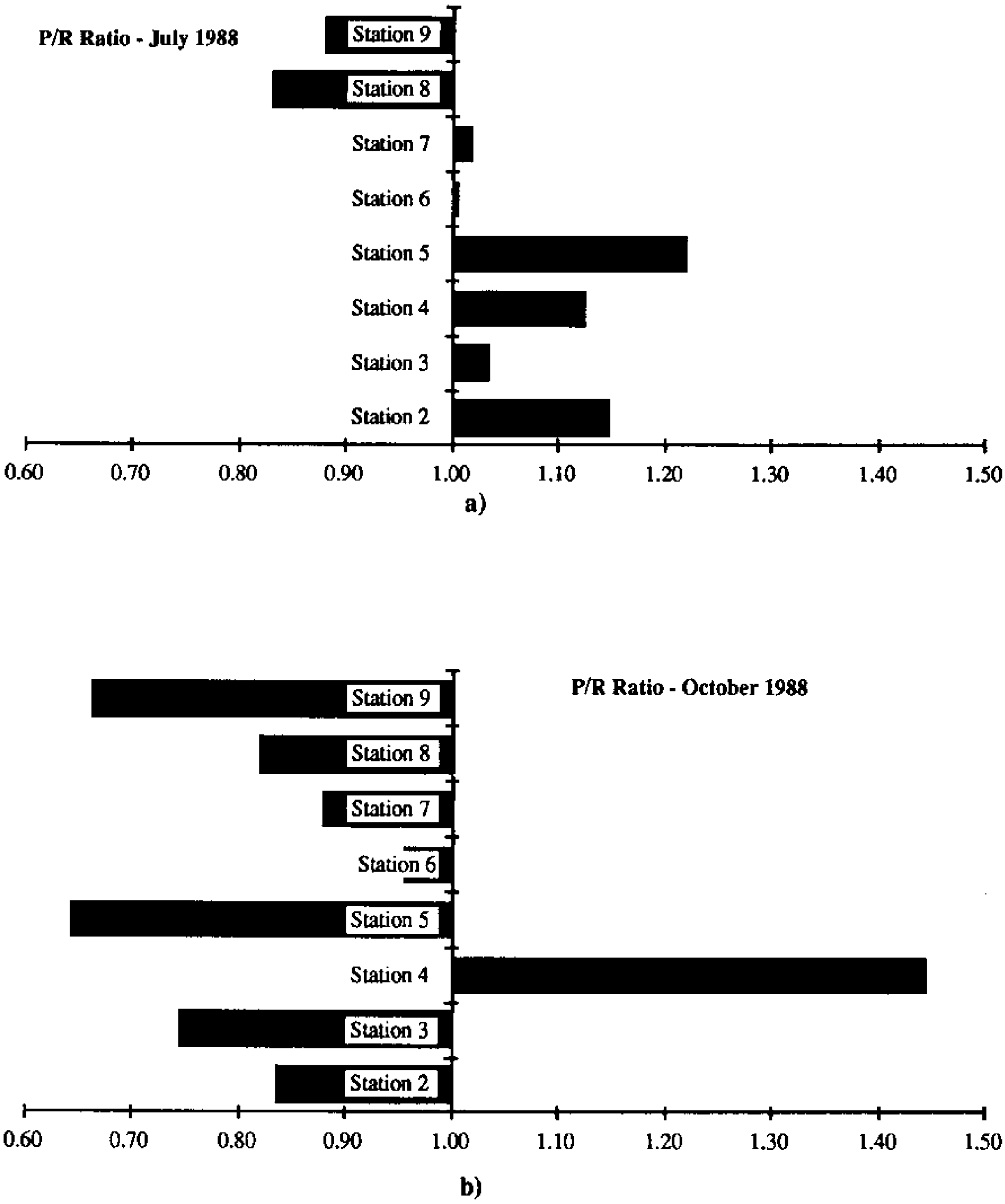


Figure 2.3 Ratio of gross primary productivity to respiration (P/R) for Old Woman Creek sampling stations for a) July 1988 and b) October 1988

Table 2.1 Results of diurnal oxygen measurements at Old Woman Creek Wetland, July 11-12, 1988

Station 1			Depth:	0.65 m
Time (hrs)	Temp (deg C)	DO1 (g/m3)	DO2 (g/m3)	DO ave (g/m3)
12.67	27	6.2	6.7	6.45
15.08	x	9.2	9.2	9.2
18.58	x	8.4	8.6	8.5
22.33	23	8.5	8.6	8.55
25.02	x	8.8	8.9	8.85
27.97	22.5	8.2	8	8.1
30.90	24	7.5	7.6	7.55
33.92	x	9.3	8.5	8.9
36.08	x	5.2	5.6	5.4
39.08	x	7.8	7.2	7.5
42.17	x	6.7	6.5	6.6
45.17	x	7	6.5	6.75
32.50 hours				

Station 2			Depth:	0.5 m			Secchi disk	0.17 m
Time (hrs)	Temp (deg C)	DO1 (g/m3)	DO2 (g/m3)	DO ave (g/m3)	Rate (g/m3-hr)	Rate (g/m2-hr)	(g/m2)	(kcal/m2)
12.75	27	5.3	3	4.15				
15.25	27	5.2	4.5	4.85	0.28	0.14	1.00	3.61
18.75	27	7.9	7.2	7.55	0.77	0.39	2.26	8.15
22.67	25.5	5.9	6.1	6	-0.40	-0.20		
24.95	25	3.4	3.7	3.55	-1.07	-0.54		
27.80	25	3.6	3.2	3.4	-0.05	-0.03		
30.78	26	1.7	1.7	1.7	-0.57	-0.28		
33.83	25	3.4	3	3.2	0.49	0.25	1.55	5.57
36.20	26	4.4	4.3	4.35	0.49	0.24	1.19	4.30
39.20	30	6.7	6.8	6.75	0.80	0.40	1.98	7.14
42.25	26	10.1	10.1	10.1	1.10	0.55	2.47	8.90
45.32	27	6.4	6.3	6.35	-1.22	-0.61		
			Gross Primary Productivity				7.20	25.91 kcal/m2-d
32.57 hours			Respiration			-0.26	-6.27	-22.58 kcal/m2-d

Station 3			Depth:	0.65 m			Secchi disk	0.13 m
Time (hrs)	Temp (deg C)	DO1 (g/m3)	DO2 (g/m3)	DO ave (g/m3)	Rate (g/m3-hr)	Rate (g/m2-hr)	(g/m2)	(kcal/m2)
12.92	27	8.5	7.5	8				
15.50	28	11.3	12.2	11.75	1.45	0.94	3.80	13.66
18.83	23	12.25	10.4	11.325	-0.13	-0.08	1.48	5.31
21.83	26	9	9.1	9.05	-0.76	-0.49		
24.80	25	3.5	3.7	3.6	-1.84	-1.19		
27.62	24	3.2	3.5	3.35	-0.09	-0.06		
30.70	24.5	1.7	1.6	1.65	-0.55	-0.36		
33.75	24	6.4	4.9	5.65	1.31	0.85	4.20	15.13
36.28	27	7.4	7.1	7.25	0.63	0.41	2.37	8.54
39.28	29	10.3	10.1	10.2	0.98	0.64	3.49	12.58
42.45	28.5	12.6	11.9	12.25	0.65	0.42	3.00	10.79
45.43	27.5	11.1	11.3	11.2	-0.35	-0.23		
			Gross Primary Productivity				13.07	47.04 kcal/m2-d
32.52 hours			Respiration			-0.53	-12.62	-45.43 kcal/m2-d

Station 4			Depth:	0.52 m			Secchi disk	0.125 m
Time (hrs)	Temp (deg C)	DO1 (g/m3)	DO2 (g/m3)	DO ave (g/m3)	Rate (g/m3-hr)	Rate (g/m2-hr)	(g/m2)	(kcal/m2)
13.08	27	3.6	3.2	3.4				
16.00	28	6.5	6.8	6.65	1.11	0.58	2.41	8.68
18.92	28	6.4	6.5	6.45	-0.07	-0.04	0.62	2.23
21.58	26	4.7	4.4	4.55	-0.71	-0.37		
24.67	26	1.2	1.8	1.5	-0.99	-0.51		
27.45	24.5	2.6	2.7	2.65	0.41	0.21		
30.53	25	0.8	0.7	0.75	-0.62	-0.32		
33.63	25	2.1	2.1	2.1	0.44	0.23	1.47	5.29
36.42	26	4	4.1	4.05	0.70	0.36	1.70	6.13
39.35	28	7.2	7.5	7.35	1.13	0.59	2.44	8.79

Table 2.1 continued

42.53	28	7.3	8.5	7.9	0.17	0.09	1.07	3.87
45.55	27	5.1	5.2	5.15	-0.91	-0.47		
			Gross Primary Productivity				6.69	24.08 kcal/m2-d
32.47 hours			Respiration			-0.25	-5.94	-21.39 kcal/m2-d
Station 5			Depth:	0.43 m				
Time (hrs)	Temp (deg C)	DO1 (g/m3)	DO2 (g/m3)	DO ave (g/m3)	Rate (g/m3-hr)	Rate (g/m2-hr)	(g/m2)	(kcal/m2)
13.25	27	6.8	8	7.4				
15.67	28	10.9	9.8	10.35	1.22	0.52	1.82	6.55
19.17	28.5	8.3	8.4	8.35	-0.57	-0.25	-0.06	-0.22
21.35	26	8.8	8.6	8.7	0.16	0.07		
24.42	26	4.9	6.6	5.75	-0.96	-0.41		
27.25	24	3.6	3.7	3.65	-0.74	-0.32		
30.35	25	1.8	1.9	1.85	-0.58	-0.25		
33.47	25	3.8	4.5	4.15	0.74	0.32	1.70	6.12
36.58	27	5.2	6.1	5.65	0.48	0.21	1.36	4.88
39.47	27	9.6	9.7	9.65	1.39	0.60	2.38	8.56
42.57	29	10.4	11.4	10.9	0.40	0.17	1.25	4.48
45.63	28	11.8	11.9	11.85	0.31	0.13		
			Gross Primary Productivity				6.68	24.05 kcal/m2-d
32.38 hours			Respiration			-0.23	-5.48	-19.72 kcal/m2-d
Station 6			Depth:	0.3 m			Secci disk	0.09 m
Time (hrs)	Temp (deg C)	DO1 (g/m3)	DO2 (g/m3)	DO ave (g/m3)	Rate (g/m3-hr)	Rate (g/m2-hr)	(g/m2)	(kcal/m2)
12.75	26	7.1	7.8	7.45				
15.17	28	11.3	11.2	11.25	1.57	0.47	1.84	6.61
18.38	28.5	15.2	14.3	14.75	1.09	0.33	1.98	7.11
21.33	27.5	12.1	7.7	9.9	-1.64	-0.49		
24.25	25.5	7.6	7.7	7.65	-0.77	-0.23		
27.33	26	3.5	3.4	3.45	-1.36	-0.41		
30.23	23	3.2	3.35	3.275	-0.06	-0.02		
33.25	23	5.8	5.8	5.8	0.84	0.25	1.63	5.85
36.25	26	7.7	7.7	7.7	0.63	0.19	1.43	5.16
39.17	29	13.3	13.7	13.5	1.99	0.60	2.58	9.29
41.92	31	15.4	15	15.2	0.62	0.19	1.30	4.69
45.28	27	13.4	13	13.2	-0.59	-0.18		
			Gross Primary Productivity				6.94	24.99 kcal/m2-d
32.53 hours			Respiration			-0.29	-6.91	-24.87 kcal/m2-d
Station 7			Depth:	0.33 m			Secchi disk	0.07 m
Time (hrs)	Temp (deg C)	DO1 (g/m3)	DO2 (g/m3)	DO ave (g/m3)	Rate (g/m3-hr)	Rate (g/m2-hr)	(g/m2)	(kcal/m2)
13.17	26	6.8	6.9	6.85				
15.48	27.5	12.1	11.8	11.95	2.20	0.73	2.23	8.03
18.75	25.5	11	9.7	10.35	-0.49	-0.16	0.25	0.88
21.58	26.5	8.3	8.2	8.25	-0.74	-0.24		
24.45	25	4.6	4.7	4.65	-1.26	-0.41		
27.53	26	2.6	2.7	2.65	-0.65	-0.21		
30.45	24	2	2	2	-0.22	-0.07		
33.50	24.5	3.1	3.7	3.4	0.46	0.15	1.18	4.26
36.50	25.5	5.7	5.8	5.75	0.78	0.26	1.49	5.35
39.33	28.5	13.4	12.1	12.75	2.47	0.82	2.98	10.73
42.20	31	10.9	11.3	11.1	-0.58	-0.19	0.13	0.48
45.50	27	9.5	9.8	9.65	-0.44	-0.15		
			Gross Primary Productivity				5.78	20.82 kcal/m2-d
32.33 hours			Respiration			-0.24	-5.68	-20.45 kcal/m2-d
Station 8			Depth:	0.9 m			Secchi disk	0.17 m
Time (hrs)	Temp (deg C)	DO1 (g/m3)	DO2 (g/m3)	DO ave (g/m3)	Rate (g/m3-hr)	Rate (g/m2-hr)	(g/m2)	(kcal/m2)
13.42	26.5	6	6.8	6.4				
15.70	27.5	11.2	11.2	11.2	2.10	1.89	6.13	22.08
18.90	27	11.6	13	12.3	0.34	0.31	3.53	12.71
21.78	26	4.8	4.7	4.75	-2.62	-2.36		
24.68	25.5	3.2	3.2	3.2	-0.53	-0.48		

Table 2.1 continued

27.87	27	2	2	2	-0.38	-0.34		
30.58	24	2	2	2	0.00	0.00		
33.75	24.5	4.8	3.2	4	0.63	0.57	4.32	15.53
36.63	25.5	5.1	4.9	5	0.35	0.31	3.19	11.48
39.47	27	9.3	9.1	9.2	1.48	1.33	6.03	21.71
42.40	29	8.5	9.8	9.15	-0.02	-0.02	2.28	8.23
45.67	26.5	6.5	6.5	6.5	-0.81	-0.73		
			Gross Primary Productivity				15.82	56.95 kcal/m2-d
32.25 hours			Respiration			-0.79	-19.06	-68.62 kcal/m2-d
Station 9			Depth:	0.3 m			Secchi disk	0.135 m
Time (hrs)	Temp (deg C)	DO1 (g/m3)	DO2 (g/m3)	DO ave (g/m3)	Rate (g/m3-hr)	Rate (g/m2-hr)	(g/m2)	(kcal/m2)
13.58	26.5	6.5	6.5	6.5				
15.83	27.5	10.6	10.8	10.7	1.87	0.56	1.69	6.10
19.08	27	9.5	9.5	9.5	-0.37	-0.11	0.27	0.96
21.92	26	6.6	6.5	6.55	-1.04	-0.31		
24.87	25	5	4.7	4.85	-0.58	-0.17		
27.72	26	3	3	3	-0.65	-0.19		
30.68	24	2	2.2	2.1	-0.30	-0.09		
34.00	25	3.7	4.2	3.95	0.56	0.17	1.19	4.30
36.75	26	6.3	6	6.15	0.80	0.24	1.19	4.28
39.75	28	11.9	14.2	13.05	2.30	0.69	2.65	9.53
42.62	29.5	7.2	8.8	8	-1.76	-0.53	-0.96	-3.46
45.87	26	4.5	4.9	4.7	-1.02	-0.30		
			Gross Primary Productivity				4.07	14.65 kcal/m2-d
32.28 hours			Respiration			-0.19	-4.63	-16.65 kcal/m2-d

Table 2.2 Results of Diurnal Oxygen Measurements at Old Woman Creek Wetland, October 8-9, 1988

Station 1 Depth: 0.4 m

Time (hrs)	Temp (deg C)	DO1 (g/m3)	DO2 (g/m3)	DO ave (g/m3)
6.33	x	9.4	9.4	9.4
9.00	9.5	9.4	9.6	9.5
12.50	12.5	9.5	8.2	8.85
15.50	16	5.8	5.6	5.7
18.50	13	9.2	8.8	9
20.75	12	7.8	5.8	6.8
24.25	12	9.4	9.4	9.4
26.75	11.5	8.1	7.8	7.95
30.17	11.5	9.2	9.4	9.3
23.84 hours				

Station 2 Depth: 0.5 m

Time (hrs)	Temp (deg C)	DO1 (g/m3)	DO2 (g/m3)	DO ave (g/m3)	Rate (g/m3-hr)	Rate (g/m2-hr)	(g/m2)	(kcal/m2)
6.58	8	6.3	6.6	6.45				
9.33	8	6.6	6.6	6.6	0.05	0.03	0.30	1.08
12.83	8	6.9	6	6.45	-0.04	-0.02	0.21	0.76
15.85	12.5	5	3.2	4.1	-0.78	-0.39	-0.93	
18.33	x	6.9	8.7	7.8	1.49	0.75	2.05	
21.00	10	5.2	6	5.6	-0.82	-0.41		
24.42	9	8.5	8.9	8.7	0.91	0.45		
27.17	9	5.15	5.15	5.15	-1.29	-0.65		0.00
30.50	9	7.2	6.8	7	0.56	0.28		0.00
			Gross Primary Productivity				1.63	5.88 kcal/m2-d
23.92 hours			Respiration			-0.08	-1.96	-7.05 kcal/m2-d

Station 3 Depth: 0.3 m

Time (hrs)	Temp (deg C)	DO1 (g/m3)	DO2 (g/m3)	DO ave (g/m3)	Rate (g/m3-hr)	Rate (g/m2-hr)	(g/m2)	(kcal/m2)
6.75	5.3	8.4	8.2	8.3				
9.50	5.3	9	9	9	0.25	0.08	0.31	1.13
13.08	9	7.4	8	7.7	-0.36	-0.11	-0.26	-0.92
16.15	14	3.8	5.4	4.6	-1.01	-0.30	-0.82	
18.17	11	8.3	9.9	9.1	2.23	0.67	1.43	
21.08	10	6.8	6.8	6.8	-0.79	-0.24		
24.58	9	8.3	8	8.15	0.39	0.12		
27.11	11	6.9	6.05	6.475	-0.66	-0.20		0.00
30.67	8	7.6	9.4	8.5	0.57	0.17		0.00
			Gross Primary Productivity				0.67	2.40 kcal/m2-d
23.92 hours			Respiration			-0.04	-0.90	-3.23 kcal/m2-d

Station 4 Depth: 0.6 m

Time (hrs)	Temp (deg C)	DO1 (g/m3)	DO2 (g/m3)	DO ave (g/m3)	Rate (g/m3-hr)	Rate (g/m2-hr)	(g/m2)	(kcal/m2)
7.57	10	7.3	7.3	7.3				
9.33	8	6.6	6.6	6.6	-0.40	-0.24	-0.36	-1.29
12.580	11	6.6	6.4	6.5	-0.03	-0.02	0.06	0.20
14.920	12	6.7	5.4	6.05	-0.19	-0.12	-0.19	-0.67
19.000	12	8	8	8	0.48	0.29	1.32	4.74
20.800	12	8.65	8.5	8.575	0.32	0.19	0.41	1.47
24.500	11	8	8.3	8.15	-0.11	-0.07		
30.570	10	8.15	8.1	8.125	0.00	0.00		
			Gross Primary Productivity				1.24	4.45 kcal/m2-d
23.00 hours			Respiration			-0.04	-0.86	-3.08 kcal/m2-d

Station 5 Depth: 0.45 m

Time (hrs)	Temp (deg C)	DO1 (g/m3)	DO2 (g/m3)	DO ave (g/m3)	Rate (g/m3-hr)	Rate (g/m2-hr)	(g/m2)	(kcal/m2)
7.750	8	7.9	8.5	8.2				
10.00	8	5.7	6.5	6.1	-0.93	-0.42	-0.51	-1.85
12.92	11	9.2	8.8	9	0.99	0.45	1.87	6.72
15.17	14	8.9	8.9	8.9	-0.04	-0.02	0.39	1.39
18.80	13	8	8.1	8.05	-0.23	-0.11	0.31	1.13
20.97	12	9.5	8.8	9.15	0.51	0.23	0.91	3.28
24.83	11	8.7	8.7	8.7	-0.12	-0.05		
30.90	11	4.25	4.2	4.225	-0.74	-0.33		
			Gross Primary Productivity				2.97	10.68 kcal/m2-d
23.15 hours			Respiration			-0.19	-4.61	-16.60 kcal/m2-d

Table 2.2 continued

Station 6			Depth:	0.15 m				
Time (hrs)	Temp (deg C)	DO1 (g/m3)	DO2 (g/m3)	DO ave (g/m3)	Rate (g/m3-hr)	Rate (g/m2-hr)	(g/m2)	(kcal/m2)
7.950	4	6.1	6.1	6.1				
10.50	8	7.8	8	7.9	0.71	0.11	0.42	1.50
13.23	11	8.8	8.7	8.75	0.31	0.05	0.29	1.03
15.50	15.5	9.7	10.1	9.9	0.51	0.08	0.30	1.10
18.55	10.3	10.9	10.8	10.85	0.31	0.05	0.32	1.15
21.17	12	8.7	8.2	8.45	-0.92	-0.14		
25.33	11	7.2	7.7	7.45	-0.24	-0.04		
30.35	10.5	7.21	7.65	7.43	0.00	0.00		
			Gross Primary Productivity				1.33	4.78 kcal/m2-d
22.40 hours			Respiration			-0.06	-1.39	-5.01 kcal/m2-d

Station 7			Depth:	0.3 m				
Time (hrs)	Temp (deg C)	DO1 (g/m3)	DO2 (g/m3)	DO ave (g/m3)	Rate (g/m3-hr)	Rate (g/m2-hr)	(g/m2)	(kcal/m2)
7.250	6	7.4	7.7	7.55				
9.950	10	5.3	4.4	4.85	-1.00	-0.30	-0.53	-1.89
13.250	11.2	10.8	10.8	10.8	1.80	0.54	2.13	7.68
15.250	13	9.62	9.4	9.51	-0.65	-0.19	-0.18	-0.63
19.070	11	11	10.6	10.8	0.34	0.10	0.79	2.84
21.700	14.7	9	10.16	9.58	-0.46	-0.14		
24.250	15	4.9	5	4.95	-1.82	-0.54		
27.500	11	9	9.65	9.325	1.35	0.40		
30.300	11	7.8	8.2	8	-0.47	-0.14		
			Gross Primary Productivity				2.22	8.00 kcal/m2-d
23.05 hours			Respiration			-0.11	-2.53	-9.11 kcal/m2-d

Station 8			Depth:	0.87 m				
Time (hrs)	Temp (deg C)	DO1 (g/m3)	DO2 (g/m3)	DO ave (g/m3)	Rate (g/m3-hr)	Rate (g/m2-hr)	(g/m2)	(kcal/m2)
6.75	7	6.7	6.5	6.6				
10.23	10	5	4.6	4.8	-0.52	-0.45	-0.65	-2.33
12.80	12	6.5	8.2	7.35	0.99	0.86	2.90	10.43
15.53	13	6.91	7.15	7.03	-0.12	-0.10	0.44	1.59
18.97	12	8.9	8.8	8.85	0.53	0.46	2.49	8.97
21.57	14.5	7.6	7.4	7.5	-0.52	-0.45		
24.50	12	5.6	5.9	5.75	-0.60	-0.52		
27.80	12	5.5	4.8	5.15	-0.18	-0.16		
30.47	11	5.65	5.1	5.375	0.08	0.07		
			Gross Primary Productivity				5.18	18.66 kcal/m2-d
23.72 hours			Respiration			-0.26	-6.34	-22.81 kcal/m2-d

Station 9			Depth:	0.3 m				
Time (hrs)	Temp (deg C)	DO1 (g/m3)	DO2 (g/m3)	DO ave (g/m3)	Rate (g/m3-hr)	Rate (g/m2-hr)	(g/m2)	(kcal/m2)
7.000	8	7.5	7.6	7.55				
10.470	10	5.8	5.2	5.5	-0.59	-0.18	0.01	0.05
12.670	11.5	6.4	7.2	6.8	0.59	0.18	0.79	2.84
15.700	14	11.05	9.35	10.2	1.12	0.34	1.57	5.65
18.750	13	9.8	10.3	10.05	-0.05	-0.01	0.51	1.83
21.500	14.5	7.8	8.5	8.15	-0.69	-0.21		
25.000	12	4.2	x	4.2	-1.13	-0.34		
28.300	11	6.1	6.45	6.275	0.63	0.19		
30.580	11	4.35	2.6	3.475	-1.23	-0.37		
			Gross Primary Productivity				2.88	10.37 kcal/m2-d
23.58 hours			Respiration			-0.18	-4.35	-15.67 kcal/m2-d

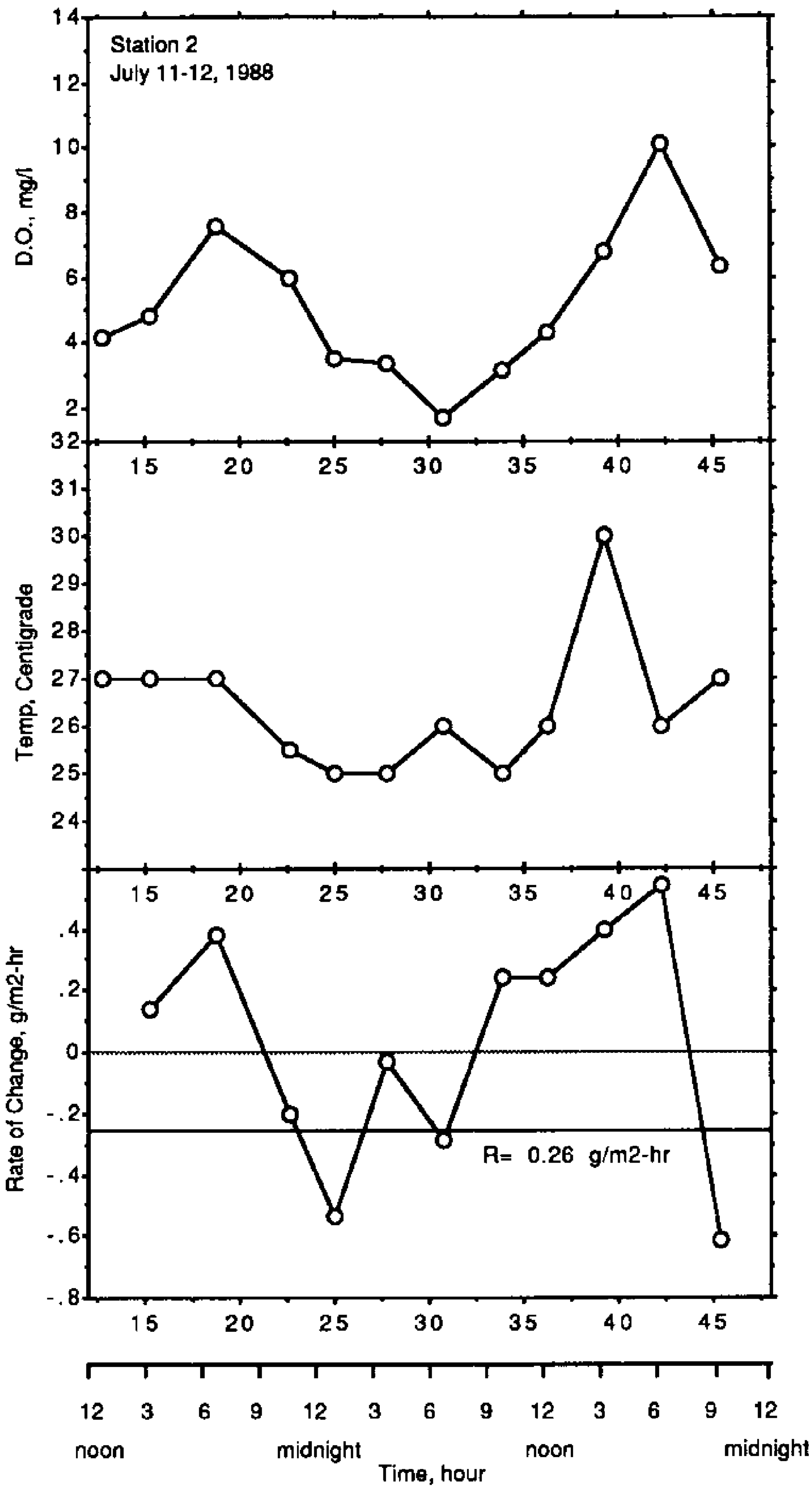


Figure 2.4 Diurnal oxygen patterns, water temperature and oxygen rate of change curves for Old Woman Creek Wetland, station 2, July 11–12, 1988

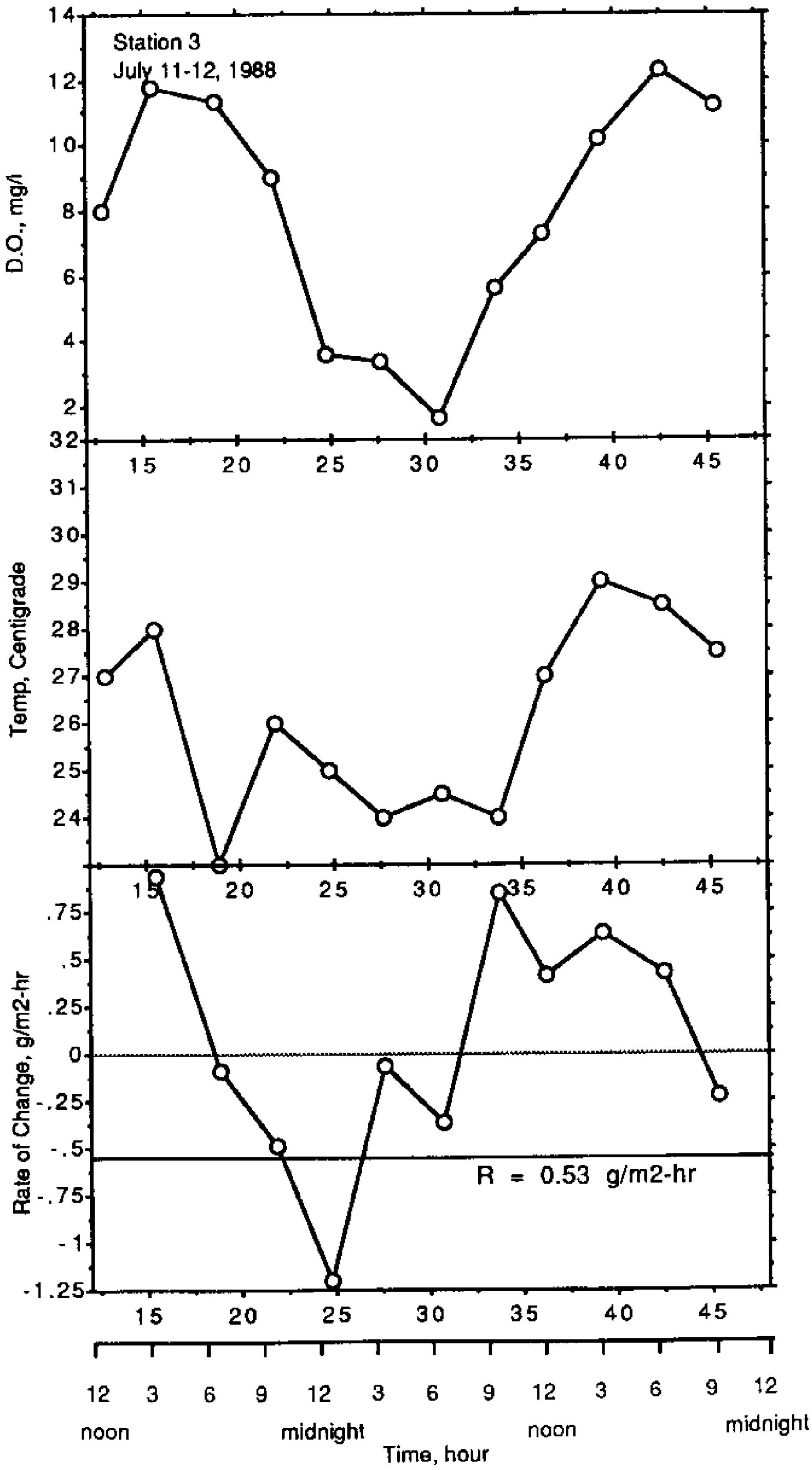


Figure 2.5 Diurnal oxygen patterns, water temperature and oxygen rate of change curves for Old Woman Creek Wetland, station 3, July 11–12, 1988

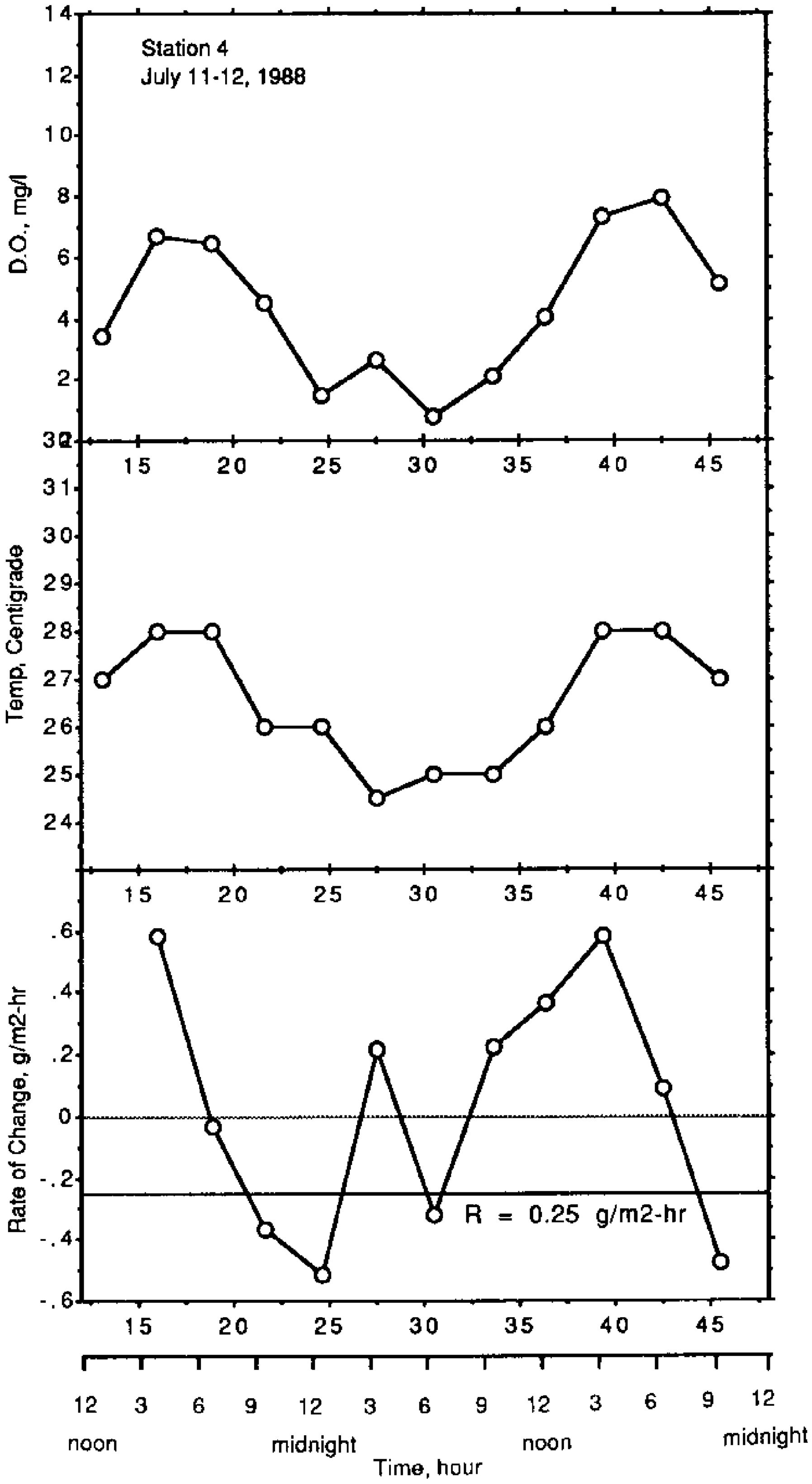


Figure 2.6 Diurnal oxygen patterns, water temperature and oxygen rate of change curves for Old Woman Creek Wetland, station 4, July 11–12, 1988

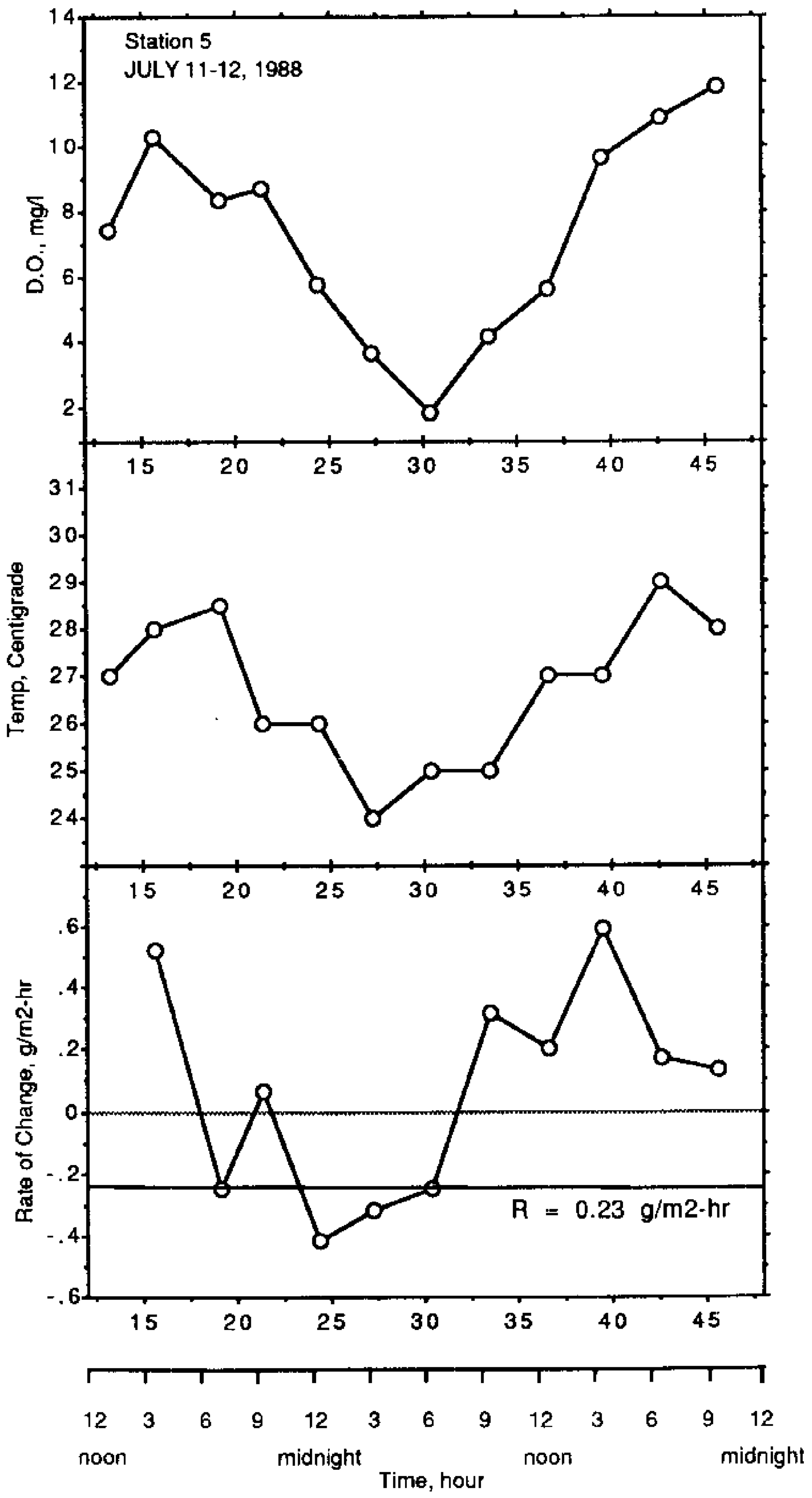


Figure 2.7 Diurnal oxygen patterns, water temperature and oxygen rate of change curves for Old Woman Creek Wetland, station 5, July 11-12, 1988

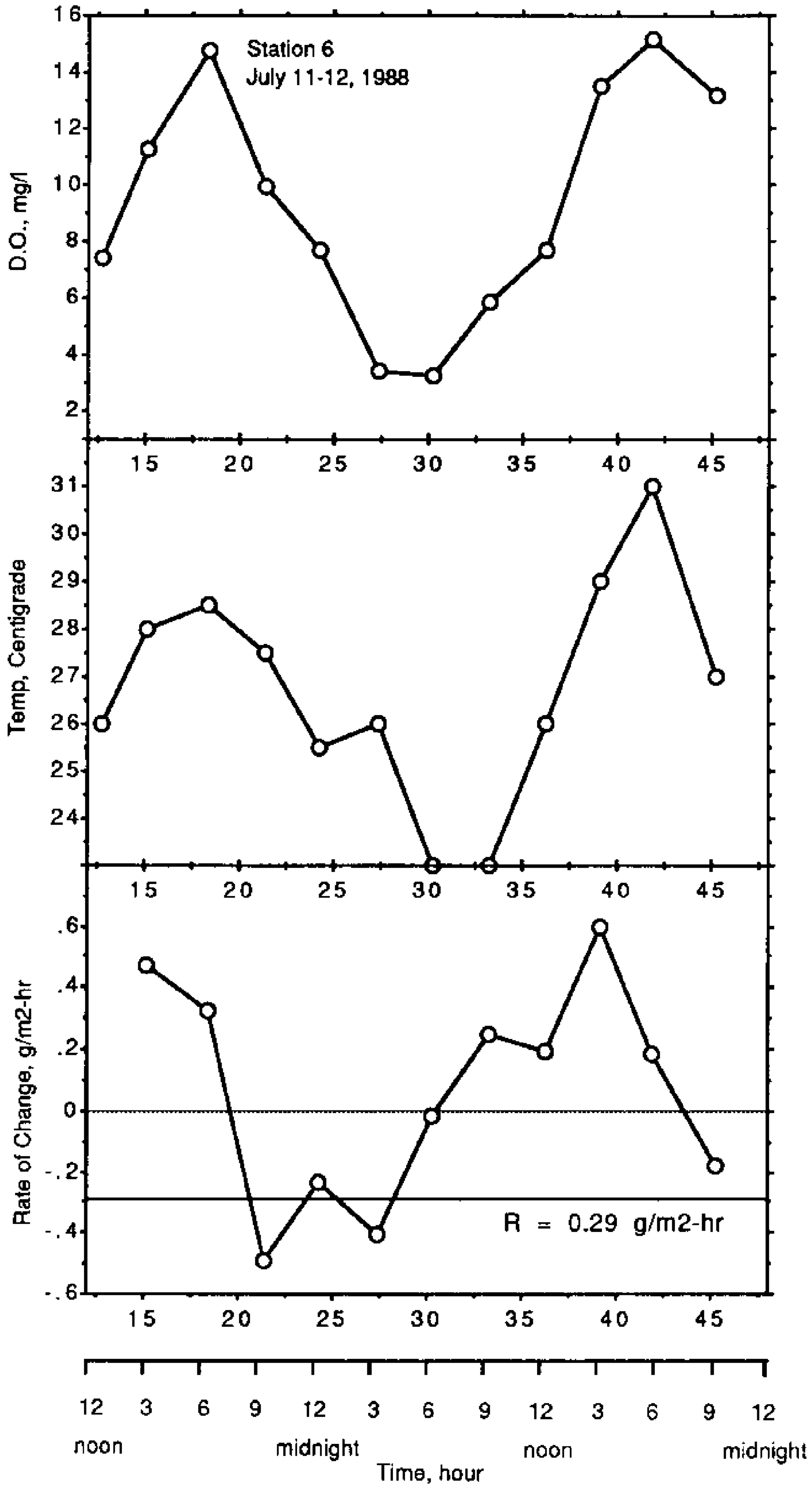


Figure 2.8 Diurnal Diurnal oxygen patterns, water temperature and oxygen rate of change curves for Old Woman Creek Wetland, station 6, July 11–12, 1988

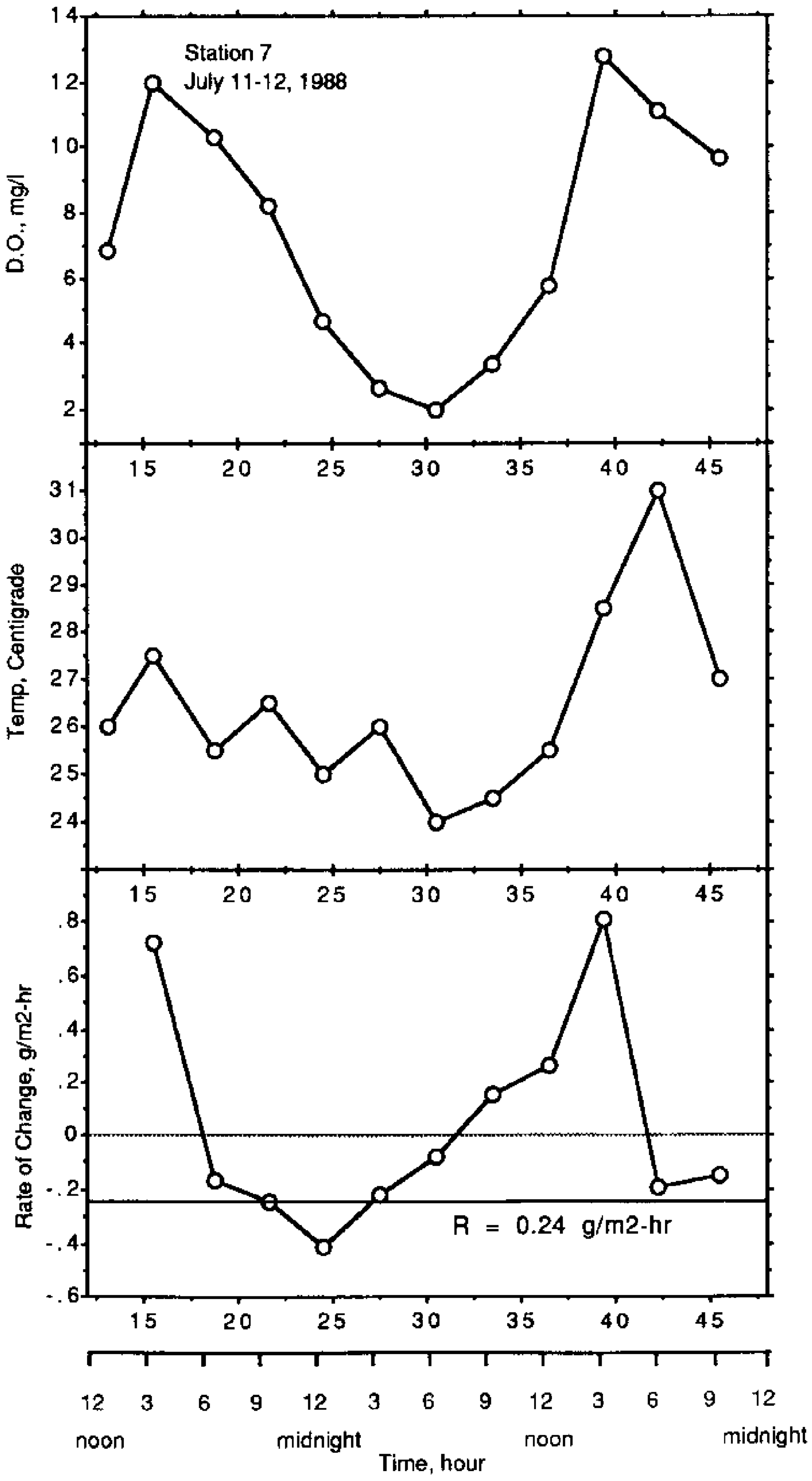


Figure 2.9 Diurnal oxygen patterns, water temperature and oxygen rate of change curves for Old Woman Creek Wetland, station 7, July 11–12, 1988

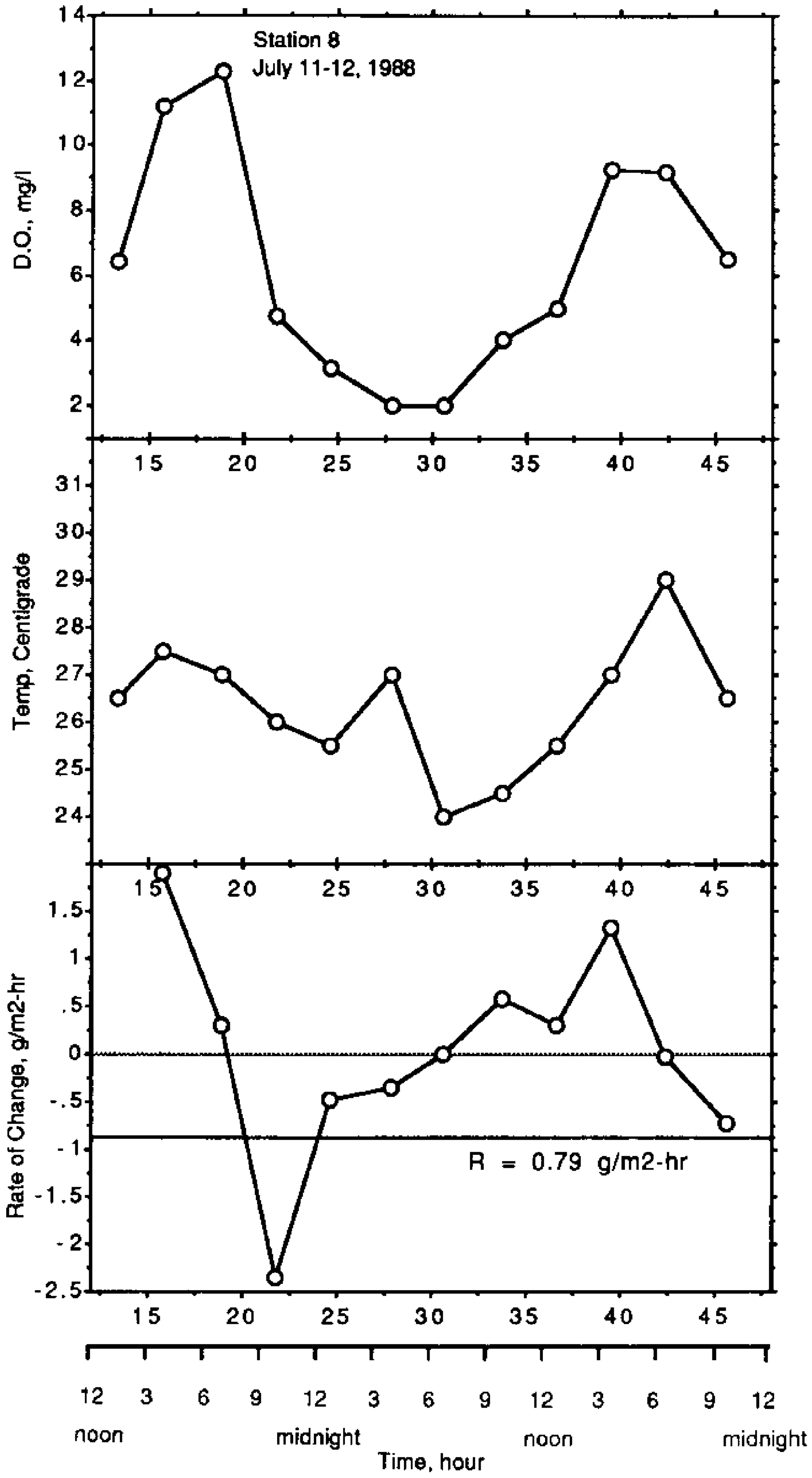


Figure 2.10 Diurnal oxygen patterns, water temperature and oxygen rate of change curves for Old Woman Creek Wetland, station 8, July 11–12, 1988

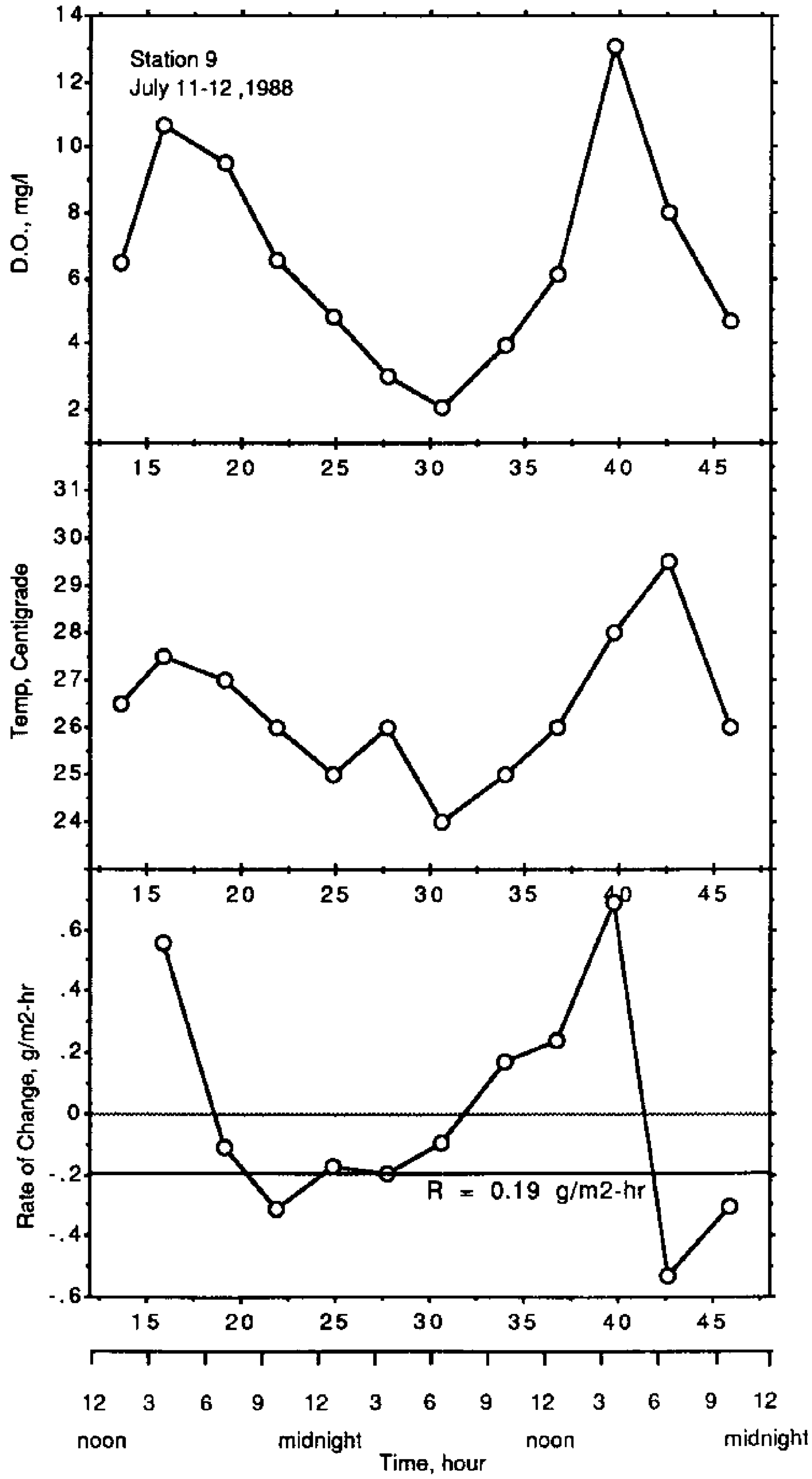


Figure 2.11 Diurnal oxygen patterns, water temperature and oxygen rate of change curves for Old Woman Creek Wetland, station 9, July 11–12, 1988

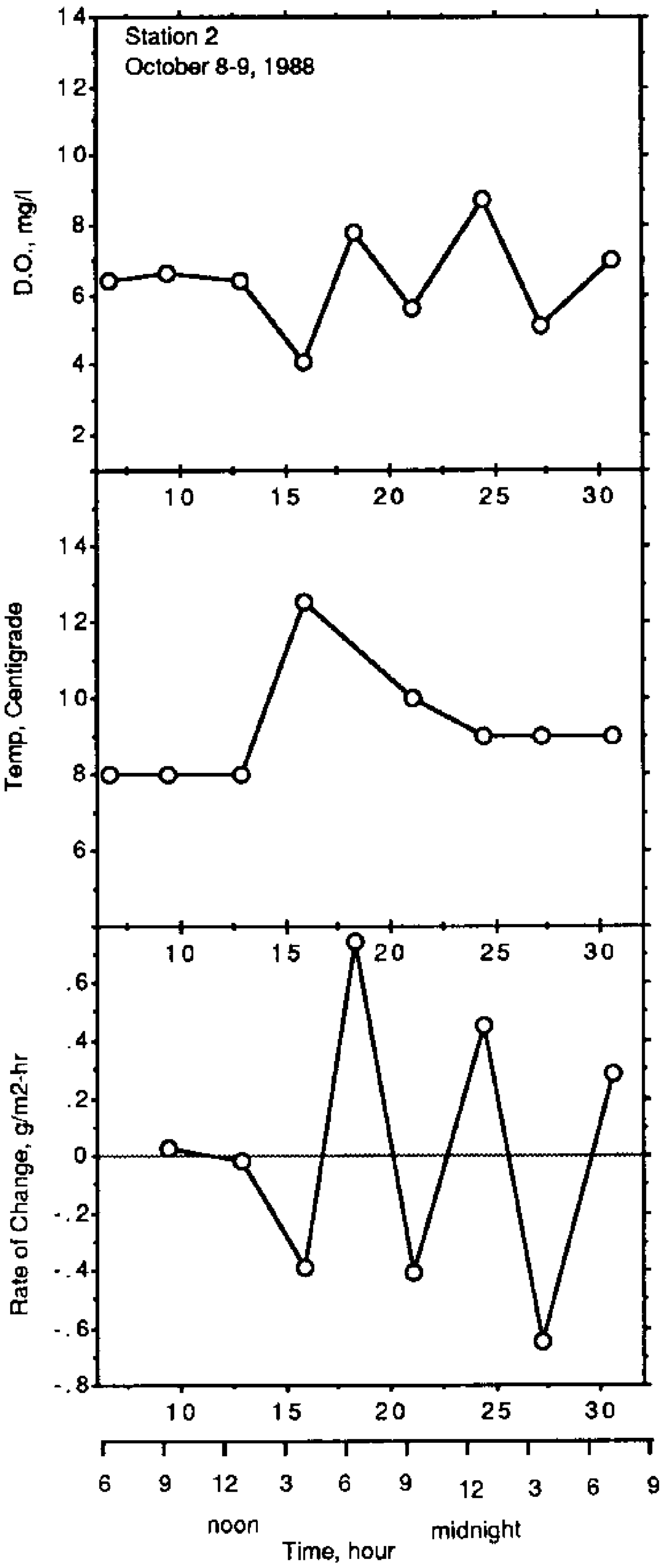


Figure 2.12 Diurnal oxygen patterns, water temperature and oxygen rate of change curves for Old Woman Creek Wetland, station 2, October 8–9, 1988

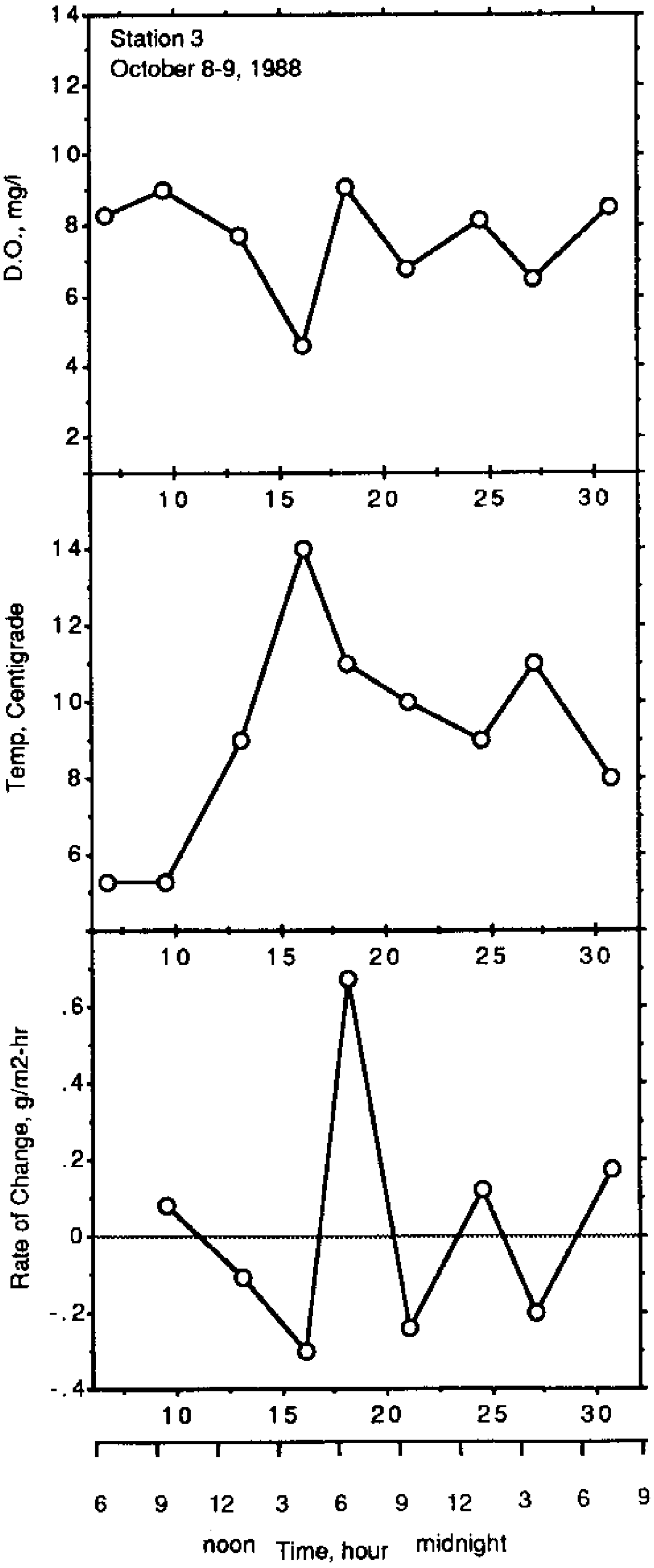


Figure 2.13 Diurnal oxygen patterns, water temperature and oxygen rate of change curves for Old Woman Creek Wetland, station 3, October 8-9, 1988

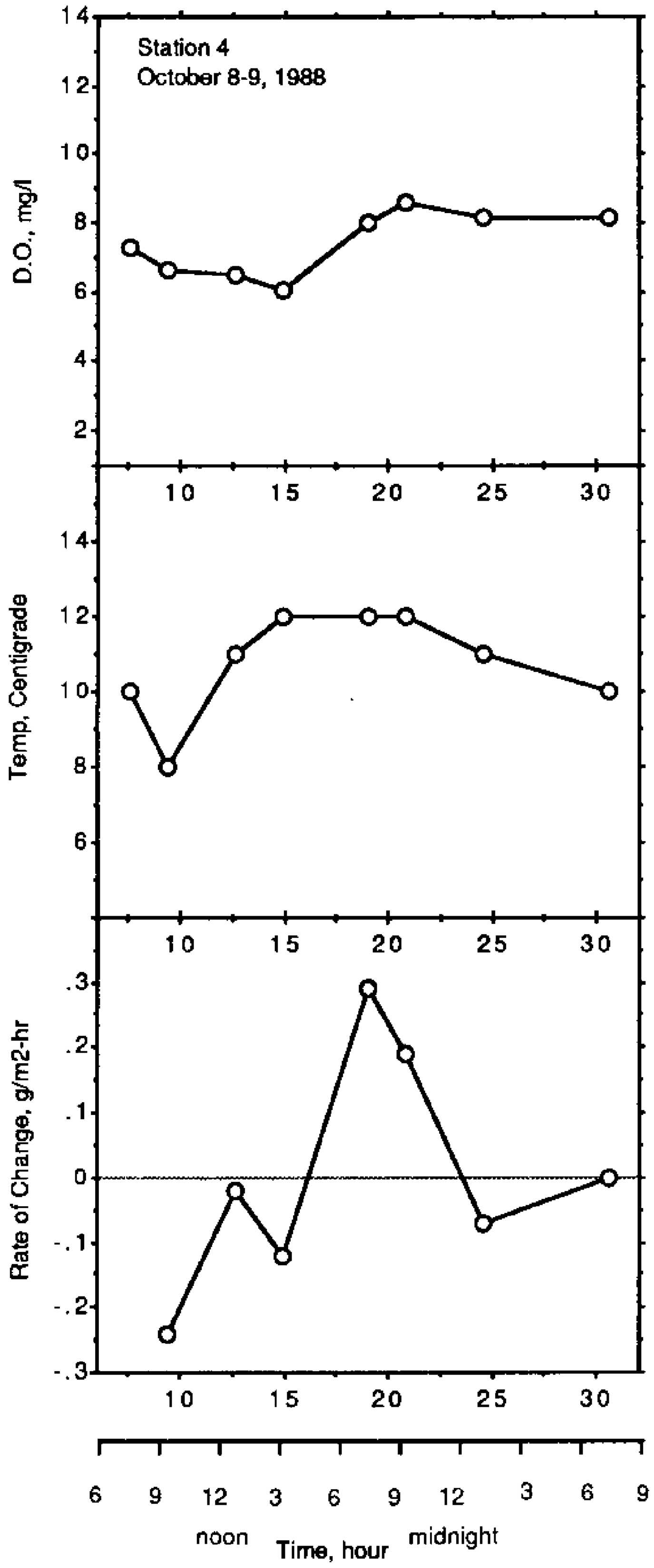


Figure 2.14 Diurnal oxygen patterns, water temperature and oxygen rate of change curves for Old Woman Creek Wetland, station 4, October 8–9, 1988

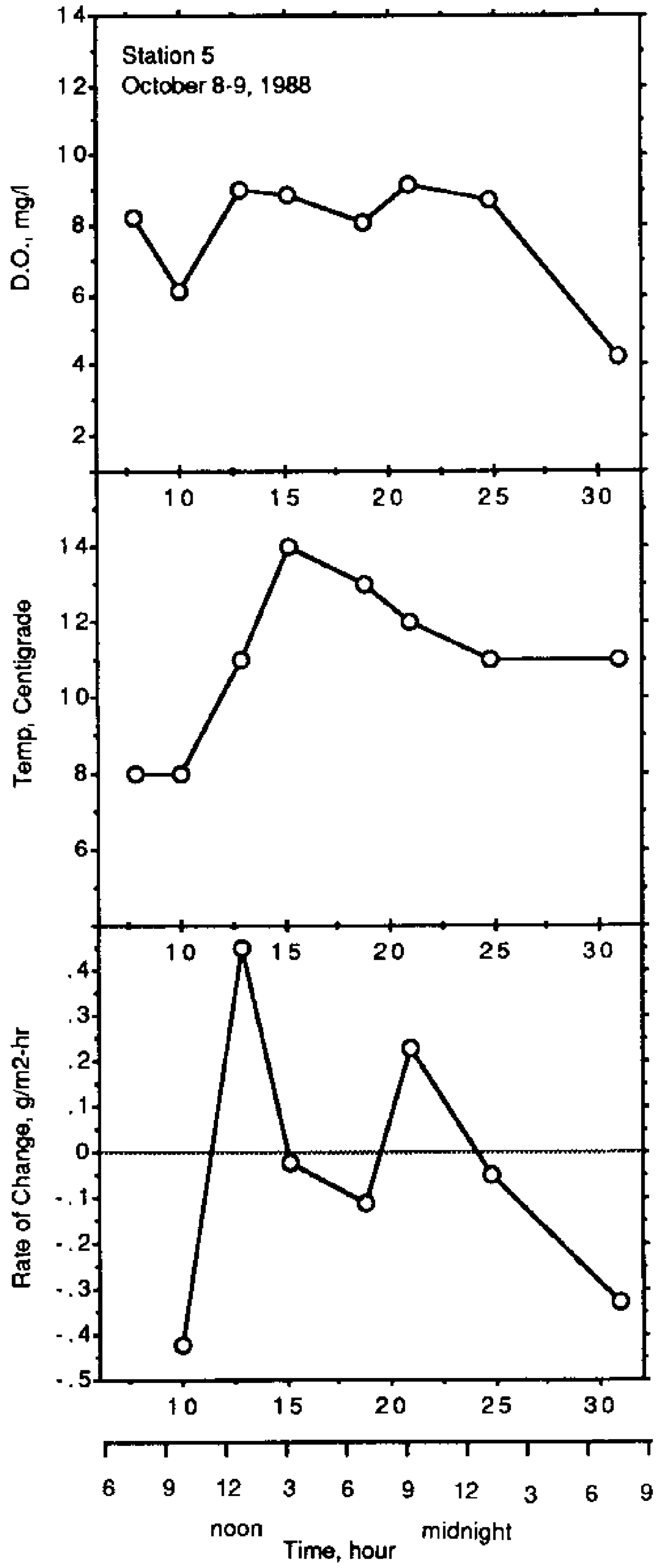


Figure 2.15 Diurnal oxygen patterns, water temperature and oxygen rate of change curves for Old Woman Creek Wetland, station 5, October 8–9, 1988

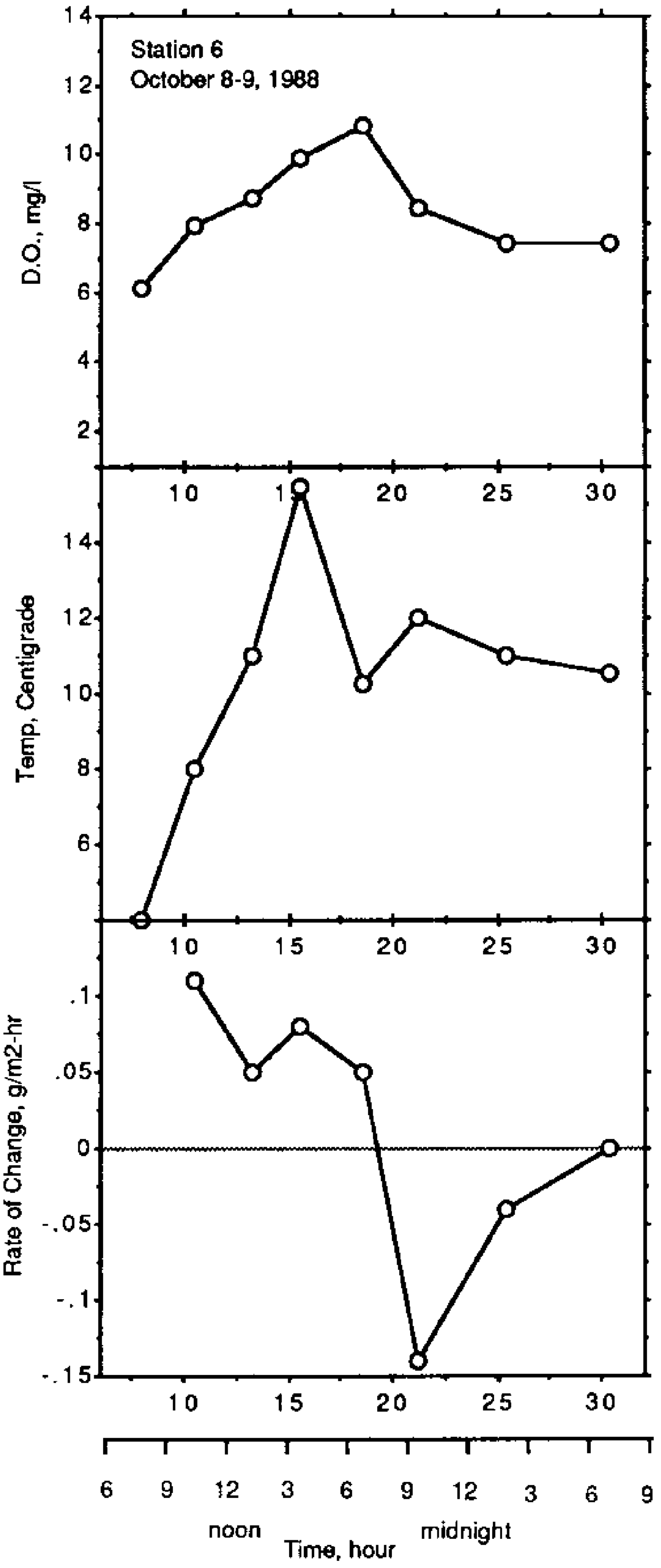


Figure 2.16 Diurnal oxygen patterns, water temperature and oxygen rate of change curves for Old Woman Creek Wetland, station 6, October 8-9, 1988

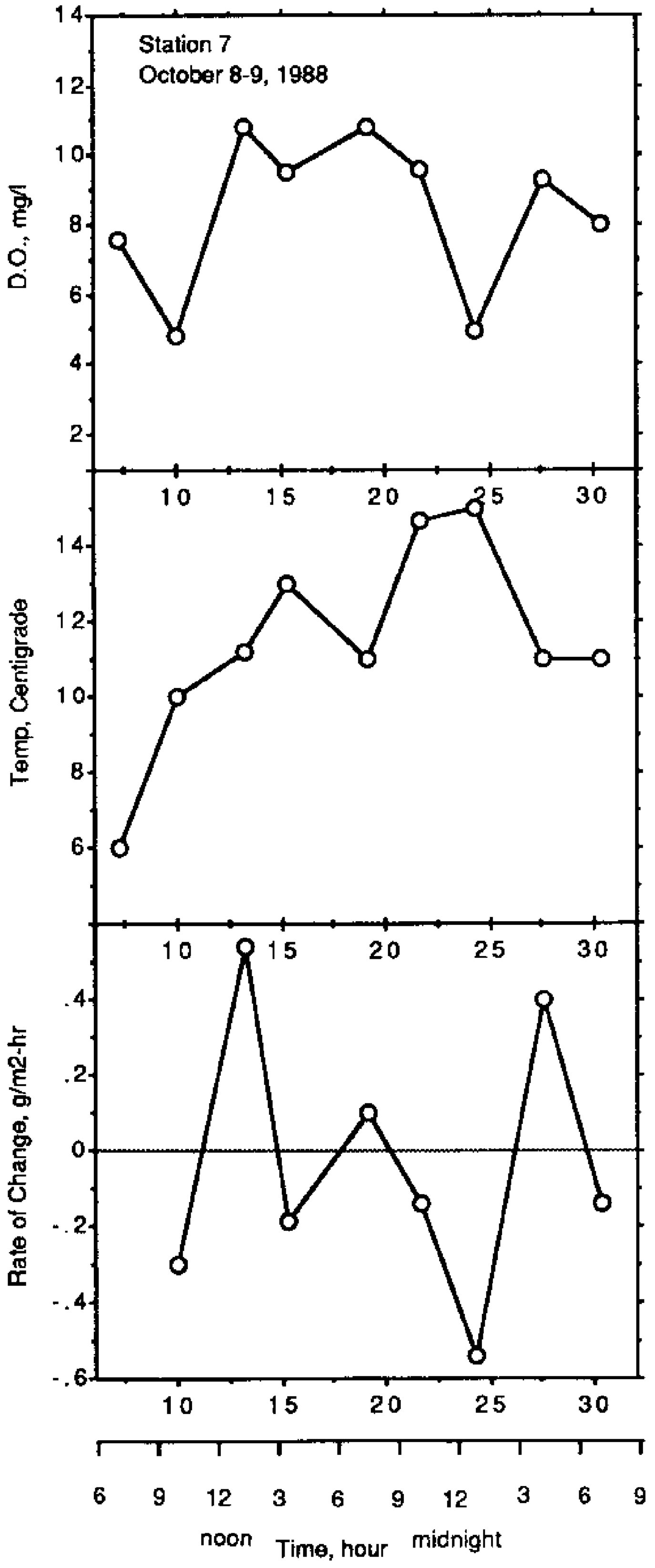


Figure 2.17 Diurnal oxygen patterns, water temperature and oxygen rate of change curves for Old Woman Creek Wetland, station 7, October 8–9, 1988

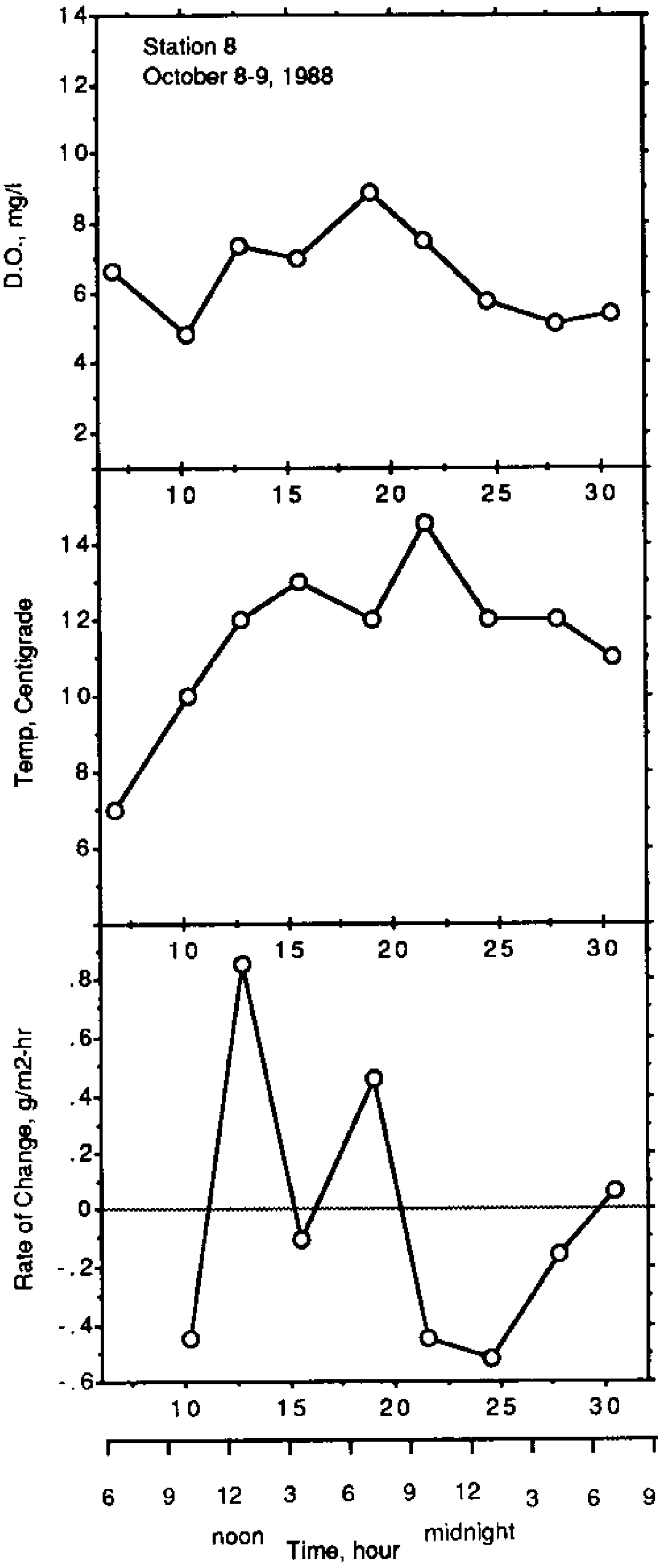


Figure 2.18 Diurnal oxygen patterns, water temperature and oxygen rate of change curves for Old Woman Creek Wetland, station 8, October 8-9, 1988

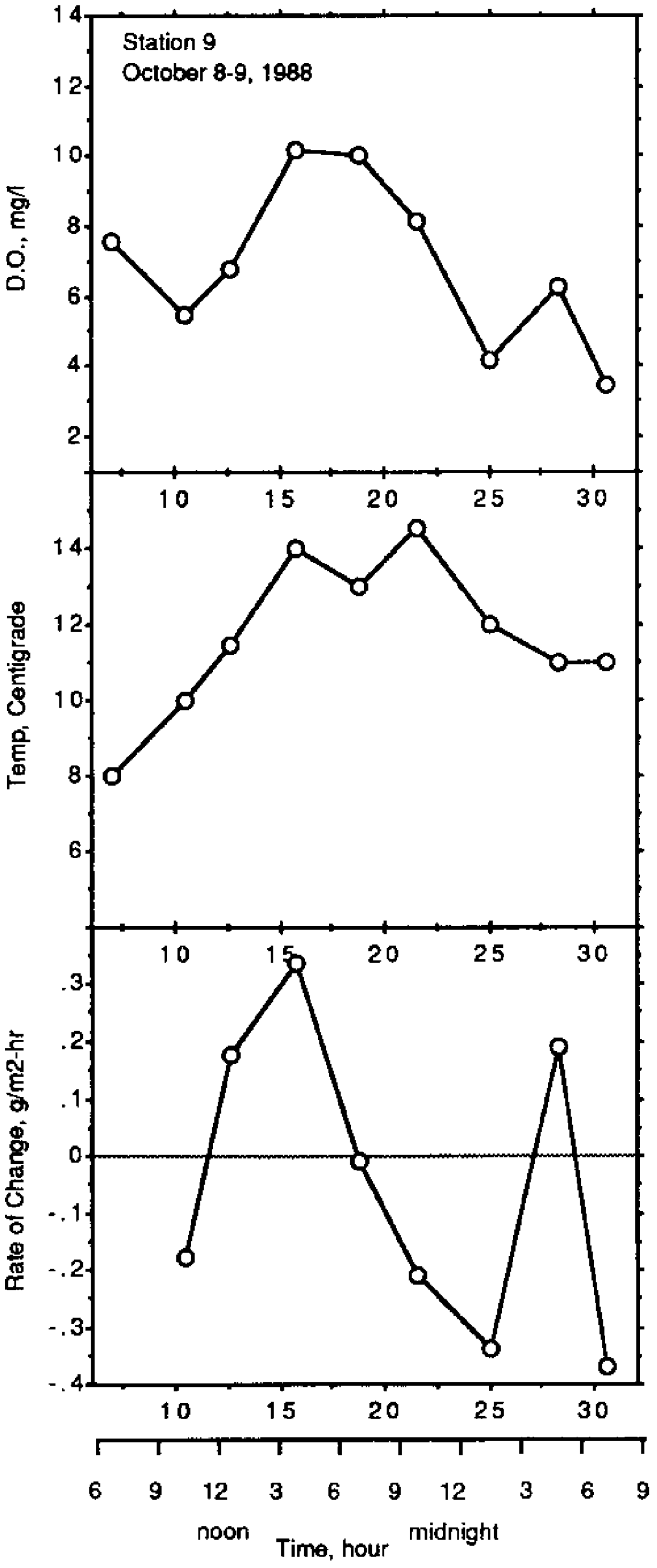


Figure 2.19 Diurnal oxygen patterns, water temperature and oxygen rate of change curves for Old Woman Creek Wetland, station 9, October 8–9, 1988

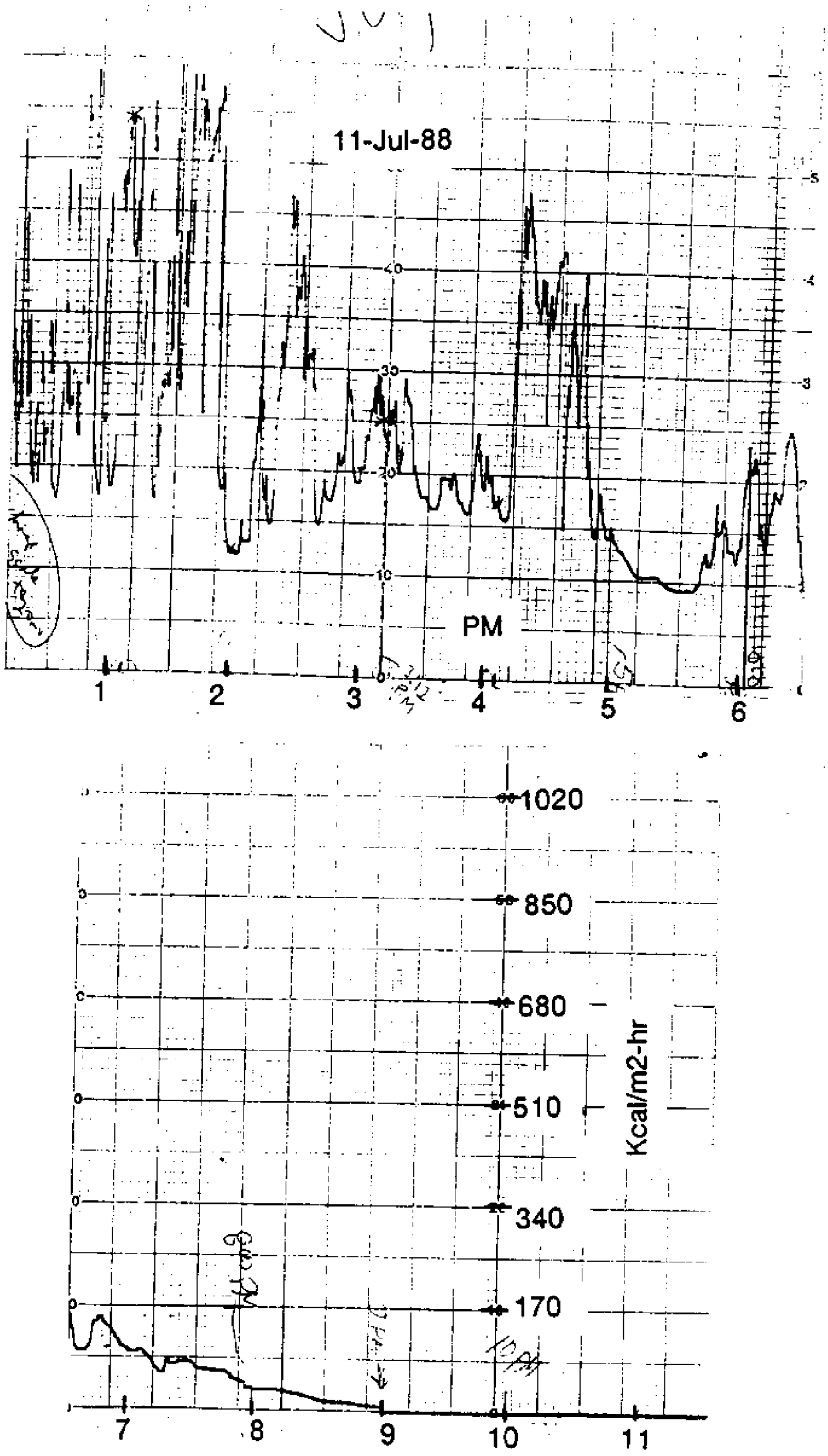


Figure 2.20 Solar radiation pattern for July 11-12, 1988 at Old Woman Creek wetland

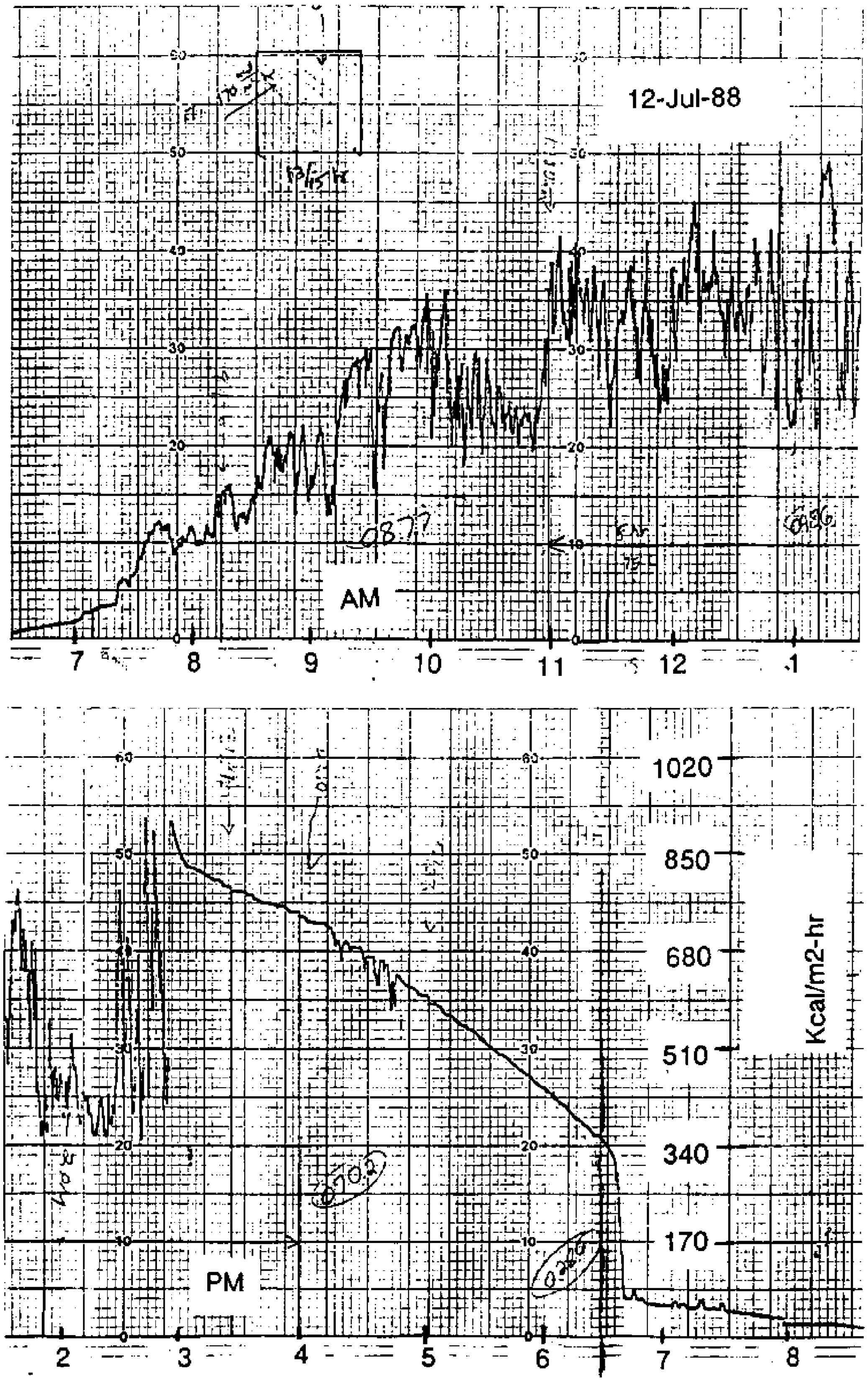


Figure 2.20 continued

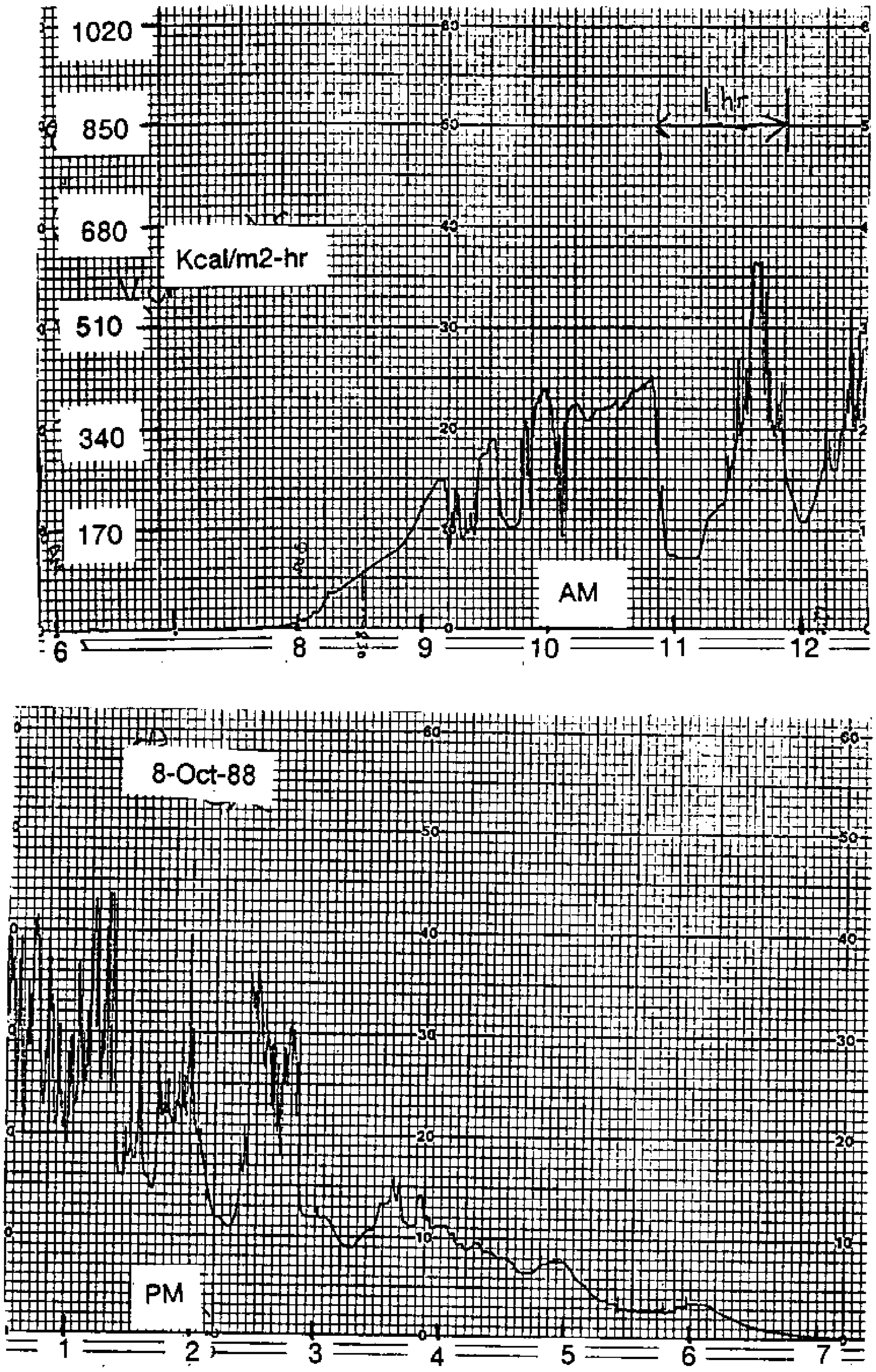


Figure 2.21 Solar radiation pattern for October 8, 1988 at Old Woman Creek wetland

3

Seasonal Patterns of Planktonic and Macrophyte Productivity of a Freshwater Coastal Wetland

Brian C. Reeder
William J. Mitsch

Introduction

Heath (1987), Klarer (1988) and Mitsch et al. (1989) have suggested, with some preliminary data, that Old Woman Creek wetland may be an effective sink and transformer of phosphorus, a chemical determined to be a culprit in the eutrophication of adjacent Lake Erie. The productivity of a wetland may be directly linked to its ability to function as a sink or transformer of nutrients (Mitsch et al. 1989). Few studies have been done to determine the primary productivity of a Lake Erie coastal wetland; the previous chapter reports on the planktonic productivity of Old Woman Creek wetland for two intensive sampling efforts. In order to accurately quantify the ability of these systems to internally cycle phosphorus, estimates of annual primary productivity are needed in addition to data on water chemistry. A measurement of systems level productivity of plankton and macrophytes can be modelled to predict wetland functioning and efficiency. This has been done on a number of other wetlands to determine the role of productivity in nutrient cycling (Nixon et al. 1976; Mitsch 1977; Mitsch et al. 1979; Pomeroy and Weigert 1981; Ewel and Odum 1984). This paper estimates the primary productivity of the open water and *Nelumbo lutea* communities of Old Woman Creek wetland and suggests reasons for the observed patterns of productivity.

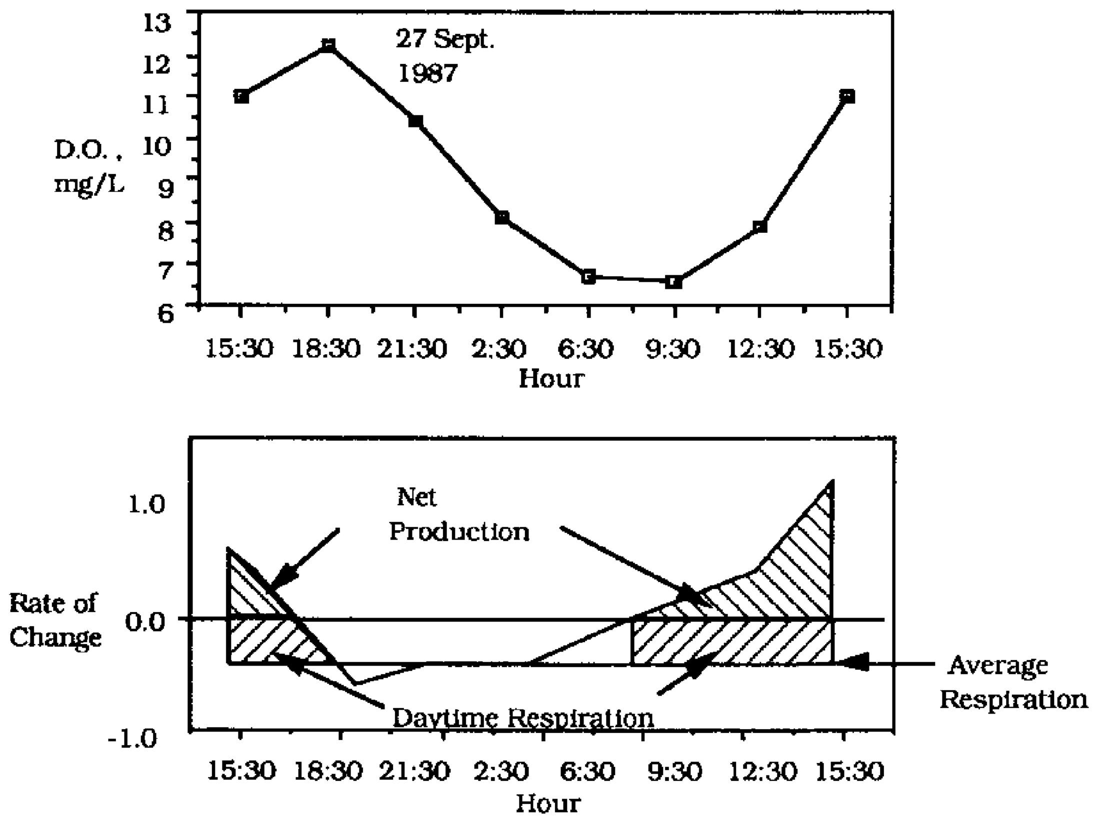
Methods

Whole System Metabolism

Productivity and respiration were estimated on ten occasions by evaluation of the diurnal changes in dissolved oxygen (Odum and Hoskin 1958). Measurements were taken every three to six hours (taking care to get data near dawn and dusk) at sites #3, #4, #5, #6, #7, and #9 (shown in Figure 2.1). Dissolved oxygen was measured with the azide modification of the Winkler technique (APHA 1985) at dawn, dusk, and dawn, and frequently in between with a YSI model 54 dissolved oxygen meter (calibrated by the Winkler method). During winter water temperatures were near or below 0° C; therefore, planktonic activity was assumed to be insignificant.

Daily net productivity was determined by summing the changes in oxygen concentration between sunrise and sunset. Daily respiration was calculated as the mean of the nighttime respiration over the day (assuming that daylight respiration was nearly equal to nighttime respiration). Gross primary production was estimated by adding the daily net production to the sum of the mean daily respiration during the daylight hours. Figure 3.1 shows a diurnal sample curve and productivity calculation.

Measurements were made to determine possible corrections for diffusion with a floating dome (Copeland and Duffer 1964). A 5-liter plastic dome fitted with a YSI dissolved oxygen probe (Figure 3.2) was purged with nitrogen to a near zero dissolved oxygen reading. The rate at which the oxygen recovered was then used to calculate the diffusion rate. Although measured for at least five hours at numerous times during the course of the study, the highest rate of diffusion was 0.012 mg 02 m-2 hr-1, which could possibly be due to leaks in the dome system. This rate does not contribute a significant error in metabolism calculations, even at low saturation.



$$\text{Rate of Change (g/m2-hr)} = \frac{\Delta\ \text{D.O. (g/m3)}}{\Delta\ \text{t (hours)} * \text{depth (m)}}$$

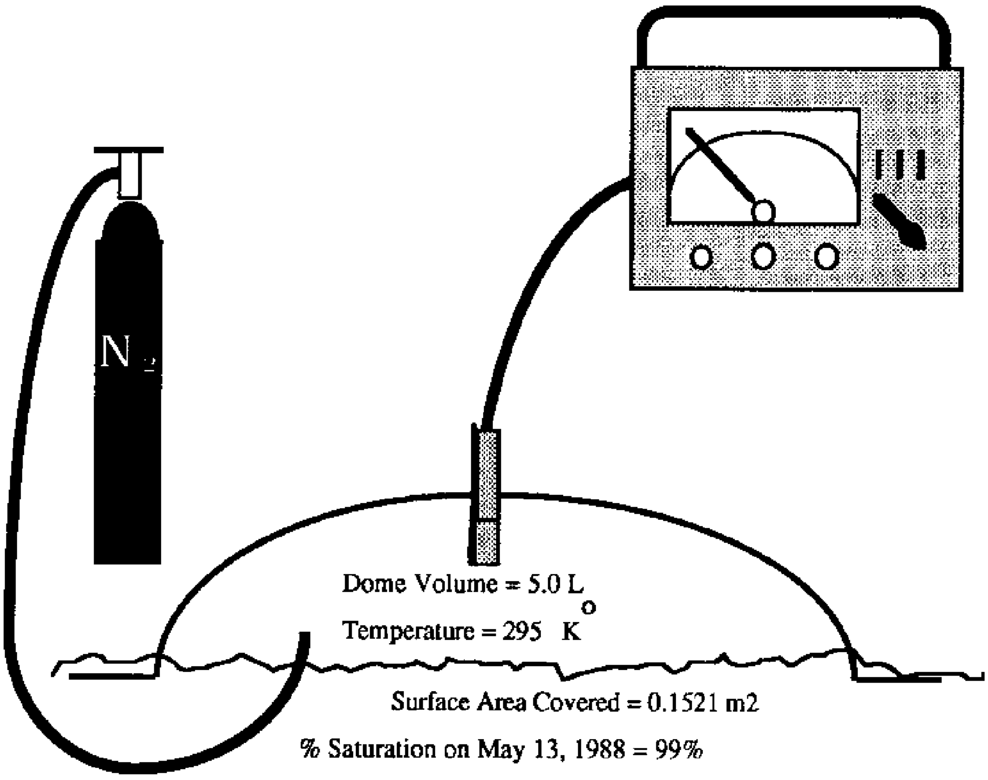
▧ For Net Productivity (g/m2-day), integrate rate of change above 0 for daytime hours

For Total Respiration, find average nighttime respiration (R) (g/m2/hr) * 24 hours/day

▨ For daytime respiration, integrate rate of change below 0 for daytime hours and above average respiration line

Daytime Respiration + Net Productivity =
Gross Primary Productivity (g/m2-day)

Figure 3.1 Example of metabolism calculations from diurnal change in dissolved oxygen as used in Old Woman Creek wetland



% Saturation on May 13, 1988 = 99%

% Increase of O2 in dome = 0.075 ml/hr

According to Odum and Hoskin (1958):

$$\frac{0.075 * \frac{273}{295} * \frac{32\ gO2}{2400\ ml}}{0.1521 * .99} = .00068\ g\ \ O2/m2\text{-}hr$$

Figure 3.2 Diffusion dome used to estimate oxygen diffusion in Old Woman Creek wetland

Chlorophyll *a*

Water samples were taken at the 10 sites shown in Figure 2.1 every two weeks and analyzed for chlorophyll *a*. Fifty ml of fresh sample were filtered through a 0.45 μm membrane filter; the filter was placed in a 50-ml centrifuge tube using 15 ml of 90% acetone as an extractant. The extract was kept at a maximum of 4°C for at least 24 hours and centrifuged to clarity. The top 3.5 ml was decanted into a 1-cm path length spectrophotometer cell. Absorbances were read at 750 and 665 nm. The sample was then acidified in the spectrometer cell with 3 drops of 1 N HCl to correct for degradation using Lorenzen's (1967) equation:

$$\text{Percent Native Chlorophyll} = \frac{A665 - A665a}{0.7 * A665} \times 100$$

where,

A665 = absorbance at 665 nm before acidification, and

A665a = absorbance at 665 nm after acidification.

Macrophytes

Estimates of macrophyte (*Nelumbo lutea*) productivity were obtained with a technique which minimized harvesting impact. During July and August of 1988 three 40-m transects were taken through *Nelumbo* patches and the maximum diameters of the floating leaf heads were recorded. Random measured plants were harvested and dried at 104°C overnight, then weighed. The area under the transect was then determined by summing the areas of each leaf (πr^2), which allowed the calculation of dry weight/area (Σ dry weights/ $\Sigma \pi r^2$).

The standard method of harvesting at peak biomass (Vollenwieder 1974) was also used to test the reliability of the new method. In April 1987, six randomly placed 1 m^2 quadrats were placed in areas were *Nelumbo* was known to grow. These were harvested at peak biomass (based on flowering time) and the plants dried at 104°C overnight and weighed. In 1988, eight 2.25 m^2 quadrats were randomly chosen and harvested in May, July, and at peak biomass in late August. To provide an estimate of total uptake of nutrients, twenty-five randomly selected samples from the August harvest were analyzed for chemical composition by the Ohio Agricultural Research and Development laboratory.

The total area covered by *Nelumbo* was estimated from infra-red aerial slides of the wetland taken within one week of the August 1988 harvest by the Ohio Department of Natural Resources. The slides were projected onto a map of the wetland, the *Nelumbo* patches drawn on the map, and the area calculated by a digital planimeter.

Insolation

Daily insolation data were obtained from a continuous recording pyroheliometer located about 35 km northwest of the site at the light house on South Bass Island (in Lake Erie). The area for each day on a weekly strip chart was measured by planimeter. Due to data gaps in the record (Sunday is almost always incomplete), weekly average insolation was estimated.

Results

Results of planktonic metabolism in Old Woman Creek are summarized in Table 3.1 and Figure 3.3. Complete data on dissolved oxygen readings and calculations are given in Appendix 3.1. Planktonic productivity peaked in late June and mid-July, leveled off until late August, then fell in early September to a level that was no longer discernible by the diurnal method (during a brief cold spell accompanied by heavy rainfall). Productivity increased again in late September and continued until cold weather. Ecological efficiency on the particular day the diurnals were done is generally low. Chlorophyll *a* did not correlate well with whole system metabolism measurements; however, when average values for both whole system metabolism and chlorophyll *a* are plotted together, they follow the same pattern, and a correlation for the means is significant (Figure 3.4). Annual gross planktonic productivity translates to a total water column productivity of 976 g O_2/m^2-yr. This is equivalent to 366 g C/m^2-yr or 3,700 kcal/m^2-yr.

Floating-leaf vegetation (*Nelumbo lutea*) began to appear in early May. Peak biomass occurred around late August, and by late September most of the plants were dead or decaying. The dry weights obtained for these plants from the quadrat studies were compared to the weights obtained from the transect-regression method (Figure 3.5a) and found to yield similar results. The quadrat method suggested a peak biomass of 160 ± 30 g dry wt/m^2 while the transect method yielded an average of 131 g dry wt/m^2 (Table 3.2; see also Appendices 3.2 and 3.3). Macrophyte net productivity, conservatively estimated by biomass at peak harvest, is thus 75 g C/m^2-yr or 750 kcal/m^2-yr.

Phosphorus concentration of *Nelumbo* ranged from 2.17 to 6.07 mg P/g dry wt (ave± std dev. = 3.41 ± 1.07 mg P/g, n = 13). An inverse relationship between leaf diameter and phosphorus concentration was found (Figure 3.5b) and was used to calculate the phosphorus stored in the *Nelumbo* biomass in the wetland. Phosphorus in the biomass of the macrophytes averaged 0.34 g P/m^2 in the *Nelumbo* beds

Table 3.1 Gross primary productivity of water column at Old Woman Creek wetland
All values in g O_2/m^2-day.

date	3	4	station 5	6	7	9	mean ±SD	weighted mean
June 27 87	10.8	7.6	6.1	-	5.4	6.4	7.2 ±2.1	6.8
Sept 26 87	6.9	9.7	2.8	-	3.2	2.1	4.9 ±3.2	5.3
May 14 88	6.2	7.7	7.7	6.8	8.1	8.1	7.4 ±0.77	7.6
May 28 88	4.0	6.0	4.1	3.0	4.1	4.4	4.3±0.98	4.1
June 19 88	7.1	7.7	9.1	6.5	10.6	9.5	8.4±1.6	7.7
June 27 88	7.6	5.8	9.8	6.8	7.8	9.0	7.8±1.4	7.4
July 12 88	13.8	7.4	7.8	7.2	6.0	3.5	7.6 ±3.4	7.0
July 26 88	3.7	8.1	2.7	5.2	7.8	5.9	5.6 ±2.2	6.4
Aug 25 88	5.9	5.8	4.5	4.9	8.9	2.6	5.4 ±2.1	6.1
Sept 24 88	8.4	5.3	7.7	2.5	9.9	6.3	6.7 ±2.6	6.7
mean ±SD	7.1±3.2	6.7±1.1	6.7 ±2.6	5.4±1.8	7.9±2.1	6.2±2.6		

Table 3.2 Biomass and phosphorus concentrations of *Nelumbo lutea* for Old Woman Creek wetland

date	Quadrat Method g dry/m^2, mean±SD	Transect Method g dry/m^2, mean	Phosphorus mg/g dry wt
Sept 6 87	109 ± 48	-	-
May 14 88	10 ± 2	-	-
July 12 88	101 ± 32	125	3.3
Aug 25 88	160 ± 30	131 (n=3)	3.4 (n=3)
total/OWC 1987 (kg)		12,971	
total/OWC 1988 (kg)		14,827	63.5

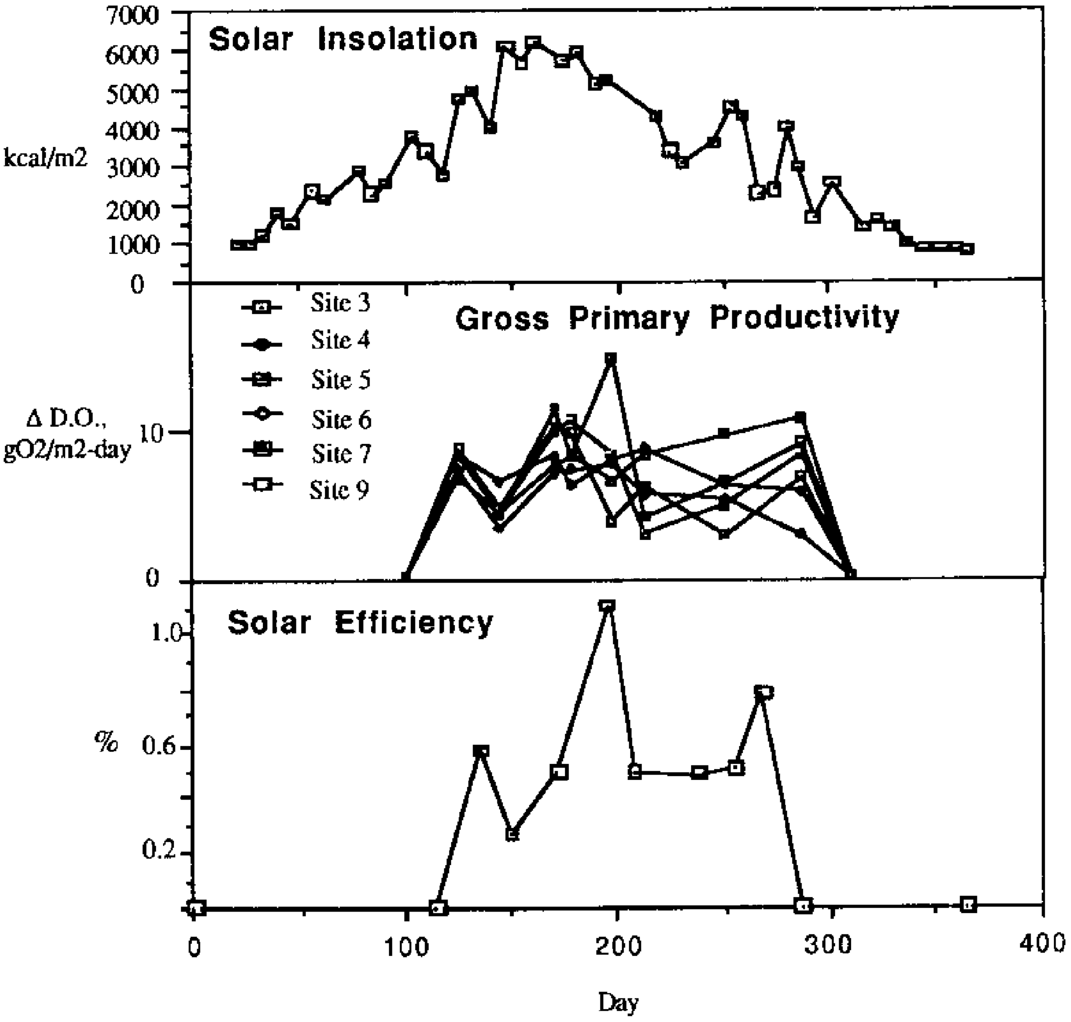


Figure 3.3 Annual patterns of insolation, gross primary productivity, and solar efficiency for Old Woman Creek wetland open water in 1988

during July and August (calculations shown in Appendix 3.2).

Discussion

As the waters warm and cool, and as the nutrient and sediment loads change, so do the planktonic communities (Wetzel 1983). Planktonic productivity is high during the initial diatom blooms in Old Woman Creek wetland as the water begins to warm. Throughout the summer, productivity is high and seems to be limited only by the length of the day. Since the waters are turbid, photoinhibition is probably not significant. However, significant changes must be occurring in the planktonic community structure. For the majority of the growing season, the wetland is dominated be small green flagellates and Euglenas, suggesting that climax communities never form or that nutrients are in such high supply that reproduction continually exceeds losses. Kreiger (1985) noted dramatic changes in planktonic population assemblages of Old Woman Creek wetland. This may explain why chlorophyll *a* values do not correlate with whole system metabolism values. As the community moves from diatoms or cyanobacteria to green algae, the chlorophyll *a* increases, but the productivity may not. Additionally, community structure is affected by hydrologic conditions. If the barrier beach is open, a large number of lake plankton may be found in the water. During storms, the plankton populations may be almost completely flushed out into the lake, allowing the establishment of pioneer communities (Klarer 1989).

The presence of macrophytes did not significantly alter productivity in the water column, even though they covered a significant portion of the wetland. Even at peak plant biomass, those sites in or near *Nelumbo* beds did not vary greatly from the other sites. In fact site 4, which had the most influence from *Nelumbo*, was often the most productive site.

Old Woman Creek wetland is relatively productive on a planktonic basis, but it lacks the higher productivity values that can be obtained in marshes where different types of vegetation are prevalent. *Typha, Scirpus*, and similar wetland plants may have up to 5 times more biomass at peak harvest than did the *Nelumbo* harvested here (Westlake 1963, Good et al. 1982). This makes sense when one considers the nature of *Nelumbo*. Aquatic macrophyte productivity usually averages around 500 g dry wt/m^2 (Westlake 1963; Good et al. 1982). On the low end of the scale are water lilies, which range around 250 g dry wt/m^2 (Good et al. 1982). Our *Nelumbo* beds were approximately 60 percent as productive as this benchmark. A *Nelumbo* based wetland, created presumably by high water levels, will never have the macrophyte productivity characteristic of many other types of wetlands where emergent plants such as *Typha* and *Scirpus* dominate.

At lower water levels, many more emergent species have been present at Old Woman Creek wetland (Marshall and Stuckey 1974). Lower water level would probably increase macrophyte productivity but the more significant contributions of the plankton may be lost as water volume would be less. However, it is unlikely that planktonic productivity would decrease in direct proportion to water volume, especially because highest productivity values were often seen in the shallowest portions of the wetland.

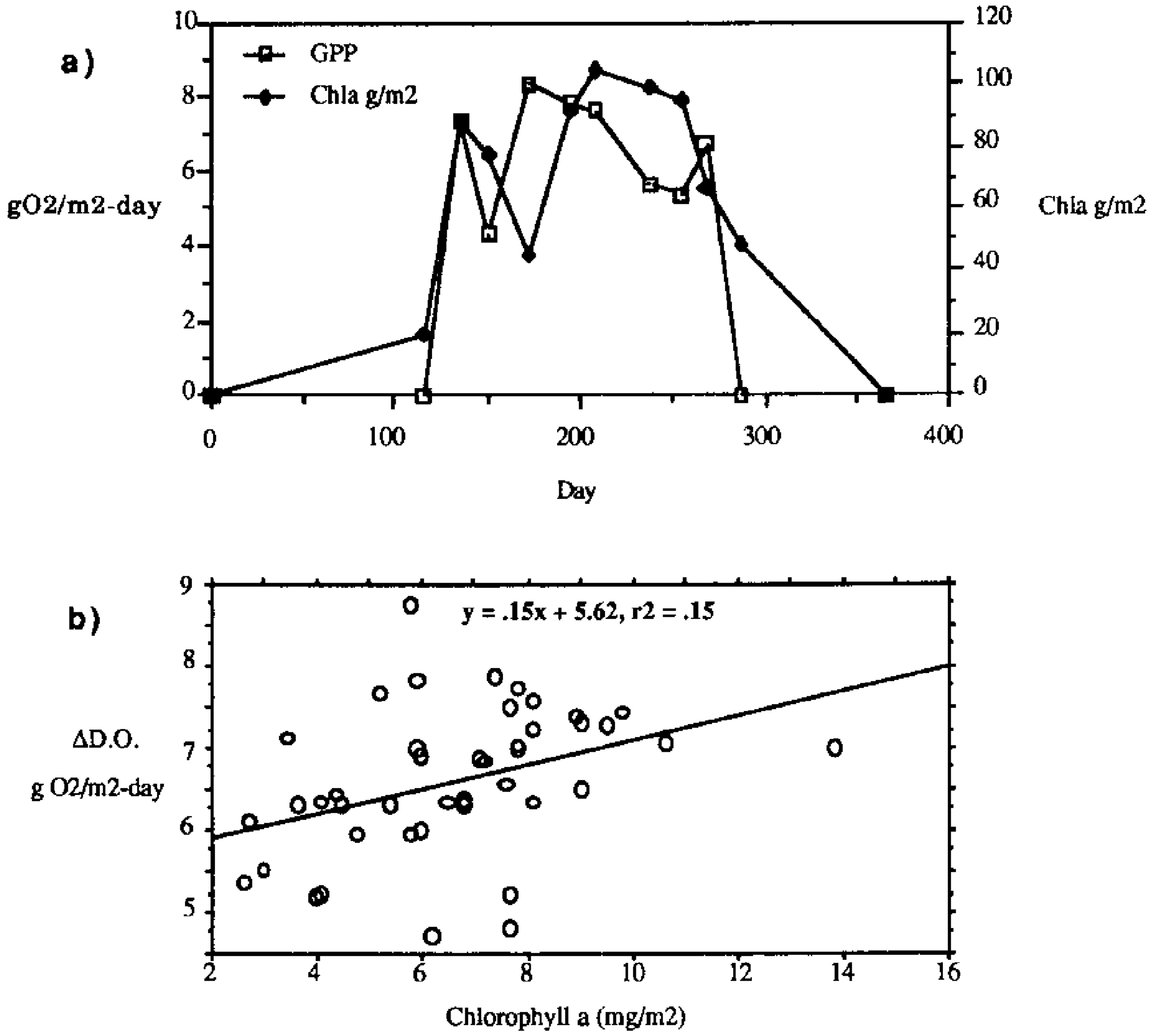


Figure 3.4 Comparisons of chlorophyll *a* concentrations and primary productivity in Old Woman Creek wetland for 1988: a) average productivity compared to chlorophyll readings; b) regression of diurnal productivity at each site versus chlorophyll at each site

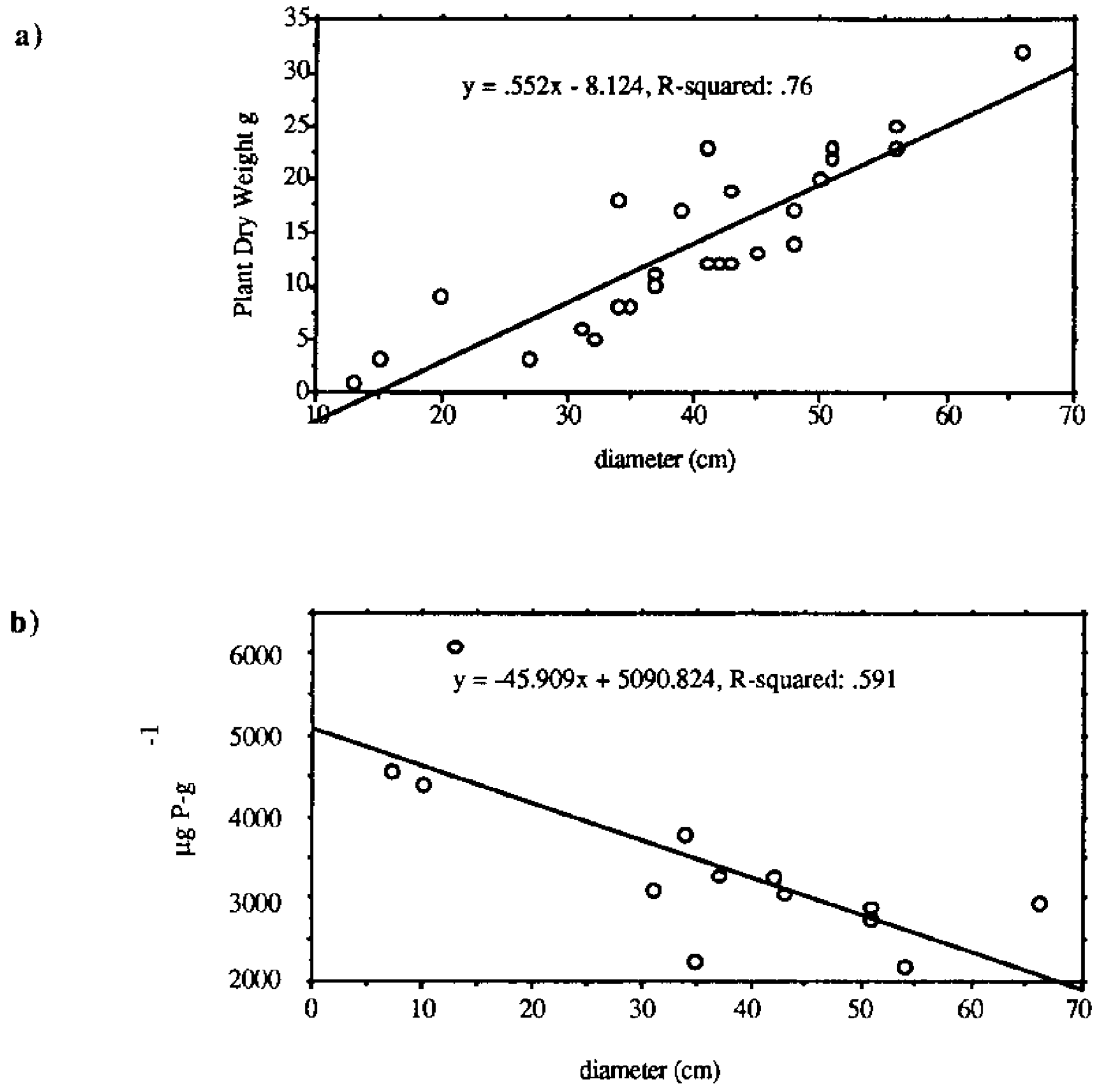


Figure 3.5 Relationships of a) plant dry weight and b) phosphorus concentrations versus leaf diameter for *Nelumbo lutea* from Old Woman Creek wetland

Appendix 3.1 Diurnal dissolved oxygen of Old Woman Creek and productivity calculations

27-Jul-87				**hour**				
	14:00	**18:00**	**21:30**	**1:00**	**4:00**	**7:00**	**11:00**	**14:00**
Station		**D.O. Concentration in g/m3**						
3	14.20	14.40	14.00	9.70	7.90	5.50	9.80	14.50
4	11.50	13.00	12.20	10.40	8.70	8.40	10.70	11.50
5	13.90	15.20	14.00	12.50	10.40	8.50	11.00	13.90
7	11.20	13.20	12.00	11.20	10.20	8.50	10.40	11.20
9	10.80	12.90	11.50	9.80	8.30	6.00	9.90	10.80
		Rate of Change in g/m3/hr						
3	0.05	-0.11	-1.23	-0.60	-0.80	1.08	0.94	
4	0.38	-0.23	-0.51	-0.57	-0.10	0.58	0.16	
5	0.33	-0.34	-0.43	-0.70	-0.63	0.63	0.58	
7	0.50	-0.34	-0.23	-0.33	-0.57	0.48	0.16	
9	0.53	-0.40	-0.49	-0.50	-0.77	0.98	0.18	
		Rate of change in g/m2/hr						**depth (m)**
3	0.04	-0.08	-0.86	-0.42	-0.56	0.75	0.66	0.70
4	0.34	-0.21	-0.46	-0.51	-0.09	0.52	0.14	0.90
5	0.16	-0.17	-0.21	-0.35	-0.32	0.31	0.29	0.50
7	0.30	-0.21	-0.14	-0.20	-0.34	0.29	0.10	0.60
9	0.26	-0.20	-0.24	-0.25	-0.38	0.49	0.09	0.50
Avg.	**Res. g/m2-hr**		**g/m2-day**		**GPP**	**g/m2-day**	**Kcal/m2-day**	
3	-0.48		-11.52		10.82		38.97	
4	-0.32		-7.61		7.62		27.44	
5	-0.26		-6.31		6.07		21.84	
7	-0.22		-5.30		5.39		19.40	
9	-0.27		-6.46		6.36		22.91	
Average	-0.31		-7.44		7.25		26.11	

26-Sep-87				**hour**				
	15:30	**18:30**	**21:30**	**2:30**	**6:30**	**9:30**	**12:30**	**15:30**
Station		**D.O. concentration in g/m3**						
3	10.00	11.20	7.60	7.40	6.20	6.10	7.90	10.00
4	11.00	12.20	10.40	8.10	6.70	6.60	7.90	11.00
5	8.10	8.70	7.70	7.50	6.10	5.90	7.90	8.10
7	9.20	9.20	9.00	8.20	6.40	6.30	8.10	9.20
9	8.90	8.90	7.50	7.10	6.10	6.10	7.20	8.90
		Rate of change in g/m3/hr						
3	0.40	-1.20	-0.04	-0.30	-0.03	0.60	0.70	
4	0.40	-0.60	-0.46	-0.35	-0.03	0.43	1.03	
5	0.20	-0.33	-0.04	-0.35	-0.07	0.67	0.07	
7	0.00	-0.07	-0.16	-0.45	-0.03	0.60	0.37	
9	0.00	-0.47	-0.08	-0.25	0.00	0.37	0.57	
		Rate of change in g/m2/hr						**Depth (m)**
3	0.32	-0.96	-0.03	-0.24	-0.03	0.48	0.56	0.80
4	0.44	-0.66	-0.51	-0.39	-0.04	0.48	1.14	1.10
5	0.12	-0.21	-0.02	-0.22	-0.04	0.41	0.04	0.62
7	0.00	-0.05	-0.11	-0.32	-0.02	0.42	0.26	0.70
9	0.00	-0.21	-0.04	-0.11	0.00	0.17	0.26	0.45
Avg.	**Resp. g/m2/hr**			**/day**	**GPP**	**g/m2-day**		**Kcal/m2-day**
3	-0.31			-7.55	6.91			24.88
4	-0.40			-9.53	9.73			35.04
5	-0.12			-2.94	2.84			10.22
7	-0.12			-2.98	3.15			11.33
9	-0.09			-2.15	2.07			7.44
Average	-0.21			-5.03	4.94			17.78

14-May-88			**hour**				
	5:45	**9:45**	**16:45**	**21:00**	**1:45**	**5:45**	
Station		**D.O.**	**Concentration**	**in**	**g/m3**		
3	5.80	8.20	9.80	11.00	8.60	5.80	
4	6.10	8.40	8.90	11.00	8.60	6.00	
5	3.60	5.90	7.10	10.20	5.20	3.10	
6	3.10	5.90	6.00	10.80	4.90	2.90	
7	3.70	9.20	11.00	13.90	9.00	4.00	
9	4.20	8.50	11.40	10.00	8.90	3.70	
	Rate	**of change**	**ing/m3/hr**				
3	0.60	0.23	0.28	-0.64	-0.70		
4	0.58	0.07	0.49	-0.64	-0.65		
5	0.58	0.17	0.73	-1.33	-0.53		
6	0.70	0.01	1.13	-1.57	-0.50		
7	1.38	0.26	0.68	-1.31	-1.25		
9	1.08	0.41	-0.33	-0.29	-1.30		
	Rate	**of change**	**on g/m2/hr**			**Depth (m)**	
3	0.24	0.09	0.11	-0.26	-0.28	0.40	
4	0.30	0.04	0.26	-0.33	-0.34	0.52	
5	0.21	0.06	0.27	-0.49	-0.19	0.37	
6	0.20	0.00	0.33	-0.46	-0.15	0.29	
7	0.48	0.19	-0.15	-0.13	-0.59	0.45	
9	0.48	0.19	-0.15	-0.13	-0.59	0.45	
Avg.	**Resp. g/m2/hr**			**/day**	**GPP**	**g/m2-day**	**Kcal/m2-day**
3	-0.27			-6.43	6.17		22.20
4	-0.34			-8.05	7.66		27.59
5	-0.34			-8.25	7.68		27.67
6	-0.30			-7.22	6.82		24.54
7	-0.36			-8.60	8.08		29.08
9	-0.36			-8.60	8.08		29.08
Average	-0.33			-7.86	7.41		26.69

28-May-88		**hour**				
	5:30	**11:30**	**20:45**	**5:30**		
Station	**D.O.**	**concentration**	**in**	**g/m3**		
3	3.20	6.10	6.90	3.60		
4	3.50	5.80	7.40	3.80		
5	3.60	5.80	7.00	3.60		
6	5.00	6.10	8.20	4.50		
7	4.20	5.80	7.50	4.30		
9	3.80	5.60	6.60	3.20		
	Rate	**of change**	**in g/m3/hr**			
3	0.48	0.09	-0.38			
4	0.38	0.17	-0.41			
5	0.37	0.13	-0.39			
6	0.18	0.23	-0.42			
7	0.27	0.18	-0.37			
9	0.30	0.11	-0.39			
	Rate	**of change**	**in g/m2/hr**		**Depth (m)**	
3	0.23	0.03	-0.15		0.40	
4	0.23	0.10	-0.24	0.59		
5	0.16	0.06	-0.17	0.44		
6	0.07	0.07	-0.13	0.30		
7	0.15	0.08	-0.16	0.45		
9	0.15	0.05	-0.19	0.50		
Repiration	**g/m2/hr**			**/day**	**GPP g/m2-day**	**Kcal/m2-day**
3	-0.15			-3.62	4.00	14.41

4	-0.24		-5.83	5.99	21.55
5	-0.17		-4.10	4.09	14.73
6	-0.13		-3.04	2.99	10.78
7	-0.16		-3.95	4.14	14.91
9	-0.19		-4.66	4.35	15.66
Average	-0.18		-4.20	4.26	15.34

19-Jun-88		**hour**			
5:15	**11:30**	**21:00**	**5:15**		
Station	**D.O. concentration in g/m3**				
3	3.20	4.40	6.70	1.80	
4	1.70	2.40	5.90	1.90	
5	3.20	4.90	8.50	1.80	
6	2.40	4.00	7.10	2.00	
7	2.60	4.00	8.40	2.20	
9	2.80	4.20	8.50	2.40	
	Rate of change in g/m3/hr				
3	0.19	0.24	-0.59		
4	0.11	0.37	-0.48		
5	0.27	0.38	-0.81		
6	0.26	0.33	-0.62		
7	0.22	0.46	-0.75		
9	0.22	0.45	-0.74		
	Rate of change in g/m2/hr				**depth (m)**
3	0.11	0.13	-0.33		0.55
4	0.07	0.24	-0.32		0.65
5	0.14	0.19	-0.41		0.50
6	0.12	0.15	-0.28		0.45
7	0.13	0.28	-0.45		0.60
9	0.12	0.25	-0.41		0.55
Avg. Resp.	**g/m2/hr**		**/day**	**GPP g/m2-hr**	**Kcal/m2-day**
3	-0.33		-7.84	7.07	25.45
4	-0.32		-7.56	7.69	27.70
5	-0.41		-9.75	9.05	32.56
6	-0.28		-6.68	6.50	23.39
7	-0.45		-10.82	10.58	38.09
9	-0.41		-9.76	9.54	34.34
Average	-0.36		-8.73	8.40	30.26

27-Jun-88		**hour**			
5:15	**11:30**	**20:30**	**5:15**		
Station	**D.O. concentration in g/m3**				
3	4.80	7.00	9.90	4.90	
4	4.40	7.80	8.30	4.20	
5	4.00	4.50	10.20	4.40	
6	4.30	5.20	11.20	4.00	
7	4.80	5.10	11.00	4.60	
9	4.20	8.00	12.50	4.30	
	Rate of change in g/m3/hr				
3	0.35	0.32	-0.57		
4	0.54	0.06	-0.47		
5	0.08	0.63	-0.66		
6	0.14	0.67	-0.82		
7	0.05	0.66	-0.73		
9	0.61	0.50	-0.94		
	Rate of change in g/m2/hr				**depth (m)**
3	0.19	0.18	-0.31		0.55

4	0.13	0.04	-0.30			0.65
5	0.05	0.38	-0.40			0.60
6	0.05	0.23	-0.29			0.35
7	0.02	0.30	-0.33			0.45
9	0.24	0.20	-0.37			0.40
Avg. Resp.	**g/m2/hr**		**/day**	**GPP**	**g/m2-day**	**Kcal/m2-day**
3	-0.31		-7.54	7.60		27.35
4	-0.30		-7.31	5.76		20.72
5	-0.40		-9.55	9.79		35.23
6	-0.29		-6.91	6.81		24.51
7	-0.33		-7.90	7.81		28.11
9	-0.37		-9.00	9.04		32.53
Average	-0.33		-8.03	7.80		28.08

12-Jul-88					**hour**				
	6:30	**9:30**	**12:30**	**15:30**	**18:30**	**21:30**	**0:30**	**3:30**	**6:30**
Station				**D.O. concentration in g/m3**					
3	1.65	5.65	7.25	10.20	12.25	11.20	3.60	3.35	1.65
4	0.75	2.10	4.05	7.35	7.90	5.15	2.65	1.50	0.75
5	1.85	4.15	5.65	9.65	10.90	11.85	5.75	3.65	1.85
6	3.28	5.80	7.70	13.50	15.20	13.20	7.65	3.45	3.28
7	2.00	3.40	5.75	12.75	11.10	9.65	4.65	2.65	2.00
9	2.10	3.95	6.15	13.05	8.00	4.85	4.70	3.00	2.10
			Rate of change in g/m3/hr						
3	1.33	0.53	0.98	0.68	-0.35	-2.53	-0.08	-0.57	
4	0.45	0.65	1.10	0.18	-0.92	-0.83	-0.38	-0.25	
5	0.77	0.50	1.33	0.42	0.32	-2.03	-0.70	-0.60	
6	0.84	0.63	1.93	0.57	-0.67	-1.85	-1.40	-0.06	
7	0.47	0.78	2.33	-0.55	-0.48	-1.67	-0.67	-0.22	
9	0.62	0.73	2.30	-1.68	-1.05	-0.05	-0.57	-0.30	
		Rate of change in g/m2/hr							**Depth, m**
3	0.87	0.35	0.64	0.44	-0.23	-1.65	-0.05	-0.37	0.65
4	0.23	0.34	0.57	0.10	-0.48	-0.43	-0.20	-0.13	0.52
5	0.33	0.22	0.57	0.18	0.14	-0.87	-0.30	-0.26	0.43
6	0.25	0.19	0.58	0.17	-0.20	-0.56	-0.42	-0.02	0.30
7	0.15	0.26	0.77	-0.18	-0.16	-0.55	-0.22	-0.07	0.33
9	0.19	0.22	0.69	-0.51	-0.32	-0.02	-0.17	-0.09	0.30
	Avg. Resp.	**g/m2/hr**		**/day**	**GPP**	**g/m2-day**		**Kcal/m2-day**	
3		-0.57		-13.78	13.78			49.608	
4		-0.31		-7.436	7.436			26.7696	
5		-0.32		-7.783	7.783			28.0188	
6		-0.30		-7.155	7.155			25.758	
7		-0.25		-6.006	6.006			21.6216	
9		-0.15		-3.54	3.54			12.744	
Average		-0.32		-7.62	7.62			27.42	

26-Jul-88		**hour**		
	6:00	**15:00**	**18:00**	**6:00**
Station	**D.O. concentration in g/m3**			
3	4.00	7.20	8.60	3.90
4	2.10	11.20	12.50	2.60
5	3.00	5.80	7.40	2.80
6	3.10	7.80	11.20	3.20
7	3.50	10.80	12.00	3.50
9	4.00	10.80	11.20	3.60
	Rate of change in g/m3/hr			
3	0.36	0.47	-0.39	

4	1.01	0.43	-0.83	
5	0.31	0.53	-0.38	
6	0.52	1.13	-0.67	
7	0.81	0.40	-0.71	
9	0.76	0.13	-0.63	
	Rate of change in g/m2/hr			**depth (m)**
3	0.14	0.19	-0.16	0.40
4	0.40	0.17	-0.33	0.40
5	0.09	0.16	-0.12	0.30
6	0.17	0.36	-0.21	0.32
7	0.37	0.18	-0.33	0.46
9	0.30	0.05	-0.25	0.40

Avg. Resp.	**g/m2/hr**	**/day**	**GPP g/m2-day**	**Kcal/m2-day**
3	-0.16	-3.76	3.72	13.39
4	-0.33	-7.92	8.12	29.23
5	-0.12	-2.76	2.70	9.72
6	-0.21	-5.12	5.15	18.55
7	-0.33	-7.82	7.82	28.15
9	-0.25	-6.08	5.92	21.31
Average	-0.23	-5.58	5.57	20.06

25-Aug-88				**hour**				
	7:15	**10:15**	**12:45**	**16:00**	**20:00**	**23:30**	**3:00**	**7:15**
Station		**D.O. Concentration in g/m3**						
3	1.80	7.10	9.00	12.20	8.50	7.00	3.70	1.80
4	1.50	2.40	5.00	8.70	6.80	4.80	3.20	1.50
5	0.60	5.80	6.20	8.40	7.00	1.40	1.20	0.60
6	1.00	9.20	10.40	11.80	7.60	4.00	2.20	1.00
7	0.90	4.20	5.00	8.20	7.60	3.00	1.30	0.90
9	1.20	5.00	6.00	8.00	7.20	4.10	2.70	1.20
		Rate of change in g/m3/hr						
3	1.77	0.76	0.98	-0.93	-0.43	-0.94	-0.45	
4	0.30	1.04	1.14	-0.48	-0.57	-0.46	-0.40	
5	1.73	0.16	0.68	-0.35	-1.60	-0.06	-0.14	
6	2.73	0.48	0.43	-1.05	-1.03	-0.51	-0.28	
7	1.10	0.32	0.98	-0.15	-1.31	-0.49	-0.09	
9	1.27	0.40	0.62	-0.20	-0.89	-0.40	-0.35	
		Rate of change in g/m2/hr						**depth (m)**
3	0.53	0.23	0.30	-0.28	-0.13	-0.28	-0.13	0.30
4	0.12	0.42	0.46	-0.19	-0.23	-0.18	-0.16	0.40
5	0.52	0.05	0.20	-0.11	-0.48	-0.02	-0.04	0.30
6	0.68	0.12	0.11	-0.26	-0.26	-0.13	-0.07	0.25
7	0.66	0.19	0.59	-0.09	-0.79	-0.29	-0.06	0.60
9	0.25	0.08	0.12	-0.04	-0.18	-0.08	-0.07	0.20
Avg. Resp.	**g/m2/hr**			**/day**	**GPP g/m2-day**			**Kcal/m2-day**
3	-0.21			-4.94	5.92			21.32
4	-0.19			-4.57	5.84			21.01
5	-0.16			-3.87	4.48			16.12
6	-0.18			-4.31	4.85			17.45
7	-0.31			-7.36	8.86			31.89
9	-0.09			-2.21	2.59			9.34
Average	-0.19			-4.54	5.42			19.52

24-Sep-88			**hour**		
6:15	**12:15**	**17:15**	**19:15**	**2:15**	**6:15**
Station	**D.O. Concentration in g/m3**				

3	2.30	8.50	13.90	12.00	4.90	2.40	
4	3.40	6.80	9.50	8.30	4.60	2.90	
5	3.20	10.20	14.90	9.50	5.00	3.00	
6	4.00	10.70	16.60	12.50	4.80	3.60	
7	3.60	11.20	15.50	10.80	5.10	3.80	
9	3.10	8.90	12.60	10.20	5.20	3.50	
	Rate of change in g/m3/hr						
3	1.03	1.08	-0.95	-1.01	-0.63		
4	0.57	0.54	-0.60	-0.53	-0.43		
5	1.17	0.94	-2.70	-0.64	-0.50		
6	1.12	1.18	-2.05	-1.10	-0.30		
7	1.27	0.86	-2.35	-0.81	-0.33		
9	0.97	0.74	-1.20	-0.71	-0.43		
	Rate of change in g/m2/hr						**depth (m)**
3	0.41	0.43	-0.38	-0.41	-0.25		0.40
4	0.26	0.24	-0.27	-0.24	-0.19		0.45
5	0.35	0.28	-0.81	-0.19	-0.15		0.30
6	0.11	0.12	-0.21	-0.11	-0.03		0.10
7	0.51	0.34	-0.94	-0.33	-0.13		0.40
9	0.34	0.26	-0.42	-0.25	-0.15		0.35
Avg. Res.	**g/m2/hr**		**/day**	**GPP**	**g/m2-day**		**Kcal/m2-day**
3	-0.35		-8.29	8.44			30.38
4	-0.23		-5.59	5.31			19.11
5	-0.38		-9.22	7.74			27.85
6	-0.12		-2.76	2.53			9.09
7	-0.47		-11.17	9.88			35.56
9	-0.27		-6.55	6.33			22.78
Average	-0.30		-7.26	6.70			24.13

Appendix 3.2 Vegetation transect data for Nelumbo lutea at Old Woman Creek wetland

Jul-88

Diameter, cm	Area, cm2	Weight, g dry wt	Phosphorus mg P/g dry wt	mgP
48	1,810	18.92	2.89	54.61
40	1,257	14.55	3.25	47.34
28	616	8.00	3.81	30.42
32	804	10.18	3.62	36.87
28	616	8.00	3.81	30.42
41	1,320	15.09	3.21	48.43
35	962	11.82	3.48	41.17
60	2,827	25.47	2.34	59.50
35	962	11.82	3.48	41.17
60	2,827	25.47	2.34	59.50
35	962	11.82	3.48	41.17
60	2,827	25.47	2.34	59.50
42	1,385	15.64	3.16	49.46
43	1,452	16.19	3.12	50.44
55	2,376	22.74	2.57	58.34
45	1,590	17.28	3.02	52.26
37	1,075	12.91	3.39	43.79
60	2,827	25.47	2.34	59.50
18	254	2.54	4.26	10.81
54	2,290	22.19	2.61	57.96
39	1,195	14.00	3.30	46.21
48	1,810	18.92	2.89	54.61
22	380	4.72	4.08	19.26
27	573	7.45	3.85	28.69
32	804	10.18	3.62	36.87
41	1,320	15.09	3.21	48.43
25	491	6.36	3.94	25.07
34	908	11.27	3.53	39.79
51	2,043	20.55	2.75	56.51
55	2,376	22.74	2.57	58.34
46	1,662	17.82	2.98	53.09
40	1,257	14.55	3.25	47.34
36	1,018	12.36	3.44	42.51
29	661	8.54	3.76	32.11
37	1,075	12.91	3.39	43.79
48	1,810	18.92	2.89	54.61
46	1,662	17.82	2.98	53.09
32	804	10.18	3.62	36.87
29	661	8.54	3.76	32.11
37	1,075	12.91	3.39	43.79
48	1,810	18.92	2.89	54.61
46	1,662	17.82	2.98	53.09
32	804	10.18	3.62	36.87
29	661	8.54	3.76	32.11
50	1,964	20.01	2.80	55.93
38	1,134	13.46	3.35	45.02
26	531	6.90	3.90	26.90
30	707	9.09	3.71	33.75
51	2,043	20.55	2.75	56.51
26	531	6.90	3.90	26.90
27	573	7.45	3.85	28.69
55	2,376	22.74	2.57	58.34
57	2,552	23.83	2.47	58.95
44	1,521	16.73	3.07	51.38
32	804	10.18	3.62	36.87
32	804	10.18	3.62	36.87
36	1,018	12.36	3.44	42.51
37	1,075	12.91	3.39	43.79
23	415	5.27	4.03	21.24
27	573	7.45	3.85	28.69
54	2,290	22.19	2.61	57.96
39	1,195	14.00	3.30	46.21
48	1,810	18.92	2.89	54.61
45	1,590	17.28	3.02	52.26
52	2,124	21.10	2.70	57.04
59	2,734	24.92	2.38	59.37
31	755	9.63	3.67	35.33
26	531	6.90	3.90	26.90
59	2,734	24.92	2.38	59.37
37	1,075	12.91	3.39	43.79
30	707	9.09	3.71	33.75
50	1,964	20.01	2.80	55.93
48	1,810	18.92	2.89	54.61
43	1,452	16.19	3.12	50.44
24	452	5.81	3.99	23.18
23	415	5.27	4.03	21.24
27	573	7.45	3.85	28.69
40	1,257	14.55	3.25	47.34
37	1,075	12.91	3.39	43.79
32	804	10.18	3.62	36.87
38	1,134	13.46	3.35	45.02
37	1,075	12.91	3.39	43.79
40	1,257	14.55	3.25	47.34
57	2,552	23.83	2.47	58.95
48	1,810	18.92	2.89	54.61
44	1,521	16.73	3.07	51.38
35	962	11.82	3.48	41.17
50	1,964	20.01	2.80	55.93
38	1,134	13.46	3.35	45.02
42	1,385	15.64	3.16	49.46
22	380	4.72	4.08	19.26
44	1,521	16.73	3.07	51.38
55	2,376	22.74	2.57	58.34
33	855	10.73	3.58	38.35
53	2,206	21.65	2.66	57.52
26	531	6.90	3.90	26.90
53	2,206	21.65	2.66	57.52
17	227	1.99	4.31	8.57
52	2,124	21.10	2.70	57.04
33	855	10.73	3.58	38.35
32	804	10.18	3.62	36.87
31	755	9.63	3.67	35.33
28	616	8.00	3.81	30.42
Sum	135,775	1,469.95	337.60	4,511.96
Ave 39		14.27	3.28	43.81

9 Flowers @ 25 grams ea.

Biomass = 125 g dry wt/m2

Aug-88

	Diameter, cm	Area, cm2	Weight, g dry wt	Phosphorus	
				mg P/g dry wt	mgP
	30	707	8.44	3.71	31.33
	34	908	10.64	3.53	37.57
	19	284	2.36	4.22	9.97
	42	1,385	15.06	3.16	47.63
	37	1,075	12.30	3.39	41.72
	47	1,735	17.82	2.93	52.27
	42	1,385	15.06	3.16	47.63
	43	1,452	15.61	3.12	48.66
	48	1,810	18.37	2.89	53.04
	34	908	10.64	3.53	37.57
	36	1,018	11.75	3.44	40.39
	29	661	7.88	3.76	29.64
	17	227	1.26	4.31	5.43
	35	962	11.20	3.48	39.01
	15	177	0.16	4.40	0.69
	38	1,134	12.85	3.35	43.01
	59	2,734	24.44	2.38	58.23
	35	962	11.20	3.48	39.01
	29	661	7.88	3.76	29.64
	51	2,043	20.03	2.75	55.07
	31	755	8.99	3.67	32.96
	38	1,134	12.85	3.35	43.01
	36	1,018	11.75	3.44	40.39
	35	962	11.20	3.48	39.01
	39	1,195	13.40	3.30	44.24
	33	855	10.09	3.58	36.09
	50	1,964	19.48	2.80	54.44
	51	2,043	20.03	2.75	55.07
	41	1,320	14.51	3.21	46.55
	43	1,452	15.61	3.12	48.66
	46	1,662	17.27	2.98	51.44
	50	1,964	19.48	2.80	54.44
	27	573	6.78	3.85	26.11
	38	1,134	12.85	3.35	43.01
	32	804	9.54	3.62	34.55
	24	452	5.12	3.99	20.44
	24	452	5.12	3.99	20.44
	39	1,195	13.40	3.30	44.24
	40	1,257	13.96	3.25	45.42
	42	1,385	15.06	3.16	47.63
	45	1,590	16.72	3.02	50.56
	38	1,134	12.85	3.35	43.01
	30	707	8.44	3.71	31.33
	27	573	6.78	3.85	26.11
	26	531	6.23	3.90	24.27
	48	1,810	18.37	2.89	53.04
	40	1,257	13.96	3.25	45.42
	42	1,385	15.06	3.16	47.63
	26	531	6.23	3.90	24.27
	26	531	6.23	3.90	24.27
	18	254	1.81	4.26	7.73
	15	177	0.16	4.40	0.69
	21	346	3.47	4.13	14.31
	39	1,195	13.40	3.30	44.24
	25	491	5.68	3.94	22.38
	45	1,590	16.72	3.02	50.56
	41	1,320	14.51	3.21	46.55
	23	415	4.57	4.03	18.45
	42	1,385	15.06	3.16	47.63
	22	380	4.02	4.08	16.40
	26	531	6.23	3.90	24.27
	48	1,810	18.37	2.89	53.04
	39	1,195	13.40	3.30	44.24
	42	1,385	15.06	3.16	47.63
	40	1,257	13.96	3.25	45.42
	45	1,590	16.72	3.02	50.56
	28	616	7.33	3.81	27.90
	36	1,018	11.75	3.44	40.39
	23	415	4.57	4.03	18.45
	19	284	2.36	4.22	9.97
	41	1,320	14.51	3.21	46.55
	49	1,886	18.92	2.84	53.77
	39	1,195	13.40	3.30	44.24
	52	2,124	20.58	2.70	55.64
	31	755	8.99	3.67	32.96
	38	1,134	12.85	3.35	43.01
	36	1,018	11.75	3.44	40.39
	28	616	7.33	3.81	27.90
	26	531	6.23	3.90	24.27
	21	346	3.47	4.13	14.31
	43	1,452	15.61	3.12	48.66
	44	1,521	16.16	3.07	49.64
	28	616	7.33	3.81	27.90
	28	616	7.33	3.81	27.90
	39	1,195	13.40	3.30	44.24
	41	1,320	14.51	3.21	46.55
	34	908	10.64	3.53	37.57
	28	616	7.33	3.81	27.90
	26	531	6.23	3.90	24.27
	28	616	7.33	3.81	27.90
	25	491	5.68	3.94	22.38
	31	755	8.99	3.67	32.96
	42	1,385	15.06	3.16	47.63
	54	2,290	21.68	2.61	56.63
	49	1,886	18.92	2.84	53.77
	26	531	6.23	3.90	24.27
	40	1,257	13.96	3.25	45.42
	39	1,195	13.40	3.30	44.24
	53	2,206	21.13	2.66	56.16
	44	1,521	16.16	3.07	49.64
Sum		**107,335**	**1,156.58**	**345.32**	**3,755.0**
Ave	36		11.57	3.45	37.55
		10 Seed Heads	25	grams ea.	

Biomass = 131 g dry wt/m2

Aug-88

	Diameter, cm	Area, cm2	Weight, g dry wt	Phosphorus mg P/g dry wt	Phosphorus mgP
	35	962	11.20	3.48	39.01
	48	1,810	18.37	2.89	53.04
	23	415	4.57	4.03	18.45
	35	962	11.20	3.48	39.01
	30	707	8.44	3.71	31.33
	44	1,521	16.16	3.07	49.64
	29	661	7.88	3.76	29.64
	48	1,810	18.37	2.89	53.04
	36	1,018	11.75	3.44	40.39
	35	962	11.20	3.48	39.01
	27	573	6.78	3.85	26.11
	23	415	4.57	4.03	18.45
	37	1,075	12.30	3.39	41.72
	26	531	6.23	3.90	24.27
	36	1,018	11.75	3.44	40.39
	44	1,521	16.16	3.07	49.64
	28	616	7.33	3.81	27.90
	39	1,195	13.40	3.30	44.24
	27	573	6.78	3.85	26.11
	21	346	3.47	4.13	14.31
	20	314	2.92	4.17	12.17
	29	661	7.88	3.76	29.64
	34	908	10.64	3.53	37.57
	30	707	8.44	3.71	31.33
	27	573	6.78	3.85	26.11
	41	1,320	14.51	3.21	46.55
	48	1,810	18.37	2.89	53.04
	42	1,385	15.06	3.16	47.63
	38	1,134	12.85	3.35	43.01
	56	2,463	22.79	2.52	57.42
	47	1,735	17.82	2.93	52.27
	43	1,452	15.61	3.12	48.66
	47	1,735	17.82	2.93	52.27
	43	1,452	15.61	3.12	48.66
	42	1,385	15.06	3.16	47.63
	38	1,134	12.85	3.35	43.01
	13	133	-0.95	4.49	-4.26
	36	1,018	11.75	3.44	40.39
	28	616	7.33	3.81	27.90
	24	452	5.12	3.99	20.44
	33	855	10.09	3.58	36.09
	43	1,452	15.61	3.12	48.66
	43	1,452	15.61	3.12	48.66
	47	1,735	17.82	2.93	52.27
	36	1,018	11.75	3.44	40.39
	42	1,385	15.06	3.16	47.63
	24	452	5.12	3.99	20.44
	21	346	3.47	4.13	14.31
	30	707	8.44	3.71	31.33
	29	661	7.88	3.76	29.64
	49	1,886	18.92	2.84	53.77
	46	1,662	17.27	2.98	51.44
	36	1,018	11.75	3.44	40.39
	34	908	10.64	3.53	37.57
	39	1,195	13.40	3.30	44.24
	48	1,810	18.37	2.89	53.04
	45	1,590	16.72	3.02	50.56
	28	616	7.33	3.81	27.90
	24	452	5.12	3.99	20.44
	43	1,452	15.61	3.12	48.66
	23	415	4.57	4.03	18.45
	34	908	10.64	3.53	37.57
	26	531	6.23	3.90	24.27
	15	177	0.16	4.40	0.69
	30	707	8.44	3.71	31.33
	54	2,290	21.68	2.61	56.63
	58	2,642	23.89	2.43	58.01
	39	1,195	13.40	3.30	44.24
	39	1,195	13.40	3.30	44.24
	21	346	3.47	4.13	14.31
	34	908	10.64	3.53	37.57
	38	1,134	12.85	3.35	43.01
	36	1,018	11.75	3.44	40.39
	36	1,018	11.75	3.44	40.39
	25	491	5.68	3.94	22.38
	37	1,075	12.30	3.39	41.72
	36	1,018	11.75	3.44	40.39
	27	573	6.78	3.85	26.11
	25	491	5.68	3.94	22.38
	35	962	11.20	3.48	39.01
	26	531	6.23	3.90	24.27
	36	1,018	11.75	3.44	40.39
	50	1,964	19.48	2.80	54.44
	42	1,385	15.06	3.16	47.63
	41	1,320	14.51	3.21	46.55
	55	2,376	22.24	2.57	57.05
	57	2,552	23.34	2.47	57.74
	37	1,075	12.30	3.39	41.72
	28	616	7.33	3.81	27.90
	44	1,521	16.16	3.07	49.64
	43	1,452	15.61	3.12	48.66
	37	1,075	12.30	3.39	41.72
	44	1,521	16.16	3.07	49.64
	46	1,662	17.27	2.98	51.44
	39	1,195	13.40	3.30	44.24
	19	284	2.36	4.22	9.97
	17	227	1.26	4.31	5.43
	42	1,385	15.06	3.16	47.63
	49	1,886	18.92	2.84	53.77
	46	1,662	17.27	2.98	51.44
	40	1,257	13.96	3.25	45.42
Sum		**110,783**	**1,190.41**	**346.93**	**3,844.36**
Ave	36	1,097	11.79	3.43	38.06

15 Seed Heads 25 grams ea.

Biomass = 141 g dry wt/m2

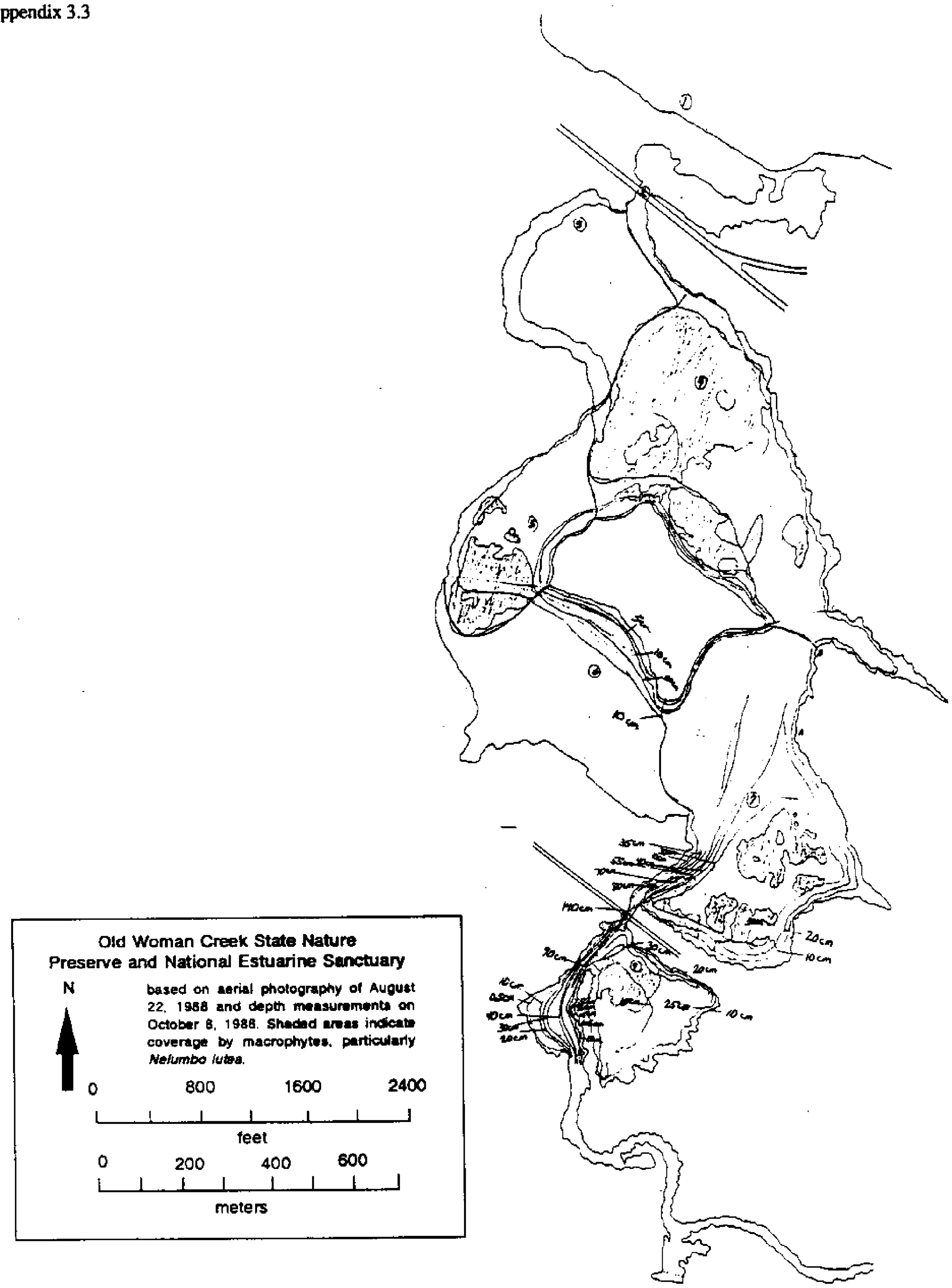
Aug-88

Diameter, cm	Area, cm2	Weight, g dry wt	Phosphorus mg P/g dry wt	Phosphorus mgP
47	1,735	17.82	2.93	52.27
41	1,320	14.51	3.21	46.55
43	1,452	15.61	3.12	48.66
42	1,385	15.06	3.16	47.63
30	707	8.44	3.71	31.33
40	1,257	13.96	3.25	45.42
34	908	10.64	3.53	37.57
41	1,320	14.51	3.21	46.55
33	855	10.09	3.58	36.09
38	1,134	12.85	3.35	43.01
50	1,964	19.48	2.80	54.44
38	1,134	12.85	3.35	43.01
50	1,964	19.48	2.80	54.44
36	1,018	11.75	3.44	40.39
61	2,922	25.55	2.29	58.51
38	1,134	12.85	3.35	43.01
47	1,735	17.82	2.93	52.27
28	616	7.33	3.81	27.90
24	452	5.12	3.99	20.44
43	1,452	15.61	3.12	48.66
20	314	2.92	4.17	12.17
62	3,019	26.10	2.24	58.58
23	415	4.57	4.03	18.45
30	707	8.44	3.71	31.33
45	1,590	16.72	3.02	50.56
38	1,134	12.85	3.35	43.01
22	380	4.02	4.08	16.40
61	2,922	25.55	2.29	58.51
30	707	8.44	3.71	31.33
31	755	8.99	3.67	32.96
38	1,134	12.85	3.35	43.01
33	855	10.09	3.58	36.09
48	1,810	18.37	2.89	53.04
47	1,735	17.82	2.93	52.27
54	2,290	21.68	2.61	56.63
43	1,452	15.61	3.12	48.66
40	1,257	13.96	3.25	45.42
57	2,552	23.34	2.47	57.74
53	2,206	21.13	2.66	56.16
39	1,195	13.40	3.30	44.24
35	962	11.20	3.48	39.01
39	1,195	13.40	3.30	44.24
27	573	6.78	3.85	26.11
26	531	6.23	3.90	24.27
45	1,590	16.72	3.02	50.56
24	452	5.12	3.99	20.44
45	1,590	16.72	3.02	50.56
35	962	11.20	3.48	39.01
33	855	10.09	3.58	36.09
26	531	6.23	3.90	24.27
34	908	10.64	3.53	37.57
16	201	0.71	4.36	3.08
38	1,134	12.85	3.35	43.01
22	380	4.02	4.08	16.40
42	1,385	15.06	3.16	47.6
51	2,043	20.03	2.75	55.0
44	1,521	16.16	3.07	49.6
49	1,886	18.92	2.84	53.7
42	1,385	15.06	3.16	47.6
21	346	3.47	4.13	14.3
28	616	7.33	3.81	27.9
45	1,590	16.72	3.02	50.5
59	2,734	24.44	2.38	58.2
17	227	1.26	4.31	5.4
38	1,134	12.85	3.35	43.0
32	804	9.54	3.62	34.5
29	661	7.88	3.76	29.6
19	284	2.36	4.22	9.9
36	1,018	11.75	3.44	40.3
21	346	3.47	4.13	14.3
49	1,886	18.92	2.84	53.7
37	1,075	12.30	3.39	41.7
36	1,018	11.75	3.44	40.3
35	962	11.20	3.48	39.0
32	804	9.54	3.62	34.5
40	1,257	13.96	3.25	45.4
23	415	4.57	4.03	18.4
61	2,922	25.55	2.29	58.5
39	1,195	13.40	3.30	44.2
35	962	11.20	3.48	39.0
22	380	4.02	4.08	16.4
22	380	4.02	4.08	16.4
33	855	10.09	3.58	36.0
35	962	11.20	3.48	39.0
19	284	2.36	4.22	9.9
45	1,590	16.72	3.02	50.5
64	3,217	27.20	2.15	58.5
45	1,590	16.72	3.02	50.5
34	908	10.64	3.53	37.5
39	1,195	13.40	3.30	44.2
58	2,642	23.89	2.43	58.0
38	1,134	12.85	3.35	43.0
21	346	3.47	4.13	14.3
10	79	-2.60	4.63	-12.
50	1,964	19.48	2.80	54.4
30	707	8.44	3.71	31.3
34	908	10.64	3.53	37.5
47	1,735	17.82	2.93	52.2
39	1,195	13.40	3.30	44.2
45	1,590	16.72	3.02	50.5

	Diameter, cm	Area, cm2	Weight, g dry wt	mg P/g dry wt	mgP
Sum		**120,897**	**1,259.26**	**336.79**	**3,909**
Ave	38	2,394	24.94	6.67	77.4
		8 Seed Heads	25	grams ea.	

Biomass = 121 g dry wt/m2

Appendix 3.3


Old Woman Creek State Nature Preserve and National Estuarine Sanctuary
N
based on aerial photography of August 22, 1988 and depth measurements on October 8, 1988. Shaded areas indicate coverage by macrophytes, particularly *Nelumbo lutea*.
0
800
1600
2400
feet
0
200
400
600
meters
10cm
20cm
10cm
25cm
30cm
140cm
10cm

4

Hydrology of a Freshwater Coastal Wetland During Severe Drought Conditions

William J. Mitsch
Brian C. Reeder
Cynthia Carlson

Introduction

The hydrology of a wetland plays a significant role in that wetland's biogeochemical processes and biological integrity (Gosselink and Turner 1978, Mitsch and Gosselink 1986). It is constructive to develop hydrologic budgets of wetlands for estimating nutrient budgets and patterns of productivity. Hydrologic budgets are also necessary for the development of simulation models that accurately portray the biological functions. High flow-through conditions, for example, can stimulate the production of some wetlands while decreasing the productivity of plankton-based systems. This chapter develops a hydrologic budget for Old Woman Creek wetland for a seven month period over the 1988 growing season. This study has added interest because there was a significant drought throughout the Midwest through this period and the wetland may have provided a biological and hydrologic haven while the rest of the watershed was suffering for dramatic lack of water.

Old Woman Creek wetland is fed primarily by a 68.6 km^2 watershed. The wetland is formed as a backwater behind a sand barrier beach that is frequently breached either due to high water in the wetland or storms surges along Lake Erie. Therefore its water level reflects the runoff from uplands, the state of the barrier beach, and, if the beach is open, the water level of Lake Erie.

Methods

Daily rainfall was recorded at Old Woman Creek using a National Oceanographic and Atmospheric Administration (NOAA) certified gauge. Daily inflows (at the Darrow Road bridge) and wetland levels (near the center of the marsh) were recorded by the United States Geologic Survey (USGS). Evapotranspiration was estimated from evaporation pan data measured at Old Woman Creek. On days when the pan was not functioning properly, values from pan evaporation data at Tiffin, Ohio were used. Ken Krieger (pers. comm.) averaged the data to obtain monthly estimates. Daily evapotranspiration (ET) was determined by weighting the monthly averages by daily temperatures and multiplying the value by 0.7 to correct for the effects of the pan. The condition of the barrier beach was recorded daily by Old Woman Creek staff. The volume of water in the marsh was determined by integrating the values obtained from a bathymetric survey on October 11, 1988. Outflow (or inflow from Lake Erie) was determined using the following equation:

$$S_o = S_i + P - ET - \Delta V/\Delta t$$

where,

S_o = surface outflow (+) or Lake Erie Inflow (-)
S_i = surface inflow
P = direct precipitation
ET = evapotranspiration
$\Delta V/\Delta t$ = daily increase in water level

Results and Discussion

The water budget for March 1 through September 30, 1988 for Old Woman Creek is summarized in Figures 4.1 through 4.3. A complete set of data are included in Table 4.1. The precipitation pattern reflects a significant drought that occurred from early April through the middle of July throughout the Midwest. Most of the surface inflow, which peaked at 300,000 m^3/day in late March, was completed by the end of April and did not resume through the rest of the study period. The barrier beach was open for most of March, half of April, and for a short period during May. The wetland was open to Lake Erie for 50 days, or 23 percent of the study period. It is normal for the wetland to be opened to Lake Erie during the spring and then closed during the summer. The water level of the wetland reached a high of 4.56 m above datum on May 8 before a storm of only 1.37 cm led to a breakthrough of the barrier beach and a water level drop of 4.01 m in two days. The barrier beach was closed by May 16 for the rest of the study period. This caused the water level to rise to 4.32 m before beginning a consistent drop during the drought until a 2.6 cm rain storm in late August.

The influence of Lake Erie on the wetland is most significant, of course, while the barrier beach is open in March through mid-May. Our calculations also show several peaks of flow into the wetland, either from Lake Erie or as an error estimate in the hydrologic budget through the rest of the study period. These anomalies were not frequent. In May, the water level in the wetland increased 8 cm with no rainfall event and no increase in inflow due to the stream. We estimated that 44,000 m^3/day entered the wetland from Lake Erie during that time. The wetland again had a slight increase at the end of August (9 cm) that suggested 24,000 m^3/day from sources other than those measured.

We provide an estimate of the daily water budget for the study period of March through September 1988 in Figure 4.3. Surface inflow from the watershed averaged 15,200 m^3/day while Lake Erie is estimated to provide 3,500 m^3/day on the average or 19 percent of the surface flow into the wetland. As expected, evapotranspiration was 80 percent higher than precipitation during this summer of drought. The water level actually increased slightly during the study period by 7,000 m^3/day, even with the drought conditions. Outflow from the wetland to Lake Erie averaged 17,200 m^3/day.

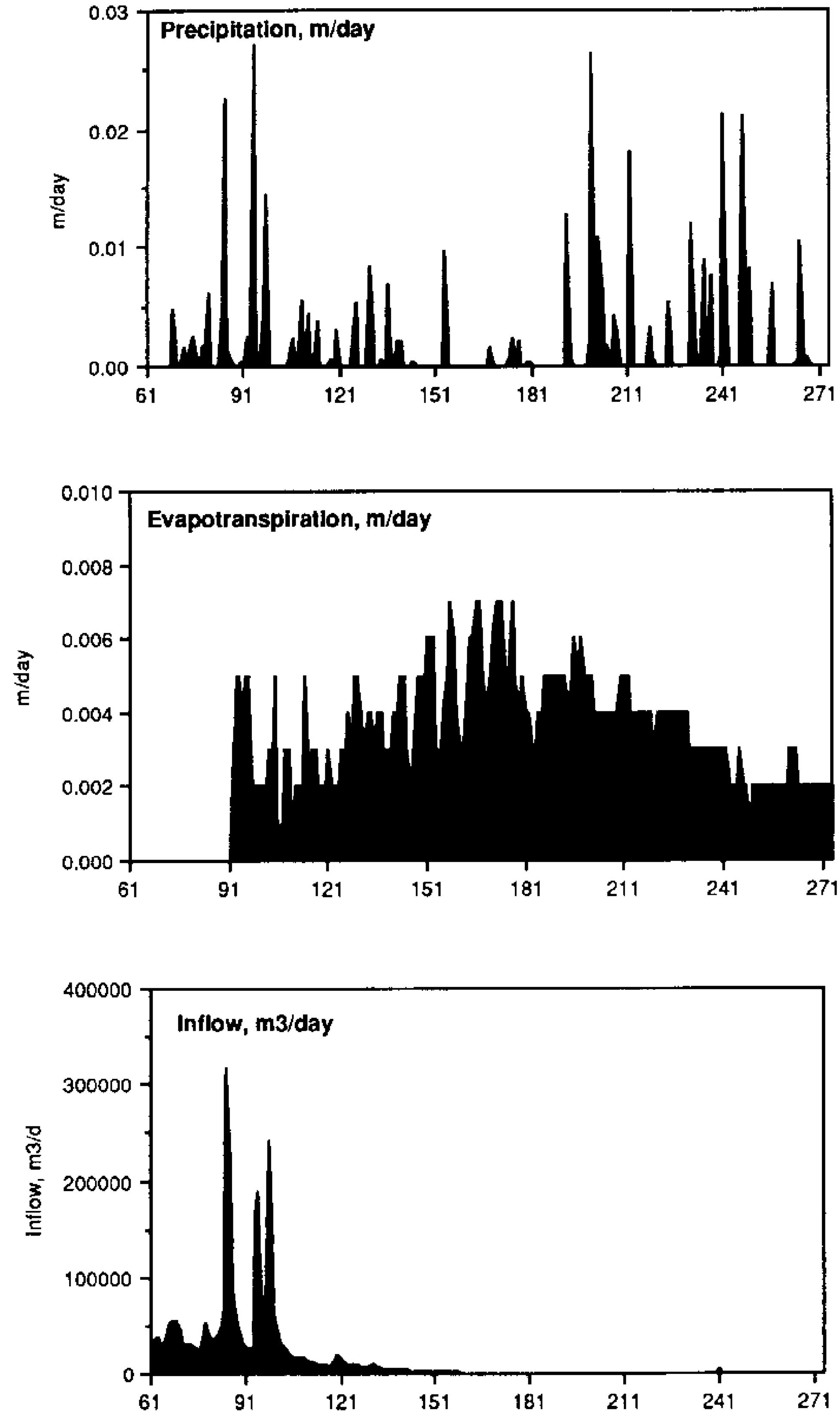


Figure 4.1 Precipitation, evapotranspiration, and inflow components of hydrologic budget of Old Woman Creek wetland for March 1 through September 30, 1988

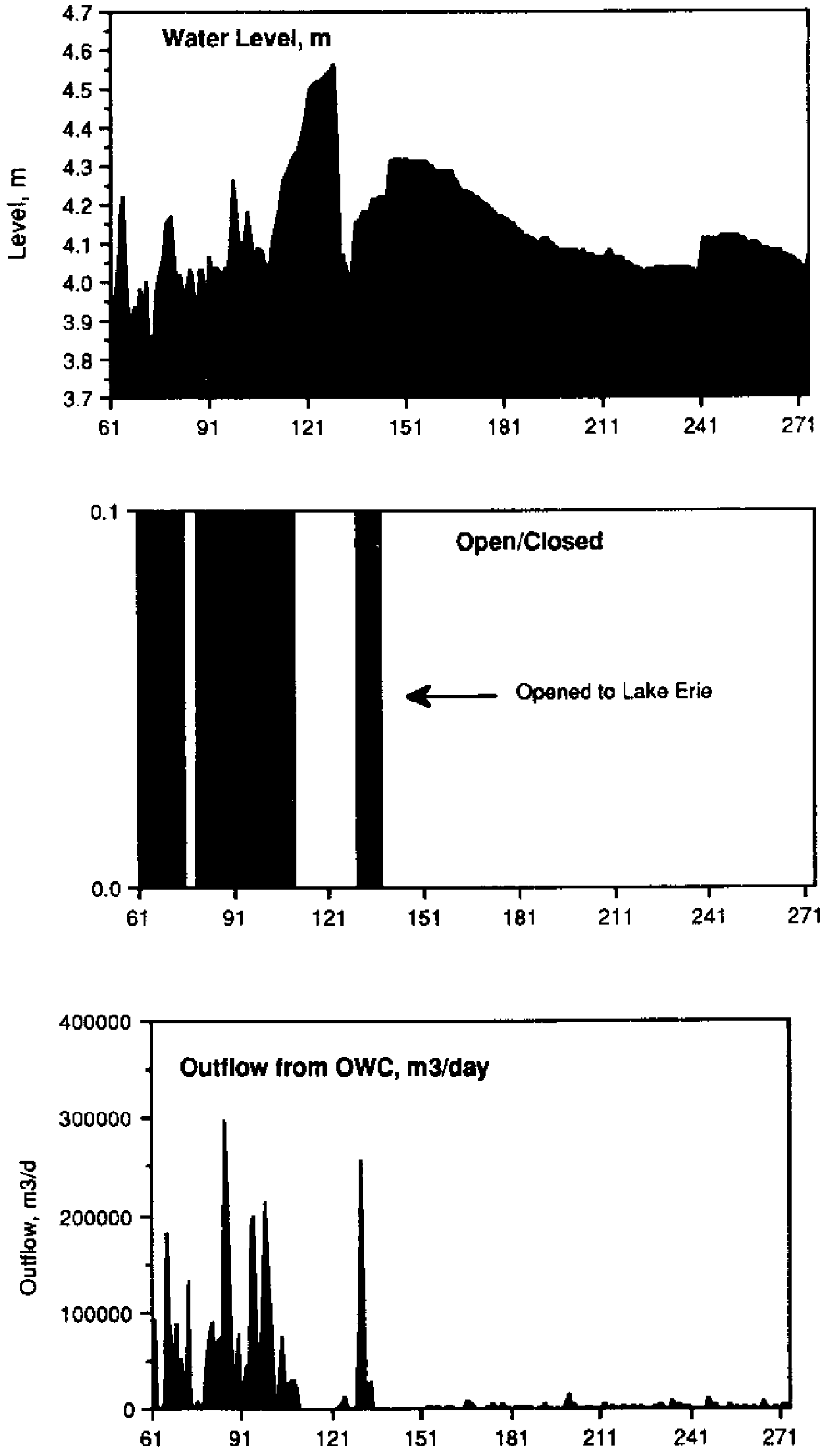


Figure 4.2 Water level and exchanges between Old Woman Creek wetland and Lake Erie for March 1 through September 30, 1988

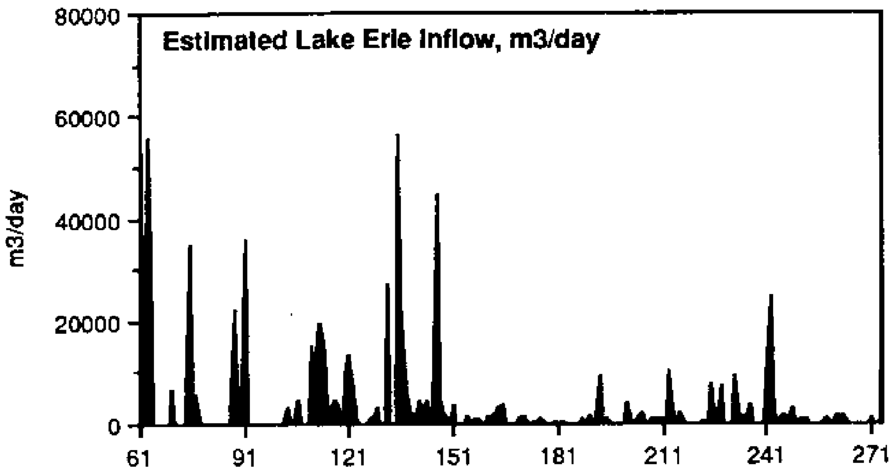


Figure 4.2 continued

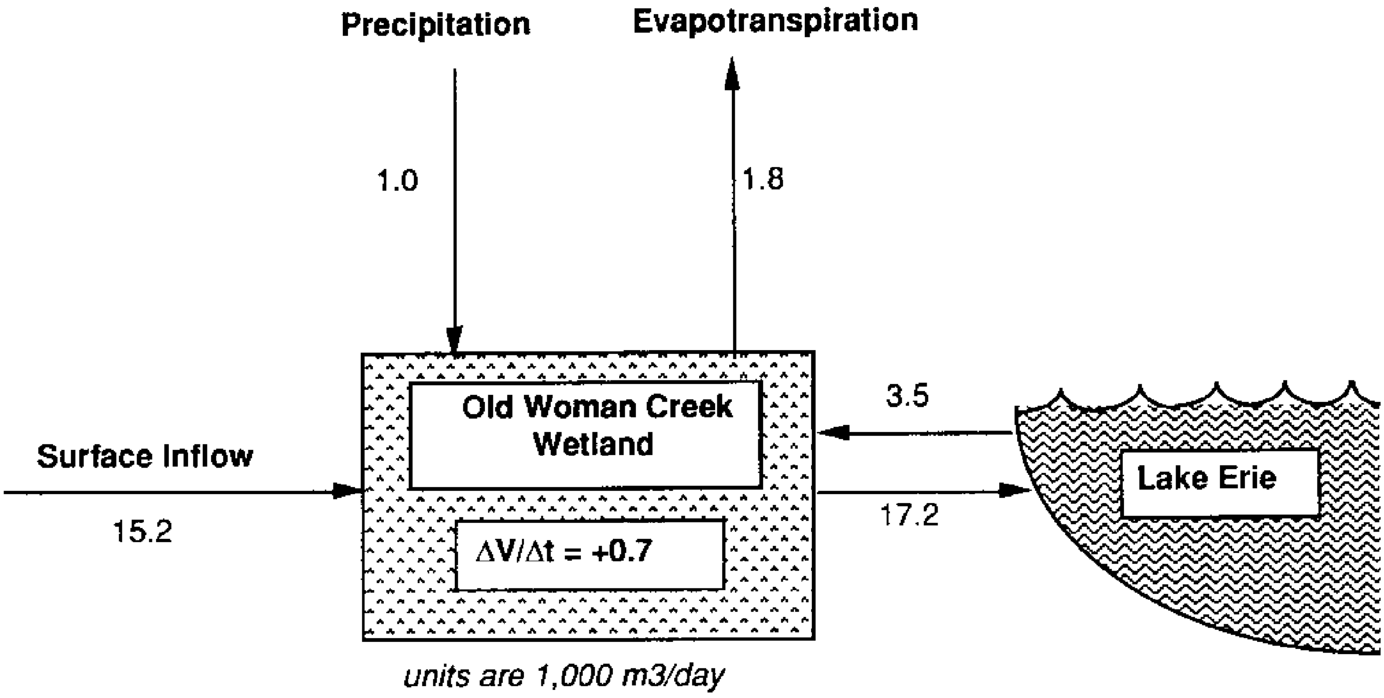


Figure 4.3 Estimated water budget for March 1 through September 30, 1988 for Old Woman Creek wetland Units are m^3/day x 1,000.

Table 4.1 Hydrology Budget for Old Woman Creek Wetland, March 1 through September 30, 1989

Date	Day	Level	Volume	ΔV	Inflow	Precipitation		Pan Ev	Evapotranspiration		Net Outflow	Mouth*	Lake Erie Inflow	Outflow
		m	m3	m3/day	m3/day	m/day	m3/day	m/day	m/day	m3/day	m3/day		m3/day	m3/day
1-Mar-88	61	3.99	102,311	97,839	31,806	0.0000	0	0.000	0.000	0	-66,034	1	66,034	0
2-Mar-88	62	3.89	44,722	-57,590	34,252	0.0000	0	0.000	0.000	0	91,842	1	0	91,842
3-Mar-88	63	4.05	137,214	92,493	36,699	0.0000	0	0.000	0.000	0	-55,794	1	55,794	0
4-Mar-88	64	4.17	201,784	64,570	31,806	0.0000	0	0.000	0.000	0	-32,765	1	32,765	0
5-Mar-88	65	4.22	229,707	27,922	34,252	0.0000	0	0.000	0.000	0	6,330	1	0	6,330
6-Mar-88	66	3.97	86,605	-143,102	39,145	0.0000	0	0.000	0.000	0	182,247	1	0	182,247
7-Mar-88	67	3.89	42,977	-43,629	51,378	0.0000	0	0.000	0.000	0	95,007	1	0	95,007
8-Mar-88	68	3.94	74,389	31,413	53,825	0.0000	0	0.000	0.000	0	22,412	1	0	22,412
9-Mar-88	69	3.89	44,722	-29,667	53,825	0.0048	2,727	0.000	0.000	0	86,219	1	0	86,219
10-Mar-88	70	3.98	95,331	50,609	44,039	0.0000	0	0.000	0.000	0	-6,570	1	6,570	0
11-Mar-88	71	3.94	74,389	-20,942	31,806	0.0000	0	0.000	0.000	0	52,747	1	0	52,747
12-Mar-88	72	4.00	105,802	31,413	31,806	0.0015	861	0.000	0.000	0	1,254	1	0	1,254
13-Mar-88	73	3.83	6,329	-99,473	31,806	0.0005	287	0.000	0.000	0	131,566	1	0	131,566
14-Mar-88	74	3.87	30,761	24,432	29,359	0.0010	574	0.000	0.000	0	5,501	1	0	5,501
15-Mar-88	75	3.98	93,586	62,825	26,912	0.0025	1,435	0.000	0.000	0	-34,478	0	34,478	0
16-Mar-88	76	4.01	111,037	17,451	24,466	0.0013	718	0.000	0.000	0	7,732	0	0	7,732
17-Mar-88	77	4.07	145,940	34,903	29,359	0.0000	0	0.000	0.000	0	-5,544	0	5,544	0
18-Mar-88	78	4.15	194,804	48,864	51,378	0.0018	1,005	0.000	0.000	0	3,519	0	0	3,519
19-Mar-88	79	4.17	203,530	8,726	48,932	0.0010	574	0.000	0.000	0	40,780	0	0	40,780
20-Mar-88	80	4.10	163,391	-40,138	36,699	0.0061	3,444	0.000	0.000	0	80,281	1	0	80,281
21-Mar-88	81	4.01	109,292	-54,099	34,252	0.0000	0	0.000	0.000	0	88,352	1	0	88,352
22-Mar-88	82	4.02	118,018	8,726	36,699	0.0000	0	0.000	0.000	0	27,973	1	0	27,973
23-Mar-88	83	3.98	95,331	-22,687	46,485	0.0000	0	0.000	0.000	0	69,172	1	0	69,172
24-Mar-88	84	3.97	90,095	-5,235	66,058	0.0046	2,583	0.000	0.000	0	73,877	1	0	73,877
25-Mar-88	85	4.03	123,253	33,158	318,057	0.0226	12,772	0.000	0.000	0	297,671	1	0	297,671
26-Mar-88	86	4.01	112,782	-10,471	222,640	0.0013	718	0.000	0.000	0	233,828	1	0	233,828
27-Mar-88	87	3.90	51,702	-61,080	83,184	0.0003	144	0.000	0.000	0	144,408	1	0	144,408
28-Mar-88	88	4.03	124,998	73,296	51,378	0.0000	0	0.000	0.000	0	-21,918	1	21,918	0
29-Mar-88	89	4.03	121,508	-3,490	41,592	0.0000	0	0.000	0.000	0	45,082	1	0	45,082
30-Mar-88	90	3.95	77,879	-43,629	34,252	0.0003	144	0.000	0.000	0	78,024	1	0	78,024
31-Mar-88	91	4.06	140,705	62,825	26,912	0.0000	0	0.000	0.000	0	-35,913	1	35,913	0
1-Apr-88	92	4.03	123,253	-17,451	26,912	0.0025	1,435	0.003	0.002	1,198	44,601	1	0	44,601
2-Apr-88	93	4.04	128,489	5,235	26,912	0.0000	0	0.007	0.005	2,694	18,983	1	0	18,983
3-Apr-88	94	4.03	123,253	-5,235	166,368	0.0277	15,643	0.007	0.005	2,844	184,402	1	0	184,402
4-Apr-88	95	4.01	111,037	-12,216	188,387	0.0000	0	0.006	0.004	2,245	198,358	1	0	198,358
5-Apr-88	96	4.04	128,489	17,451	63,611	0.0000	0	0.008	0.005	2,994	43,166	1	0	43,166
6-Apr-88	97	4.03	124,998	-3,490	41,592	0.0041	2,296	0.008	0.005	2,994	44,385	1	0	44,385
7-Apr-88	98	4.26	252,394	127,395	242,212	0.0145	8,180	0.003	0.002	1,148	121,850	1	0	121,850
8-Apr-88	99	4.20	222,726	-29,667	185,941	0.0000	0	0.002	0.002	898	214,710	1	0	214,710

Table 4.1 Hydrology Budget for Old Woman Creek Wetland, March 1 through September 30, 1989

Date	Day	Level	Volume	ΔV	Inflow	Precipitation		Pan Ev	Evapotranspiration		Net Outflow	Mouth*	Lake Erie Inflow	Outflow
		m	m3	m3/day	m3/day	m/day	m3/day	m/day	m/day	m3/day	m3/day		m3/day	m3/day
9-Apr-88	100	4.12	173,862	-48,864	61,165	0.0000	0	0.002	0.002	948	109,081	1	0	109,081
10-Apr-88	101	4.08	152,921	-20,942	41,592	0.0000	0	0.003	0.002	998	61,536	1	0	61,536
11-Apr-88	102	4.13	182,588	29,667	31,806	0.0000	0	0.003	0.002	998	1,140	1	0	1,140
12-Apr-88	103	4.18	210,510	27,922	26,912	0.0000	0	0.005	0.003	1,846	-2,856	1	2,856	0
13-Apr-88	104	4.09	156,411	-54,099	23,487	0.0000	0	0.005	0.003	1,946	75,641	1	0	75,641
14-Apr-88	105	4.05	137,214	-19,197	19,817	0.0003	144	0.006	0.005	2,545	36,613	1	0	36,613
15-Apr-88	106	4.09	159,901	22,687	17,126	0.0023	1,292	0.001	0.001	549	-4,818	1	4,818	0
16-Apr-88	107	4.08	149,430	-10,471	16,392	0.0003	144	0.002	0.001	699	26,308	1	0	26,308
17-Apr-88	108	4.05	133,724	-15,706	15,658	0.0003	144	0.005	0.003	1,796	29,712	1	0	29,712
18-Apr-88	109	4.04	131,979	-1,745	15,658	0.0056	3,157	0.004	0.003	1,497	19,064	1	0	19,064
19-Apr-88	110	4.09	159,901	27,922	13,701	0.0000	0	0.001	0.001	549	-14,770	0	14,770	0
20-Apr-88	111	4.13	182,588	22,687	11,988	0.0043	2,440	0.003	0.002	1,148	-9,407	0	9,407	0
21-Apr-88	112	4.18	212,255	29,667	11,010	0.0000	0	0.002	0.002	948	-19,606	0	19,606	0
22-Apr-88	113	4.23	238,432	26,177	10,031	0.0000	0	0.003	0.002	1,148	-17,294	0	17,294	0
23-Apr-88	114	4.27	261,119	22,687	9,786	0.0038	2,153	0.008	0.005	2,994	-13,742	0	13,742	0
24-Apr-88	115	4.29	271,590	10,471	9,052	0.0000	0	0.004	0.002	1,397	-2,816	0	2,816	0
25-Apr-88	116	4.31	282,061	10,471	8,318	0.0000	0	0.004	0.003	1,647	-3,799	0	3,799	0
26-Apr-88	117	4.33	292,532	10,471	8,074	0.0000	0	0.005	0.003	1,946	-4,343	0	4,343	0
27-Apr-88	118	4.34	303,003	10,471	7,829	0.0005	287	0.004	0.002	1,397	-3,752	0	3,752	0
28-Apr-88	119	4.37	316,964	13,961	14,924	0.0000	0	0.003	0.002	1,048	-85	0	85	0
29-Apr-88	120	4.42	346,631	29,667	19,083	0.0030	1,722	0.004	0.002	1,397	-10,259	0	10,259	0
30-Apr-88	121	4.47	372,808	26,177	14,680	0.0000	0	0.005	0.003	1,796	-13,294	0	13,294	0
1-May-88	122	4.50	390,260	17,451	11,988	0.0000	0	0.004	0.002	1,396	-6,859	0	6,859	0
2-May-88	123	4.51	400,731	10,471	10,520	0.0000	0	0.003	0.002	1,240	-1,191	0	1,191	0
3-May-88	124	4.52	404,221	3,490	9,786	0.0000	0	0.003	0.002	1,202	5,094	0	0	5,094
4-May-88	125	4.51	398,985	-5,235	8,808	0.0015	861	0.004	0.003	1,434	13,470	0	0	13,470
5-May-88	126	4.53	407,711	8,726	8,563	0.0053	3,014	0.004	0.003	1,551	1,300	0	0	1,300
6-May-88	127	4.54	414,692	6,981	8,074	0.0000	0	0.005	0.004	2,093	-1,000	0	1,000	0
7-May-88	128	4.55	421,672	6,981	7,095	0.0000	0	0.004	0.003	1,512	-1,397	0	1,397	0
8-May-88	129	4.56	428,653	6,981	6,606	0.0000	0	0.007	0.005	2,636	-3,011	0	3,011	0
9-May-88	130	4.44	358,847	-69,806	7,340	0.0084	4,736	0.007	0.005	2,636	79,245	0	0	79,245
10-May-88	131	4.01	114,527	-244,320	10,520	0.0053	3,014	0.006	0.004	2,403	255,450	1	0	255,450
11-May-88	132	4.07	147,685	33,158	7,829	0.0000	0	0.004	0.003	1,628	-26,957	1	26,957	0
12-May-88	133	4.04	126,743	-20,942	6,116	0.0000	0	0.006	0.004	2,210	24,849	1	0	24,849
13-May-88	134	3.99	102,311	-24,432	5,627	0.0005	287	0.005	0.004	2,171	28,175	1	0	28,175
14-May-88	135	4.10	161,646	59,335	4,649	0.0000	0	0.004	0.003	1,473	-56,159	1	56,159	0
15-May-88	136	4.15	189,568	27,922	4,159	0.0069	3,875	0.006	0.004	2,520	-22,408	1	22,408	0
16-May-88	137	4.16	200,039	10,471	5,382	0.0018	1,005	0.006	0.004	2,326	-6,410	0	6,410	0
17-May-88	138	4.18	207,020	6,981	4,649	0.0000	0	0.004	0.003	1,706	-4,038	0	4,038	0

Table 4.1 Hydrology Budget for Old Woman Creek Wetland, March 1 through September 30, 1989

Date	Day	Level	Volume	ΔV	Inflow	Precipitation		Pan Ev	Evapotranspiration		Net Outflow	Mouth*	Lake Erie Inflow	Outflow
		m	m3	m3/day	m3/day	m/day	m3/day	m/day	m/day	m3/day	m3/day		m3/day	m3/day
18-May-88	139	4.18	212,255	5,235	4,159	0.0020	1,148	0.005	0.003	1,783	-1,711	0	1,711	0
19-May-88	140	4.19	217,491	5,235	3,915	0.0020	1,148	0.005	0.003	1,783	-1,956	0	1,956	0
20-May-88	141	4.21	224,471	6,981	4,404	0.0000	0	0.005	0.004	2,132	-4,709	0	4,709	0
21-May-88	142	4.21	227,962	3,490	3,915	0.0000	0	0.006	0.004	2,326	-1,902	0	1,902	0
22-May-88	143	4.22	233,197	5,235	3,425	0.0000	0	0.007	0.005	2,869	-4,679	0	4,679	0
23-May-88	144	4.22	234,942	1,745	2,936	0.0003	144	0.008	0.005	3,062	-1,728	0	1,728	0
24-May-88	145	4.22	234,942	0	2,936	0.0000	0	0.005	0.003	1,861	1,075	0	0	1,075
25-May-88	146	4.30	280,316	45,374	2,447	0.0000	0	0.003	0.002	1,318	-44,245	0	44,245	0
26-May-88	147	4.31	285,551	5,235	2,373	0.0000	0	0.005	0.003	1,822	-4,684	0	4,684	0
27-May-88	148	4.32	287,296	1,745	2,226	0.0000	0	0.007	0.005	2,752	-2,271	0	2,271	0
28-May-88	149	4.32	287,296	0	1,859	0.0000	0	0.007	0.005	2,830	-970	0	970	0
29-May-88	150	4.31	285,551	-1,745	1,713	0.0000	0	0.008	0.005	3,101	357	0	0	357
30-May-88	151	4.32	287,296	1,745	1,517	0.0000	0	0.009	0.006	3,411	-3,640	0	3,640	0
31-May-88	152	4.31	285,551	-1,745	1,443	0.0000	0	0.008	0.006	3,256	-68	0	68	0
1-Jun-88	153	4.31	282,061	-3,490	1,199	0.0000	0	0.009	0.006	3,441	1,248	0	0	1,248
2-Jun-88	154	4.31	283,806	1,745	1,566	0.0097	5,453	0.005	0.003	1,938	3,336	0	0	3,336
3-Jun-88	155	4.31	285,551	1,745	1,835	0.0000	0	0.005	0.003	1,859	-1,769	0	1,769	0
4-Jun-88	156	4.31	282,061	-3,490	1,859	0.0000	0	0.005	0.004	2,017	3,333	0	0	3,333
5-Jun-88	157	4.31	282,061	0	1,590	0.0000	0	0.007	0.005	2,729	-1,139	0	1,139	0
6-Jun-88	158	4.30	280,316	-1,745	1,248	0.0000	0	0.010	0.007	3,797	-804	0	804	0
7-Jun-88	159	4.30	276,826	-3,490	881	0.0000	0	0.009	0.006	3,560	812	0	0	812
8-Jun-88	160	4.29	271,590	-5,235	685	0.0000	0	0.006	0.004	2,294	3,627	0	0	3,627
9-Jun-88	161	4.29	271,590	0	514	0.0000	0	0.005	0.003	1,859	-1,345	0	1,345	0
10-Jun-88	162	4.29	271,590	0	367	0.0000	0	0.005	0.003	1,938	-1,571	0	1,571	0
11-Jun-88	163	4.29	271,590	0	220	0.0000	0	0.006	0.004	2,333	-2,113	0	2,113	0
12-Jun-88	164	4.29	271,590	0	147	0.0000	0	0.008	0.006	3,164	-3,017	0	3,017	0
13-Jun-88	165	4.29	271,590	0	98	0.0000	0	0.009	0.006	3,441	-3,343	0	3,343	0
14-Jun-88	166	4.27	261,119	-10,471	24	0.0000	0	0.010	0.007	3,915	6,580	0	0	6,580
15-Jun-88	167	4.25	248,903	-12,216	0	0.0000	0	0.010	0.007	3,915	8,301	0	0	8,301
16-Jun-88	168	4.24	245,413	-3,490	0	0.0015	861	0.007	0.005	2,887	1,464	0	0	1,464
17-Jun-88	169	4.24	241,923	-3,490	0	0.0000	0	0.006	0.004	2,333	1,157	0	0	1,157
18-Jun-88	170	4.23	240,178	-1,745	0	0.0000	0	0.007	0.005	2,729	-984	0	984	0
19-Jun-88	171	4.23	238,432	-1,745	0	0.0000	0	0.009	0.006	3,401	-1,656	0	1,656	0
20-Jun-88	172	4.22	234,942	-3,490	0	0.0000	0	0.010	0.007	3,915	-425	0	425	0
21-Jun-88	173	4.22	229,707	-5,235	0	0.0000	0	0.010	0.007	3,836	1,399	0	0	1,399
22-Jun-88	174	4.21	226,216	-3,490	0	0.0008	431	0.011	0.007	4,232	-311	0	311	0
23-Jun-88	175	4.20	220,981	-5,235	0	0.0023	1,292	0.007	0.005	2,689	3,838	0	0	3,838
24-Jun-88	176	4.20	219,236	-1,745	0	0.0000	0	0.007	0.005	2,689	-944	0	944	0
25-Jun-88	177	4.19	215,746	-3,490	0	0.0020	1,148	0.010	0.007	4,074	565	0	0	565

Table 4.1 Hydrology Budget for Old Woman Creek Wetland, March 1 through September 30, 1989

Date	Day	Level	Volume	ΔV	Inflow	Precipitation		Pan Ev	Evapotranspiration		Net Outflow	Mouth*	Lake Erie Inflow	Outflow
		m	m3	m3/day	m3/day	m/day	m3/day	m/day	m/day	m3/day	m3/day		m3/day	m3/day
26-Jun-88	178	4.18	208,765	-6,981	0	0.0000	0	0.007	0.005	2,769	4,212	0	0	4,212
27-Jun-88	179	4.17	203,530	-5,235	0	0.0000	0	0.006	0.004	2,492	2,744	0	0	2,744
28-Jun-88	180	4.17	201,784	-1,745	0	0.0003	144	0.007	0.005	2,610	-722	0	722	0
29-Jun-88	181	4.16	198,294	-3,490	0	0.0000	0	0.006	0.004	2,492	999	0	0	999
30-Jun-88	182	4.16	196,549	-1,745	0	0.0000	0	0.005	0.004	2,057	-311	0	311	0
1-Jul-88	183	4.15	191,314	-5,235	0	0.0000	0	0.004	0.003	1,609	3,626	0	0	3,626
2-Jul-88	184	4.15	189,568	-1,745	0	0.0000	0	0.005	0.003	1,848	-103	0	103	0
3-Jul-88	185	4.14	184,333	-5,235	0	0.0000	0	0.006	0.004	2,265	2,970	0	0	2,970
4-Jul-88	186	4.13	180,843	-3,490	0	0.0000	0	0.006	0.004	2,504	987	0	0	987
5-Jul-88	187	4.12	175,607	-5,235	0	0.0000	0	0.007	0.005	2,623	2,613	0	0	2,613
6-Jul-88	188	4.12	173,862	-1,745	0	0.0000	0	0.007	0.005	2,831	-1,086	0	1,086	0
7-Jul-88	189	4.11	170,372	-3,490	0	0.0000	0	0.007	0.005	2,891	599	0	0	599
8-Jul-88	190	4.11	168,627	-1,745	0	0.0000	0	0.008	0.005	3,100	-1,355	0	1,355	0
9-Jul-88	191	4.10	165,137	-3,490	0	0.0000	0	0.008	0.005	2,980	510	0	0	510
10-Jul-88	192	4.10	163,391	-1,745	0	0.0127	7,176	0.007	0.005	2,921	6,000	0	0	6,000
11-Jul-88	193	4.11	170,372	6,981	0	0.0005	287	0.007	0.005	2,682	-9,376	0	9,376	0
12-Jul-88	194	4.11	166,882	-3,490	0	0.0000	0	0.006	0.004	2,474	1,016	0	0	1,016
13-Jul-88	195	4.10	165,137	-1,745	0	0.0000	0	0.006	0.005	2,563	-818	0	818	0
14-Jul-88	196	4.10	161,646	-3,490	0	0.0000	0	0.008	0.006	3,130	361	0	0	361
15-Jul-88	197	4.09	158,156	-3,490	0	0.0000	0	0.007	0.005	2,772	718	0	0	718
16-Jul-88	198	4.08	154,666	-3,490	0	0.0000	0	0.008	0.006	3,308	182	0	0	182
17-Jul-88	199	4.08	152,921	-1,745	0	0.0018	1,005	0.007	0.005	2,653	97	0	0	97
18-Jul-88	200	4.08	149,430	-3,490	0	0.0264	14,925	0.007	0.005	2,742	15,673	0	0	15,673
19-Jul-88	201	4.08	151,175	1,745	0	0.0010	574	0.007	0.005	2,682	-3,854	0	3,854	0
20-Jul-88	202	4.08	149,430	-1,745	0	0.0109	6,171	0.006	0.004	2,384	5,532	0	0	5,532
21-Jul-88	203	4.08	149,430	0	0	0.0064	3,588	0.006	0.004	2,444	1,144	0	0	1,144
22-Jul-88	204	4.07	148,907	-524	0	0.0013	718	0.006	0.004	2,444	-1,203	0	1,203	0
23-Jul-88	205	4.08	149,430	524	0	0.0018	1,005	0.006	0.004	2,504	-2,023	0	2,023	0
24-Jul-88	206	4.07	145,940	-3,490	0	0.0000	0	0.006	0.004	2,355	1,136	0	0	1,136
25-Jul-88	207	4.07	144,195	-1,745	0	0.0041	2,296	0.006	0.004	2,444	1,597	0	0	1,597
26-Jul-88	208	4.07	144,195	0	0	0.0020	1,148	0.006	0.004	2,384	-1,236	0	1,236	0
27-Jul-88	209	4.06	142,450	-1,745	0	0.0000	0	0.006	0.004	2,355	-609	0	609	0
28-Jul-88	210	4.06	140,705	-1,745	0	0.0000	0	0.006	0.005	2,563	-818	0	818	0
29-Jul-88	211	4.06	138,959	-1,745	0	0.0000	0	0.007	0.005	2,921	-1,176	0	1,176	0
30-Jul-88	212	4.06	140,705	1,745	0	0.0180	10,189	0.007	0.005	2,802	5,642	0	0	5,642
31-Jul-88	213	4.08	149,430	8,726	856	0.0000	0	0.006	0.004	2,504	-10,373	0	10,373	0
1-Aug-88	214	4.07	147,685	-1,745	147	0.0000	0	0.005	0.004	2,056	-164	0	164	0
2-Aug-88	215	4.06	142,450	-5,235	0	0.0000	0	0.006	0.004	2,353	2,882	0	0	2,882
3-Aug-88	216	4.06	142,450	0	0	0.0000	0	0.006	0.004	2,262	-2,262	0	2,262	0

Table 4.1 Hydrology Budget for Old Woman Creek Wetland, March 1 through September 30, 1989

Date	Day	Level	Volume	ΔV	Inflow	Precipitation		Pan Ev	Evapotranspiration		Net Outflow	Mouth*	Lake Erie Inflow	Outflow
		m	m3	m3/day	m3/day	m/day	m3/day	m/day	m/day	m3/day	m3/day		m3/day	m3/day
4-Aug-88	217	4.06	138,959	-3,490	0	0.0000	0	0.006	0.004	2,399	1,091	0	0	1,091
5-Aug-88	218	4.05	137,214	-1,745	0	0.0033	1,866	0.005	0.004	2,170	1,440	0	0	1,440
6-Aug-88	219	4.05	133,724	-3,490	0	0.0005	287	0.005	0.004	2,148	1,630	0	0	1,630
7-Aug-88	220	4.04	131,979	-1,745	0	0.0000	0	0.005	0.003	1,873	-128	0	128	0
8-Aug-88	221	4.04	128,489	-3,490	0	0.0000	0	0.005	0.004	2,056	1,434	0	0	1,434
9-Aug-88	222	4.03	123,253	-5,235	0	0.0000	0	0.005	0.004	2,102	3,134	0	0	3,134
10-Aug-88	223	4.03	121,508	-1,745	0	0.0000	0	0.006	0.004	2,193	-448	0	448	0
11-Aug-88	224	4.02	119,763	-1,745	0	0.0053	3,014	0.006	0.004	2,285	2,474	0	0	2,474
12-Aug-88	225	4.03	124,998	5,235	0	0.0000	0	0.006	0.004	2,285	-7,520	0	7,520	0
13-Aug-88	226	4.03	124,998	0	0	0.0000	0	0.006	0.004	2,330	-2,330	0	2,330	0
14-Aug-88	227	4.03	124,998	0	0	0.0000	0	0.006	0.004	2,376	-2,376	0	2,376	0
15-Aug-88	228	4.04	130,234	5,235	0	0.0000	0	0.005	0.004	2,125	-7,360	0	7,360	0
16-Aug-88	229	4.04	126,743	-3,490	0	0.0000	0	0.005	0.004	2,033	1,457	0	0	1,457
17-Aug-88	230	4.03	123,253	-3,490	0	0.0000	0	0.006	0.004	2,445	1,046	0	0	1,046
18-Aug-88	231	4.03	123,253	0	0	0.0119	6,745	0.005	0.003	1,805	4,940	0	0	4,940
19-Aug-88	232	4.04	131,979	8,726	0	0.0020	1,148	0.004	0.003	1,622	-9,200	0	9,200	0
20-Aug-88	233	4.04	130,234	-1,745	0	0.0000	0	0.004	0.003	1,759	-14	0	14	0
21-Aug-88	234	4.04	130,234	0	0	0.0000	0	0.004	0.003	1,531	-1,531	0	1,531	0
22-Aug-88	235	4.04	126,743	-3,490	0	0.0089	5,023	0.004	0.003	1,485	7,028	0	0	7,028
23-Aug-88	236	4.04	128,489	1,745	0	0.0000	0	0.004	0.003	1,645	-3,390	0	3,390	0
24-Aug-88	237	4.04	126,743	-1,745	0	0.0076	4,305	0.004	0.003	1,668	4,383	0	0	4,383
25-Aug-88	238	4.03	124,998	-1,745	0	0.0000	0	0.004	0.003	1,713	32	0	0	32
26-Aug-88	239	4.03	121,508	-3,490	0	0.0000	0	0.004	0.003	1,531	1,960	0	0	1,960
27-Aug-88	240	4.02	118,018	-3,490	0	0.0008	431	0.004	0.003	1,691	2,230	0	0	2,230
28-Aug-88	241	4.06	140,705	22,687	4,404	0.0213	12,055	0.004	0.003	1,531	-7,759	0	7,759	0
29-Aug-88	242	4.11	166,882	26,177	1,174	0.0038	2,153	0.004	0.003	1,508	-24,358	0	24,358	0
30-Aug-88	243	4.11	168,627	1,745	294	0.0000	0	0.003	0.002	1,348	-2,799	0	2,799	0
31-Aug-88	244	4.11	166,882	-1,745	0	0.0000	0	0.004	0.002	1,394	352	0	0	352
1-Sep-88	245	4.11	166,882	0	0	0.0000	0	0.003	0.002	1,314	-1,314	0	1,314	0
2-Sep-88	246	4.11	166,882	0	0	0.0000	0	0.004	0.003	1,502	-1,502	0	1,502	0
3-Sep-88	247	4.11	166,882	0	416	0.0211	11,911	0.003	0.002	1,314	11,013	0	0	11,013
4-Sep-88	248	4.12	173,862	6,981	783	0.0076	4,305	0.003	0.002	1,314	-3,207	0	3,207	0
5-Sep-88	249	4.12	173,862	0	391	0.0081	4,592	0.002	0.001	826	4,158	0	0	4,158
6-Sep-88	250	4.12	173,862	0	147	0.0000	0	0.002	0.002	864	-717	0	717	0
7-Sep-88	251	4.12	173,862	0	0	0.0000	0	0.003	0.002	1,014	-1,014	0	1,014	0
8-Sep-88	252	4.12	173,862	0	0	0.0000	0	0.003	0.002	1,126	-1,126	0	1,126	0
9-Sep-88	253	4.11	172,117	-1,745	0	0.0000	0	0.004	0.002	1,369	356	0	0	356
10-Sep-88	254	4.11	166,882	-5,235	0	0.0000	0	0.003	0.002	1,352	3,884	0	0	3,884
11-Sep-88	255	4.10	165,137	-1,745	0	0.0000	0	0.003	0.002	1,277	468	0	0	468

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Date	Day	Level	Volume	ΔV	Inflow	Precipitation		Pan Ev	Evapotranspiration		Net Outflow	Mouth*	Lake Erie Inflow	Outflow
		m	m3	m3/day	m3/day	m/day	m3/day	m/day	m/day	m3/day	m3/day		m3/day	m3/day
12-Sep-88	256	4.10	165,137	0	0	0.0069	3,875	0.003	0.002	1,333	2,542	0	0	2,542
13-Sep-88	257	4.10	163,391	-1,745	0	0.0000	0	0.003	0.002	1,108	637	0	0	637
14-Sep-88	258	4.10	163,391	0	0	0.0000	0	0.003	0.002	1,089	-1,089	0	1,089	0
15-Sep-88	259	4.09	159,901	-3,490	0	0.0000	0	0.003	0.002	995	2,495	0	0	2,495
16-Sep-88	260	4.09	158,156	-1,745	0	0.0000	0	0.003	0.002	1,183	562	0	0	562
17-Sep-88	261	4.09	158,156	0	0	0.0000	0	0.004	0.003	1,539	-1,539	0	1,539	0
18-Sep-88	262	4.08	154,666	-3,490	0	0.0000	0	0.004	0.003	1,633	1,857	0	0	1,857
19-Sep-88	263	4.08	154,666	0	0	0.0000	0	0.004	0.003	1,521	-1,521	0	1,521	0
20-Sep-88	264	4.08	152,921	-1,745	0	0.0003	144	0.003	0.002	1,333	556	0	0	556
21-Sep-88	265	4.08	149,430	-3,490	0	0.0104	5,884	0.003	0.002	1,070	8,304	0	0	8,304
22-Sep-88	266	4.07	145,940	-3,490	0	0.0000	0	0.003	0.002	1,164	2,326	0	0	2,326
23-Sep-88	267	4.07	144,195	-1,745	0	0.0008	431	0.003	0.002	1,164	1,012	0	0	1,012
24-Sep-88	268	4.06	142,450	-1,745	0	0.0000	0	0.002	0.002	957	788	0	0	788
25-Sep-88	269	4.06	138,959	-3,490	0	0.0000	0	0.002	0.002	901	2,589	0	0	2,589
26-Sep-88	270	4.05	137,214	-1,745	0	0.0000	0	0.002	0.002	976	769	0	0	769
27-Sep-88	271	4.05	137,214	0	0	0.0000	0	0.003	0.002	1,239	-1,239	0	1,239	0
28-Sep-88	272	4.04	131,979	-5,235	0	0.0000	0	0.002	0.002	901	4,334	0	0	4,334
29-Sep-88	273	4.04	130,234	-1,745	0	0.0000	0	0.003	0.002	1,202	544	0	0	544
30-Sep-88	274	4.07	147,685	17,451	0	0.0000	0	0.004	0.002	1,389	-18,841	0	18,841	0
Average			182,553	669	15,201	0.002	995	0.004	0.003	1,769	13,757		3,463	17,220
Total				143,213	3,252,913	0.377	212,825	0.957	0.670	378,494	2,944,032		741,078	3,685,110

* 1=Open; 0 = Closed

5

Bioavailable Phosphorus and a Phosphorus Budget of a Freshwater Coastal Wetland

Brian C. Reeder
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Introduction

Wetlands can be important buffer systems between uplands and deepwater aquatic systems, often serving as temporary or permanent sinks for water and chemicals as they travel downstream (Mitsch and Gosselink 1986). Wetlands have been called the "kidneys of the landscape" (Mitsch and Gosselink 1986) due to their capability to "treat" inflowing waters and release them to the outflow cleansed. This ability is understood well enough to allow the use of wetlands for treatment of point sources of pollution such as sewage (Hartland-Rowe and Wright 1985; Odum et al. 1977; Kadlec 1979) and acid mine drainage (Fennesy and Mitsch 1989).

Nonpoint pollution is one of the major problems to downwater areas in agricultural landscapes (Peverly 1982; Baker et al. 1985; Kunishi and Glotfelty 1985; Kunishi 1988). Even if all phosphorus from point sources was eliminated from Lake Erie, nonpoint phosphorus could still cause major water quality problems in Lake Erie. About 90% of the phosphorus put onto farm fields is lost because the orthophosphate fertilizer is quickly sorbed by soil particles and/or bound chemically with cations such as iron, manganese and aluminum. Since phosphorus binds to soil, the initial solution was to control erosion; however, since the clay fraction sorbs phosphorus preferentially, erosion control techniques such as no-till and low-till farming techniques actually increase bioavailable phosphorus in runoff (Oloya and Logan 1980; Logan and Adams 1981).

Wetlands act as hydrologic barriers to these suspended sediments by slowing incoming waters and spreading it over a low energy landscape. Consequently, river sediments, often laden with phosphorus, tend to deposit at lower flow velocities of wetlands (Peverly 1982). Once in the wetland system, this phosphorus may remain permanently buried or be bound or transformed by the wetland's abundant biotic systems.

Great Lakes Wetlands as Nutrient Sinks

The role of Lake Erie coastal wetlands in mitigating eutrophication and/or population shifts in Lake Erie's aquatic communities due to nonpoint pollution from the agricultural watersheds is not known. Lake Erie's coastline was once fringed by large wetlands which may have acted to halt downstream eutrophication. The small percentage of natural wetlands that remain may help in the control of phosphorus from agricultural runoff.

The Laurentian Great Lakes coastal wetlands are different from many previously studied wetlands. Their hydrology is estuarine if they are undiked and open to the lake and yet they are completely freshwater systems. They are often highly productive. When open to the lake, seiches can have an effect on nutrients in Great Lakes wetlands. In addition to affecting soil chemistry and productivity (Gosselink and Turner 1978; Lyon et al. 1986), Sager et al. (1985) found that Lake Michigan seiches caused fluctuations of every major nutrient in an adjacent wetland. Levels of phosphorus rose and fell with the water level. Kreiger (1985) and Klarer (1988) found lake plankton in Old Woman Creek wetland during high lake levels and conversely after prolonged heavy storm events, the wetland plankton were exported to the lake.

Phosphorus cycling has been investigated previously at Old Woman Creek wetland. Heath (1987) investigated inflow and outflow concentrations of phosphorus in Old Woman Creek wetland. He found a significant seasonal reduction in the amount of total phosphorus leaving the wetland and noted that during the growing season bioavailable phosphorus decreased as water moved towards the outflow. He also found that phosphorus uptake was dependent on planktonic activity, not on sediment absorption-desorption kinetics. Based on the nutrient availability, laboratory bioassay results, and the lack of phosphomonoester production, he concluded that plankton were not phosphorus limited. Klarer (1988) suggested that the wetland's physical structure is conducive to regulating the amount of phosphorus that gets to the lake. He found that most of the sediments remained in the marsh and were not exported to the lake even after strong storm events. In fact, up to 70 percent of the storm water orthophosphate was retained in the marsh. He also found that orthophosphate was diluted during storm runnoff, and it seemed to be associated with the sediment fraction of the water. Both Heath (1987) and Klarer (1988) lacked critical data on inflow rates necessary to calculate a mass balance.

Methods

Water samples were taken at the ten sites shown in Figure 2.1, which includes an upstream site that receives little to no lake water, and a lakeshore water site. Samples were taken monthly or every other week with acid washed bottles and the water levels recorded. When the samples were taken the temperature, pH (portable meter--calibrated with 4.01, 7.00, and 10.00 standards), and conductivity (portable Hach meter) at each site were also measured. Within two hours of collection 100-ml of each sample was filtered through a 0.45 µm membrane filter (soaked overnight in distilled water to remove any traces of contamination). The filtered water was immediately placed in a freezer and the filter and filtrant retained for chlorophyll *a* measurements. The samples were placed on ice in the field, then kept from -5 to 4°C until analyzed. Samples were analyzed for all chemical species within 72 hours of collection.

Total suspended solids (TSS) were measured according to Standard Methods (APHA 1985). One Hundred ml of sample was vacuum filtered through a dry, pre-weighed 0.45 µm glass fiber filter. The filter and filtrant were dried for at least 24 hrs. at 104°C, and the increase in weight determined. Twenty-five ml of sample was then tested for turbidity with a Hach colorimeter (Hach Chemical Corporation 1984).

Bioavailability of phosphorus was ascertained by measurements of three phosphorus fractions following the guidelines of Logan et al. (1979) for Great Lakes tributaries. Soluble reactive phosphorus (SRP) was determined as

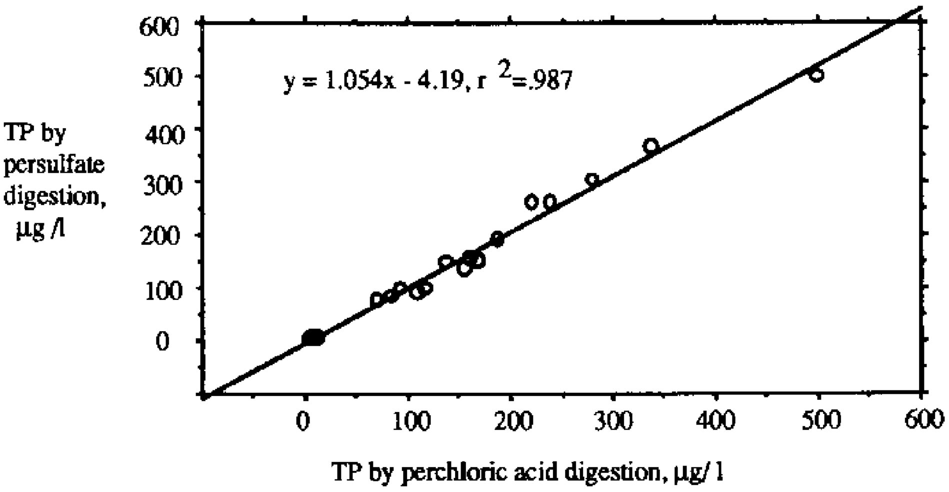

Figure 5.1 Comparison of phosphorus concentrations using the persulfate and perchloric acid digestion methods

molybdate reactive phosphorus (after APHA 1985) which passed through a 0.45 μm membrane filter. Total phosphorus in unfiltered (TP) and filtered (TSP) water was determined as othophosphate released after digestion with ammonium persulfate. Particulate phosphorus (Part P) was considered the difference between TP and TSP.

The persulfate method was checked against the more rigorous perchloric acid digestion (after Sommers and Nelson 1972) to determine if it was releasing all of the phosphorus to orthophoshate. Figure 5.1 shows a comparison of the two methods for ten water samples from Old Woman Creek and nine samples taken from other western Lake Erie wetlands (samples courtesy of D. Robb). Even with such a diverse array of samples, there was still less than 2% difference between the two methods.

The persulfate digestion was carried out as described in Standard Methods (APHA 1985). Fifty ml of acidified sample was treated with 1 ml sulfuric acid solution and 0.4 g ammonium persulfate. This was autoclaved for 30 minutes at 98-137 kPa, cooled, neutralized to a faint pink phenolphthalein with 5N sodium hydroxide then analyzed for orthophosphorus.

A nutrient budget was determined using a combination of data on hydrology (Chapter 4) and water chemistry. Inflows and outflows of phosphorus were estimated from phosphorus concentrations at the inflow, outflow, and Lake Erie. When the barrier beach was closed we assumed that no phosphorus was being exchanged with the lake. Cycling of phosphorus by plankton was determined from metabolism measurements (Chapter 3) and from an assumed ratio of 1 g P: 40 g C. To estimate macrophyte uptake, randomly selected *Nelumbo* plant samples were analyzed for phosphorus composition by the Ohio Agricultural Research and Development Center (OARDC) laboratory in Wooster (see Chapter 3). OARDC analyzes nutrients by dry ashing the sample, bringing it into solution, then recording emissions on a Inductively Coupled Plasma Spectrometer (ICP). Phosphorus sediment concentrations and sedimentation rates were determined from sediment core data presented in Chapter 6 and represent average values over several years.

Results and Discussion

Water Chemistry

Concentrations of chemical parameters at the inflow, outflow, and marsh are given in Figures 5.2 and 5.3 (Appendix 5.1 presents all the water chemistry data). Spatial variations in concentrations of phosphorus species as they flow through the wetland are given in Figure 5.4.

The pH of the wetland water remained circumneutral (annual mean of 7.9 ± 0.7 std dev). The abundance of limestone in the watershed caused relatively high alkalinity and some buffering . Diurnal shifts in pH were noted during periods of high planktonic productivity (sometimes down to 6 during the night). Little difference was seen between inflow and outflow pH.

Conductivity, turbidity and total suspended solids generally had their highest concentrations at the inflow, then decreased up to seven fold as the water flowed through the wetland. Conductivity was very low in the marsh towards the end of the growing season, although during the same period it stayed relatively the same at the bridge outlet. Differences in turbidity and total suspended solids were not as pronounced during this same period as they were during the spring and summer. The average ± standard deviation of some of the chemical parameters are as follows: conductivity 510 ± 133 μmhos/cm; turbidity 128 ± 85 FTU; and total suspended solids 123 ± 100 mg/L.

Phosphorus concentrations tended to decrease as water flowed through the wetland. Total phosphorus was more variable in its retention in the marsh, and is often higher at the outflow. During the periods of high inflow concentrations, outflow remained relatively low. Total soluble phosphorus (TSP) usually dropped about 50-75 μg/L from inflow to outflow, but this was not consistent. TSP differences were the greatest during the periods of highest productivity (Figure 5.5).

Little correlation was found between most of the variables (Figure 5.6) except for turbidity and total suspended solids which were highly correlated in a linear fashion (Figure 5.7). Turbidity and total phosphorus seem to be associated with chlorophyll *a*. Total phosphorus also shows some correlation with turbidity (hence suspended solids) and conductivity. There was little statistical relationship between total suspended solids and particulate phosphorus (Figure 5.8). Normally one would expect to find a definite relationship between particulate phosphorus and the amount of suspended sediments in the wetland. Due to significant resuspension in shallow waters, the seasonality of fertilizer-laden sediments, and the scavenging of phosphorus by smaller particles, no such relationship was found.

Nutrient Budget

Two mass balances of phosphorus in Old Woman Creek are shown in Figure 5.9. Figure 5.9a illustrates an estimate of the inflow and retention of nutrients determined from representative loading rates for similar Lake Erie watersheds (0.5 - 1.0 kg/ha-yr from Johnson et al. 1978, IJC 1980, and Novotny 1986) and from phosphorus removal efficiency plots by Richardson and Nichols (1985). An input of phosphorus to the wetland of 6.1 to 12.2 gP/m^2-yr (17 - 33 mg-

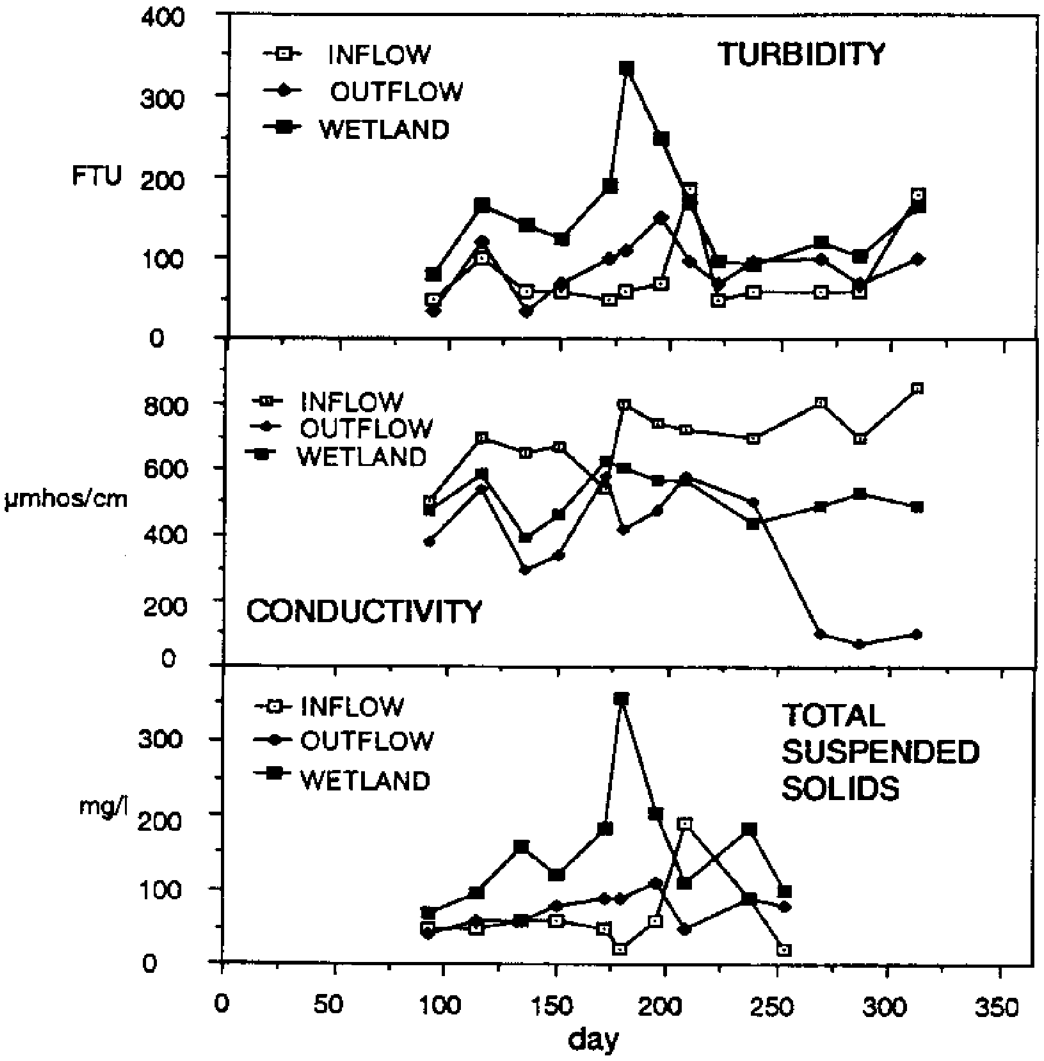

Figure 5.2 Concentration of turbidity, conductivity, and total suspended solids at the inflow, outflow, and within Old Woman Creek wetland over the 1988 growing season

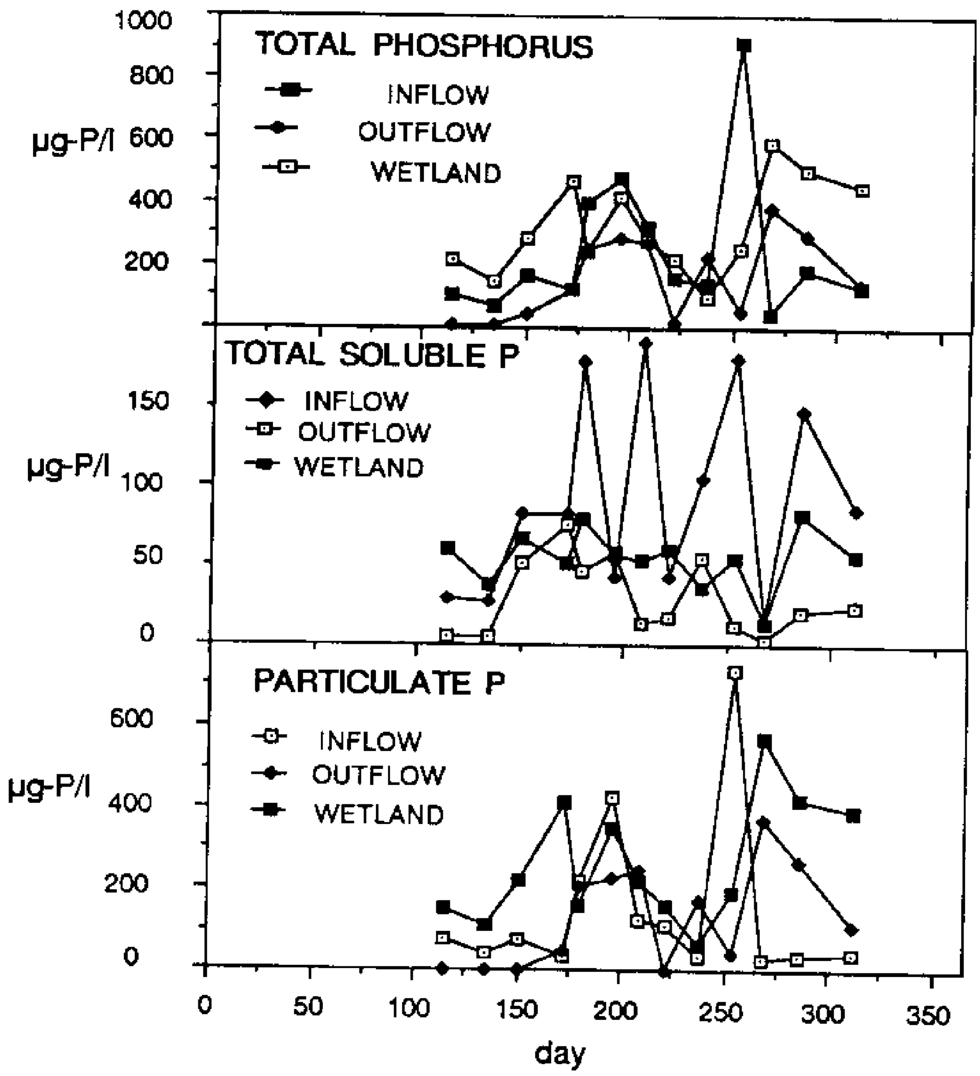

Figure 5.3 Concentration of total phosphorus, total soluble phosphorus, and particulate phosphorus at the inflow, outflow, and within Old Woman Creek wetland over the 1988 growing season

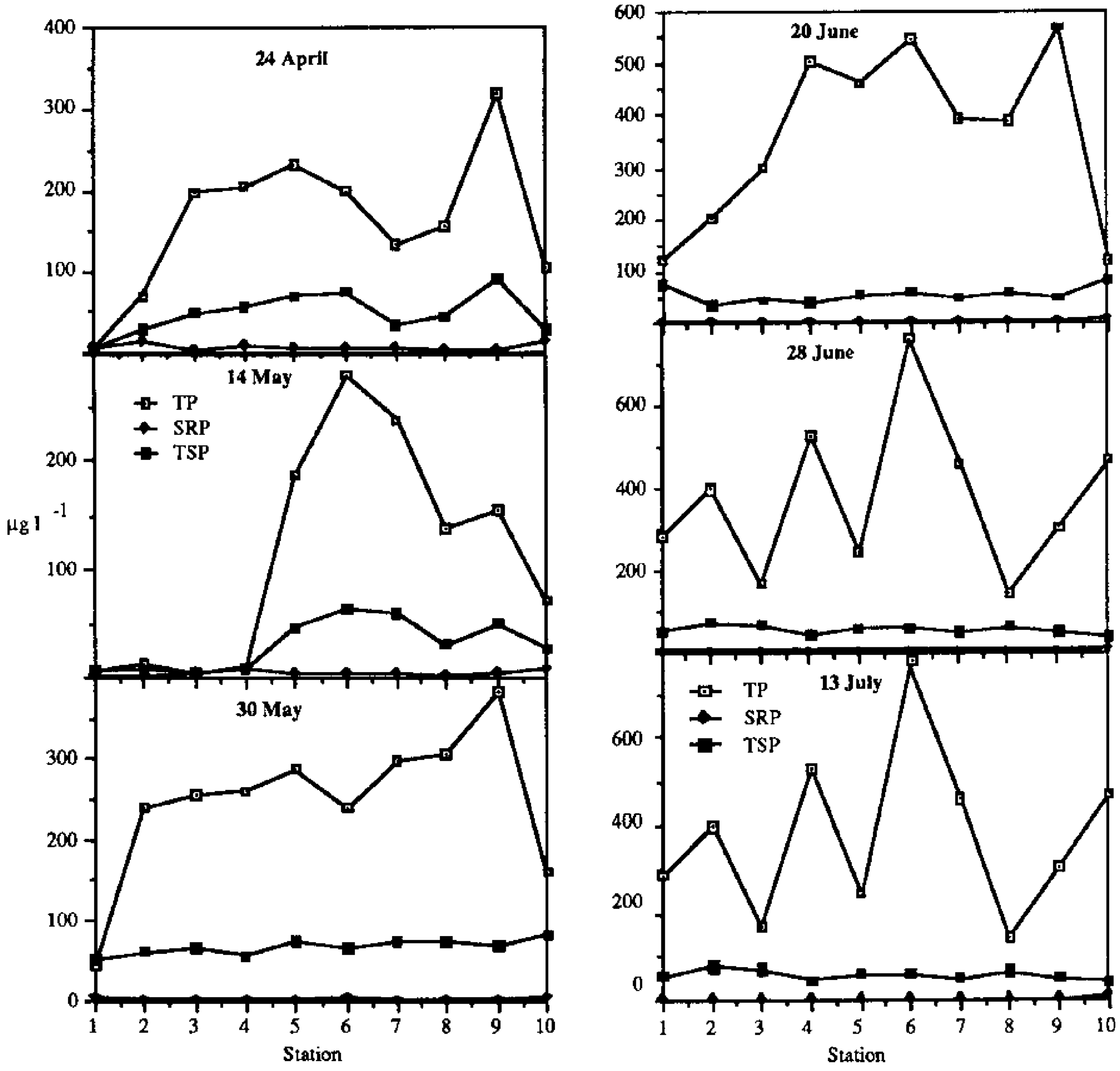

Figure 5.4 Concentration of total phosphorus (TP), soluble reactive phosphorus (SRP), and total soluble phosphorus (TSP) by sampling site shown on Figure 2.1 over the 1988 growing season

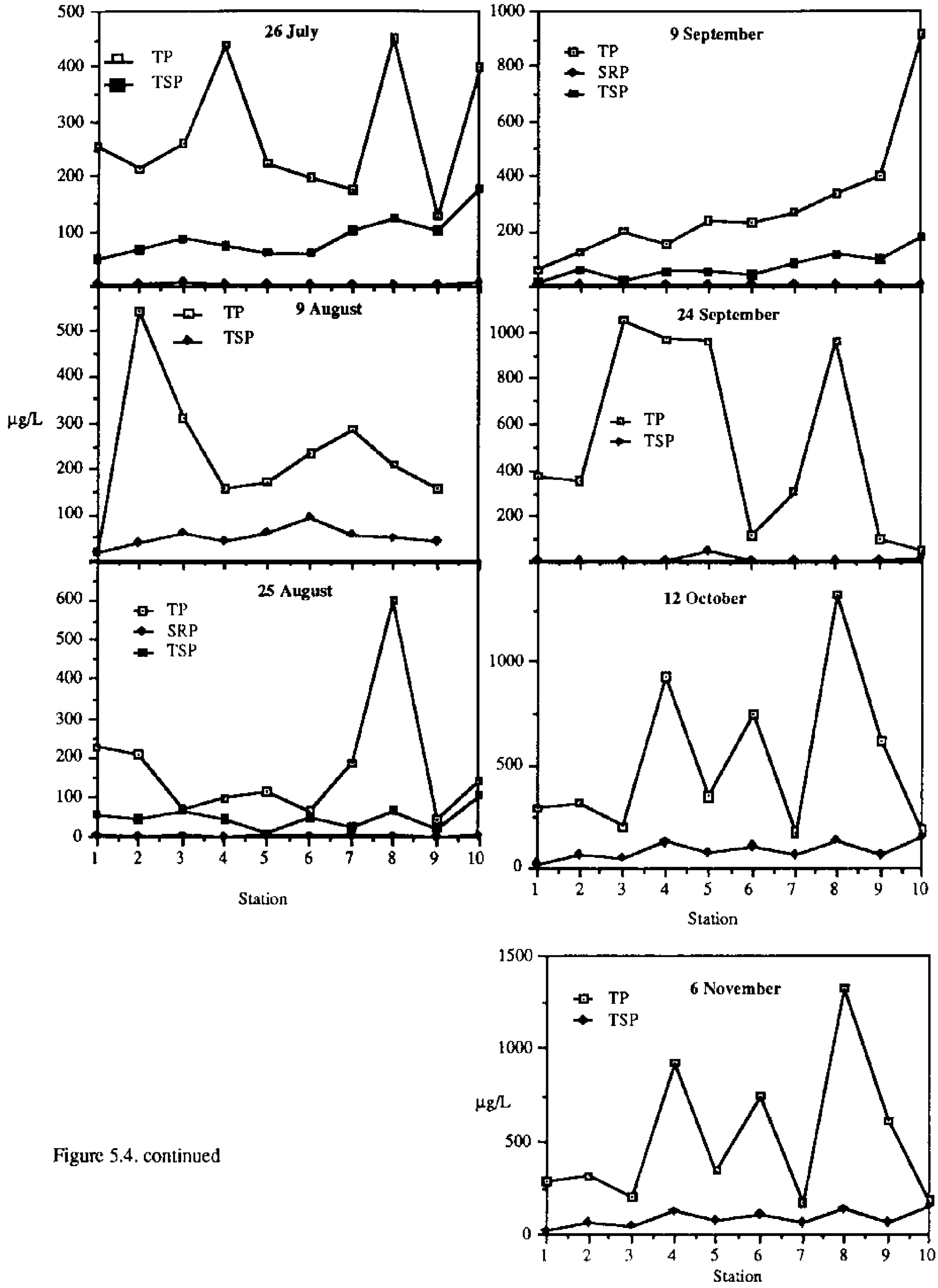

Figure 5.4. continued

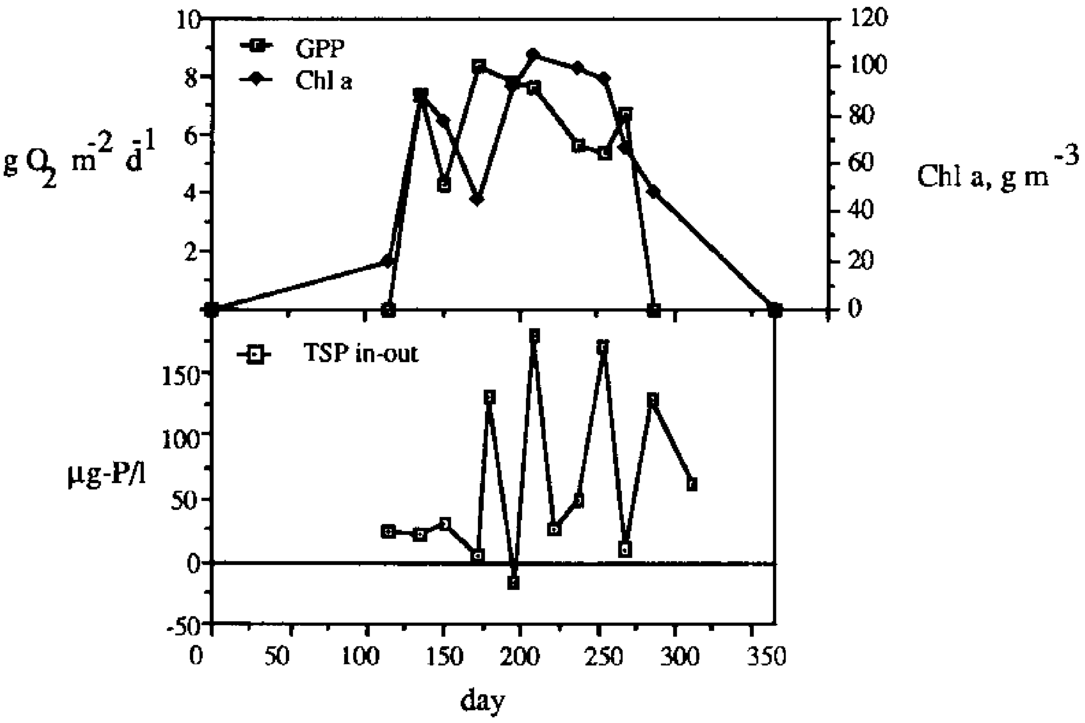

Figure 5.5 Change in total soluble phosphorus (TSP) from outflow to inflow compared to planktonic gross primary productivity (GPP) and chlorophyll *a* through the study period

	pH	Cond.	FTU	Chl a	TP	SRP	TSP	TSS	Part P
pH	1								
Cond.	.17	1							
FTU	-.02	.37	1						
Chl a	-.18	.29	.59	1					
TP	.13	.36	.36	.4	1				
SRP	.13	.37	-.09	-.12	-.06	1			
TSP	-.09	.36	.25	.2	.27	.1	1		
TSS	-.09	.24	.94	.44	.28	-.18	.23	1	
Part P	.16	.29	.31	.37	.97	-.09	.04	.24	1

Figure 5.6 Correlation matrix of chemical parameters measured in Old Woman Creek wetland in 1988

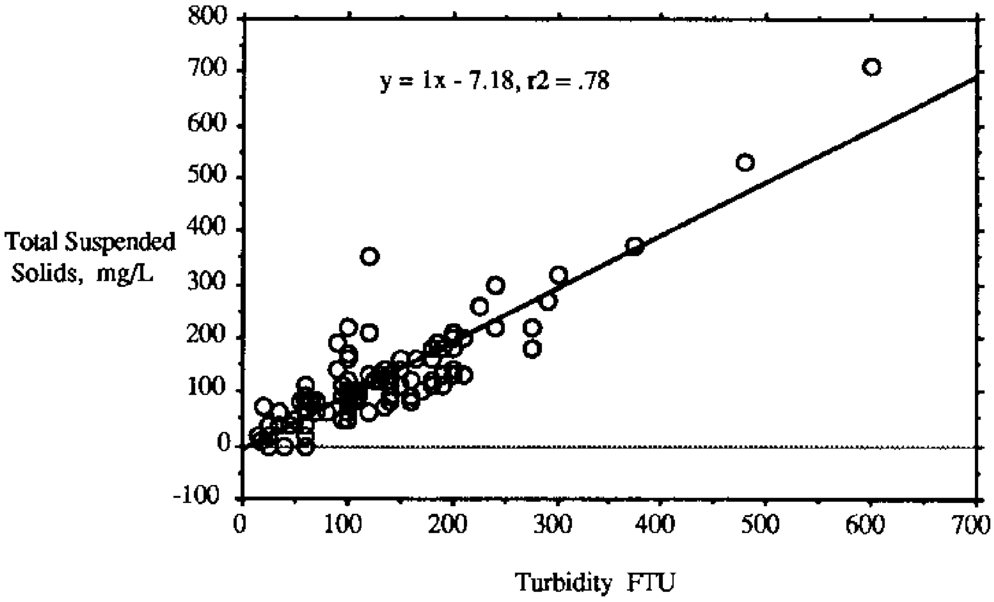

Figure 5.7. Regression of turbidity and total suspended solids for Old Woman Creek wetland from 1988 data

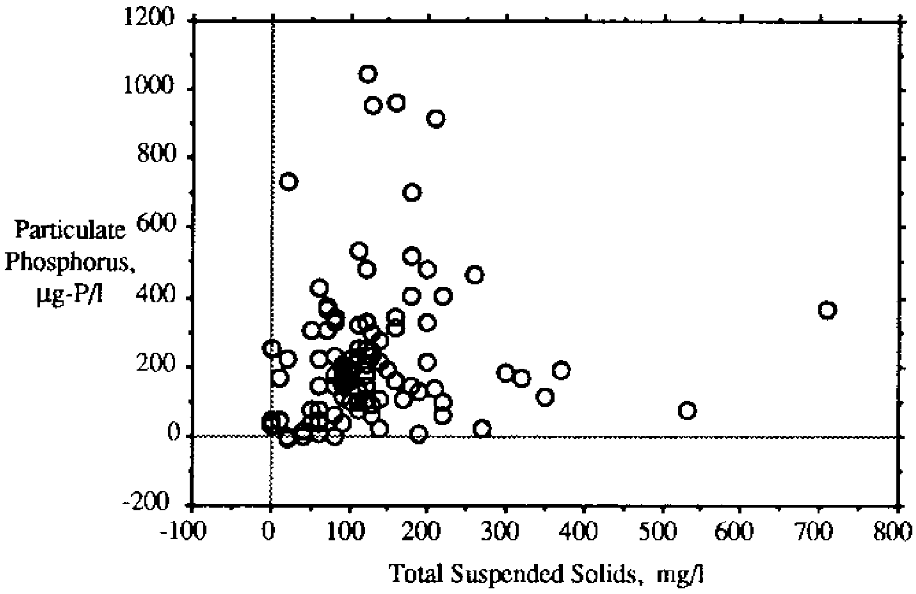

Figure 5.8 Regression between particulate phosphorus and total suspended solids for Old Woman Creek wetland from 1988 data

P/m^2-day) and a retention, ultimately in the sediments, of 2.9 to 4.6 gP/m^2-yr (8 - 13 mg-P/m^2-day) are estimated. Analysis of the data for the period March 1 through November 30, 1988 presents a different picture (Figure 5.9b). Because this phosphorus budget is for a drought year, phosphorus loading from the watershed is considerably less than that estimated from other watersheds for normal years. Outflow of phosphorus, which is assumed to occur only when the barrier beach is open, is estimated to be 36 % less than the inflow. The Richardson and Nichols model would have predicted a much higher decrease at this low loading rate.

Sedimentation is considered the most important process of intra-system cycling of phosphorus entering the wetland. Our estimate of phosphorus retention by the sediments (8 gP/m^2-yr or 22 mg P/m^2-day) is an average over several years from deep sediment cores taken from the wetland (see Chapter 6). It is considerably more than that estimated from the Richardson and Nichols model, suggesting that there is more phosphorus coming into Old Woman Creek wetland than estimated by either model in Figure 5.9.

Significant quantities of phosphorus are transformed by the plankton system and a smaller amount transformed by the wetland's macrophytes. Apparently the requirement of phosphorus by the ecosystem was not met by the supply coming from the uplands during this drought year. The deficit had to be made up through internal recycling and resuspension of phosphorus from the sediments. We have previously suggested (Mitsch et al. 1989) that phosphorus in Old Woman Creek wetland may be transformed from bioavailable to nonbioavailable forms by primary producers. Plankton seemed to be the most significant transformer, since soluble reactive phosphorus levels decreased the most when planktonic populations were most productive. Now we believe that there is a rapid recycling of phosphorus as well so that an adequate amount is available to support the productivity.

Although Old Woman Creek wetland is not dominated by macrophytes, the floating-leaved vegetation (*Nelumbo lutea*) also contributes to the transforming of phosphorus, although their source is the phosphorus-rich sediments. We estimated an uptake of 0.8 g P/m^2-yr or 0.3 mg P/m^2-day by the macrophytes. The floating-leaved plants actually may be pumping the nutrients from the sediments to the water column (when the leaves die and decay), thus in effect serving as a phosphorus source to the wetland.

We cannot conclude that Old Woman Creek wetland is a permanent sink of phosphorus based on our year of analysis, particularly since it was during a drought year. However some of the inflow of phosphorus was lost before it reached the outlet to the lake. Since the wetland is closed to the lake throughout the growing season, bioavailable phosphorus has a good probability of being transformed or buried before the barrier beach is again opened. Old Woman Creek wetland clearly has a major role to play in the nutrient dynamics of its watershed, but it is more likely as a nutrient transformer than as a nutrient sink. The accumulation of sediments, described in more detail over the wetland's history in Chapter 6, is the key to any long-term retention of nutrients.

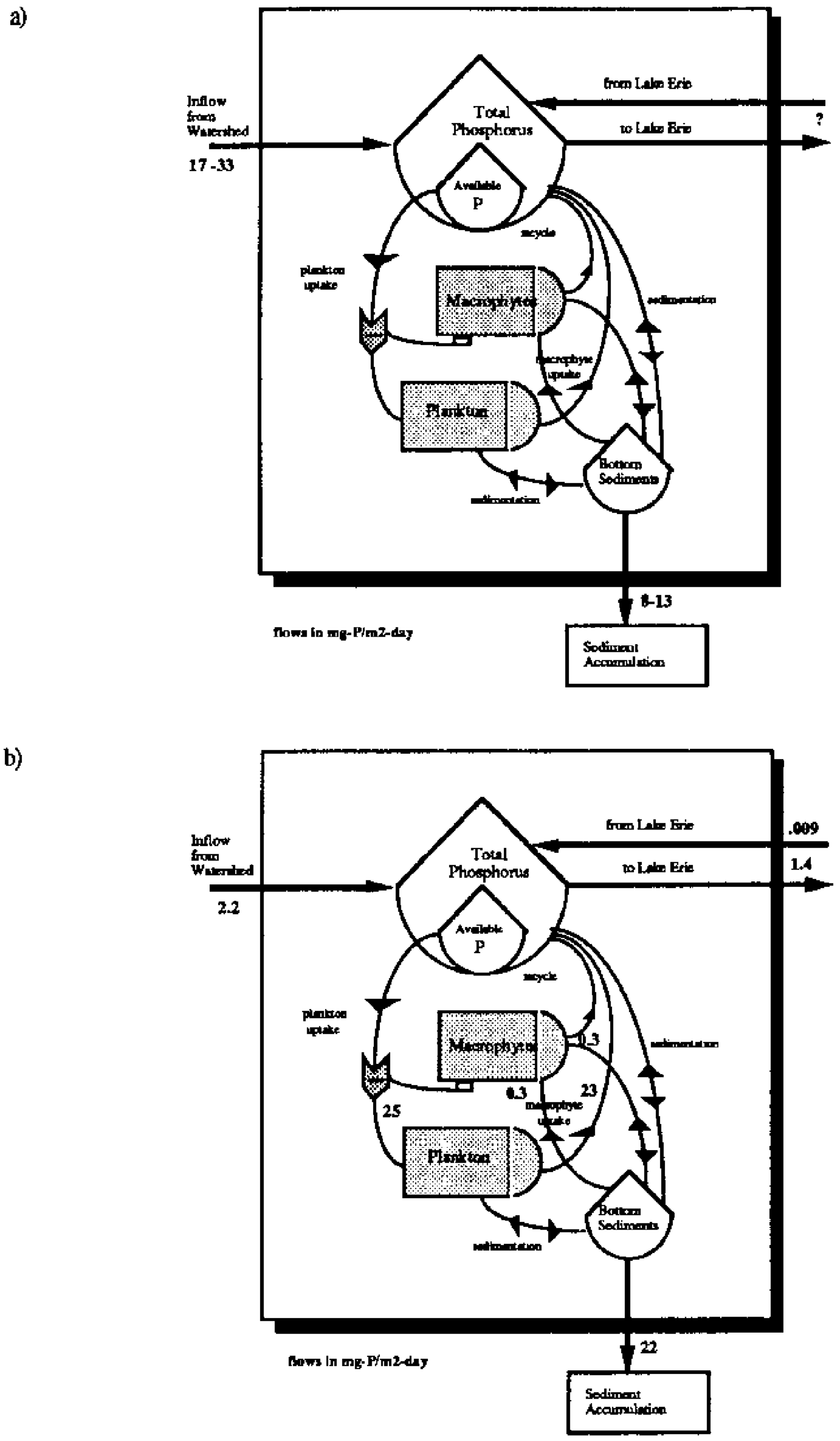

Figure 5.9 Phosphorus mass balance using daily averages for Old Woman Creek wetland a) as estimated from loading rates and Richardson and Nichols (1985) model, and b) for the period March 1 - November 30, 1988 from data in this study; calculations for b) are in Appendix 5.2

Appendix 5.1 Water chemistry analysis of Old Woman Creek wetland, 1988

Site	pH	conductivity µmhos/cm	turbidity FTU	chlorophyll a mg/m3	Total P µg/L	SRP µg/L	TSP µg/L	TSS mg/L
1-Apr-88								
1	8	300	25	0				20
2	7.9	380	35	0				40
3	7.8	450	45	5				40
4	7.7	460	65	4				80
5	7.7	450	100	9				60
6	7.8	475	60	31				80
7	7.9	460	100	10				60
8	8	400	80	2				60
9	7.8	560	110	7				100
10	7.9	500	50	0				50
24-Apr-88								
1	8.4	340	60	4	6	4.9	6	20
2	8.8	540	120	35	68	12.0	29	60
3	8.8	540	100	169	195	3.1	48	60
4	8.7	600	160	165	203	7.6	57	80
5	8.5	600	170	145	231	5.6	68	100
6	8.7	590	180	153	200	4.8	74	110
7	8.5	590	180	125	133	4.4	34	110
8	8.2	640	160	24	156	3.0	44	90
9	8.9	610	200	149	319	3.3	88	130
10	8.2	700	100	12	104	12.1	29	50
14-May-88								
1	6.5	295	25	0	6	2.1	6	40
2	7	300	35	0	13	2.3	8	60
3	7.2	300	55	0	4	3.7	4	80
4	7	300	60	8	9	8.3	8	80
5	6.7	300	180	51	187	4.1	45	180
6	6.9	400	200	219	280	3.1	64	200
7	6.9	510	240	231	238	3.2	59	300
8	6.7	540	150	239	138	2.8	31	140
9	6.8	560	125	263	155	3.6	49	120
10	7.4	650	60	4	70	7.2	27	60
30-May-88								
1	8	270	15	0	47	6.1	52	20
2	8	340	70	161	240	1.9	62	80
3	8.5	440	100	39	254	2.2	67	100
4	8.5	440	130	90	259	2.4	57	120
5	8.5	460	135	47	288	2.2	75	140
6	8.8	460	105	82	239	4.4	65	100
7	8.6	470	100	122	297	2.9	75	100
8	7.6	440	105	153	305	3.7	74	80
9	7.7	520	165	141	383	3.7	70	160
10	7.4	670	60	0	161	6.3	82	60
20-Jun-88								
1	8	280	25	125	121	4.4	76	0
2	7.9	580	100	161	203	2.1	36	90
3	8.1	570	140	161	300	3.2	47	110
4	7.8	580	225	176	506	3.7	40	260
5	7.1	820	190	149	464	3.9	56	180
6	7.9	580	200	149	545	4.8	61	200
7	8	600	180	161	392	4.7	50	160
8	8	620	140	169	390	4.1	60	80
9	8	620	200	192	568	3.8	50	180
10	8.1	540	50	51	118	6.6	83	50

Appendix 5.1 continued

Site	pH	conductivity µmhos/cm	turbidity FTU	chlorophyll a mg/m3	Total P µg/L	SRP µg/L	TSP µg/L	TSS mg/L
28-Jun-88								
1	8.6	310	100	67	254	2.2	47	90
2	7	420	110	216	213	2.4	67	90
3	8.4	600	140	169	262	4.9	85	120
4	7.8	600	600	255	440	3.3	73	710
5	8.2	600	300	188	224	3.9	59	320
6	8.4	600	200	196	198	2.2	61	210
7	8	610	480	212	176	3.1	101	530
8	7.9	500	210	212	451	2.7	125	200
9	7	620	290	270	126	4.1	103	270
10	8.1	800	60	39	399	7.7	179	20
13-Jul-88								
1	7.7	290	60	35	283	5.5	58	110
2	7.6	480	150	102	399	3.8	75	110
3	8.1	600	240	145	166	5.2	71	220
4	7.9	600	140	263	528	6.0	44	120
5	7.9	590	375	219	247	5.6	60	370
6	7.9	450	275	294	765	5.1	63	180
7	8	580	275	259	461	6.2	53	220
8	7.8	540	190	290	143	6.5	64	110
9	7.9	600	180	329	304	7.2	52	120
10	8.7	740	70	67	471	9.9	43	60
26-Jul-88								
1	8.6	290	40	0	265	2.6	14	0
2	7	580	95	133	376	3.4	71	50
3	8.4	620	140	165	185	5.2	27	90
4	7.8	580	135	169	378	4.6	13	70
5	8.2	560	160	192	342	5.3	14	120
6	8.4	580	180	408	215	6.1	69	120
7	8	550	200	251	327	7.4	53	140
8	7.9	560	210	231	290	5.5	44	130
9	4	520	190	321	209	5.5	149	130
10	8.1	720	185	27	318	9.9	192	190
9-Aug-88								
1			20		19		18.0	
2			70		544		39.5	
3			90		308		60.3	
4			120		158		41.7	
5			110		173		60.3	
6			90		232		95.9	
7			90		286		58.1	
8			100		212		51.0	
9			80		156		43.4	
10			50					
25-Aug-88								
1		300	18	0	227	2.5	56	10
2		500	95	133	210	2.2	46	90
3		120	90	314	71	2.4	67	190
4		500	100	129	100	2.1	43	220
5		500	120	219	117	2.7	7	350
6		540	60	204	68	3.2	50	40
7		450	100	184	187	2.8	27	160
8		500	95	231	600	2.4	67	110
9		520	90	133	44	2.2	24	140
10		700	60	145	142	3.4	106	90

Appendix 5.1 continued

Site	pH	conductivity µmhos/cm	turbidity FTU	chlorophyll a mg/m3	Total P µg/L	SRP µg/L	TSP µg/L	TSS mg/L
9-Sep-88								
1				0	55	4.5	12	10
2				184	119	5.6	58	80
3				137	197	5.0	16	100
4				278	152	5.6	52	100
5				200	238	4.6	48	90
6				172	229	5.2	40	150
7				102	266	5.5	83	90
8				188	335	4.5	113	60
9				227	402	8.7	97	70
10				106	916	4.6	181	20
24-Sep-88								
1		260	20	0	376		4	70
2		450	100	180	352		8	80
3		480	100	55	1057		8	120
4		480	150	169	969		7	160
5		490	120	219	962		45	210
6		495	100	176	111		8	170
7		500	130	86	305		9	130
8		510	140	212	962		6	130
9		510	120	200	97		7	130
10		805	60	0	45		15	0
12-Oct-88								
1		240	20		289		21	
2		480	70		319		64	
3		460	90		202		52	
4		460	100		926		127	
5		450	100		348		78	
6		800	120		748		109	
7		480	130		173		65	
8		480	100		1324		132	
9		540	80		609		69	
10		700	60		182		149	
6-Nov-88								
1		250	20		138		25	
2		440	100		179		28	
3		450	150		277		48	
4		500	140		262		52	
5		520	110		202		40	
6		440	320		368		81	
7		440	165		1403		67	
8		680	130		211		35	
9		580	115		191		51	
10		850	180		127		87	

Appendix 5.2 Calculations for phosphorus budget in Figure 5.9b

1) Sedimentation

sedimentation rate = 0.73 cm/yr (Chapter 6)
bulk density = 0.63 g/cm^3 (Chapter 6)
average phosphorus content = 1.76 mg P/g (Chapter 6)
0.73 cm/yr x 0.63 g/cm^3 x 1.76 mg P/g x 10^4 cm^2/m^2 x 1 yr/365 days
= 22 mg P/m^2 day

2) Macrophyte Uptake

peak biomass = 64,000 g dry wt (Chapter 3)
64 kg/yr x 1yr/365 days x 10^6 mg/kg /565,000 m^2
= 0.3 mg P/m^2 day

3) Plankton Cycling

gross primary productivity = 976 g O_2/ m^2 yr (Chapter 3)
976 g O_2/ m^2 yr x 12 g C/ 32 g O_2 x 1 g P / 40 g C x 10^3 mg/g
= 25 mg P/m^2 day

respiration = 914 g O_2/ m^2 yr
914 g O_2/ m^2 yr x 12 g C/ 32 g O_2 x 1 g P / 40 g C x 10^3 mg/g
= 23 mg P/m^2 day

4) Daily Inflow and Outflow of Phosphorus

flow (m^3/day from Chapter 4) x concentration (mgP/m^3) /565,000 m^2
= flux (mg P/ m^2 day)

It was assumed that the barrier beach would not allow transfer of phosphorus when it was closed. If the lake was flowing into the marsh (negative outflow), then the absolute value of the flow was multiplied by the Lake Erie phosphorus concentration, rather than by the outflow concentration. This provided the Lake Erie inflow value. Daily values from March 1, 1988 - November 30, 1988 were averaged for the mass balance.

6

Quaternary History of Old Woman Creek Wetland

Brian C. Reeder

Introduction

There is a paucity of information on the climatic, vegetational and water level histories of the Lake Erie Lake-Plain and Till-Plain areas following the retreat of the Wisconsin Glacier (maxima about 20K). The western portion of Lake Erie is surrounded by a Lake-Plain (remnants of ancient lakes from previous glaciations and glacial retreat) whose gentle slopes are conducive to the formation of wetlands. Before drainage for agriculture, much of this whole area was known as the Great Black Swamp. Few studies have been done to describe the hydrologic and biogeochemical history of these wetlands to determine their historic ecosystem functioning and values.

Old Woman Creek State Nature Preserve and National Estuarine Sanctuary remains as one of the last remnants of presettlement wetlands. The geologic history of the Old Woman Creek area has been documented with the most site specific study by Herdendorf (1963). The glacial history has been described by Campbell (1955) and the depositional history by Buchanan (1982) and Frizado et al. (1986). This paper will explore the historic hydrology and biogeochemistry of Old Woman Creek wetland through the analysis of sediment cores to estimate if and how the wetland functions as a buffer between Lake Erie and the surrounding watershed and to assess what changes occur with rising and falling lake levels.

Review of Great Lakes Paleoecology

Most previous historic studies contain either incomplete stratigraphies or poor dates. A regional history of vegetational changes along climatic gradients for the area is provided in Braun (1961) and Spear and Miller (1976). Buchanan (1982) provides an indescript pollen diagram for Old Woman Creek wetland with a valid C14 date.

Major studies of pollen and macrofossil areas near the study site include those done at Sunbeam Prairie (Kapp and Gooding 1964), Silver Lake (Ogden 1966), Corry Bog (Karrow et al. 1984), Nichols Brook (Calkin and McAndrews 1980), Refugee Road (Garrison 1967), Pretty Lake (Williams 1974), and Frains Lake (Kerfoot 1974). A complete pollen zone stratigraphy for the area was devised by Shane (1987) who analyzed the data from previous sites, as well as data from six of her own cores (Brown's Lake, Battaglia bog, Quillin, Stotzel-Leis, Carter, and Pyle). Other stratigraphies are available for fossil pigments in Brown's Lake (Sanger and Crowl 1979) and diatoms at Summit Lake (Gray and Olive 1986). Analysis of sediment chemistry to provide additional insight into understanding the pollen, pigment, or diatom zones has been mostly ignored.

Few studies have ever been undertaken to determine the past hydrology of a Great Lakes coastal wetland over a long time scale. Little data are available to directly determine the fluctuations of recent Lake Erie water levels and their effects on adjacent ecosystems. Currently, there are two slightly different interpretations as to Lake Erie level fluctuations over the past 14,000 years. Coakly and Lewis (1985) and Herdendorf and Bailey (1989) agree about ancient lake levels but disagree about the recent history. Analysis of sediment chemistry can provide further evidence into how lake levels fluctuated. If a more accurate picture can be determined, we may be able to determine if the adjacent wetlands move back and forth with rising and retreating water levels, as suggested by Herdendorf and Braidech (1972) and Mitsch et al. (1989), and what effect this has on biogeochemical cycling of nutrients.

Sediment chemistry has been used successfully to gain insight into past biogeochemistry of lakes (Engstrom and Wright 1984, Davis et al. 1985, Engstrom et al. 1985), and could presumably be used in wetlands. For example, analysis of phosphorus from sediment cores has been used successfully to determine past productivity and trophic status (Hutchinson and Wollack 1940, Livingstone 1957, Livingstone and Boykin 1962, Williams et al. 1971, 1976a, b, 1980, Holdren and Armstrong 1980). In addition to phosphorus, iron and manganese can be used to reconstruct past redox conditions because of their increased and differential solubility under reduced conditions (Makereth 1966, Pennington et al. 1972).

Methods

Coring was done on January 29, 1988 using a modified Livingstone piston sampler (Livingstone 1955). Two parallel cores were sampled 30 meters directly North of the Eastern "point" of Star Island (Figure 2.1)— near the location where a long core was drawn, analyzed, and dated by Buchanan (1982). Cores were x-rayed before opening to ascertain particle size fractionations which may not be visible to the human eye. The x-rays were taken on 14 in. x 17 in. film with an exposure time of 28 seconds, and developed on an automatic industrial developer at the Buckeye Steel Company.

Analysis of the x-ray films revealed that the first core yielded approximately 2.5 m of sediment and the second core yielded 5.3 meters of sediment, the depositional patterns of both cores seemed to be identical (in regards to particle size). The first core (brought up in 3 1-m casings) has remained unopened. The longer core (brought up in 7 1m sections) was the subject of all subsequent analysis. When not under analysis cores were stored in a refrigeration chamber at a constant temperature of 4°C. Once opened, the cores were always kept wrapped in at least three standard width sheets of cellophane-type cling wrap. Both cores are currently housed at the Old Woman Creek Visitor's Center, where they are being analyzed for diatoms.

Chemistry

Fifty samples were taken for chemical analysis at 10 cm intervals, starting 5 cm from the bottom of each core. Within 72 hours of opening, the sediments were analyzed for degradation products of the chlorophyllous pigments (SCDP). Analysis of SCDP followed the procedure of Sanger and Gorham (1972). SCDPs were extracted from 1-cc samples with 100 ml of 90% acetone (the acetone was added in 20 ml portions and shaken vigorously and extensively with each addition, then allowed to settle overnight before measuring absorbances) and measuring spectrophotomic absorbances at 660-670 nm peaks in a 1 cm^3 cell. The values are expressed per grams organic matter in SCDP units (see Swain 1985 for a discussion of the units).

To estimate organic matter a one cm^3 sample was placed in a clean dry crucible, weighed, placed in a drying oven at about 105°C for at least 24 hours, reweighed (dry weight or water loss), then placed in a 550°C muffle furnace for one hour, and weighed again (organic matter loss) after the methodology outlined in Dean (1974). Sediment particle size was analyzed for samples from the middle of each zone of differential organic deposition by the OARDC laboratory using suspension analysis.

Aliquots of dried sediment (0.8 g) were analyzed for bioavailable phosphorus (NaOH-P) after Chang and Jackson (1957) by placing them in 5 ml centrifuge tubes with 40 ml of 0.1 M sodium hydroxide. This was mixed mechanically for at least 24 hours, then centrifuged for 15 min. at 2400 rpm. In samples with high organic matter (>10%), concentrated sulfuric acid was added dropwise to flocculate the organic matter. After 50 ml of sample was acidified with 5 N sulfuric acid to phenolphthalein end-point, the sample was analyzed for orthophosphate (APHA 1985).

Perchloric acid digestions for total phosphorus (TP) in sediments were carried out after Sommers and Nelson (1972). A 0.1 g dried sample was pre-treated with 5.0 ml of nitric acid and heated to dryness in a digestion tube to insure no organic matter was available for explosive reactions. The sample was then digested with 3 ml of 70% perchloric acid at 203°C for 75 min. The tube was cooled, diluted to 50 ml with distilled water, mixed, and allowed to settle overnight. Next, 3 ml of the supernatant was removed and neutralized with 5N sodium hydroxide to a p-nitrophenol end-point in a 50 ml volumetric flask, and brought to mark with distilled water. Standards were also carried through the digestion process so that an accurate standard curve could be obtained. The extracts and standards were then analyzed for orthophosphate (APHA 1985).

Digestion of samples for Fe and Mn was done with an Aqua Regia/HF mixture in Teflon bombs similar to those described by Burnas (1967). Fifty mg of sample was taken using a Teflon-coated spatula, taking care to get the sample from the very center of the core barrel. The sample was then placed in the Teflon vessel, and first completely saturated with 0.5 ml of Aqua Regia, and then next with 3.0 ml 48% HF. The container was sealed and secured in the bomb, then placed in a 110°C oven for one hour. After cooling for at least 20 minutes in a -15°C freezer, the bombs were opened and 2.8 g of boric acid with 5ml distilled water added and stirred; the volume taken up to 40 ml with distilled water; then finally, taken up to 100-ml in a volumetric flask. Standards for were made by mixing 0.5 ml Aqua Regia, 3.0 ml HF, and 2.8 g of boric acid with a standard solution in a 100-ml volumetric flask.

Metals were determined using a model 451 Instrumental Laboratory AA/AE Spectrophotometer. The final concentration was determined by the average of three readings, with the standard error never exceeding 0.002. Manganese was run at a 0.5 bandwidth at 279.5 nm; iron with a 0.03 bandwidth at 248 nm.

Pollen

Pollen was extracted by a modification of Faegri and Iverson's (1975) methods from 0.5-cc of sediment at 20 cm intervals along the core (adjacent to sites of chemical analysis), and at 5 cm intervals along the zone of *Ambrosia* intrusion. Samples were first washed with 9 ml of concentrated HCl in a 15 ml centrifuge tube to remove all carbonates, and a known volume Ecalyptus pollen added. Each sample was then washed with 7-8 ml 10% NaOH, and heated at 90°C for 15 minutes, then five-ml of 0.1 M sodium pyrophosphate was added to flocculate the organic matter. The sample was then rinsed twice with 7-8 ml of distilled water to remove the traces of pyrophosphate, and dehydrated with a washing of 8 ml concentrated glacial acetic acid (to prepare the pollen for acetolosis).

Acetolosis solution was prepared by very slowly adding 10-ml concentrated sulfuric acid to 90 ml acetic anhydride, then 7-8 ml of this solution carefully stirred into the sample. This was heated in a digestion block until the solution either reached a "gummy orange" consistency or a 30-minute time limit. The pollen was washed with glacial acetic acid, then water, and then three times with acetone. The pollen was then extracted into 3 ml of bromoform/ acetone solution (specific gravity = 1.9), and the supernatant placed in a clean centrifuge tube filled with 9 ml of acetone, and the bromoform procedure repeated to yield a solution with 6 ml of bromoform, 9 ml acetone and the cleaned pollen. The final pollen was centrifuged, rinsed with 5-ml of ethanol, and mixed with 1 to 2 drops of glycerin/ saffarin solution and placed in a drying oven overnight.

Pollen was mounted on glass slides with glycerin and counted with the aid of a computerized pollen counting program (Eisner and Sprauge 1988). Identification of pollen was done at a 250 magnification on a light microscope. Counts were made until 300 grains/depth were counted (not including *Eucalyptus* grains) when possible. In those samples with low concentrations of pollen, counts were made to 200 or 100 (dependent upon the amount present). The major keys used for identification were by McAndrews et al. (1973) and Kapp (1969).

Dating

Recent dating of the core was obtained from pollen analysis; the *Ambrosia* intrusion is considered to be a result of deforestation due to European settlement (forest clearance for ship building and agriculture occurring about 180 YBP (Sears 1938)). Older samples were taken from 1.96-2.01 m; 2.46-2.56 m; 2.83-3.03 m; 3.74-3.94 m; and the bottom of the core (5.13-5.33 m) and submitted to Beta Analytic Inc. for ^{14}C dating using international conventional techniques. Samples were pretreated with repeated washing of warm acid, washed with distilled water to neutrality, sythesized to benzene and counted by Beta Analytic. Low carbon samples were kept in extended counting to insure the smallest possible error. According to Beta Analytic, all information was rechecked and no error was found, and the low carbon content did not cause significant difficulties.

Results

Chemical Stratigraphy

The stratigraphy of the core is shown in Figure 6.1, which also shows the dates and their relative position in the core, and the particle size for three zones. The core contains three main zones: IV) a zone of intermediate organic content consisting of silty loam (according to dating this is recent sedimentation); III) a high organic matter peat zone (from about the time of final glacial retreat to the era of industrialization); and I) a very low organic matter zone of silty clay (throughout a series of glacial events). A fourth zone (II) was determined as an intermediate between zones I and III. A diagram of the deposition of the chemical parameters tested for is shown in Figure 6.2. Additionally, a correlation matrix of all the chemical data is shown in Figure 6.3.

Organic matter content is closely correlated to productivity as evidenced from data on sedimentary chlorophyllous degradation products. The highest productivity (or the time of maximal preservation of chlorophylls) is at 223 cm. Productivity remains relatively stable (about a 3-fold decrease from the initial peak) from 250 cm to the top of the core, with the exception of two peaks (each about a 2-fold increase) at 123 cm and 100 cm. The latter coincides with a peak in phosphorus, as does the only record of productivity in the lower portion of the core (at about 433 cm).

Phosphorus deposition is quite variable. The deposition of bioavailable phosphorus (NaOH-P) decreases to nothing or near nothing when productivity (organic matter and SCDP) is highest. Peak values of NaOH-P correlate closely with peak values for total phosphorus. Average ± standard deviation of total phosphorus (mg/g) for zones IV through I are: 1.8±0.3; 2.0±0.3; 2.0±0.2; and 2.0±0.3, respectively. Average ± standard deviation of concentrations of NaOH-P (mg/g) for zones IV through I are: 0.2±0.2; 0.03±0.04; 0.06±0.04; and 0.2±0.2, respectively.

If manganese deposition rises in respect to iron depositions, it may be indicative of mildly reducing conditions (Mackreth 1966), thus providing a method of determining paleoredox. Fe:Mn relationships show eras of mildly reduced conditions at about 503 cm, 438 cm, and at 368 cm. The increase in both iron and manganese at 63 cm is indicative of a zone of migration due to oxidative conditions in the soil. Average concentrations of iron (mg/g) for zones IV through I are: 42± 5; 33±5; 32±3; and 36±5, respectively. Average concentrations of manganese (mg/g) for zones IV through I are: 0.35 ±0.15; 0.27±0.024; 0.25±0.006; and 0.36±0.22, respectively.

Pollen Stratigraphy

Pollen concentrations shown in Figure 6.4 were determined from the *Eucalyptus* spike. Zone III and IV pollen was deposited at about 70,000 grains/cc; zone I and II pollen at roughly 15,000 grains/cc. The marked decrease in pollen deposition should coincide with either rapid sedimentation, poor preservation, or lack of pollen producing vegetation. Concentrations of individual types of pollen are shown in Figure 6.5.

The pollen percentage diagram, shown in Figure 6.6, outlines the environmental history of the area. The sharp *Ambrosia* rise due to deforestation is at approximately 131 cm (first appearing at 203 cm). There is also a rise of another disturbance indicator, *Chenopodium*, at the height of the rise (20-50 cm). Trees and shrubs begin to arrive in Zone II. *Quercus*, *Ulmus*, and *Carya* are the first to arrive, followed in Zone III by a sharp domination of *Carya*, and the prevalence of *Betula* and *Pinus*. In Zone IV, *Quercus* and *Salix* dominate, and *Ulmus*, *Juglans*, *Carya*, *Fraxinus*, *Pinus*, and *Tilia* are all present.

The little pollen found in zone I is dominated by hydrophytes, such as Nyphaeaceae, Typhaceae, and Cyperaceae, along with some Lycopodiaceae and Graminae. No trees are found in this zone. This is a contrast to Zone IV herbs, which are dominated by *Ambrosia*, Graminae, *Typha*, Compositae, *Artemisia*, and Nymphaeaceae. Graminae and Cyperaceae are prevalent throughout all zones. An interesting rise in *Artemisia*, *Rumex*, and *Lycopodium* coincides with the appearance of trees in Zone II and the beginning of Zone III.

Discussion

Recent History

The most important parmeter in a historical investigation is to accurately define time. For this area of the United States, the *Ambrosia* rise at 131 cm probably marks about 180 Years Before 1988 (YBP). This translates to a sedimentation rate of 0.73 cm/yr. The rapid rate means that the sampling regime provides a high resolution of this zone.

Lake levels must have been lower than present averages at the time of peat formation, and/or some barrier must have protected the marsh. However, the peat of Zone III may not be a complete stratigraphy. Everett (1988) shows that the *Scirpus* histsols such as the one found in this core should deposit at about 1 cm/yr, more than an order of magnitude more than the rate found. This could be explained if the lake level rises periodically scoured portions of this peat from the marsh. Evidence of this is seen in the beach zone (uniform pebbles) between zones III and IV, where the lake edge reached to this portion of the marsh.

Deforestation had a drastic effect on the marsh. As marshes and forest upstream were channelized, the velocity of the Old Woman Creek increased due to increased flow and intensity. In addition, the soils once held by vegetation were now being eroded and carried into the fast flowing waters. As a result, the wetland began to silt in as sediments laden in the incoming waters precipitated out in the low energy waters of the marsh. This caused the sedimentation rate to increase an order of magnitude. These changes, coupled with rising marsh levels (due both to lake level rise and increased inflow) changed the marsh from a *Scirpus* dominated system (which deposited peat) to the marsh currently found and described by Marshall and Stuckey (1974).

An interesting phenomenon is that even under heavy sediment loading, the marsh remains a wetland and does not fill in. This has been observed under the drastic lake level fluctuations of the past 15 years. Some hydraulic equilibrium must be maintained as pollen shows it to remain wetland, and the steep eroded edges of the marsh indicate that it has existed under higher water levels (probably when drowned further by high Lake Erie levels).

Since deforestation, productivity has remained high, the deposition rate of phosphorus has greatly increased, as has the percentage of phosphorus which is bioavailable. During the time of peat formation, almost no bioavialable phosphorus is found. Presumably, the macrophytes and plankton

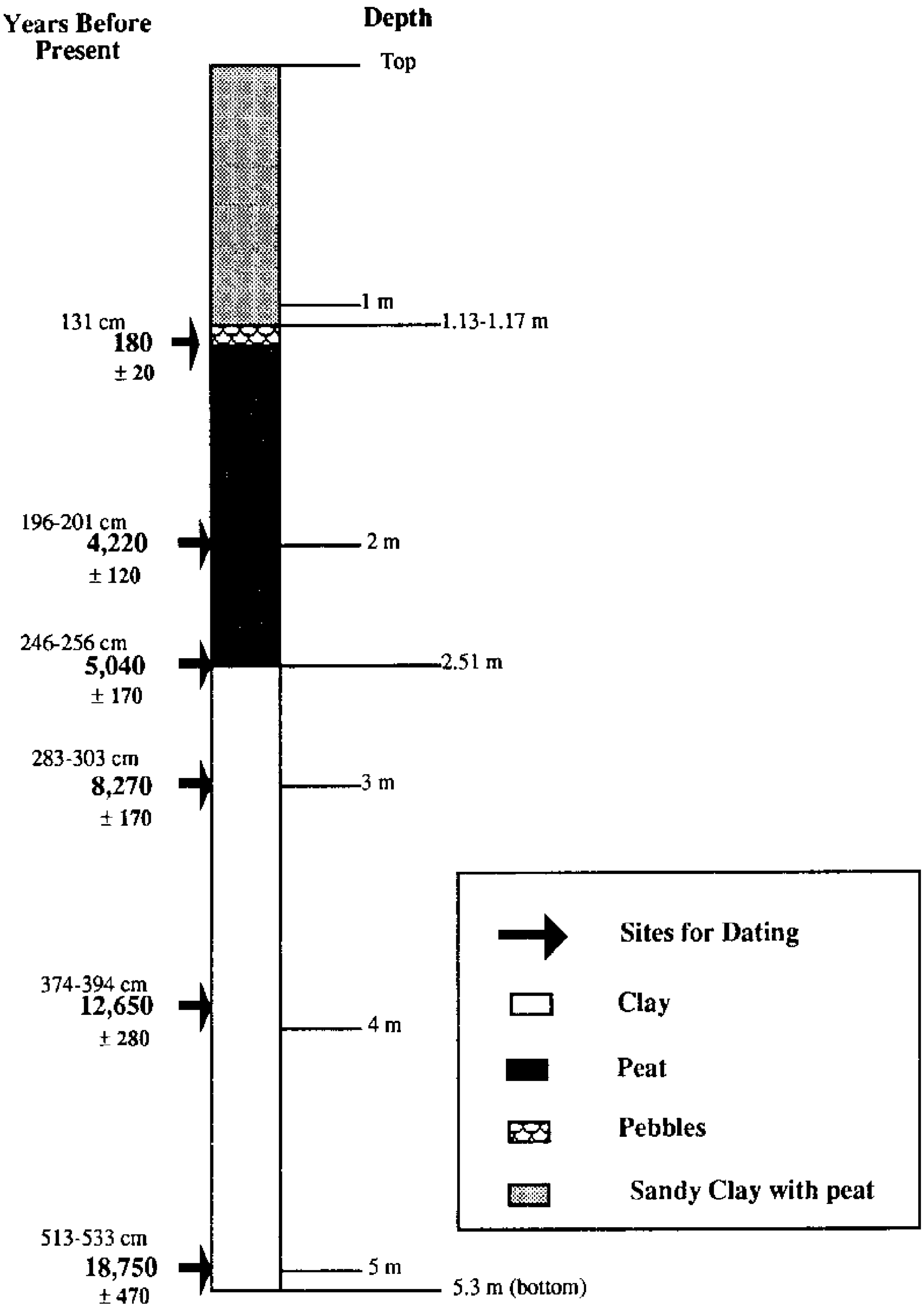

Figure 6.1 Stratigraphy of sediment core from Old Woman Creek wetland, with carbon-14 dates and sediment composition

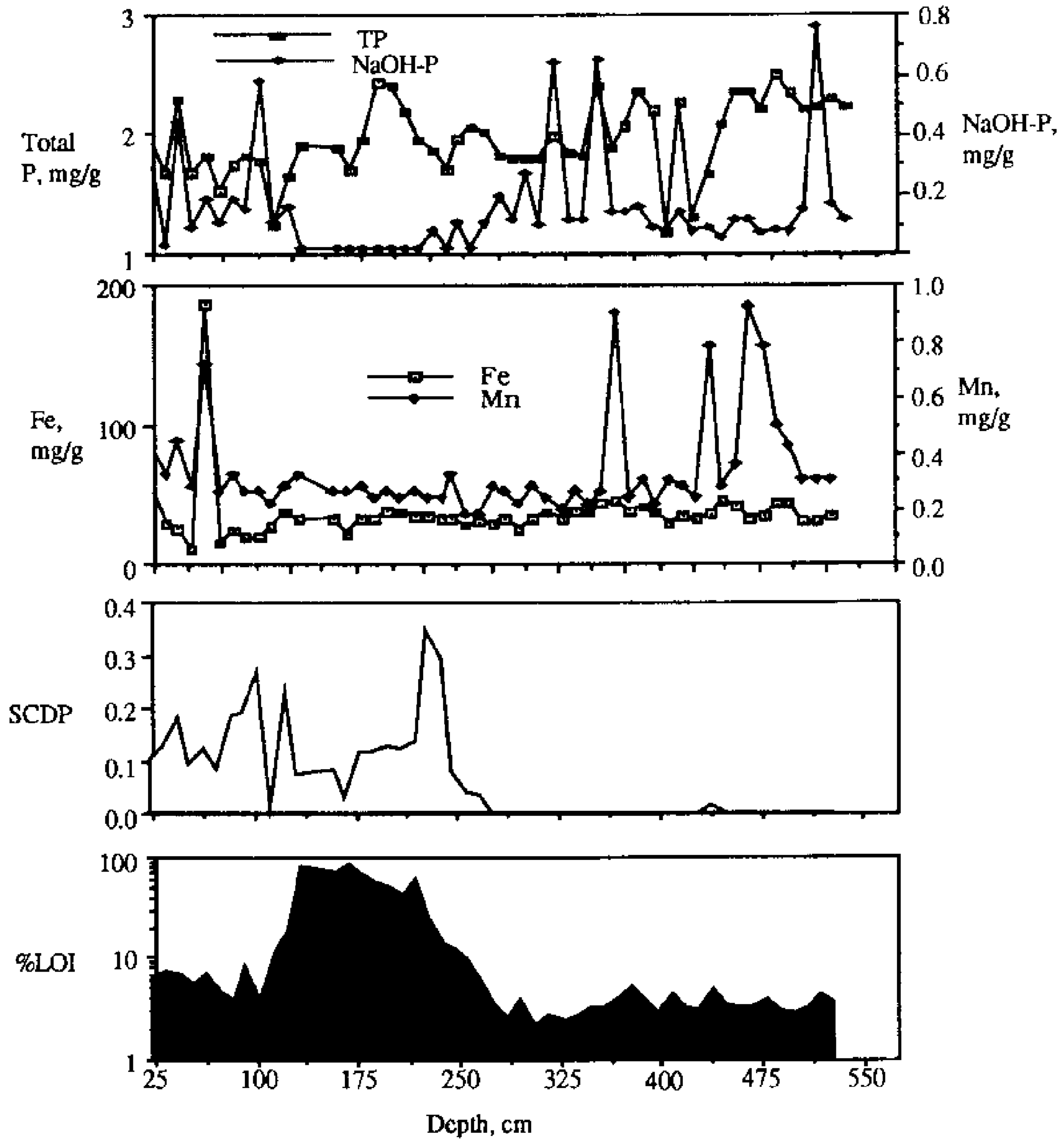

Figure 6.2 Patterns of organic matter (LOI = loss on ignition), degradation products of chlorophyllous pigments (SCDP), iron, manganese, total phosphorus (TP) and bioavailable phosphorus (NaOH-P) versus depth for sediment core

	Depth	Age	% LOI	BD	TP	NaOHP	Fe	Mn
Depth	1							
Age	.983	1						
% LOI	-.358	-.359	1					
BD	.549	.515	-.847	1				
TP	.416	.436	.011	-.01	1			
NaOHP	.034	.015	-.355	.383	.159	1		
Fe	-.046	-.042	-.077	.042	.066	.015	1	
Mn	.218	.184	-.181	.221	.288	-.055	.382	1
SCDP	-.655	-.642	.272	-.591	-.184	-.02	-.001	-.146

Figure 6.3 Correlation matirix for chemical characteristics of sediment core. Abbreviations as in Figure 6.2; BD = bulk density

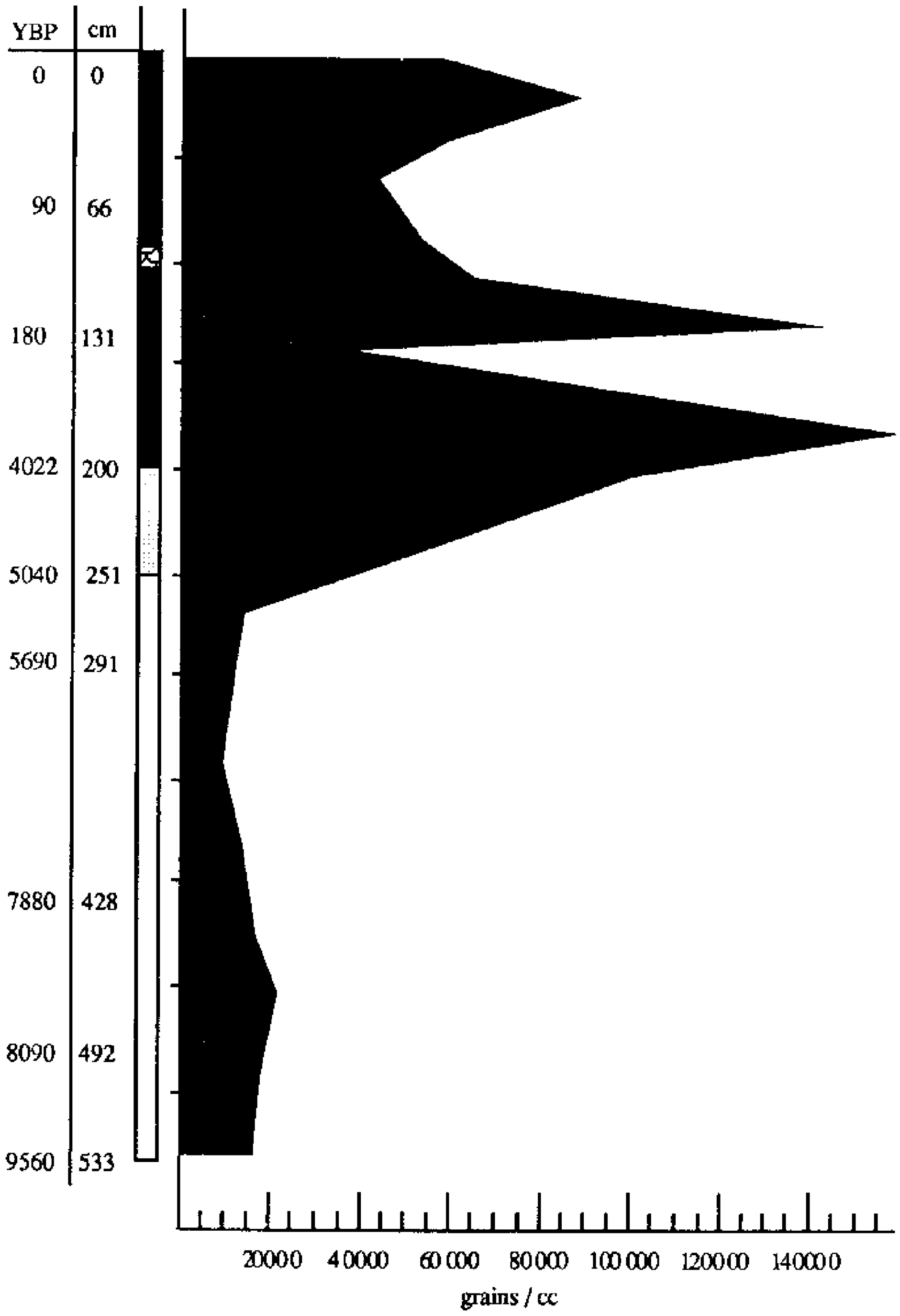

Figure 6.4 Total pollen concentration in sediment core from Old Woman Creek

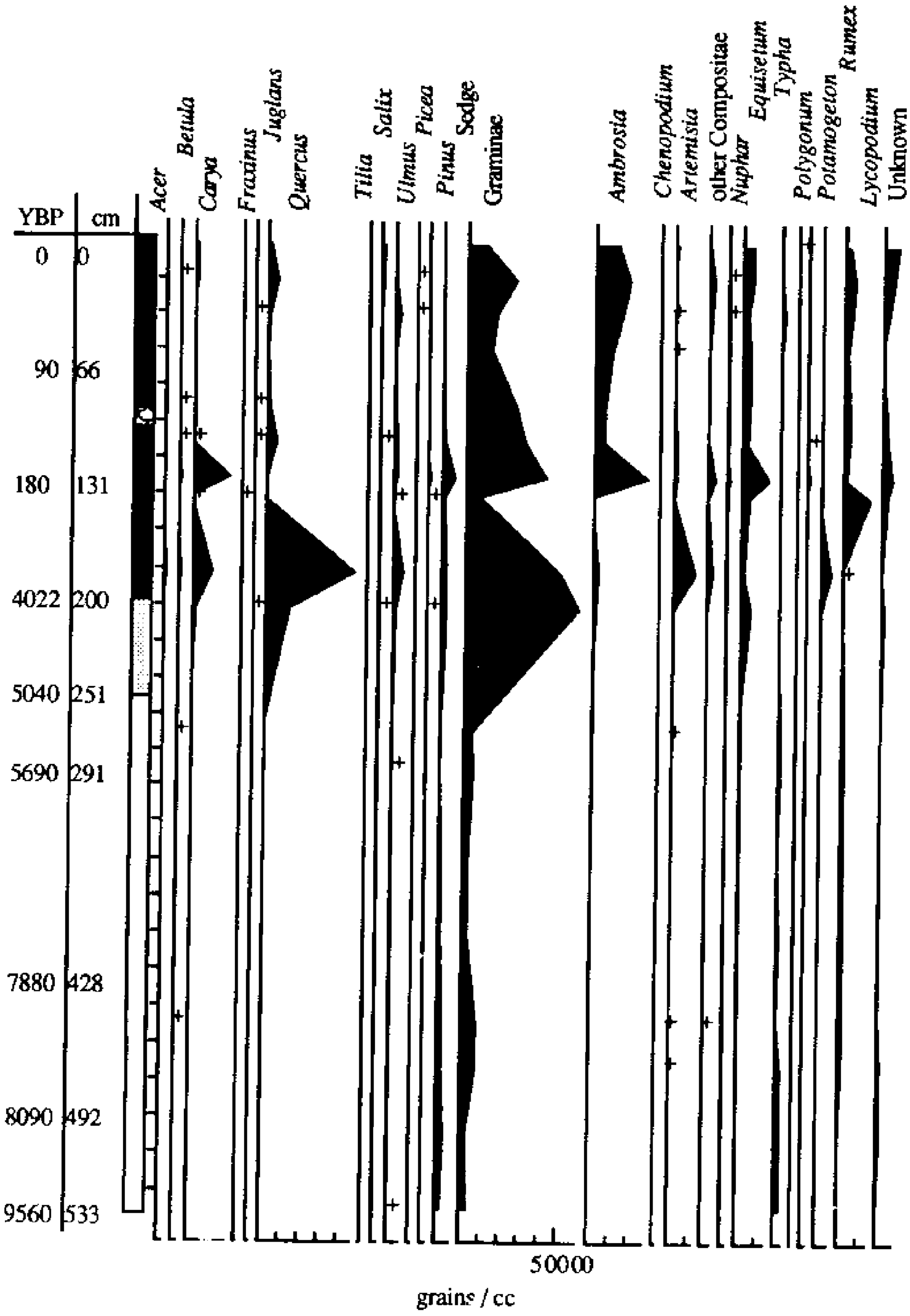

Figure 6.5 Concentration of pollen by species for Old Woman Creek wetland sediment core

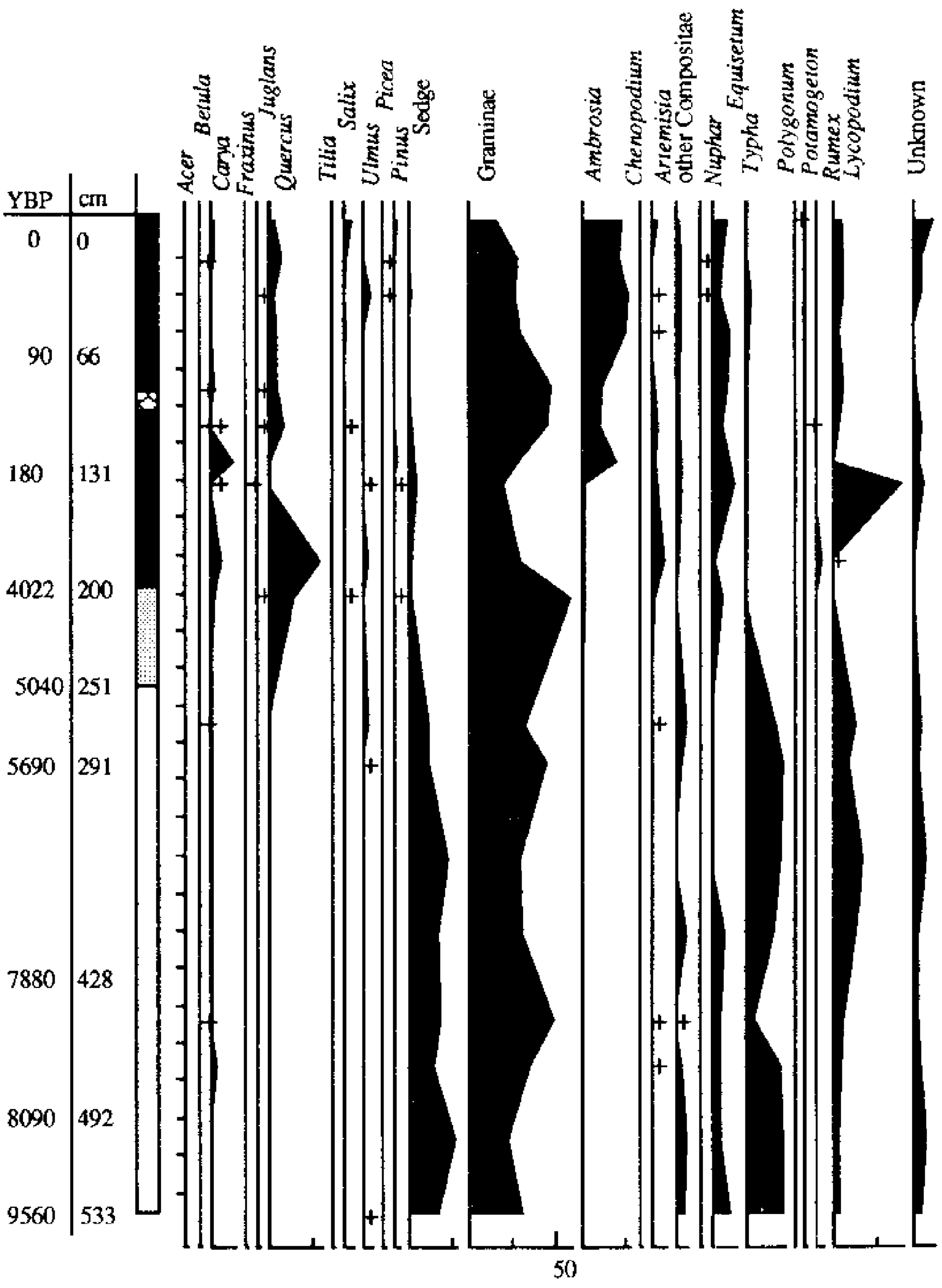

Figure 6.6 Percentage of pollen by species for Old Woman Creek wetland sediment core

were transforming almost all of the bioavailable phosphorus into organic matter. As peat formation stopped and loading increased, the ability of the marsh to work as a biotic transformer diminished, but its abiotic ability to permanently bury all the phosphorus forms was increased. In fact, on a per year basis much more phosphorus is buried now than when the marsh was forming peat.

Before Deforestation

Changes occurring during glaciation and just afterwards are harder to ascertain with resolution from the present core. Since glacial till was not reached, it is presumed that the core represents post glacial events. No erosional event, except for the possible scouring of the peat, is discernible from the core. Carbon-14 dates show no inversions and line up to show an even sedimentation rate (Figure 6.7). All dates were in time zones where C14 dating is accurate, however, the bottom 3 dates were taken from huge quantities of sample (up to 350 g), and none yielded more than 0.5 g of carbon. Buchanan (1982) came up with a sedimentation rate of 0.076 cm/yr in a similar zone with an excellent date (taken from a piece of wood). When my dates are examined, the sedimentation rate is much slower (0.02 cm/yr), and the core much older. This could explain the low pollen concentrations.

A few problems arise from the above dating of the core. First, pollen is shown as being deposited during a number of glacial maxima, when the area is well known to have been covered by about two miles of ice. Second, no erosional events or glacial till have been noted throughout this time span. Third, a fairly decent zonation pattern in vegetation described by Shane (1987) is completely absent. However, if one assumes the sedimentation rate from the samples with a high carbon content is correct (0.064 cm/yr, or nearly the same as the rate of 0.076 cm/yr obtained by Buchanan (1982)), then the stratigraphy makes sense within the current knowledge of the glacial history of the area.

There are, however, reasons against throwing out these dates which otherwise look appropriate. It is possible that there is some error in the known glacial history, but given the great number of Carbon-14 dates and other evidence (Herdendorf and Baily 1989, Coakley and Lewis 1985), this is unlikely. When placed in a standardized flow chart to determine the validity of C14 dates in this area (King 1985), the dates fail to meet criteria for acceptance. A number of explanations for inaccurate dates can be given: 1) with such a small amount of carbon, even a slight contamination from older carbon (it is a limestone watershed) could significantly alter the results; 2) there is a probability that plankton were processing older carbon, which could have skewed the results significantly (no C13 data were available to test this theory); and 3) due to extensive glaciations in the area, the deposited sediments may have been old.

Therefore, the following conclusions are based on the two good dates. The bottom of the core is about 9,560 YBP. Since the sedimentation rate was so slow, this makes the resolution of the chemical and pollen stratigraphies very poor. Zone I may represent a post-glacial lake bottom. The sediments are very similar, and an oxidized shallow lake (near shore area) could account for the poor deposition of SCDP and pollen. It is obvious that the first trees to forest the area were *Acer*, *Quercus*, and *Carya*. Conifers came in shortly afterwards, possibly due to some climatic cooling. The oldest zones (just after glaciation) are dominated by aquatic macrophytes, which would also be indicative of a shallow lake nearshore zone.

As for ancient lake levels throughout this span, it is possible that the changes that occurred were not gradual, but fast and drastic. This closely follows the theory on punctuated equilibrium most notably expressed by Gould. From this core I suggest that the post glacial lake levels suggested by Coakley and Lewis (1985) and Herdendorf and Baily (1989) are in error by linking this zone with a slow gradual rise. Figure 6.8 suggests an alternative pattern of post glacial lake levels. A second theory suggests that this evaluation is wrong because the barrier beach may maintain some sort of equilibrium in the wetland.

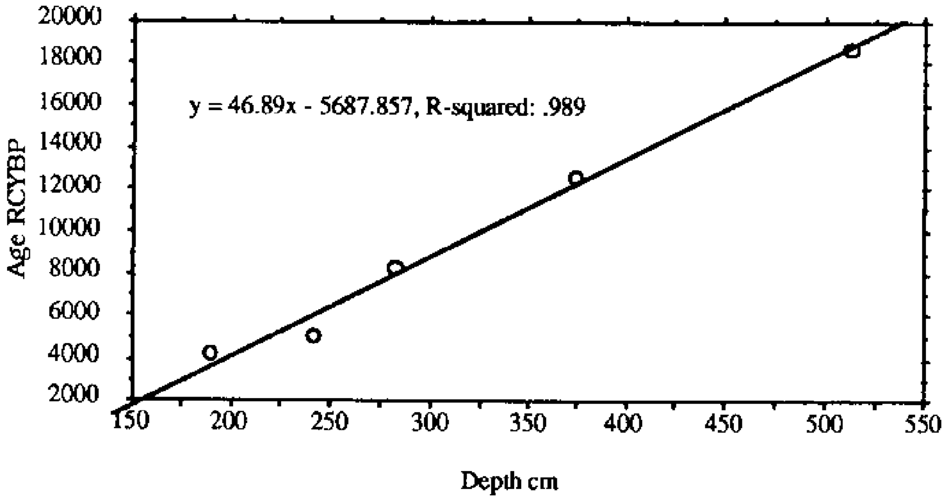

Figure 6.7 Regression of sediment age and depth for Old Woman Creek sediment core

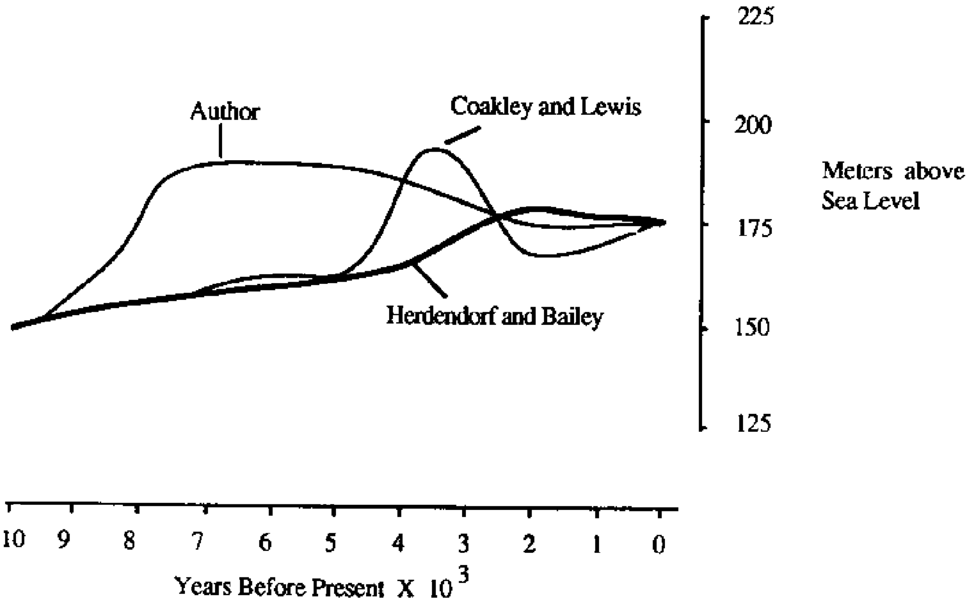

Figure 6.8 Lake levels as hypothesized by this study and others for past 10,000 years

Appendix 6.1 Chemical data from sediment core of Old Woman Creek

Depth cm	Age YBP	LOI %	Bulk Denstiy g/cm3	Total P mg/g	NaOH-P mg/g	Fe mg/g	Mn mg/g	SCDP SCDP
528	9644	3.47	1.32	2.23	0.11	35.2	0.3	0.000
518	9479	4.19	1.38	2.29	0.17	30.4	0.3	0.000
508	9313	3.23	1.55	2.23	0.76	30.6	0.3	0.000
498	9147	2.88	1.46	2.20	0.15	44.2	0.42	0.000
488	8982	3.09	1.42	2.34	0.07	44.2	0.5	0.000
478	8816	3.76	1.36	2.49	0.08	34	0.78	0.000
468	8651	3.28	1.43	2.20	0.07	33.6	0.92	0.000
458	8485	3.27	1.44	2.35	0.11	42.4	0.36	0.000
448	8319	3.42	1.49	2.35	0.11	44.8	0.28	0.000
438	8154	4.67	1.61	2.08	0.05	36.4	0.78	0.013
428	7988	3.03	1.59	1.66	0.09	31.6	0.24	0.000
418	7822	3.21	1.46	1.30	0.07	34.4	0.28	0.000
408	7657	4.27	1.22	2.25	0.14	29	0.3	0.000
398	7491	2.85	1.54	1.19	0.08	36.6	0.22	0.000
388	7325	3.84	1.41	2.19	0.08	40.4	0.3	0.000
378	7159	4.91	1.30	2.35	0.16	39	0.24	0.000
368	6994	3.67	1.44	2.06	0.14	45.4	0.9	0.000
358	6828	3.26	1.56	1.88	0.14	44.2	0.26	0.000
348	6662	3.16	1.62	2.38	0.64	36.8	0.22	0.000
338	6497	2.71	1.58	1.82	0.11	38.2	0.26	0.000
328	6331	2.34	1.54	1.83	0.11	33	0.2	0.000
316	6132	2.75	1.49	1.97	0.63	37	0.24	0.000
306	5966	2.11	1.38	1.79	0.10	32.6	0.28	0.000
296	5801	3.79	1.24	1.80	0.26	26	0.22	0.000
286	5635	2.53	1.38	1.80	0.11	33.6	0.26	0.000
276	5469	3.43	1.25	1.82	0.18	29.6	0.28	0.000
266	5303	5.60	1.00	2.00	0.10	31.2	0.18	0.036
256	5138	9.90	0.81	2.05	0.02	27.8	0.18	0.038
246	4942	12.15	0.64	1.96	0.10	33.2	0.32	0.077
238	4785	13.61	0.57	1.70	0.02	33.8	0.24	0.295
228	4589	24.92	0.32	1.86	0.08	34.4	0.24	0.350
218	4394	58.38	0.19	1.94	0.02	34.8	0.26	0.139
208	4198	40.86	0.28	2.17	0.02	36.6	0.24	0.123
198	4022	50.00	0.20	2.38	0.02	38.6	0.26	0.127
188	3561	56.11	0.18	2.43	0.02	32	0.24	0.119
178	2963	68.13	0.16	1.94	0.02	33.4	0.28	0.119
168	2364	84.21	0.15	1.70	0.02	22.4	0.26	0.031
158	1766	71.97	0.13	1.88	0.02	32.8	0.26	0.084
132	180	81.82	0.13	1.89	0.02	32.2	0.32	0.074
122	166	18.45	0.31	1.63	0.15	37.4	0.28	0.228
112	153	11.82	1.46	1.24	0.10	26.6	0.22	0.012
102	139	3.75	1.49	1.77	0.57	19.6	0.26	0.268
92	126	7.91	0.72	1.82	0.15	19.2	0.26	0.193
83	111	3.77	1.27	1.74	0.18	24.6	0.32	0.188
73	97	4.57	1.27	1.53	0.10	15.2	0.26	0.086
63	84	6.62	1.09	1.82	0.18	187.8	0.72	0.125
53	70	5.22	1.21	1.68	0.09	10.8	0.28	0.095
43	56	6.69	0.90	2.29	0.43	25.8	0.44	0.183
33	42	7.09	0.89	1.68	0.03	29.2	0.32	0.127
23	29	6.48	0.90	1.97	0.35	56.4	0.42	0.103

Part II. Regional Scale Studies

Ohio's Coastal Wetlands

7

Hydroperiod and Water Chemistry of Diked and Undiked Wetlands in Western Lake Erie

Doreen M. Robb
William J. Mitsch

Introduction

The eleven marshes sampled during this study consist of six diked marshes with artificially manipulated water levels and five undiked marshes whose water levels change according to the dynamics of the lake and bay level fluctuations and incoming water from surrounding watersheds. Water level fluctuation or "hydroperiod" is one of the single most important forcing functions in a wetland, ultimately influencing both water chemistry and vegetational patterns (Gosselink and Turner 1978). The water chemistry of a wetland is an important indicator of the nutrient dynamics and productivity of a wetland. Our study in diked and undiked wetlands was undertaken to determine if the differences imposed by the dikes have led to any differences in water levels and chemistry in these systems. We were interested in a synoptic survey of several wetlands in the Sandusky Bay region rather than detailed study of one or two sites to establish a baseline from which to direct more intensive studies. Preliminary results from the study are reported here.

Methods

The eleven marshes chosen for this study represent both diked and undiked wetlands (Table 1.2 and Figure 1.4). Sampling stations were established by placing staff gauges (metered stakes) within major vegetational communities in each marsh. Water levels represent relative changes over the study period and not absolute numbers. The number of stations per wetland varied from three to six based on the marsh size and the vegetational diversity.

Water samples for chemical analyses were collected at each sampling station over a six month period from May through October 1988. Sample periods are referred to as sample weeks 0 through 11 for this period. Samples were collected twice a month during May (Week 1 and 2), June (Week 3 and 4), and August (Week 6, 7 and 8) and monthly during July (Week 5), September (Week 9), and October (Week 10 and 11). One-liter acid washed polyethylene bottles were used for sample collection. Samples were kept at 4°C until analyzed. Twenty percent subsamples were collected and analyzed to determine the natural heterogeneity of the water mass and twenty percent replicates were analyzed to determine the precision of the methods. Table 7.1 lists the methods used for chemical analyses. Temperature, pH, and dissolved oxygen were determined in the field. Due to diurnal fluctuations in these parameters and the impossibility of a consistent sampling time for all of the wetland sites, these three field parameters are used for reference and not reported in detail in the results.

Results and Discussion

Water Level Fluctuations

Water level fluctuations for the undiked and diked wetland study areas are presented in Figures 7.1 and 7.2, respectively. In general, due to below normal precipitation in 1988, the undiked marshes show a general decline in water level until all except Old Woman Creek were not able to be sampled (Figure 7.1). Pickerel Creek marsh water level increased approximately 18 cm during the first week due to a Lake Erie seiche and was back at previous levels the following week. The water level declined throughout the

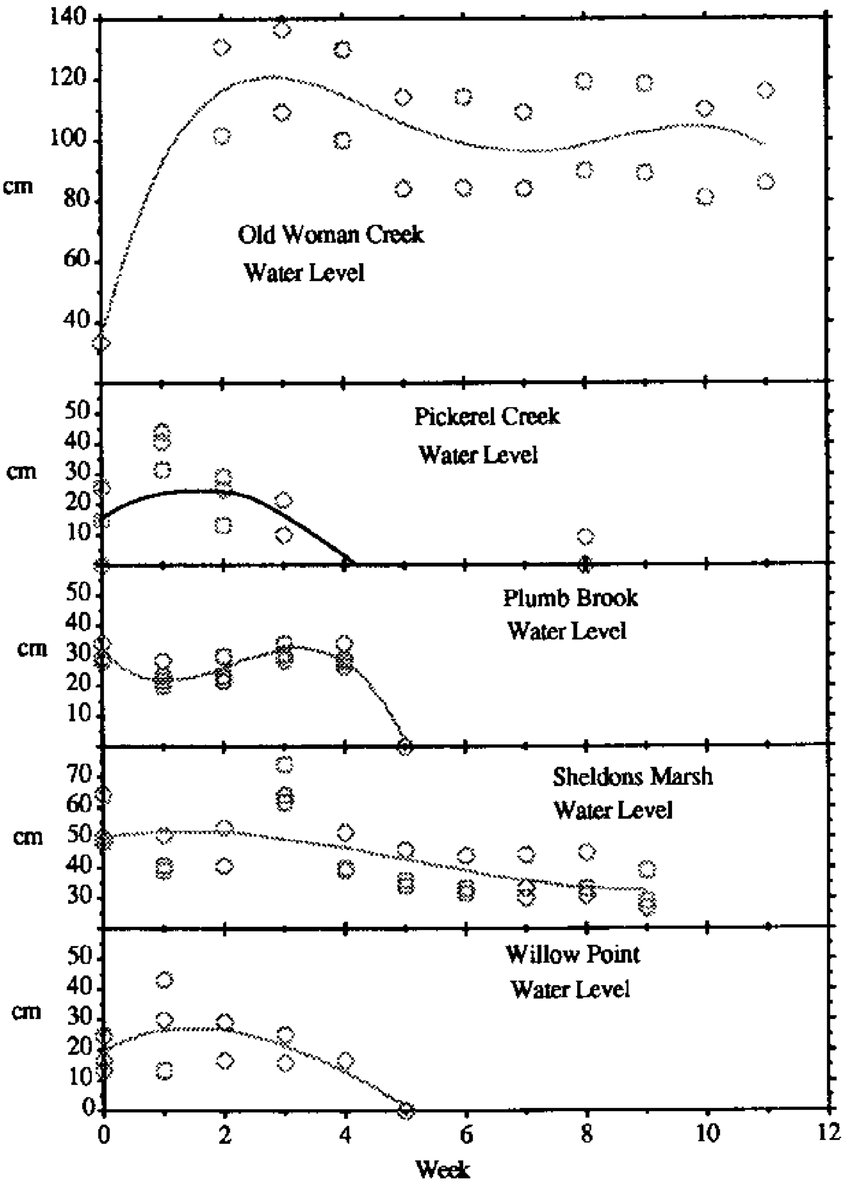

Figure 7.1 Changes in water level for May through October, 1988, in undiked wetlands of coastal Lake Erie

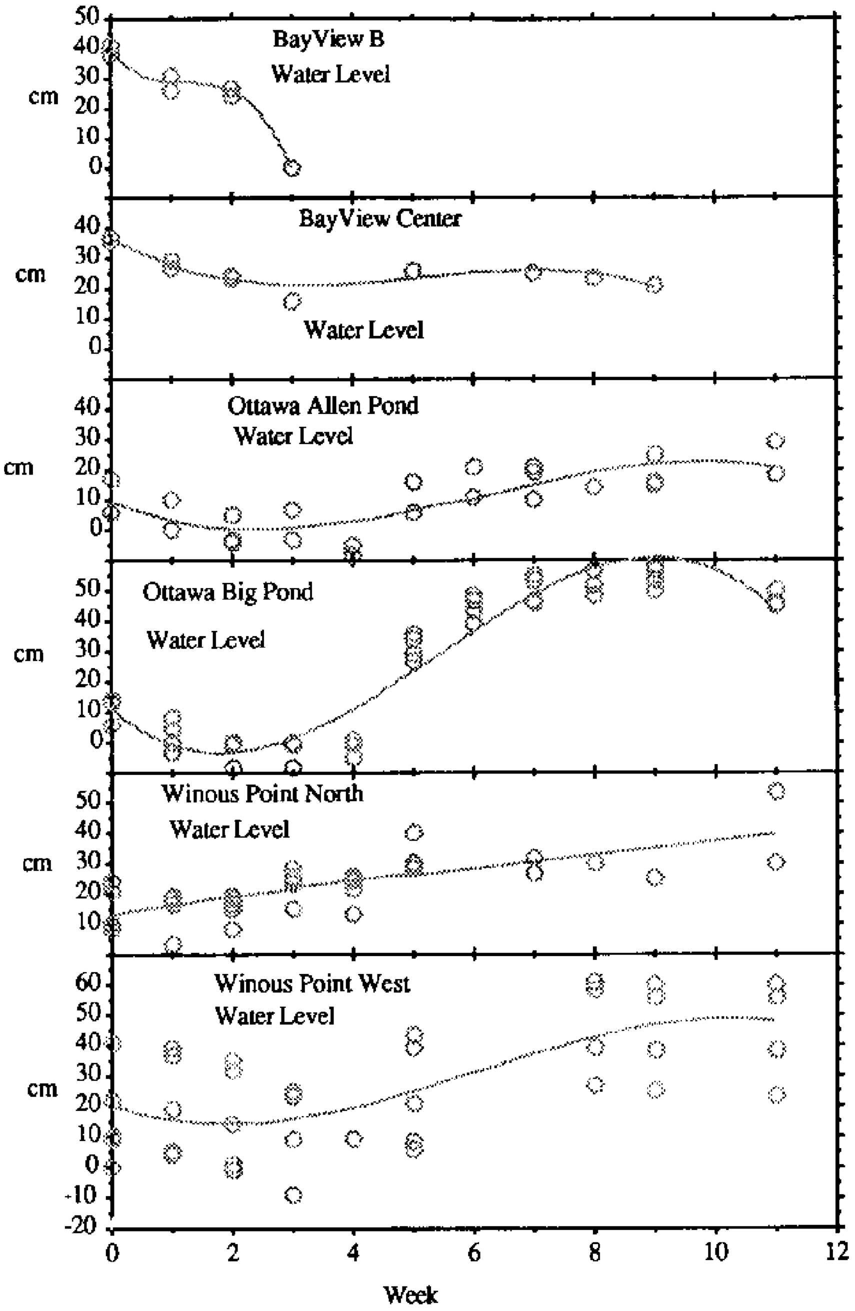

Figure 7.2 Changes in water level for May through October, 1988, in diked wetlands of coastal Lake Erie

Table 7.1 Methods used for the chemical analysis of water samples

Analysis	Method	Citation
Alkalinity	pH 4.5 endpoint	APHA (1985)
Conductivity	electrometrically	-----
Turbidity	electrometrically	-----
Nitrate	Cadmium Reduction	APHA (1985)
Nitrite	----	APHA (1985)
Ammonia	----	Zadorojny et al. (1973)
Orthophosphate	Ascorbic Acid	APHA (1985)
Total Phosphorus	Persulfate Digestion	APHA (1985)

remainder of the study. Willow Point marsh water level also increased 18 cm during the first week due to the Lake Erie seiche and then declined until the fourth week, when water levels could no longer be registered. This showed a net decline of 9 cm in the first four weeks. Plum Brook marsh water levels decreased by 8 cm during the first sampling time due to a seiche and then returned to previous levels. By the fourth sampling period, further sampling was impossible due to low water levels. Sheldons Marsh had a slower overall decline of 23 cm, probably due to the direct connection to Lake Erie. Old Woman Creek water levels are greatly influenced by the barrier beach that blocks the only outlet of Old Woman Creek for most of the summer. The beach was closed for all but one day of the study. The water level rose during the first three weeks of May by a total of 104 cm; however, as the drought continued, the water level decreased (see Chapter 4).

The water manipulation strategy for most diked marshes is to maintain lower water levels in the spring to promote vegetative growth, maintain water levels at a minimum throughout the summer and then raise the water in the autumn to attract waterfowl. This strategy is reflected in the water levels measured (Figure 7.2). Winous Point North increased approximately 43 cm and Winous Point West increased 15 cm over the study period. Water was pumped from Sandusky Bay to both sites starting in mid-June and continued throughout the remainder of the study. Approximately 5 cm were added every two to three weeks. Ottawa Allen Pond and Ottawa Big Pond had net increases of 11 cm and 38 cm, respectively. Bay View "B" water level decreased 38 cm during the first three weeks of the study until it could no longer be measured. The water levels in Bay View Center had a net decrease of 15 cm. Water was pumped from Sandusky Bay to the Bay View study sites from June 24th to July 15th; however, the amount added was not documented.

Water Chemistry

Patterns for chemical parameters in selected diked (Ottawa and Winous Point) and undiked (Old Woman Creek and Sheldons Marsh) wetlands are presented in Figures 7.3 through 7.5. Tables 7.2 through 7.8 summarize least square means of water chemistry in the diked and undiked marshes. Temperature, dissolved oxygen, and pH are not discussed because of their diurnal fluctuations and the different times of day at which they were collected. All water level and water chemistry data for each marsh and station are listed in Appendix 7.1.

Alkalinity — Alkalinity is related to the buffering capacity of the water and is influenced by the carbonate and bicarbonate content of the water. Because of plentiful limestone in the region, alkalinity should be adequate in the streams and wetlands of the region. Alkalinity averaged 161 mg $CaCO_3$/l for the diked wetlands and 131 mg/l for the undiked sites (Table 7.2). No consistent trends were observed for alkalinity in either the diked and undiked wetlands. For example, alkalinity decreased slightly in Winous Point North while it decreased and then increased over the same period in Ottawa Big Pond (Figure 7.3). Alkalinity in Old Woman Creek , which was open to Lake Erie only briefly in May (see Chapter 4), and in Sheldons Marsh, which is open to the Lake, appears to be cyclic but the two patterns do not match (Figure 7.3).

Conductivity — Conductivity is a measure of the total dissolved ions in water. The diked and undiked marshes had conductivities averaging 1,053 and 766 µmhos, respectively (Table 7.3). Conductivity decreased in the wetlands that received active pumping (Winous Point and Ottawa) while it was relatively constant in the undiked wetlands through the season (Figure 7.3). The diked marshes increased to a peak during the fourth sampling period then decreased with a final spike the last week. Within the diked wetland grouping, conductivity was generally higher in the Ottawa

Table 7.2 Alkalinity least square means for diked and undiked marshes

Date	Diked	Undiked	Overall
1	197	123	160
2	190	123	156
3	177	112	144
4	181	142	161
5	139	168	150
6	147	165	156
7	161	152	155
8	149	130	138
9	156	124	137
10	128	156	128
11	155	141	144
Overall	161	131	

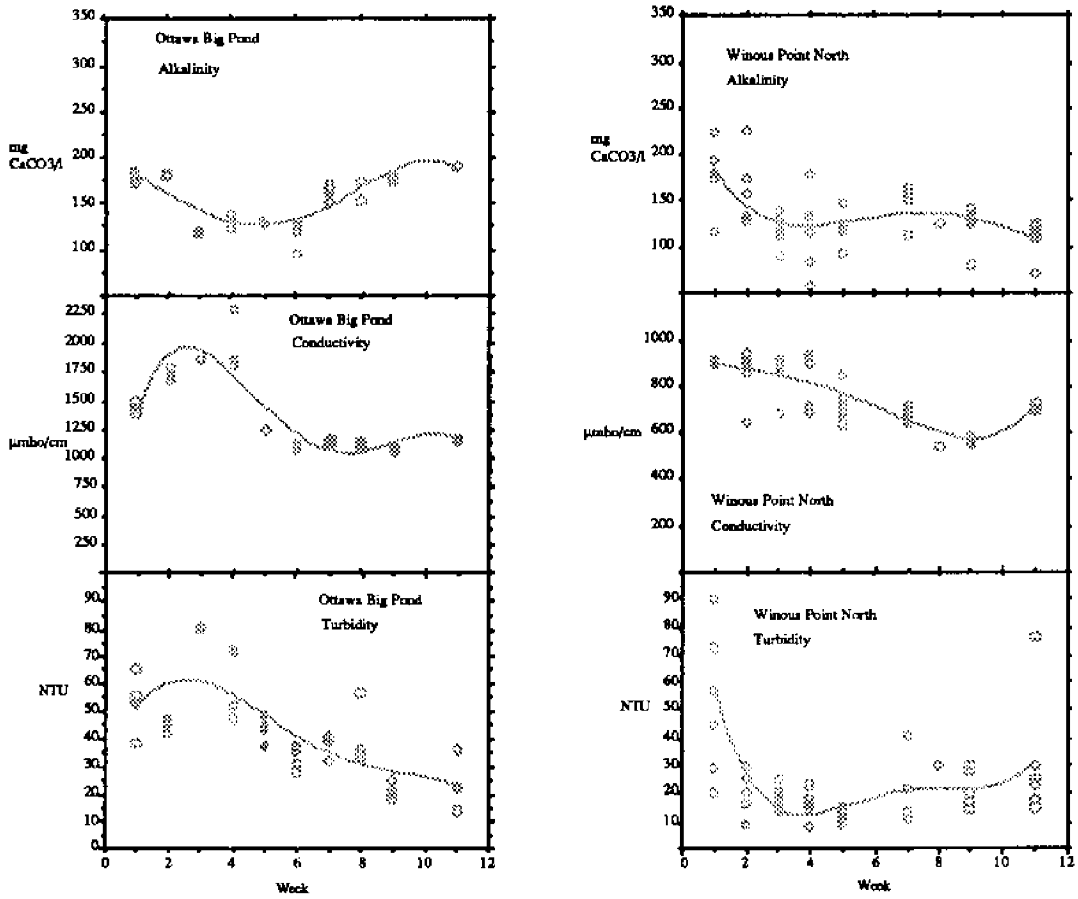

Figure 7.3 Alkalinity, conductivity, and turbidity in standing water of two diked wetlands (Ottawa Big Pond and Winous Point North) and undiked wetlands (Old Woman Creek and Sheldons Marsh), May through October, 1988

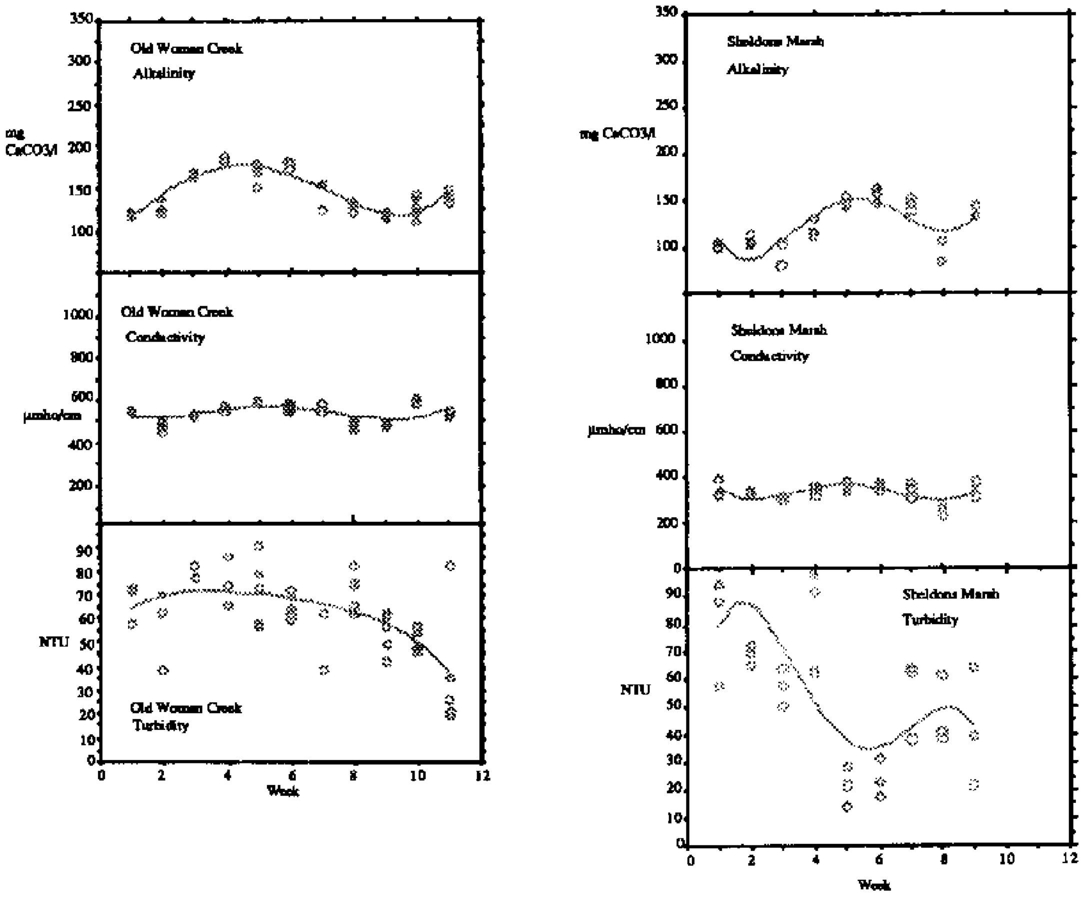

Figure 7.3 continued

Table 7.3. Conductivity least square means for diked and undiked marshes

Date	Diked	Undiked	Overall
1	1062	638	845
2	1129	724	923
3	1220	609	912
4	1409	744	1076
5	1046	942	972
6	978	462	720
7	1008	960	992
8	995	848	915
9	880	406	717
10	—	586	586
11	1056	528	835
Overall	1053	766	

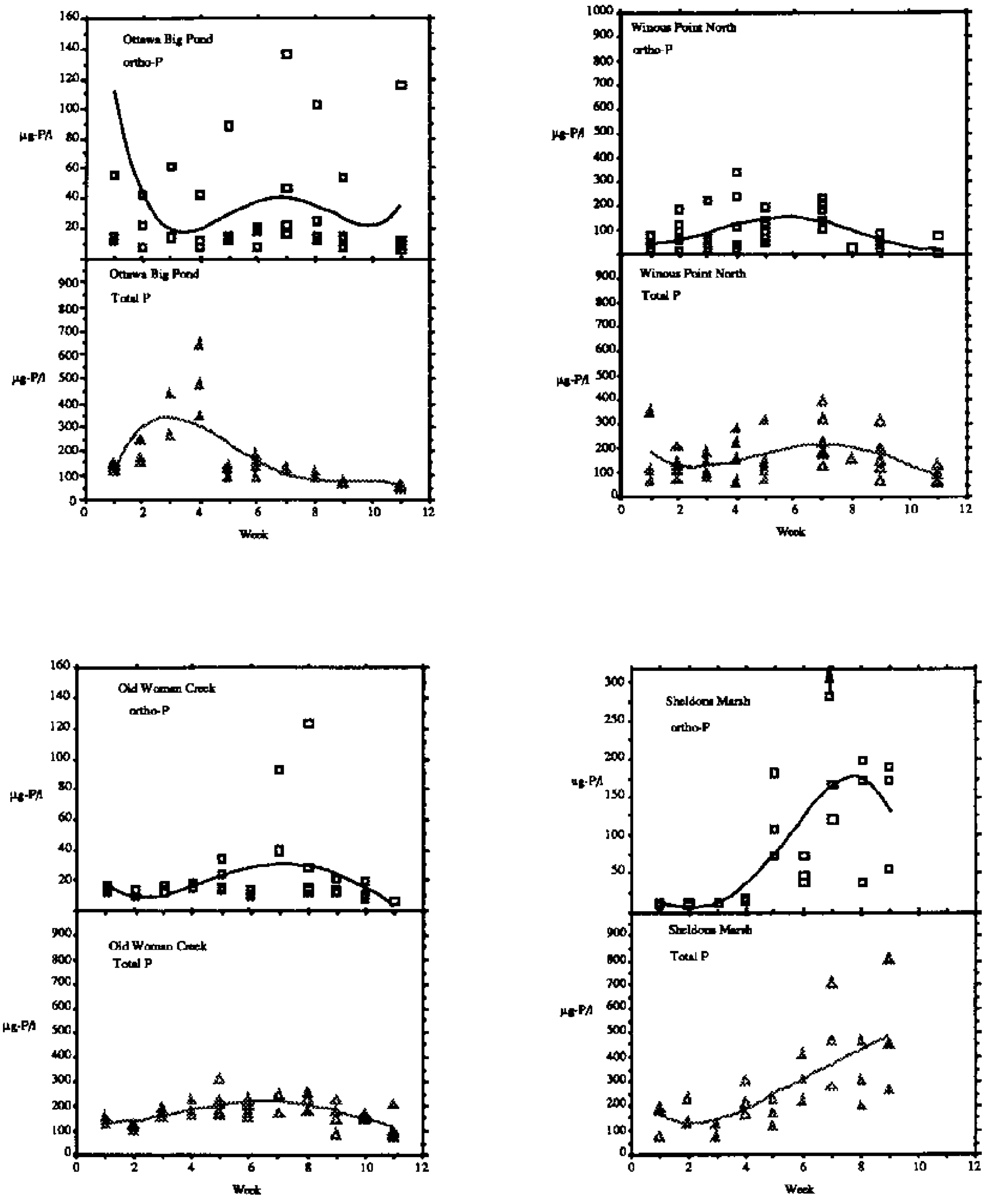

Figure 7.4 Ortho-phosphate and total phosphorus in standing water of two diked wetlands (Ottawa Big Pond and Winous Point North) and undiked wetlands (Old Woman Creek and Sheldons Marsh), May through October, 1988

Table 7.4 Turbidity least square means for diked and undiked marshes

Date	Diked	Undiked	Overall
1	42	69	58
2	31	73	53
3	38	59	50
4	44	109	78
5	23	46	41
6	31	45	38
7	20	50	40
8	23	49	42
9	22	45	42
10	-	50	50
11	23	37	38
Overall	26	57	

Table 7.5 Ortho-phosphate least square means for diked and undiked marshes

Date	Diked	Undiked	Overall
1	70	36	51
2	95	17	54
3	52	27	38
4	73	23	47
5	60	57	57
6	30	33	33
7	132	128	124
8	80	71	75
9	69	66	64
10	–	12	12
11	75	7	49
Overall	73	55	

Table 7.6 Total phosphorus least square means for diked and undiked marshes

Date	Diked	Undiked	Overall
1	146	159	154
2	165	176	170
3	205	202	204
4	265	269	268
5	125	190	170
6	184	238	211
7	164	330	252
8	122	238	190
9	128	292	225
10	—	152	152
11	96	111	141
Overall	149	237	

Shooting Club and Bay View B wetlands than in Winous Point and Bay View Center wetlands.

Turbidity — Turbidity averaged 26 NTU in diked wetlands and 57 NTU in undiked wetlands (Table 7.4). The dikes prevent inflows of sediment-laden streams and sometimes serve as wind breaks, often keeping the system in a state of lower turbulence. A management strategy in some diked wetlands to eliminate and/or prevent carp from entering the wetland gives another reason why turbidity may be generally less in diked wetlands. Turbidity in diked wetlands generally declined during the study period as vegetation stabilized the sediments. The undiked wetlands had an overall declining trend but with greater variability over the duration of the study (Figure 7.3).

Phosphorus — Ortho-phosphate averaged 73 µg-P/l for diked marshes and 55 µg-P/l for undiked wetlands (Table 7.5), while total phosphorus averaged 149 µg-P/l for diked wetlands and 237 µg-P/l for undiked wetlands (Table 7.6). While the diked wetlands had lower concentrations of total phosphorus, a greater percent of phosphorus was bioavailable (49%) compared to that in undiked wetlands (23%). Part of this may be due to greater water-column productivity in the undiked wetlands. Ortho-phosphates remained generally low in the plankton-dominated Old Woman Creek wetland (approximately 30 µg-P/l) compared to either undiked Sheldons Marsh (concentrations start low at < 25 µg-P/l but increase as water levels decrease) or the diked Winous Point North (approximately 100 µg-P/l) (Figure 7.4). Total phosphorus increased from about 100 to 400 µg-P/l as water levels decreased in undiked Sheldons Marsh while it appeared to peak in June in Ottawa Big Pond before decreasing to 100 µg-P/l.

Nitrogen — Nitrate-nitrogen (nitrate + nitrite) appeared to be similar and relatively low in both the diked and undiked wetlands. The nitrate averaged 0.36 mg N/l in undiked marshes and 0.33 mg-N/l in diked marshes (Table 7.7). Winous Point North and Ottawa Big Pond diked wetlands showed similar patterns of nitrates increasing in late spring, then decreasing through the rest of the growing season (Figure 7.5). Old Woman Creek wetland generally had very low concentrations of nitrate (<0.2 mg-N/l), while Sheldons Marsh nitrate decreased dramatically as water level decreased and the water was closer to the anaerobic sediments (Figure 7.5). Changing water levels may encourage denitrification by first causing nitrification during high water then denitrification during low water levels. Nitrite-nitrogen concentrations were low in general and averaged 3 and 6 µg/l for the diked and undiked marshes, respectively. Ammonia-nitrogen trends for both types of marshes were parallel with generally low concentrations (Figure 7.5). Averages were 0.05 mg-N/l and 0.04 mg-N/l for the diked and undiked marshes, respectively (Table 7.8).

Limiting Nutrients — The low concentrations of available nitrogen (NO_3 and NH_4) and the pattern of rapidly decreasing nitrate and ammonia nitrogen in some of the wetlands (e.g. Sheldons Marsh, Figure 7.5) suggest that nitrogen may be the limiting nutrient in these wetlands. The relatively low N/P ratios of available nutrients (5.2:1 and 7.2:1 for diked and undiked wetlands respectively) are close to the ratio required of aquatic algae and macrophytes of 7:1 (Wetzel 1983) and therefore neither support nor disprove the hypothesis of nitrogen limitation.

Conclusions

There are definite differences in hydroperiods between diked and undiked wetlands that led to different biogeochemistry in each system. The water levels dropped precipitously during the summer 1988 drought in the natural wetlands but were maintained with artificial pumping in the diked wetlands. Our study showed generally higher conductivity, alkalinity, and ortho-phosphate in diked wetlands and higher turbidity and total phosphorus in the natural (undiked) wetlands. Inorganic nitrogen species (nitrate and ammonia) were similar in the two types of wetlands. It is clear from the above discussion that the physical (e.g., water depth, time of season) and chemical variables measured in this study are not independent of one another. Further correlation analysis between variables and analysis of variance may show additional patterns and relationships.

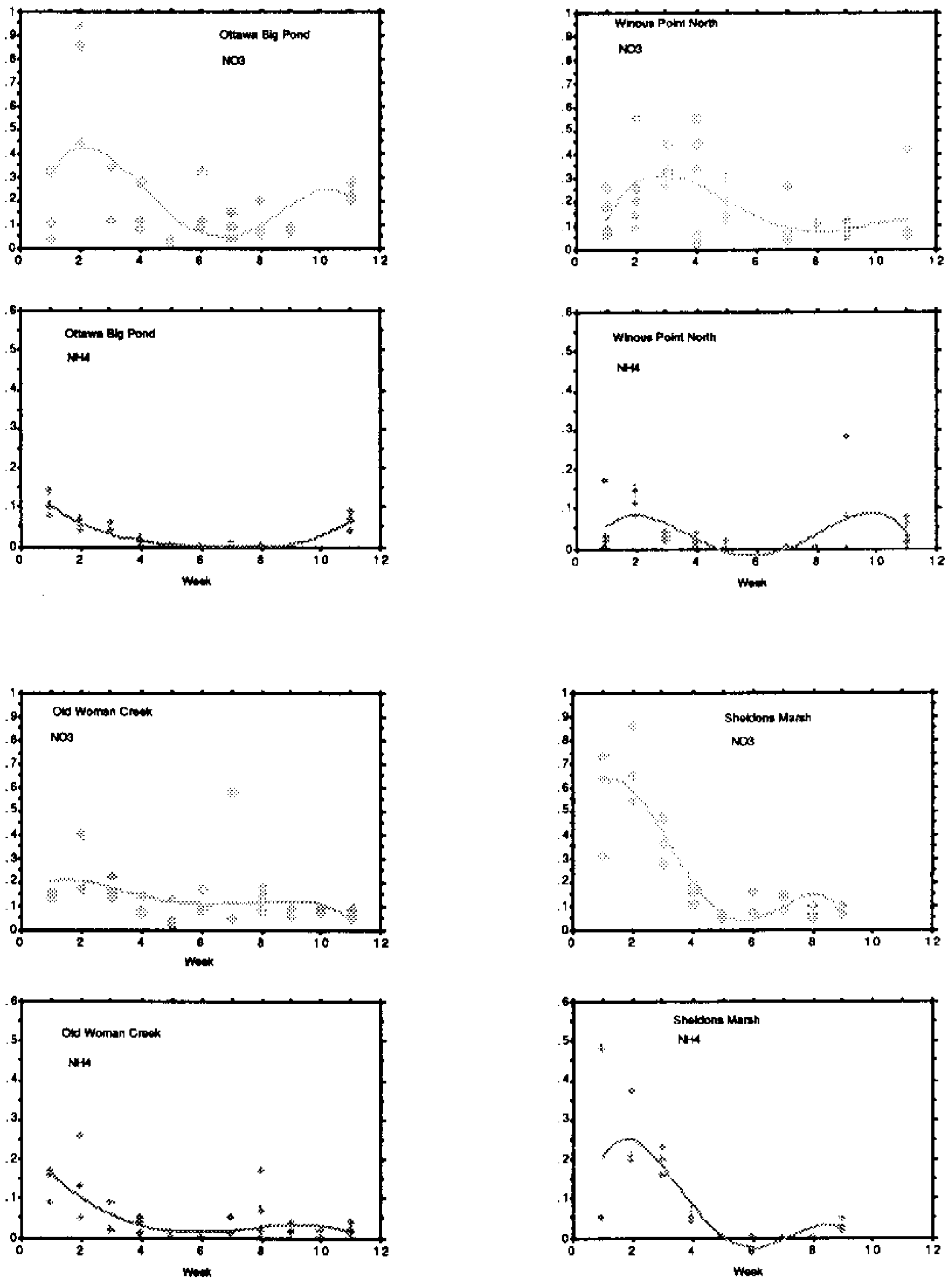

Figure 7.5 Nitrate-nitrogen and ammonia-nitrogen (mg-N/l) in standing water of two diked wetlands (Ottawa Big Pond and Winous Point North) and undiked wetlands (Old Woman Creek and Sheldons Marsh), May through October, 1988

Table 7.7 Nitrate least square means for diked and undiked marshes

Date	Diked	Undiked	Overall
1	0.29	0.79	0.54
2	0.82	0.72	0.77
3	0.51	0.48	0.49
4	0.34	0.13	0.23
5	0.18	0.14	0.15
6	0.17	0.12	0.15
7	0.21	0.22	0.21
8	0.20	0.26	0.23
9	0.13	0.09	0.13
10	—	0.08	0.08
11	0.20	0.07	0.17
Overall	0.33	0.36	

Table 7.8 Ammonia least square means for diked and undiked marshes

Date	Diked	Undiked	Overall
1	0.08	0.13	0.11
2	0.14	0.15	0.15
3	0.04	0.09	0.07
4	0.03	0.03	0.03
5	0.01	0.00	0.01
6	0.01	0.00	0.00
7	0.02	0.02	0.02
8	0.01	0.05	0.03
9	0.03	0.02	0.02
10	----	0.00	0.00
11	0.04	0.02	0.03
Overall	0.05	0.04	

APPENDIX 7.1. Water chemistry data for stations within sites between May and October, 1988. Week 0 denotes the initial water level reading when station was established.

Station	Week	Water Leve cm	Alkalinity mg CaCO3/l	Conductivity µmhos/cm	Turbidity NTU	ortho P µg-P/l	Nitrate mg-N/l	Nitrite µg-N/l	Ammonia mg-N/l	D.O. mg/l	Temp C	pH	Total P µg-P/l
Bay View B													
1	0	41											
1	1	31	115	1130	4	83	0.14	1	0.16	15	21	8.77	20
1	2	27	81	1251	8	358	1.06	1	0.55	11.5	12	6.87	86
1	3		132	1418	15	15	0.62	2	0.06	13.5	30	7.24	61
1	5		114	1764	7	51	0.04	2	0.02			6.93	67
1	8		174	1537	12	9	0.08	2	0	4.5	21	6.83	78
2	0	38											
2	1	26	195	1228	16	16	0.19	1	0.14	12.5	20	8.45	42
2	2	24	137	1353	22	32	2.43	1	0.34	12	14	7.46	105
2	3												
3	1		190	1232	8	7	0.06	1	0	6.5	19	8.33	18
3	2		153	1285	9	10	1.41	1	0.16	10	13	7.69	24
3	3		153	1393	5	6	0.65	2	0.06	15	28	8.23	20
3	4		179	1915	35	8	0.45	4	0.1	6.8	25	7.88	146
3	5		132	1704	8	8	0.14	2	0			7.87	37
3	7		58	1503	6	30	0.07	2	0.06	14.5	33	8.18	48
3	8		52	1330	9	8	0.1	2	0.01	14.5	23	8.12	44
3	9		46	1237	18	8	0.14	5	0.04	12.5	25	8.67	59
Bay View Center													
1	1		188	905	10	82	0.39	1	0.06	9.5	17	8.26	26
1	2		178	972	13	85	1.12	1	0.12	9.3	12	8.18	37
1	3		167	1070	13	18	0.99	2	0.05	9.5	20	7.9	53
1	4		179	1225	19	18	0.36	3	0	4	21	7.52	81
1	5		175	858	30	11	0.07	2	0			7.62	69
1	7		156	828	12	14	0.14	2	0	7.5	31	7.98	51
1	8		146	825	11	8	0.09	2	0	8.8	22	7.75	42
1	9		143	811	12	7	0.08	3	0	9	21	7.86	28
1	11		153	868	30	6	0.11	5	0.08	11.8	7	7.91	43
2	0	37											
2	1	29	189	920	10	6	0.03	1	0	10.3	19	8.29	28
2	2	24	173	983	9	14	1.11	1	0.22	7.3	10	7.38	32
2	3	16	178	1120	7	6	0.05	2	0.06	6.8	20	7.49	68
2	4		159	1406	19	6	0.1	3	0.01	9.5	23	8.22	48
2	5	26	164	911	18	9	0.04	2	0			7.45	72
2	7	25	124	854	11	11	0.12	2	0.03	8.3	31	7.61	46
2	8	23	121	812	8	9	0.06	2	0	8.5	21	7.55	52

APPENDIX 7.1. Water chemistry data for stations within sites between May and October, 1988. Week 0 denotes the initial water level reading when station was established.

Station	Week	Water Leve cm	Alkalinity mg CaCO3/l	Conductivity µmhos/cm	Turbidity NTU	ortho P µg-P/l	Nitrate mg-N/l	Nitrite µg-N/l	Ammonia mg-N/l	D.O. mg/l	Temp C	pH	Total P µg-P/l
2	9	21	120	790	15	8	0.1	4	0	9.3	22	7.63	51
3	0	36											
3	1	27	193	919	20	7	0.27	1	0.02	7.5	19	8.26	25
3	2	23	180	983	18	8	1.48	1	0.14	8.5	13	7.88	36
3	3		160	1086	9	7	1.13	2	0.04	12.5	30	7.96	42
3	5		183	1077	7	7	0.19	2	0			7.22	35
3	7		166	970	9	8	0.57	3	0.19	7.8	34	7.73	50
3	8		154	865	7	8	0.05	2	0	9.3	24	7.64	35
3	9		158	863	5	7	0.08	3	0.02	10.8	23	7.71	20
Ottawa Shooting Club - Allen Pond													
1	0	6											
1	1	0	244	993	145	13	0.06	1	0.04	9.5	12	8.32	444
1	2	-4	277	1087	140	23	1.13	6	0.07	9	18	8.11	505
1	3	-3	250	1472	137	36	1.01	3	0.04	7.5	13	7.07	796
1	4	-8	305	1606	135	62	0.78	6	0.02	4.8	21	7.87	532
1	5	6	127	943	63	61	0.34		0.01	6.5	23	7.48	179
1	6	11	172	936	43	33	0.19	3	0.02	2.3	26	7.37	218
1	7	19	235	1022	51	303	0.51	4	0.01	2.4	26	7.52	302
1	8	14	252	992	42	257	0.23	4	0	6.5	20	7.77	264
1	9	16	241	907	27	152	0.11	4	0.01	5	18	7.5	153
1	11	18	248	935	35	37	0.2	5	0.01	12.4	6	7.93	89
2	0	6											
2	1	0	241	1008	77	15	0.09	2	0.07	9.5	12	8.45	435
2	2	-3	282	1120	115	100	0.16	4	0.09	7.8	18	7.94	677
2	3	-3	279	1447	79	51	0.12	3	0.02	10.8	11	7.82	446
2	4	-5	304	1623	120	77	0.07	3	0.03	8	21	7.95	541
2	5	6	127	830	36	192	0.03		0	2	23	7.22	299
2	6	11	158	899	42	27	0.1	5	0	2.8	26	7.09	229
2	7	10	191	975	38	248	0.19	4	0.01	3	26	7.45	233
2	8	14	211	930	29	373	0.09	4	0	8.8	22	7.99	189
2	9	15	232	852	57	102	0.05	5	0	6.5	19	7.61	213
2	11	18	242	942	37	46	0.16	5	0	12.6	6	7.37	101
3	0	17											
3	1	10	246	971	65	22	0.51	2	0.17	11	11	8.38	359
3	2	5	303	1198	36	140	0.81		0.2	9.5	19	7.56	362
3	3	7	290	1456	110	26	0.13	3	0.04	10.3	14	7.74	293
3	5	37*	148	930	15	22	0.12		0.06	2.5	22	6.85	103

APPENDIX 7.1. Water chemistry data for stations within sites between May and October, 1988. Week 0 denotes the initial water level reading when station was established.

Station	Week	Water Leve cm	Alkalinity mg CaCO3/l	Conductivity µmhos/cm	Turbidity NTU	ortho P µg-P/l	Nitrate mg-N/l	Nitrite µg-N/l	Ammonia mg-N/l	D.O. mg/l	Temp C	pH	Total P µg-P/l
3	6	42	179	850	10	14	0.08	5	0.02	1.3	25	6.82	181
3	7	42	243	967	9	444	0.27	3	0	1.6	24	6.98	400
3	8	46	222	916	5	329	0.12	3	0	0.8	19	7.14	255
3	9	46	275	828	14	796	0.04	5	0	1	16	7.27	685
3	11	50	195	967	29	42	0.1	4	0	11.2	5	6.83	135

*new water level measurement after stake fell down

Ottawa Big Pond

1	0	14											
1	1	8	173	1395	53	11	0.11	1	0.1	9.8	11	8.42	121
1	2	-1	179	1680	47	8	0.45	1	0.04	9.3	18	7.9	169
1	3	-1	118	1842	81	14	0.12	2	0.06	11.8	11	7.91	438
1	4	1	124	1840	71	8	0.12	2	0.01	8.3	20	8.55	345
1	5	36	131	1214	37	11	0.03		0	7.8	26	8.22	92
1	6	48	96	1094	31	20	0.33	4	0	3.8	27	7.34	185
1	7	55	160	1113	39	16	0.15	3	0	4	27	7.75	122
1	8	57	174	1099	36	12	0.08	3	0	9.3	21	8.13	93
1	9	58	179	1038	18	7	0.08	3	0	7	18	7.78	66
1	11	50	191	1160	14	6	0.22	14	0.07	12.2	6	8.14	62
2	0	6											
2	1	-3	184	1482	38	387	0.04	1	0.14	10.5	15	8.42	136
2	2	0											
2	3	0											
2	4	-5	138	2287	47	42	0.08	2	0.02	12.5	24	8.65	641
2	5	27	129	1244	43	88	0.04		0	13	26	8.45	126
2	6	39	125	1105	36	18	0.31	4	0	6.5	27	7.89	135
2	7	46	165	1129	41	136	0.16	2	0.01	6	26	7.77	123
2	8	48	175	1125	35	102	0.2	3	0	10.3	21	7.92	117
2	9	50	177	1066	22	54	0.07	3	0	8	18	7.81	76
2	11	45	191	1164	23	11	0.23	17	0.09	12.4	5	8.02	43
3	0	13											
3	1	4	179	1434	55	15		1	0.1	10	14	8.46	148
3	2	-1	181	1780	46	22	0.94	1	0.07	11	24	7.84	151
3	3	0											
3	4	-1	137	2277	52	11	0.08	3	0.01	10.8	26	8.66	475
3	5	34	127	1234	48	14	0.03		0	10.5	25	8.1	144
3	6	47	127	1057	28	8	0.12	3	0	6.5	27	7.91	94
3	7	53	170	1150	32	47	0.09	3	0	7.2	27	7.58	129

APPENDIX 7.1. Water chemistry data for stations within sites between May and October, 1988. Week 0 denotes the initial water level reading when station was established.

Station	Week	Water Leve cm	Alkalinity mg CaCO3/l	Conductivity µmhos/cm	Turbidity NTU	ortho P µg-P/l	Nitrate mg-N/l	Nitrite µg-N/l	Ammonia mg-N/l	D.O. mg/l	Temp C	pH	Total P µg-P/l
3	8	57	154	1076	33	25	0.09	3	0	10.5	22	7.99	94
3	9	57	174	1056	25	15	0.07	4	0	8.8	19	7.76	72
3	11		189	1162	36	9	0.2	12	0.04	13	5	8.09	52
4	0	6											
4	1	0	172	1396	65	55	0.33	1	0.08	10.3	13	8.57	155
4	2	-8	181	1710	42	42	0.85	2	0.05	10.5	19	7.96	246
4	3	-8	119	1838	80	61	0.34	3	0.04	12.5	14	8.15	269
4	4	-5	122	1809	72	42	0.28	3	0	14.5	24	8.7	345
4	5	34*	127	1227	45	13	0.04		0	10.8	25	8.33	124
4	6	48	121	1058	37	8	0.09	3	0	6.5	27	7.85	159
4	7	52	151	1124	40	22	0.04	2	0	6.8	26	7.68	115
4	8	57	173	1112	57	15	0.06	3	0	10.8	22	8.16	85
4	9	58	176	1082	20	13	0.09	2	0	9.5	19	7.8	68
4	11	51		1134	22	115	0.28			12.4	6	7.72	
surement after stake fell down													
Winous Point North													
1	0	8											
1	1	3	224	884	20	74	0.08	4	0.03	9.5	22	7.94	108
1	2	8	127	638	9	118	0.14	1	0.11	12.5	21	7.63	143
1	3	15	113	678	18	62	0.3	3	0.03	11.3	24	7.87	98
1	4	13	133	685	16	342	0.34	3	0	13.8	25	7.5	279
1	5		146	684	10	198	0.2		0			7.34	316
1	7		162	638	13	201	0.04	3	0	2	31	7.35	395
1	9		133	578	28	14	0.06	3	0	7.5	19	7.66	312
1	11		120	691	15	7	0.05	4	0.08	11.5	1	7.85	62
2	0	10											
2	1	17	179	908	57	45	0.18	3	0.02	9.5	21	8.03	108
2	2	15	133	860	16	95	0.56	2	0.14	10	19	7.43	130
2	3	23	89	851	13	223	0.27	3	0.03	14	23	8.22	148
2	4	22	180	891	15	243	0.44	3	0.01	6.5	24	7.25	151
2	5	28	120	695	11	100	0.3		0			7.25	107
2	7	27	112	676	11	134	0.27	4	0	2.5	25	7.06	124
2	9	25	79	544	14	87	0.06	4	0.08	7.5	17	7.5	115
2	11	53	70	722	23	76	0.42	3	0.06	11.5	10	6.52	95
3	0	21											
3	1	17	179	887	44	15	0.26	3	0.17	11.5	21	8.66	116
3	2	17	173	875	30	61	0.25	2	0.16	11	19	7.82	110

APPENDIX 7.1. Water chemistry data for stations within sites between May and October, 1988. Week 0 denotes the initial water level reading when station was established.

Station	Week	Water Leve cm	Alkalinity mg CaCO3/l	Conductivity µmhos/cm	Turbidity NTU	ortho P µg-P/l	Nitrate mg-N/l	Nitrite µg-N/l	Ammonia mg-N/l	D.O. mg/l	Temp C	pH	Total P µg-P/l
3	3	25	138	892	19	69	0.31	2	0.04	7.5	25	7.54	187
3	4	24	114	923	23	46	0.55	3	0.04	9.5	25	7.53	216
3	5	30	126	718	15	136	0.15		0			7.39	145
3	7		159	691	41	211	0.07	3	0	2	24	7.48	322
3	9		126	569	17	60	0.12	48	0.28	2.5	17	7.4	149
3	11		123	692	30	7	0.06	3	0.02	12	1	7.94	87
4	0	24											
4	1	19	175	898	90	10	0.08	3	0	9	18	8.29	346
4	2	19	158	910	25	9	0.26	1	0.11	8.3	19	7.92	72
4	3	28	116	910	21	13	0.34	2	0.02	8	23	7.92	84
4	4	28	85	901	8	22	0.34	3	0	11.8	23	8.5	66
4	5	40	115	738	9	121	0.14		0			8.88	107
4	7	32	156	676	22	185	0.07	3	0	11.3	26	8.93	218
4	8	30	125	528	30	29	0.11	3	0	10.3	20	8.55	160
4	11		122	690	18	7	0.06	3	0.01	12.5	1	7.96	60
5	0	8											
5	1	18	193	899	125	11	0.08	2	0.02	7.8	20	8.18	356
5	2	18	158	896	21	19	0.2	1	0.11	9.3	19	7.75	73
5	3	26	127	853	25	27	0.44	3	0.03	8	25	7.62	106
5	4	25	56	705	18	15	0.06	2	0.02	11.5	26	8.86	57
5	5		92	628	12	65	0.12		0.01			9.3	71
5	7		162	650	13	236	0.05	3	0	11.5	26	8.7	186
5	9		128	558	30	24	0.05	5	0	8.3	20	7.85	67
5	11	30	108	704	25	7	0.06	3	0.03	11.5	1	7.41	53
6	1		116	908	29	22	0.06	3	0.02	10	18	8.13	68
6	2		226	942	21	187	0.09	1	0.08	12.5	19	7.58	205
6	3		110	879	17	73	0.33	3	0.03	9.3	22	7.95	180
6	4		134	919	15	114	0.03	2	0.04	6.8	24	7.48	161
6	5		119	849	13	51	0.14		0.02			7.31	130
6	7		148	709	11	112	0.05	3	0	1.3	25	7.37	171
6	9		142	584	20	36	0.07	4	0	2.5	16	7.29	198
6	11		111	688	76	7	0.07	3	0.03	12	1	7.96	129
Winous Point West													
1	0												
1	1	39	199	790	8	116	0.14	4	0	1.8	16	7.55	146
1	2	35	195	803	20	185	1.24	4	0.09	0	20	7.36	161
1	3	25	264	843	18	155	0.31	5	0.03	2.5	18	7.41	242

APPENDIX 7.1. Water chemistry data for stations within sites between May and October, 1988. Week 0 denotes the initial water level reading when station was established.

Station	Week	Water Leve cm	Alkalinity mg CaCO3/l	Conductivity µmhos/cm	Turbidity NTU	ortho P µg-P/l	Nitrate mg-N/l	Nitrite µg-N/l	Ammonia mg-N/l	D.O. mg/l	Temp C	pH	Total P µg-P/l
1	4		305	919	79	106	0.31	3	0.12	4.5	20	7.62	420
1	5	43	116	909	32	28	0.31		0.01	7.38			157
1	8	61	50	827	37	36	1.2	5	0.2	4.5	20	6.56	93
1	9	60	170	802	26	82	0.2	4	0.03	5.5	18	6.16	66
1	11	60	0	3984	9	218	0.1	2	0.02	13.5	1	2.08	131
2	0	41											
2	1	37	211	787	15	154	1.34	5	0.11	7.5	15	7.76	29
2	2	32	147	738	6	219	1.32	1	0.12	6.3	19	7.42	77
2	3	23	230	864	17	135	1.05	9	0.04	4.8	18	7.75	144
2	4												
2	5	39	165	798	32	112	0.25	0				7.85	146
2	8	58	137	706	24	44	0.24	4	0	7.3	20	7.22	109
2	9	56	156	694	30	52	0.17	14	0.06	6.3	18	6.93	126
2	11	56	167	677	6	276	0.12	5	0.03	12	1	7.08	163
3	0	22											
3	1	19	209	784	45	352	1.05	6	0.09	8.5	16	7.86	104
3	2	14	248	831	19	298	0.72	1	0.04	9.5	18	7.6	168
3	3	9	238	822	36	82	0.79	4	0.03	6.3	20	8.08	198
3	4	9	294	988	75	131	0.5	6	0.02	6.5	22	7.94	
3	5	21	156	790	35	65	0.21		0		7.65		192
3	8	39	143	697	22	21	0.06	2	0	6.5	20	7.31	381
3	9	38	175	723	35	22	0.12	3	0.01	6.5	19	7.38	155
3	11	38	184	738	16	568	0.09	4	0.01	5.8	2	7.25	384
4	0	9											
4	1	4	243	825	14	78	0.09	5	0.09	6.5	16	7.77	75
4	2	-1	234	859	9	70	0.22	1	0.1	5	19	7.5	78
4	3		245	836	31	60	0.32	3	0.05	7	22	8	227
4	5	6	172	864	20	22	0.11		0.01			7.39	161
4	8		135	712	32	23	0.05	3	0	6.8	20	7.36	93
4	9		174	709	19	27	0.09	4	0	5.5	18	7.45	161
4	11	23	213	758	13	19	0.06	2	0.03	13.5	1	7.28	71
5	0	10											
5	1	5	222	826	16	62	0.32	5	0.17	7.5	16	7.5	68
5	2	1	231	860	9	74	0.3	1	0.14	7.5	19	7.32	73
5	3	-9	227	1062	20	30	0.31	3	0.07	9.3	24	7.97	94
5	5	8	176	1002	14	24	0.27		0.08			7.34	72
5	8	27	126	716	26	88	0.24	3	0.03	4.8	20	7.22	101
5	9	25	132	746	37	14	0.12	3	0	3.5	18	7.11	49

APPENDIX 7.1. Water chemistry data for stations within sites between May and October, 1988. Week 0 denotes the initial water level reading when station was established.

Station	Week	Water Leve cm	Alkalinity mg CaCO3/l	Conductivity µmhos/cm	Turbidity NTU	ortho P µg-P/l	Nitrate mg-N/l	Nitrite µg-N/l	Ammonia mg-N/l	D.O. mg/l	Temp C	pH	Total P µg-P/l
5	11	60	194	756	5	19	0.09	3	0.01		1	7.56	46
Pickerel Creek													
1	0	15											
1	1	32	98	583	180	14	1.31	13	0.14	11.5	26	8.31	166
1	2	13											
1	3	10	95	717	42	15	0.39	1	0.03	11.5	17	7.81	144
1	8	0											
2	0	0											
2	1	41	100	686	34	59	1.06	12	0.09	14	20	8.39	87
2	2	29	92	693	148	25	1.59	2	0.08	14.3	25	8.03	250
2	3		94	660	42	40	0.13	3	0.05	11.5	17	8.26	121
2	7		123	1744	30	37	0.28	3	0.02	6.1	24	7.34	230
2	8	25											
3	0	26											
3	1	44	103	587	89	27	1.65	15	0.2	9.3	16	8.36	179
3	2	25	199	1751	63	26	0.48	32	0.16	13.5	24	8.1	159
3	3	22	104	883	36	24	1.06	1	0.06	12.8	17	8.45	129
3	4		191	1949	80	25	0.1	3	0.05	7	29	7.65	273
3	5		168	2157	59	16	0.07	9	0			7.57	162
3	7		202	2312	46	44	0.26	2	0.06	7.3	24	7.4	224
3	8	9	219	2128	14	12	0.68	55	0.13	6	19	7.78	88
3	9	37											
Plum Brook													
1	0	34											
1	1	28	121	424	40	7	0.66	32	0.05	9.3	14	7.83	62
1	2	30	113	399	46	8	0.85	3	0.13	10.5	15	8.2	111
1	3	34	106	358	81	8	0.42	1	0.05			8.16	183
1	4	34	116	370	185	12	0.11	7	0.03	6.5	25	7.29	275
2	0												
2	1	22	114	394	34	7	0.79	14	0	10.7	15	8.29	57
2	2	23	108	357	96	12	1.09	8	0.11	10.5	18	8.35	154
2	3	30	104	297	50	7	0.9	3	0.04			8.38	103
2	4	27	115	365	161	12	0.17	3	0.02	7.8	26	7.35	178
3	0	29											
3	1	23	109	393	26	15	1.7	14	0.02	11	15	8.33	42
3	2	23	110	353	91	14	1.49	8	0.17	8.5	16	7.94	199

APPENDIX 7.1. Water chemistry data for stations within sites between May and October, 1988. Week 0 denotes the initial water level reading when station was established.

Station	Week	Water Leve cm	Alkalinity mg CaCO3/l	Conductivity µmhos/cm	Turbidity NTU	ortho P µg-P/l	Nitrate mg-N/l	Nitrite µg-N/l	Ammonia mg-N/l	D.O. mg/l	Temp C	pH	Total P µg-P/l
3	3	31	97	296	57	19	0.96	7	0.06			8.25	115
3	4	29	118	366	128	14	0.37	3	0	8	27	7.76	216
4	0	28											
4	1	20	117	371	52	9	0.58	13	0.01	6.3	13	8.1	55
4	2	22	117	355	55	10	0.28	1	0.09	12	18	8.63	99
4	3	28	99	299	42	10	1.12	7	0.05			8.38	76
4	4	28	110	351	138	16	0.19	3	0	8.5	28	7.7	200
5	2		119	416	55	9	0.69	1	0.14			8.72	127
5	3		106	324	54	8	1.23	1	0.05			8.32	
5	4		119	364	115	23	0.08	4	0.06	8.3	27	7.88	105
Willow Point													
1	0	25											
1	1	43	110	665	113	19	1.27	25	0.22	11.8	20	7.82	342
1	2	29	138	696	70	9	0.64	1	0.07	10.5	34	7.99	228
1	3	25	173	739	67	39	0.08	7	0.31	10.8	19	7.76	449
1	4	17	91	707	68	147	0.07	2	0	11.5	32	8.27	523
2	0	13											
2	1	30	97	698	64	54	0.34	12	0.22	11.8	22	8.51	148
2	2	0											
3	0	17											
3	1	13	334	2449	24	307	1.4	1	0.2	12	26	8.08	306
3	2	17	170	2774	15	61	1.52	2	0.12	10.5	34	7.96	190
3	3	16		2070	13	209	0.67	2	0.08	13.3	23	8.04	799
4	2		83	620	90	47	0.85	1	0.12	8.5	29	7.8	
4	3		120	625	89	13	0.11	2	0.05	6.5	20	7.59	196
4	4		128	745	165	8	0.09	2	0	7	31	8.05	522
Sheldons Marsh													
1	0	64											
1	1	51	98	328	58	11	0.73	15	0.05	9	16	7.48	76
1	2	53	102	332	65	13	0.86	11	0.21	9.3	18	7.34	125
1	3	74	102	296	64	10	0.47	20	0.16	11	17	8.21	123
1	4	52	131	339	98	18	0.16	6	0.05	9	29	7.49	214
1	5	46	155	347	29	181	0.05		0	15	31	8.58	231
1	6	44	158	352	31	71	0.16	4	0	12.8	30	8.22	409
1	7	44	139	305	63	424	0.14	5	0			9.03	705
1	8	45	105	263	39	171	0.1	5	0	6.3	19	7.98	301

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Station	Week	Water Leve cm	Alkalinity mg CaCO3/l	Conductivity µmhos/cm	Turbidity NTU	ortho P µg-P/l	Nitrate mg-N/l	Nitrite µg-N/l	Ammonia mg-N/l	D.O. mg/l	Temp C	pH	Total P µg-P/l
1	9	39	143	372	40	172	0.1	7	0.02	15	26	8.96	804
2	0	50											
2	1	39	99	388	94	9	0.31	21	0.48	6.5	17	7.22	192
2	2	41	106	331	72	9	0.54	15	0.37	8.5	18	7.32	132
2	3	62	79	310	58	10	0.36	18	0.23	10.5	17	7.47	76
2	4	39	113	356	91	14	0.11	11	0.04	9.3	27	7.15	166
2	5	34	146	371	22	106	0.06		0	9.5	29	7.5	171
2	6	32	163	369	23	46	0.07	3	0	27	7.85		307
2	7	30	152	364	64	166	0.08	5	0			7.65	463
2	8	31	84	261	62	197	0.06	6	0	8.8	20	7.47	463
2	9	27	133	375	64	54	0.06	3	0.03	9.8	24	7.57	454
3	0	48											
3	1	41	106	315	88	8	0.64	17	0.05	8.5	15	7.81	181
3	2	41	113	326	120	11	0.65	12	0.2	9	17	7.52	231
3	3	64	104	289	50	13	0.28	21	0.2	9.5	16	8.59	125
3	4	40	118	312	63	14	0.19	11	0.07	5.8	26	7.35	299
3	5	36	145	344	14	74	0.05		0	12.3	28	8.5	116
3	6	33	147	344	18	39	0.16	4	0			7.87	220
3	7	33	146	346	38	121	0.08	5	0			7.67	277
3	8	33	85	232	41	36	0.05	4	0	5.5	18	7.47	199
3	9	29	143	309	22	189	0.1	6	0.05	15	23	9.32	265
Old Woman Creek													
1	0												
1	1		117	536	71	17	0.14	9	0.17	7	19	7.8	133
1	2	102	121	448	39	14	0.4	1	0.05	9.5	23	7.86	97
1	3	109	166	517	77	17	0.23	3	0.02	4.5	23	7.59	176
1	4	100	181	554	65	15	0.14	3	0.04	11.8	29	8.12	164
1	5	84	170	598	57	16	0.13		0	13.8	30	8.36	166
1	6	84	172	552	62	11	0.17	5	0			8.57	176
1	7	84	156	545	39	39	0.58	3	0.05			8.9	172
1	8	90	122	468	75	123	0.15	5	0	10.5	20	8.32	255
1	9	89	118	479	49	13	0.08	3	0.02	10.8	22	8.36	83
1	10	81	122	584	47	10	0.09	4	0.02	14.5	12	7.66	148
1	11	86	133	527	26	6	0.09	3	0.01	14		7.87	94
2	0												
2	1		120	542	73	13	0.13	11	0.16			7.99	156
2	2		138	491	70	10	0.4	2	0.26	5.5	24	7.81	116

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Station	Week	Water Leve cm	Alkalinity mg CaCO3/l	Conductivity µmhos/cm	Turbidity NTU	ortho P µg-P/l	Nitrate mg-N/l	Nitrite µg-N/l	Ammonia mg-N/l	D.O. mg/l	Temp C	pH	Total P µg-P/l
2	3		168	530	82	17	0.13	3	0.09	5.8	23	7.7	190
2	4		186	569	86	18	0.07	3	0.05	6.5	26	7.98	183
2	5		172	578	78	34	0.04		0	11	31	8.42	223
2	6		172	555	64	14	0.08	4	0			8.68	151
2	8		130	476	82	29	0.14	21	0.07	8.3	20	8.28	224
2	9		119	470	62	21	0.08	5	0.02	14.3	24	8.92	183
2	10		139	579	46	20	0.09	2	0	14.3	10	8.36	141
2	11		144	524	21	6	0.06	3	0.04	14.3		8.42	80
3	0	33											
3	1		118	543	58	15	0.16	11	0.09			8.09	140
3	2	131	126	474	62	10	0.17	1	0.13	6	24	7.73	125
3	3	137	163	532	77	13	0.16	2	0.02	6.3	23	7.56	154
3	4	130	186	570	74	15	0.08	3	0.01	9.5	27	8.12	222
3	5	114	151	599	72	14	0.02		0	13	30	7.43	206
3	6	114	173	570	69	11	0.08	4	0			8.7	227
3	7	109	124	581	62	93	0.05	3	0.01			6.88	244
3	8	119	122	474	73	13	0.08	11	0.02	9	19	7.91	229
3	9	118	121	477	57	12	0.06	3	0.01	11	22	8.5	179
3	10	110	111	602	57	9	0.08	3	0	12	10	7.75	167
3	11	116	143	526	19	7	0.06	3	0.02	14.2		8.26	78
4	5		180	579	58	15	0.04		0.01	8.5	29	8.42	173
4	6		181	575	71	10	0.09	4	0			8.69	211
4	8		121	489	62	16	0.12	8	0.07	4.5	18	7.36	251
4	9		116	481	42	12	0.09	4	0.04	4.3	25	7.53	145
4	10		128	577	47	9	0.08	3	0	11.5	9	7.76	146
4	11		148	520	35	6	0.05	2	0.02	14.6		8.51	97
5	5		177	575	90	24	0.02		0	8.5	30	8.11	312
5	6		179	582	59	11	0.09	4	0			8.4	204
5	8		133	507	65	13	0.18	24	0.17	6.5	19	7.72	183
5	9		121	486	61	12	0.09	2	0.01	11	22	8.48	222
5	10		141	586	54	11	0.07	3	0	8.8	10	7.7	160
5	11		138	545	82	7	0.07	4	0.02	12.2		7.69	207

8

Physical and Chemical Characteristics of Lake Erie Coastal Wetland Sediments

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Introduction

The sediments of Lake Erie coastal wetlands may be different in chemical and physical characteristics, depending on whether they are influenced by geologic exchange with Lake Erie or upstream watersheds, or by vegetation productivity in the wetlands themselves. More importantly, a long history of isolating wetlands from exchange by flooding rivers by diking may ultimately lead to depaupered sediments and changes in wetland productivity. Our study looked at several physical and chemical characteristics of nine coastal wetlands, five of which are sites in diked wetlands and four of which are in undiked wetlands open to Lake Erie and watershed exchanges.

Methods

In each of the nine wetlands, sampling stations were chosen on the basis of three criteria: 1) wetland vegetation was present, 2) a sample core of at least 20 cm depth could be obtained, and 3) the site was near the water sampling stations for companion studies. The coring was done with a clear plastic tube with an inside diameter of 3.3 cm. The tube was driven into the sediment with a medium-sized mallet, stoppered, quickly pulled from the sediments and capped. The cores were then transported, in vertical position, to the Ohio State University Stone Laboratory on South Bass Island where they were placed upright in a freezer and frozen solid. Freezing allowed efficient partitioning of the core into segments of equal length. Each core was divided, by hacksaw, into 5 cm segments, starting from the bottom. The top of the core, which was a mixture of ice and large pieces of organic matter, was discarded. Each core, then, had a volume of:

$$\text{Volume} = \pi r^2 h = \pi (3.3/2\ \text{cm})^2\ 5\text{cm} = 42.76\ \text{cm}^3$$

The segments were allowed to melt in a crucible until they could be pushed out of the plastic tube cleanly. The inside of the tube was not rinsed to avoid contamination by plastic shavings from the cutting. Any large amounts of sample that remained were scraped out with a spatula. The crucibles had been acid washed (10% HCl) and fired at 800°C for 10 minutes before each core was processed. Samples were dried in a drying oven at 105°C for 4 to 7 hours until constant weight. After weighing, the samples were fired in a muffle furnace at 550°C for 2-3 hours depending on the original organic content. Subsamples were checked to assure enough time to constant weight. The ashed sediment samples were placed in acid-washed vials, stoppered, labeled, and sent to the Research Extension Analytical Laboratory of OARDC in Wooster, Ohio for analysis of pH, cation exchange capacity, P,K,Ca, Mg, and Fe. Standard methods were used and are on record at the laboratory. Concentrations from that laboratory are presented in lbs/acre and are converted to ppm by dividing by 2. Concentrations in mg/cm3 are calculated using the bulk density of each core segment.

Results and Discussion

Results of the analyses are given in Tables 8.1 and 8.2 for the following diked and undiked wetlands in the study area:

Diked Marshes

Ottawa Shooting Club—Big Pond 2 (OSL)
Ottawa Shooting Club—Allen Pond 3 (OSS)
Winous Point Shooting Club—North 6 (WPN)
Bay View Marshes—Center 3 (BVC)
Bay View Marshes—B-1 (BVB)

Undiked Marshes

Old Woman Creek National Sanctuary—4 (OWC)
Sheldons Marsh—1 (SHM)
Pickerel Creek—3 (PCK)
Willow Point—2 (WLT)

Figures 8.1 and 8.2 summarize average concentrations of phosphorus, potassium, calcium, magnesium, iron, and percent organic matter. With the exception of Sheldons Marsh, which had the highest organic content (to a depth of 33 cm), the undiked wetlands appeared to have a lower organic content (10 percent) than the diked wetlands (15 percent). This probably reflects the openness of the undiked wetlands to flooding by inorganic sediments from Lake Erie and upstream watersheds. Concentrations of available phosphorus were highest in Old Woman Creek, a wetland that has a significant input of high phosphorus sediments (Klarer 1988, see Chapter 5). Both samples from the diked Bay View marshes on Sandusky Bay showed extremely low concentrations of available phosphorus. These wetlands also showed the lowest concentrations of potassium, magnesium, and iron but were among the highest in concentrations of calcium. The pH of the ashed sample solutions was also highest in the Bay View marsh samples. All of this suggests that the Bay View marshes are heavily influenced by the limestone geology prevalent in this area of Lake Erie and are dominated by calcium carbonate and bicarbonate.

Depth profiles of phosphorus in the wetlands (Figure 8.3) suggest no consistent patterns with depth. The Bay View marshes are different in concentration from the other wetlands, but no general differences are noted between the undiked and diked wetlands. There is an unexplained jump in the concentration of phosphorus to about 131 μg/cm3 at about 21 to 26 cm depth at Old Woman Creek Wetland, somewhat similar to a slight increase in the element noted in Chapter 6.

The average values of the concentrations of available phosphorus and several of the cations are compared with those measured for a productive *Scirpus* riverine wetland in Wisconsin, for a rich fen in Michigan, and for a *Typha* marsh in Czechslovakia in Table 8.3. Phosphorus and magnesium concentrations in the Lake Erie wetlands are low compared to these other wetlands, while calcium concentrations are similar, and potassium concentrations are generally higher. Such comparisons are difficult, however, without knowing more about the methodologies used in the other studies.

Table 8.1. Physical and Chemical Analyses of Sediments from Diked Lake Erie Coastal Wetlands*

Sample #	Depth, cm	Dry + Crucible, g	Ashed + Crucible, g	Crucible, g	Dry Weight, g	Organic Content, g	Inorganic Content, g	Bulk Density, g dry wt/cm3	pH	Cation Exch. Capac, meq
Diked Marshes										
Ottawa Shooting Club Big Pond-2			(removed 4 cm)							
OSL2-1-5	4--9	68.6084	64.3009	40.0359	28.5725	4.3075	24.2650	0.6682	6.3	33
OSL2-1-6	9--14	65.3155	60.5709	39.0209	26.2946	4.7446	21.5500	0.6149	6.3	28
OSL2-1-7	14--19	77.2368	71.9725	50.1292	27.1076	5.2643	21.8433	0.6339	7.1	35
Ottawa Shooting Club Allen Pond-3			(removed 3.5 cm)							
OSS3-1	3.5 -- 8.5	75.2649	68.4807	39.0147	36.2502	6.7842	29.4660	0.8478	7.9	25
OSS3-2	8.5--13.5	75.8997	67.8122	43.0890	32.8107	8.0875	24.7232	0.7673	8.1	26
OSS3-3	13.5--18.5	77.4756	69.9023	39.0013	38.4743	7.5733	30.9010	0.8998	8.0	34
OSS3-4	18.5--23.5	87.2422	81.0863	39.9360	47.3062	6.1559	41.1503	1.1063	7.4	25
Winous Point Shooting Club North-6			(removed 2 cm)							
WPN6-8	2--7	67.8439	64.8284	40.9241	26.9198	3.0155	23.9043	0.6296	5.6	28
WPN6-9	7--12	64.5301	60.2363	40.0472	24.4829	4.2938	20.1891	0.5726	5.8	29
WPN6-10	12--17	63.7240	59.3248	39.0336	24.6904	4.3992	20.2912	0.5774	5.8	28
WPN6-11	17--22	65.0579	61.1457	39.3805	25.6774	3.9122	21.7652	0.6005	6.1	31
WPN6-12	22--27	77.5058	74.2130	50.1531	27.3527	3.2928	24.0599	0.6397	6.7	31
WPN6-13	27--32	67.6566	63.8211	38.8291	28.8275	3.8355	24.9920	0.6742	6.7	31
Bay View Marshes Center-3			(removed 1 cm)							
BVC3-7	1--6	49.0963	45.5765	38.0065	11.0898	3.5198	7.5700	0.2593	10.5	69
BVC3-8	6--11	57.1983	52.5278	39.4154	17.7829	4.6705	13.1124	0.4159	10.4	74
BVC3-9	11--16	61.9733	58.2696	39.0226	22.9507	3.7037	19.2470	0.5367	10.9	51
BVC3-10	16--21	83.7466	78.9171	49.1251	34.6215	4.8295	29.7920	0.8097	11.1	44
BVC3-11	21--26	83.8404	80.4545	39.9371	43.9033	3.3859	40.5174	1.0267	10.5	33
BVC3-12	26--31	78.1619	76.8833	40.0401	38.1218	1.2786	36.8432	0.8915	10.2	31
Bay View Marshes B-1			(removed 3 cm)							
BVB1-5	3--8	62.2642	57.2961	40.0402	22.2240	4.9681	17.2559	0.5197	10.5	44
BVB1-6	8--13	73.5302	67.7531	38.0077	35.5225	5.7771	29.7454	0.8307	10.2	35
BVB1-7	13--18	61.5468	57.3401	39.4318	22.1150	4.2067	17.9083	0.5172	10.4	49
BVB1-8	18--23	65.9597	61.6220	50.9057	15.0540	4.3377	10.7163	0.3521	10.1	59

* each sample of core is 3.3 cm in diameter and 5cm long, or 42.76 cm3

Table 8.1. continued

Sample #	Phosphorus		Potassium		Calcium		Magnesium		Iron	
	lbs/acre	mg/cm3	lbs/acre	mg/cm3	lbs/acre	mg/cm3	lbs/acre	mg/cm3	lbs/acre	mg/cm3
Diked Marshes										
Ottawa Shooting Club Big Pond-2										
OSL2-1-5	108	0.0361	1305	0.4360	11550	3.8589	605	0.2021	165.0	0.0551
OSL2-1-6	50	0.0154	1308	0.4022	9290	2.8564	679	0.2088		
OSL2-1-7	70	0.0222	1125	0.3566	12480	3.9558	684	0.2168		
TOTAL g/m2(15 cm core)		3.6822		59.7384		533.5548		31.3856		
Ottawa Shooting Club Allen Pond-3										
OSS3-1	14	0.0059	1887	0.7999	8440	3.5775	380	0.1611	238.5	0.1011
OSS3-2	24	0.0092	1533	0.5882	8780	3.3685	421	0.1615		
OSS3-3	18	0.0081	1926	0.8665	11820	5.3177	396	0.1782		
OSS3-4	16	0.0089	2385	1.3193	8310	4.5968	368	0.2036		
TOTAL g/m2(20 cm core)		1.6045		178.6890		843.0252		35.2157		
Winous Point Shooting Club North-6										
WPN6-8	138	0.0434	1434	0.4514	7780	2.4490	1509	0.4750	181.0	0.0570
WPN6-9	60	0.0172	1710	0.4895	8110	2.3218	1581	0.4526		
WPN6-10	74	0.0214	1719	0.4963	7720	2.2288	1563	0.4513		
WPN6-11	86	0.0258	1725	0.5179	8650	2.5972	1644	0.4936		
WPN6-12	84	0.0269	1803	0.5767	9640	3.0833	1035	0.3310		
WPN6-13	72	0.0243	1734	0.5845	9570	3.2259	1260	0.4247		
TOTAL g/m2(30 cm core)		7.9469		155.8167		795.2941		131.4119		
Bay View Marshes Center-3										
BVC3-7	2	0.0003	466	0.0604	26580	3.4468	568	0.0737	-	-
BVC3-8	2	0.0004	371	0.0771	28440	5.9138	480	0.0998		
BVC3-9	2	0.0005	225	0.0604	19800	5.3137	269	0.0722		
BVC3-10	2	0.0008	72	0.0291	17250	6.9834	191	0.0773		
BVC3-11	2	0.0010	24	0.0123	13080	6.7149	64	0.0329		
BVC3-12	2	0.0009	25	0.0111	12240	5.4562	75	0.0334		
TOTAL g/m2(30 cm core)		0.1970		12.5285		1691.4308		19.4634		
Bay View Marshes B-1										
BVB1-5	2	0.0005	127	0.0330	17250	4.4827	154	0.0400	93.5	0.0243
BVB1-6	2	0.0008	38	0.0158	13800	5.7321	75	0.0312		
BVB1-7	2	0.0005	111	0.0287	19500	5.0426	141	0.0365		
BVB1-8	2	0.0004	51	0.0090	23280	4.0980	206	0.0363		
TOTAL g/m2 (20 cm core)		0.1110		4.3234		967.7702		7.1948		

Table 8.2. Physical and Chemical Analyses of Sediments from Undiked Lake Erie Coastal Wetlands*

Sample #	Depth, cm	Dry + Crucible, g	Ashed + Crucible, g	Crucible, g	Dry Weight, g	Organic Content, g	Inorganic Content, g	Bulk Density, g dry wt/cm3	pH	Cation Exch. Capac, meq
Undiked Marshes										
Old Woman Creek Wetland-4			(removed 6 cm)							
OWC4-1	6--11	76.6604	74.1395	50.2433	26.4171	2.5209	23.8962	0.6178	7.3	21
OWC4-2	11--16	68.7522	65.7172	38.6510	30.1012	3.0350	27.0662	0.7040	8.1	20
OWC4-3	16--21	75.9137	72.6309	39.4482	36.4655	3.2828	33.1827	0.8528	7.8	14
OWC4-4	21--26	84.3057	80.6540	39.4294	44.8763	3.6517	41.2246	1.0495	8.4	10
OWC4-5	26--31	82.9300	78.8432	38.0121	44.9179	4.0868	40.8311	1.0505	9.3	13
OWC4-6	31--36	80.6119	76.6993	39.9493	40.6626	3.9126	36.7500	0.9509	NA	NA
OWC4-7	36--41	73.1092	68.3394	43.1164	29.9928	4.7698	25.2230	0.7014	7.6	11
Sheldon's Marsh -1			(removed 3 cm)							
SHM1-6	3--8	70.5860	67.3246	50.9170	19.6690	3.2614	16.4076	0.4600	8.6	20
SHM1-7	8--13	63.2027	59.5243	39.4387	23.7640	3.6784	20.0856	0.5558	7.8	22
SHM1-8	13--18	62.4003	58.6207	39.4190	22.9813	3.7796	19.2017	0.5374	7.2	21
SHM1-9	18--23	64.8255	60.4406	39.9386	24.8869	4.3849	20.5020	0.5820	6.1	16
SHM1-10	23--28	59.9037	54.2936	38.0113	21.8924	5.6101	16.2823	0.5120	6.8	18
SHM1-11	28--33	64.6338	55.1256	49.1209	15.5129	9.5082	6.0047	0.3628	8.9	41
Pickerel Creek-3			(removed 2 cm)							
PCK3-1	2--7	76.5100	73.0870	39.9293	36.5807	3.4230	33.1577	0.8555	8.3	41
PCK3-2	7--12	80.1259	76.2723	38.0025	42.1234	3.8536	38.2698	0.9851	8.3	29
PCK3-3	12--17	88.1238	83.8220	40.0300	48.0938	4.3018	43.7920	1.1247	7.8	22
PCK3-4	17--22	87.4758	82.8224	38.8042	48.6716	4.6534	44.0182	1.1383	7.7	22
PCK3-5	22--27	84.1772	79.0282	43.1023	41.0749	5.1490	35.9259	0.9606	9.2	44
PCK3-6	27--32	81.7863	76.4346	50.1387	31.6476	5.3517	26.2959	0.7401	8.8	53
Willow Point-2			(removed 1 cm)							
WLT2-5	1--6	64.7019	60.3370	39.3659	25.3360	4.3649	20.9711	0.5925	6.8	38
WLT2-6	6--11	74.8627	69.9524	38.8013	36.0614	4.9103	31.1511	0.8433	6.9	22
WLT2-7	11--16	84.0596	78.8177	39.4390	44.6206	5.2419	39.3787	1.0435	7.2	22
WLT2-8	16--21	91.3359	86.6941	39.4128	51.9231	4.6418	47.2813	1.2143	7.5	16
WLT2-9	21--26	95.7657	91.8740	40.0432	55.7225	3.8917	51.8308	1.3031	7.0	13

* each sample of core is 3.3 cm in diameter and 5cm long, or 42.76 cm3

Table 8.2. continued

Sample #	Phosphorus		Potassium		Calcium		Magnesium		Iron	
	lbs/acre	mg/cm3	lbs/acre	mg/cm3	lbs/acre	mg/cm3	lbs/acre	mg/cm3	lbs/acre	mg/cm3
Undiked Marshes										
Old Woman Creek Wetland-4										
OWC4-1	122	0.0377	828	0.2558	7320	2.2611	416	0.1285	161.0	0.0497
OWC4-2	84	0.0296	875	0.3080	6990	2.4603	419	0.1475		
OWC4-3	58	0.0247	963	0.4106	4560	1.9444	317	0.1352		
OWC4-4	250	0.1312	847	0.4445	3150	1.6530	329	0.1726		
OWC4-5	50	0.0263	880	0.4622	4000	2.1009	544	0.2857		
OWC4-6	NA	NA	NA	NA	NA	NA	NA	NA		
OWC4-7	70	0.0245	815	0.2858	3740	1.3117	175	0.0614		
TOTAL g/m2(30 cm core)		13.6990		108.3433		586.5694		46.5446		
Sheldon's Marsh -1										
SHM1-6	90	0.0207	755	0.1736	6740	1.5502	583	0.1341	147.0	0.0338
SHM1-7	78	0.0217	861	0.2393	7220	2.0063	603	0.1676		
SHM1-8	102	0.0274	948	0.2548	6820	1.8327	766	0.2058		
SHM1-9	94	0.0274	1245	0.3623	4900	1.4259	504	0.1467		
SHM1-10	90	0.0230	1035	0.2650	6120	1.5667	393	0.1006		
SHM1-11	10	0.0018	681	0.1235	15090	2.7373	485	0.0880		
TOTAL g/m2(30 cm core)		6.0996		70.9216		555.9486		42.1368		
Pickerel Creek-3										
PCK3-1	110	0.0471	1407	0.6018	14460	6.1852	719	0.3075	219.0	0.0937
PCK3-2	66	0.0325	1371	0.6753	9760	4.8073	630	0.3103		
PCK3-3	74	0.0416	1566	0.8807	7200	4.0491	493	0.2772		
PCK3-4	56	0.0319	1662	0.9459	7060	4.0180	561	0.3193		
PCK3-5	18	0.0086	1485	0.7132	16200	7.7808	461	0.2214		
PCK3-6	16	0.0059	1230	0.4552	19860	7.3494	328	0.1214		
TOTAL g/m2(30 cm core)		8.3807		213.6051		1709.4907		77.8591		
Willow Point-2										
WLT2-5	24	0.0071	1704	0.5048	12900	3.8217	844	0.2500	175.0	0.0518
WLT2-6	50	0.0211	1800	0.7590	7190	3.0318	518	0.2184		
WLT2-7	42	0.0219	1827	0.9532	7150	3.7306	449	0.2343		
WLT2-8	48	0.0291	1605	0.9745	5220	3.1693	309	0.1876		
WLT2-9	56	0.0365	1773	1.1552	3870	2.5216	240	0.1564		
TOTAL g/m2(25 cm core)		5.7869		217.3395		813.7499		52.3361		

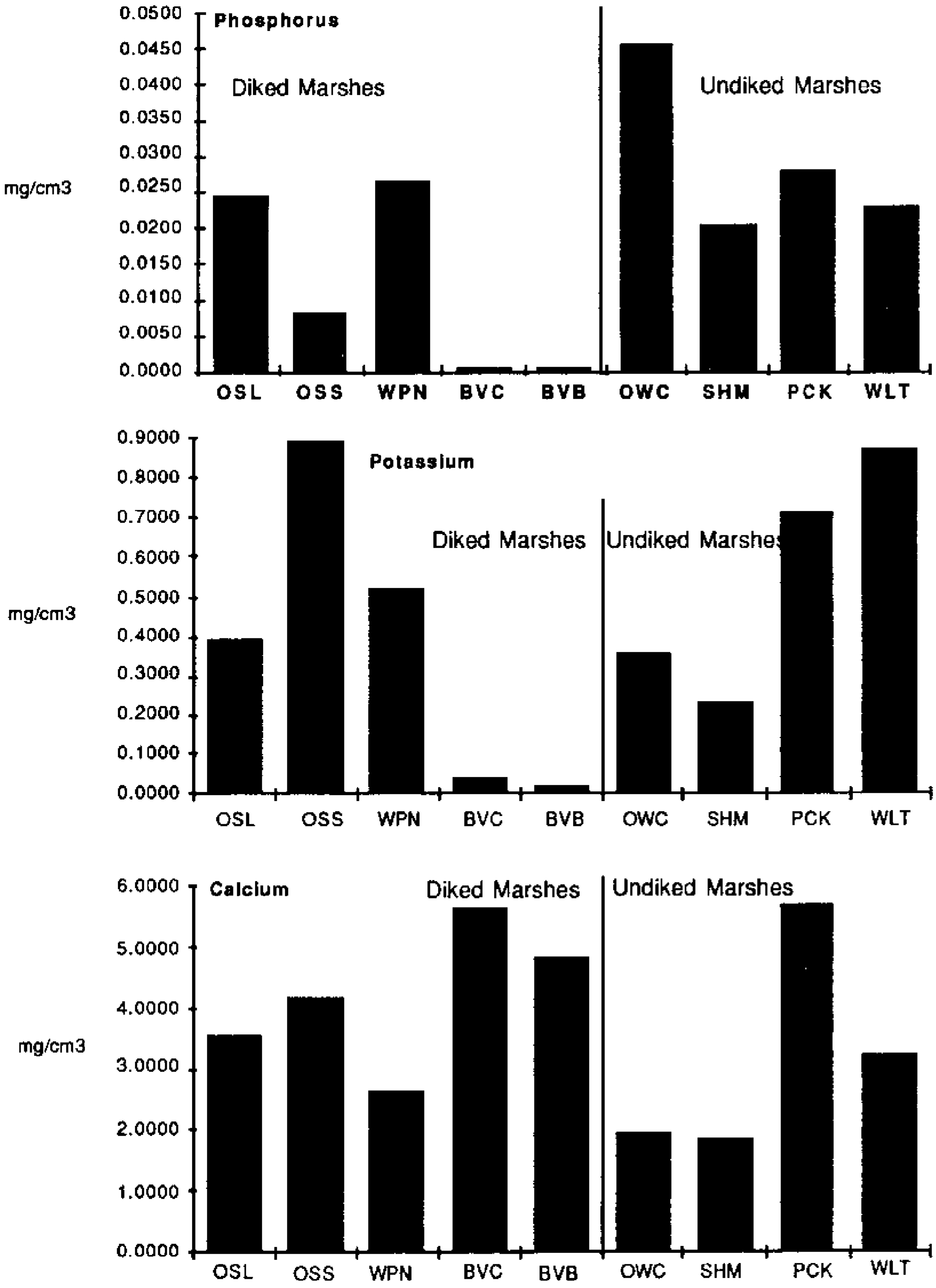


Figure 8.1 Concentrations of phosphorus, potassium, and calcium for diked and undiked Lake Erie coastal wetlands

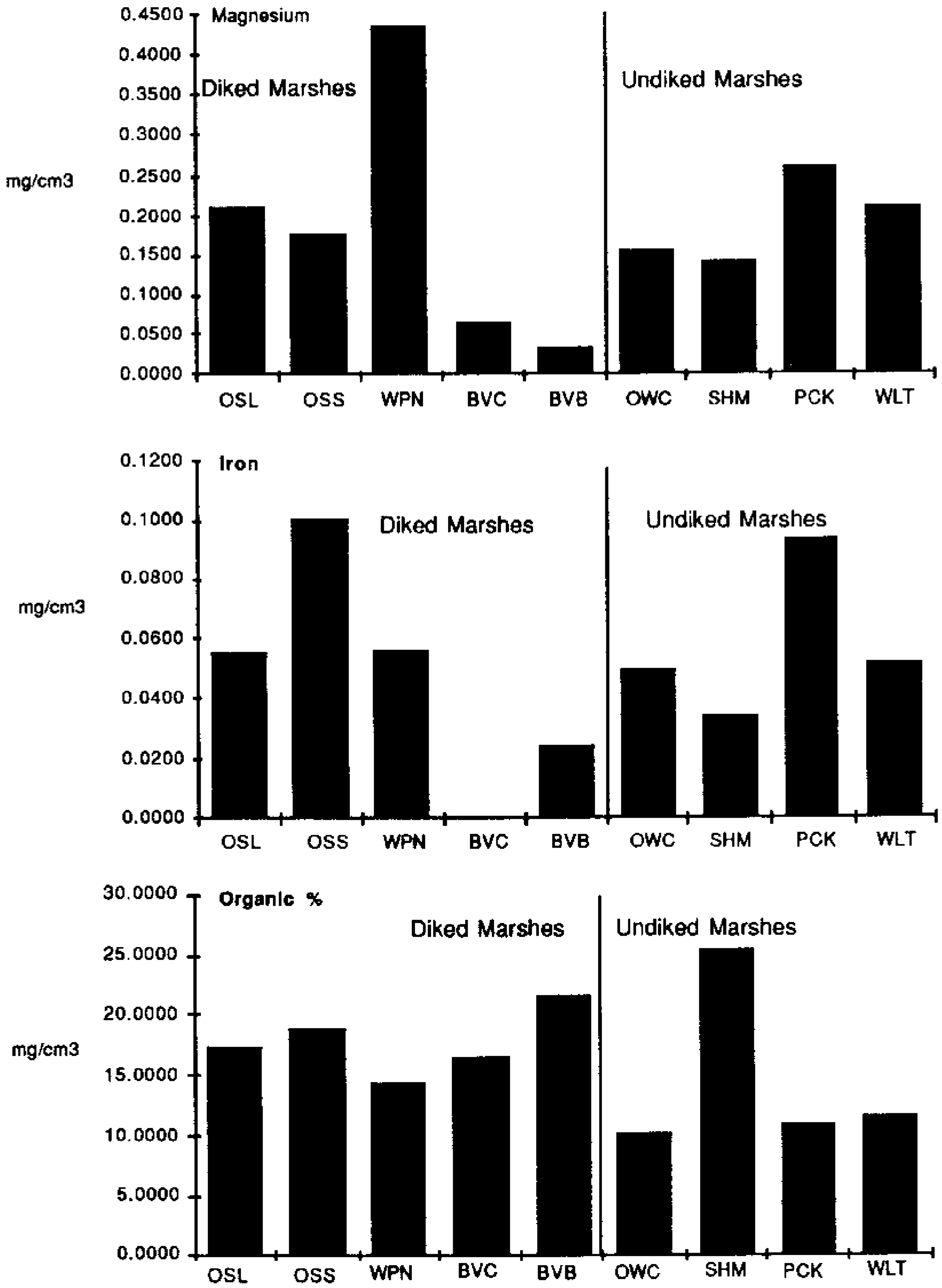
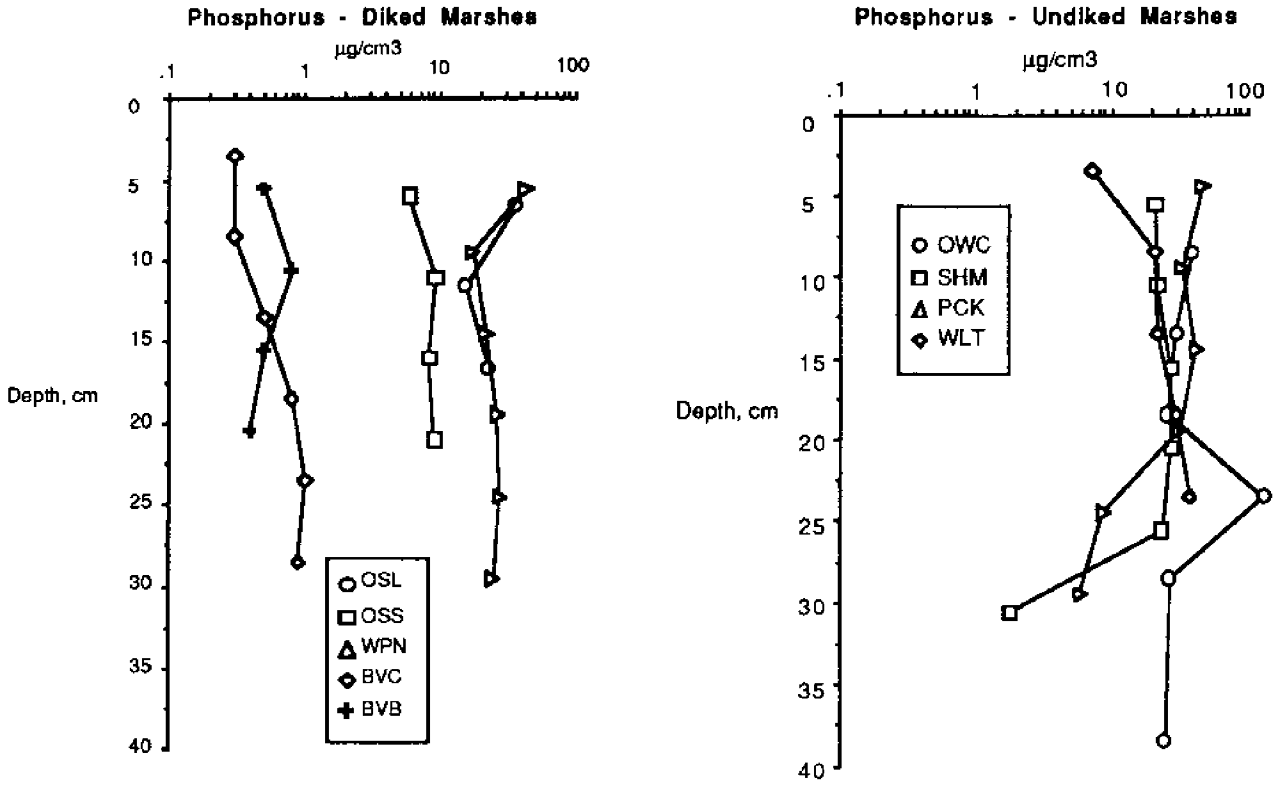


Figure 8.2 Concentrations of magnesium, iron, and organic matter for diked and undiked Lake Erie coastal wetlands



a)

b)

Figure 8.3 Profiles of available phosphorus in a) diked and b) undiked marshes of Lake Erie

Table 8.3 Concentrations of selected nutrients in Lake Erie coastal wetlands compared with other studies

Location	P, ppm	Ca, ppm	Mg, ppm	K, ppm	Reference
Lake Erie Wetlands (n=9)*	26±19	5528±2501	268±185	662±351	this study
Wisconsin Riverine Wetland	50-204	5700-12700	1219-2770	98-230	Klopatek (1978)
Czech Typha Marsh	130	5140	570	550	Dykyjova and Kvet (1982)
Michigan Rich Fen	——	10480	935	176	Richardson (1978)

* average ± standard deviation

9

Remote Sensing of Ohio's Wetlands of Western Lake Erie

Mary J. Roush
Doreen M. Robb
Gi-chul Yi
William J. Mitsch

Introduction

Much can be learned by remote sensing of wetlands. Remote sensing can be accomplished with the use of aircraft at various altitudes and satellites. The choice of platform depends on the area to be covered, the amount of detail desired, and the funds available for the project. Low-altitude aircraft is relatively inexpensive and fairly effective for surveying small areas. High-altitude aircraft may be less expensive per unit area than low-altitude aircraft if large areas are to be covered, as relatively large areas can be studied in detail on a single photo. Therefore, the total number of frames needed to cover an area is less, which reduces the cost. The most obvious disadvantage to the use of high-altitude photography is the loss of some ground detail which might normally be captured at lower altitudes. The use of satellites such as LANDSAT is available at reasonable cost, but does not offer enough detail for most studies unless a large amount of collateral data such as aerial photography and field work are included (Mitsch and Gosselink 1986).

In addition to a choice of remote sensing platforms, the wetland scientist also has a choice of color infrared photography, conventional color photography, or black-and-white photography. Color infrared (CIR) film is more useful than conventional color film for differentiating between land and water, because of the lack of color contrast between them. Because water absorbs infrared radiation to a great degree, less of the radiation is reflected from water surfaces than from surrounding land areas. Water bodies, therefore, appear dark blue to black on infrared photos. This is especially important in the identification of wetlands, because land-water boundaries are easily seen on CIR photography. In many cases a wetland area will be associated with open water with patches of wetland vegetation located around it, or with vegetation surrounded by areas of open water. In some cases, however, ground truth may be necessary for positive identification of wetland areas (Richason 1978). Earth Satellite Corporation (1972) conducted a study using both black-and-white infrared and color infrared films as well as conventional color film. They found that the color infrared film was superior to the other two as a single imaging media, but the conventional color film contributed diagnostic signature data for some plant species. They suggested that wetland inventories should be conducted with both types of color film in the future. Shima et al. (1976) used color infrared photography to delineate a tidal freshwater wetland complex in Maryland. They found for photography in the spring that if "color IR photography of a marsh is combined with careful field checking, vegetation maps of similar marshes can probably be made with relatively few spot checks." In the fall, vegetation in units dominated respectively by yellow water lily (*Nuphar advena*), rose mallow (*Hibiscus palustris*), wild rice (*Zizania aquatica*), and sweet flag (*Acorus calamus*) were recognizable from color IR photography. The relative abundance of *Polygonum* spp. caused spectral signatures to vary for other units and made vegetation identification more difficult. Hardisky et al. (1986), summarizing many years of aircraft and satellite sensing of coastal salt marshes, conclude that aircraft film cameras offer "high spatial resolution and low cost for mapping precise locations of small wetland areas."

These studies used remote sensing "to identify wetland areas accurately and to locate and delineate areas of important wetlands plant species" (Earth Science Corporation 1972). The efficiency of the remote-sensing procedures allowed the survey and subsequent mapping to be done in a short time period, thus implementing the protection of wetland areas under increasingly destructive pressure. National Wetlands Inventory (NWI) is also using high-altitude photography "to generate...scientific information on the characteristics and extent of wetlands...The purpose of this information is to foster the wise use of wetlands and to provide data for making quick and accurate decisions about wetlands by knowing how many and what type are where" (Wilen 1986). As of September 30, 1986, NWI was expected to have produced "10,000 highly-detailed maps covering 45 percent of the lower 48 states and 12 percent of Alaska. This would include roughly 85 percent of the coastal zone of the lower 48 states, including the Great Lakes Region" (Wilen 1986).

Mapping Great Lakes Wetlands

Various mappings of Great Lakes wetlands have been executed, some by the use of remote sensing and others before remote sensing was generally available. Lowden (1969) studied the vascular flora of the marshes, woodlots, dikes, and drainage ditches of Winous Point, a tract of land located about 6 km (3 1/2 miles) southwest of Port Clinton, Ohio, at the western end of Sandusky Bay. Winous Point, owned by the Winous Point Shooting Club, has been divided by a network of dikes into a number of marsh units. In most cases, there are roads on these dikes and vegetation for a distance of three feet on each side of the road with drainage ditches parallel to most of the dikes. Lowden did not draw detailed maps of this area, but rather divided the area into nineteen sites coinciding with the dike roads, and collected and identified samples of the major vegetation of each of these sites. This report also compares the vascular plants found at that time with those reported by earlier observers of Winous Point.

The area of wetlands as a function of water levels of Lake Michigan was established through measurements from seven sets of black and white aerial photographs taken between 1938 and 1977 inclusive. The data showed that an increase in water level of 0.3 m resulted in a decrease of 18% of the 438 ha of wetlands and beaches in the Straights of Mackinac (Lyon and Drobney 1984). The data were "used to develop a predictive model of long-term effects of water levels" on coastal wetlands (Lyon et al. 1986).

Balogh and Bookhout (1989) used true-color 35-mm photographs (slides) taken at 1,500 m in 1984 to map the distribution of purple loosestrife (*Lythrum salicaria*) in Ohio's southwest Lake Erie marshes. Visual ground truth by low-altitude flights was done during the flowering season of August of 1985 to improve the accuracy of the maps. "Seventy percent of the loosestrife strands were (found) within areas designated as wetlands on USGS topographic maps" (Balogh and Bookhout 1989).

Methods

Vertical aerial photographs (slides) were taken for this study of Lake Erie Wetlands on August 22, 1988, by the Division of Soil and Water Conservation of the Ohio Department of Natural Resources. Both 35-mm color and color infrared films were used. Approximately 270 photos were taken over several flight lines to include the wetlands involved in our regional study (Figure 9.1). The approximate scale of these photos was 1:39000; it ranged from 1:37680 to 1:39276 (Table 9.1). The altitude of the flight was approximately 1,300 m above sea level or approximately 1,100 m above ground surface.

Maps were drawn using the following procedure. A sheet of tracing paper was placed over a topographic map which corresponds to the area to be drawn. Three points which were readily recognizable on both the maps and the corresponding slide and which could all be found on a single slide were marked on the tracing paper. The distance between each pair of points was enlarged to a scale of 1:3. The tracing paper was taped to a smooth vertical surface over white paper and the slide was projected onto it. The three points (enlarged scale) on the tracing paper were aligned with the corresponding three points on the projected image. Differences in color, tone, and shape of patches of vegetation, water, and exposed ground were noted and delineated on the tracing paper. Two or more slides were used for each marsh area; the middle of each slide was used as much as possible to minimize distortion. Ground truth and calibration of photographs were determined before mapping was completed with the visit to Winous Point Shooting Club, a major wetland site in western Sandusky Bay. Roy Kroll provided insightful interpretation of the photos from much of the Winous Point area. Additional ground truth data were collected during the water chemistry study described in Chapter 7.

Results and Discussion

The aerial photography consists of approximately 270 color and 270 color infrared slides of the Lake Erie shoreline in the vicinity of Sandusky Bay (Figure 9.1). Representative photographs developed from the slides are shown in Figure 9.2. Wetland maps developed from the aerial photography are shown in Appendix 9.1. The area

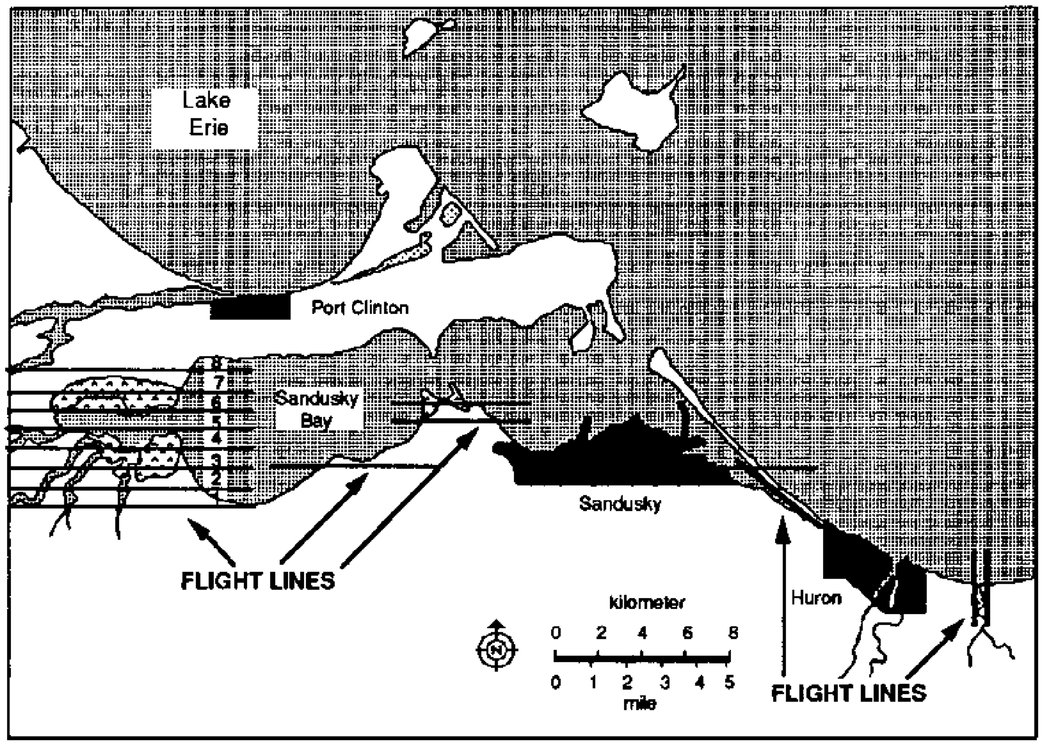


Figure 9.1 Flight lines of aerial photography of Lake Erie coastal wetlands as taken on August 22, 1988

Table 9.1 Scale and time of photography (color and color IR) taken of Lake Erie coastal wetlands on August 22, 1988. Flight lines are indicated in Figure 9.1

Wetland	Time of photography	Scale (approximate)
Old Woman Creek	9:40 A.M.	1:37,680
Sheldons Marsh	10:00	1:37,760
Plum Brook Creek	10:10	1:38,609
Bay View Marshes	10:15	1:38,400
Wilow Point	10:30	1:39,166
Western Sandusky Bay Wetlands		
FL8	10:35	1:39,027
FL7	10:46	1:38,933
FL6	11:00	1:39,092
FL5	11:10	1:38,574
FL4	11:20	1:38,503
FL3	11:30	1:38,125
FL2	11:44	1:38,933
FL1	11:55	1:38,101

courtesy of Bruce Motsch, ODNR

shown in Figure 9.2 corresponds to the area drawn in the first map and part of the second map in Appendix 9.1. We chose to use broad categories for the wetlands, including open water (W), emergent wetland (E) and floating leaved wetland (F).

As noted by Justice and Townshend (1981), there are problems involved in the drawing and interpretation of hand-drawn maps. First, an estimate must be made of the minimum size of unit which should be included on the map. Second, where an area is composed of many small units, it may be difficult to locate sample areas which are not noticeably heterogeneous. Decisions must be made to determine the point at which a site is considered to be of one type of vegetation. Finally, the human eye's perception of tone is often influenced by surrounding tones, making comparison of vegetation types in different areas of the marsh extremely difficult.

A few areas are easily recognizable, such as areas of open water which appear blue or black on the infrared slides. Wooded areas are also relatively easy to recognize by the shapes of the trees. Cattails (*Typha* spp.) appear dark green on the conventional color slides and bright red on the infrared slides, and lotus (*Nelumbo lutea*) appears blue-green on the color slides and light pink on the infrared slides, but there may be other types of vegetation which exhibit the same characteristics. The general category of emergent wetlands (E) was used in some cases where the color infrared slides appeared white. Kroll (pers. comm.) suggested that this may indicate the flowering of *Sagittaria* sp.

A significant number of areas had different densities of the same type of vegetation and were outlined accordingly on the maps. This accounts for the great number of unlabeled wetland areas in the maps. These are mostly emergent wetland vegetation or floating leaved vegetation. For a gross estimate of wetlands, all of the unlabeled areas can be considered one of these two types of wetlands.

A Preliminary Analysis of Temporal Changes

Remotely sensed data can be particularly useful for wetland assessment when they are available from several data bases. Monitoring change over time (multi-temporal analysis) is a valuable use of remote sensing. As an example of these capabilities, an assessment of Sandusky River mouth wetlands of Sandusky Bay is illustrated in Figure 9.3. The area in 1969 supported approximately 1,738 ha (4,295 acres) of wetlands. By 1983 the wetland areas had been reduced to 1,390 ha (3,434 acres), representing a reduction of 20 percent. During this period wetlands have also experienced extensive vegetation changes. Approximately 160 ha (397 acres) of emergent wetlands changed into forested wetlands. More detailed change in a smaller portion can be compared very easily by looking at Figure 9.3.

Previous studies of remote sensing have evaluated the capability to measure wetland variables and many efforts have demonstrated remote sensor data as input to wetland studies and wetland inventories (e.g., Shima et al. 1976, Lyon 1981, Mitsch et al. 1983, Lyon et al. 1984, 1986, Hardisky et al. 1986). Most researchers agree that remote sensing provides a time and cost effective method of mapping wetlands. By using multi-temporal analysis, Great Lake wetland assessment can be maintained in a timely manner. Remote sensing can provide various information such as 1) the presence of wetlands, 2) knowledge of adjacent land use which affects wetland areas, and 3) the change of wetland area and quality over long periods associated with lake water level changes.

We are currently working on various data sets (multispectral approach) for monitoring change of Ohio's wetlands along Lake Erie over a long time period . The expected benefits include production of wetland maps of Lake Erie, computerized map information, and the development of a spatial model to identify the wetland change over time. Geographic information systems, as computerized spatial data handling systems for the storage, manipulation, analysis and outputs of data, may assist us in this analysis of Ohio's wetland resources (see Chapter 11).

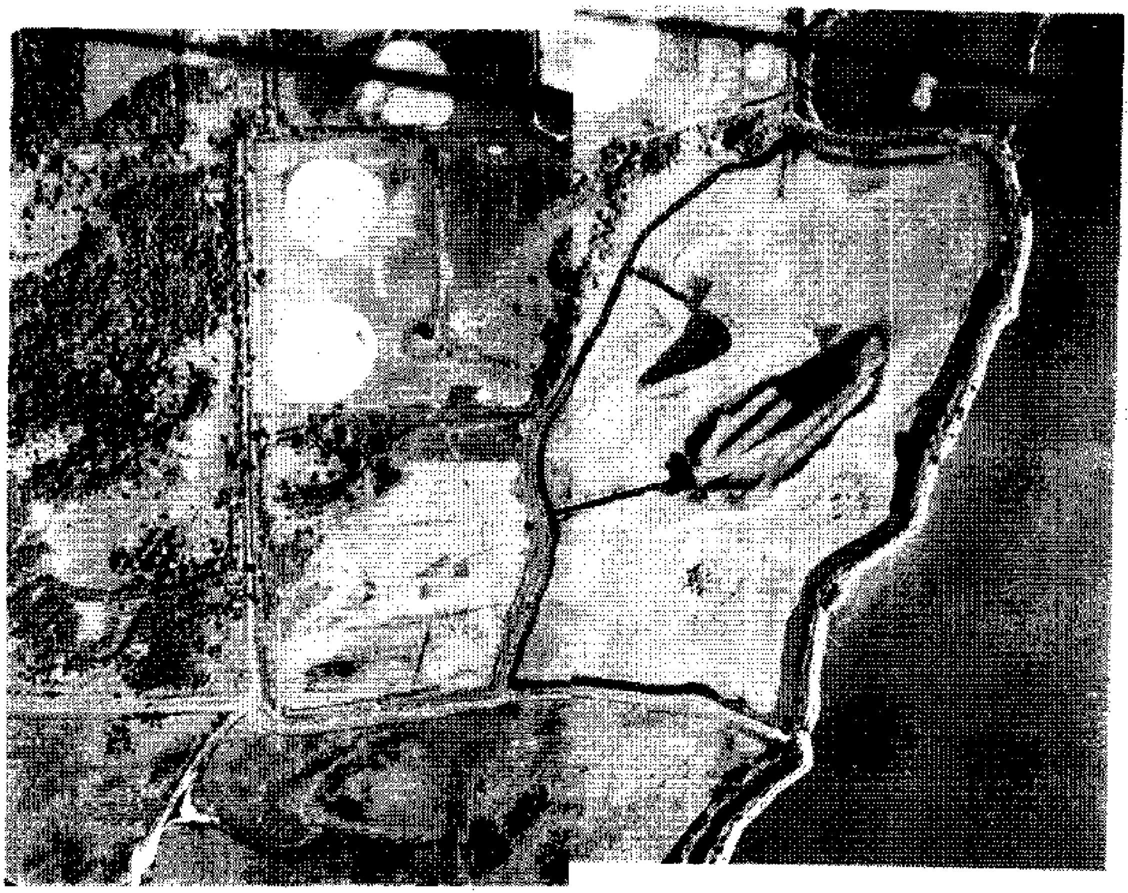
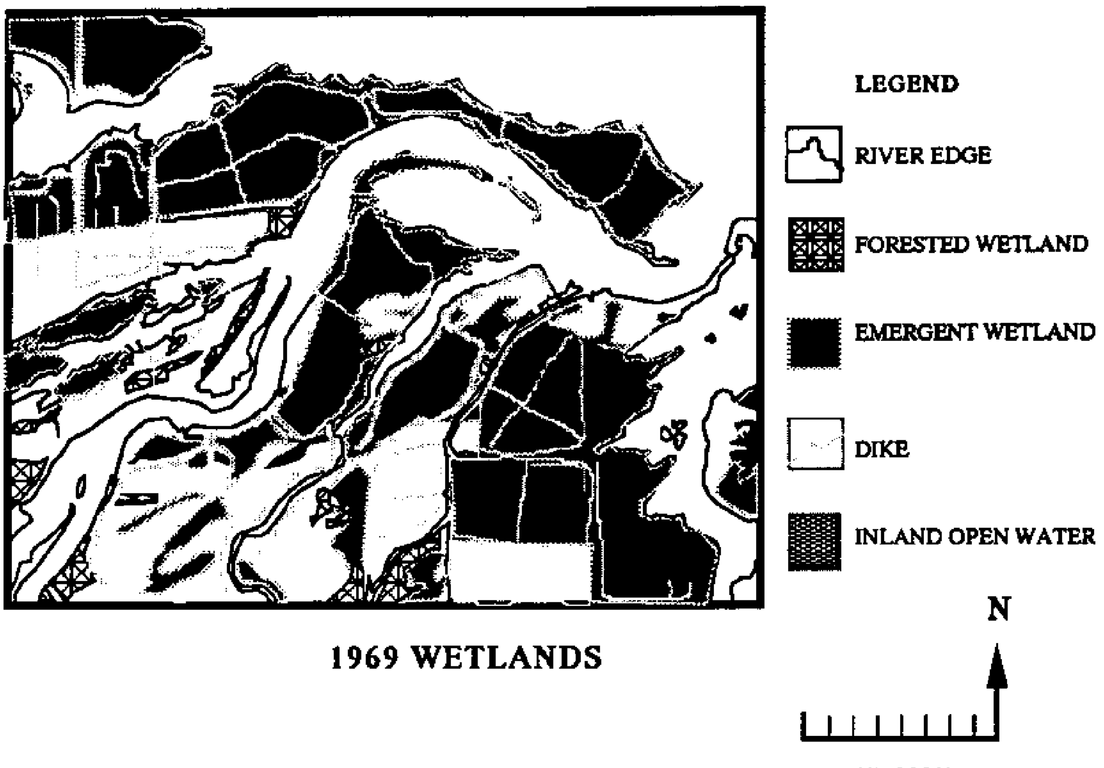
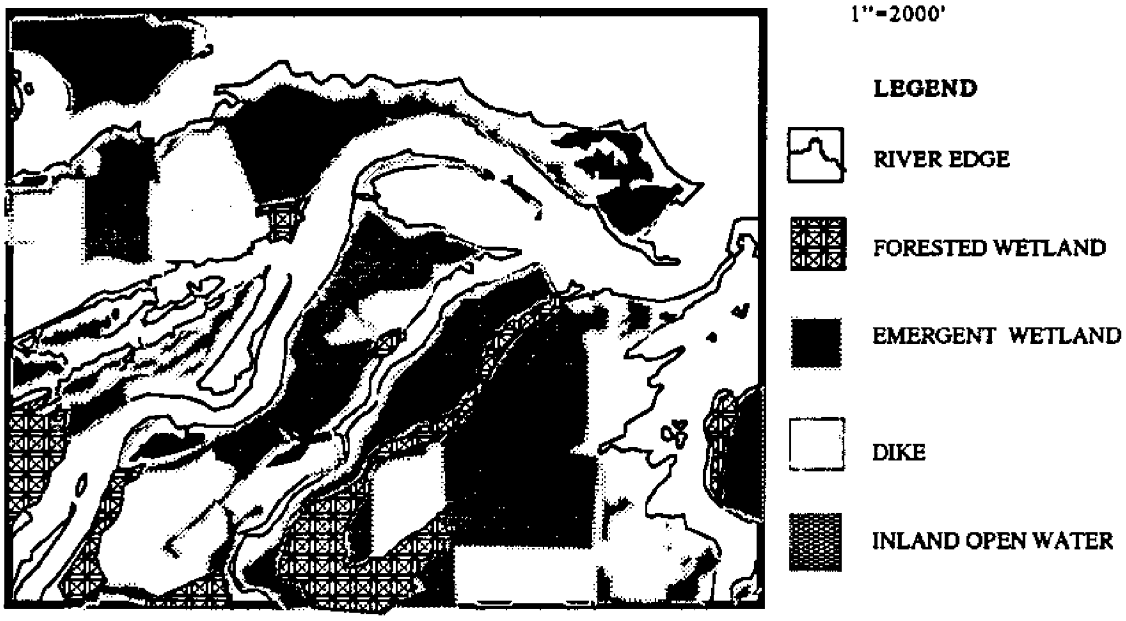


Figure 9.2 Example of aerial photography of Sandusky Bay wetlands, Flight Line 7



1969 WETLANDS



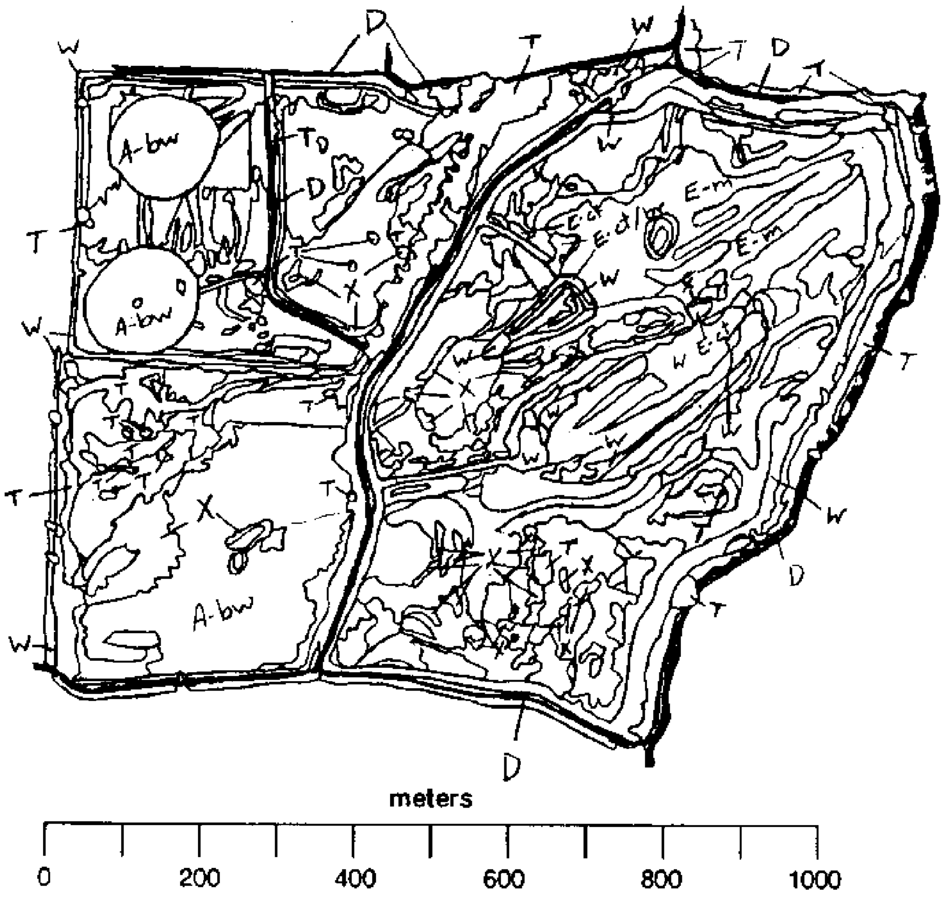
1983 WETLANDS

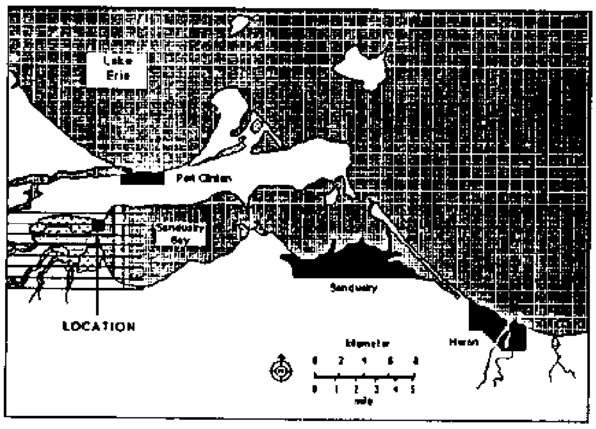
Source: U.S.G.S. 7 1/2 Topographic map and Land use map of Remote Sensing Section of ODNR

Figure 9.3 Computer generated map of Sandusky Bay wetlands from 1969 and 1983 data. Maps indicate a 20 percent loss of wetlands over this period

Appendix 9.1

Lake Erie Wetlands
Vickery Quad - Ohio
Flight 7 - Slides 21-24
from Color and IR Aerial Photography by
Ohio Department of Natural Resources
August 22, 1988





WETLANDS
W open water
E emergent wetlands
- E-ct cattails
- E-br bulrush
- E-m millet

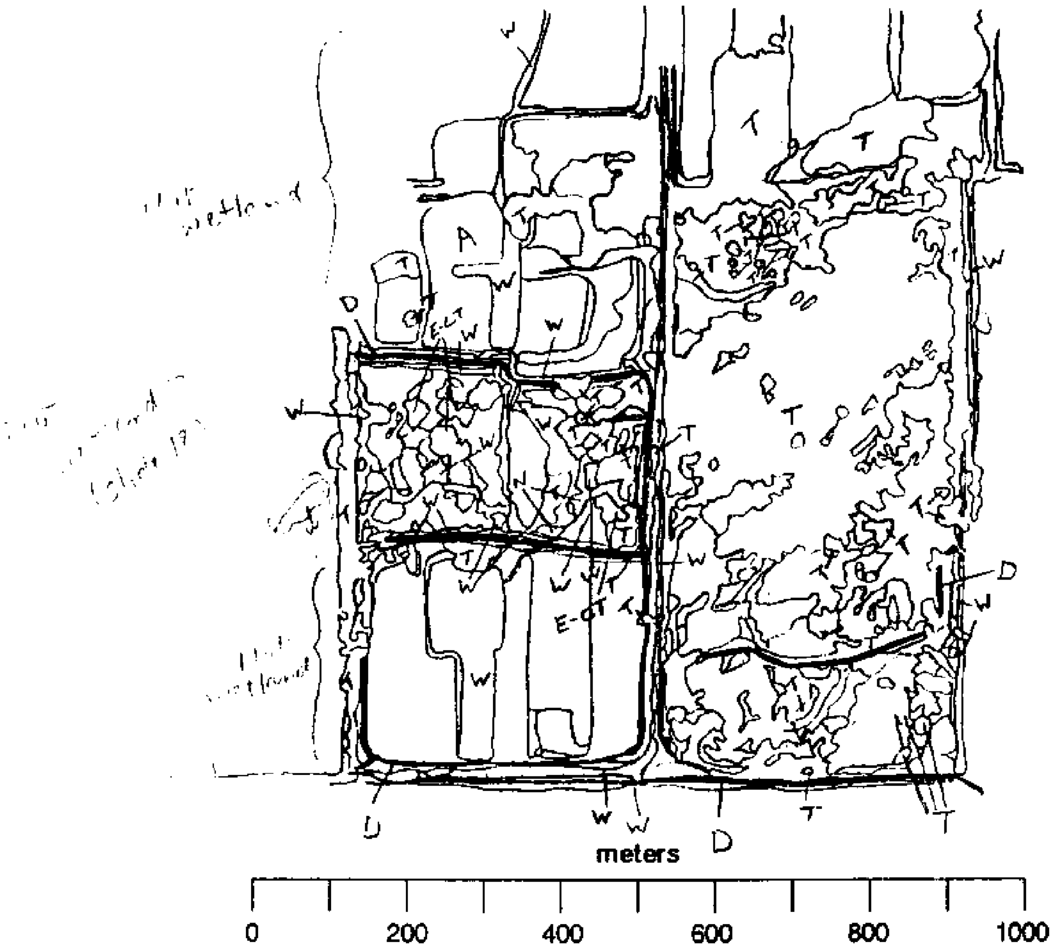
F floating-leaved wetland
- F-n water lotus

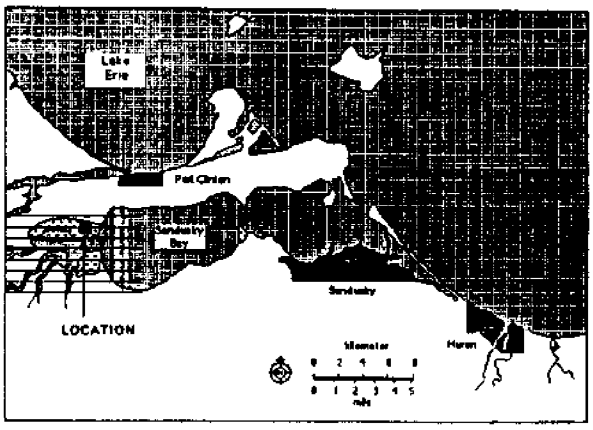
OTHER LAND USES

T forests (trees)
X exposed land
A agricultural land
- A-bw buckwheat

D dikes

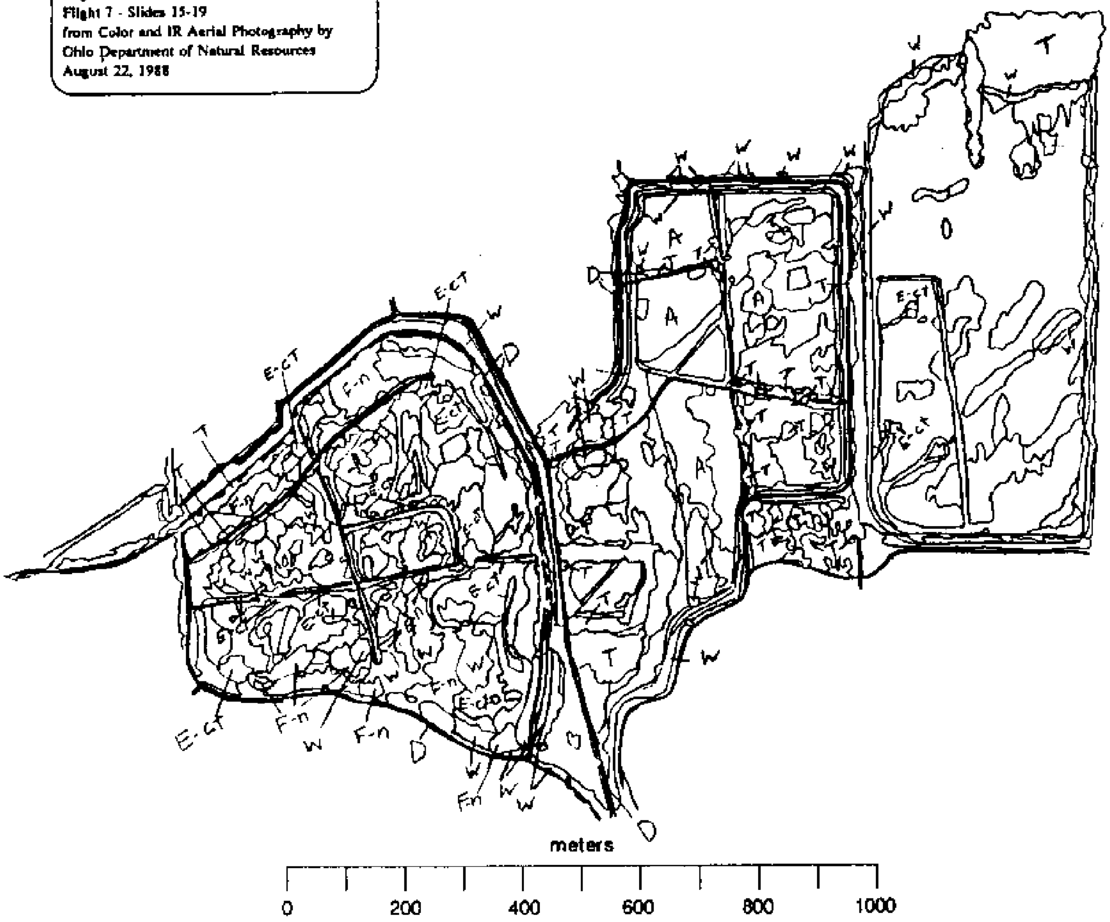
Lake Erie Wetlands
Vickery Quad - Ohio
Flight 7 - Slides 19-20
from Color and IR Aerial Photography by
Ohio Department of Natural Resources
August 22, 1988

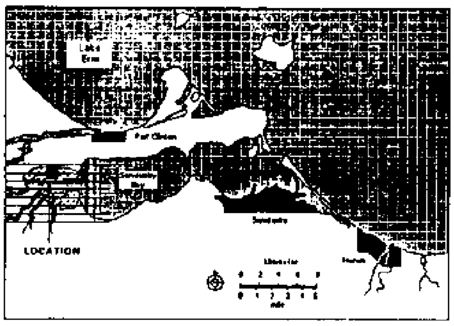




WETLANDS	OTHER LAND USES
W open water	T forests (trees)
E emergent wetlands	X exposed land
E-ct cattails	A agricultural land
E-br bulrush	A-bw buckwheat
E-m millet	D dikes
F floating-leaved wetland	
F-n water lotus	

Lake Erie Wetlands
Vickery Quad - Ohio
Wightmans Grove - Ohio
Flight 6 - Slides 16-17
Flight 7 - Slides 15-19
from Color and IR Aerial Photography by
Ohio Department of Natural Resources
August 22, 1988

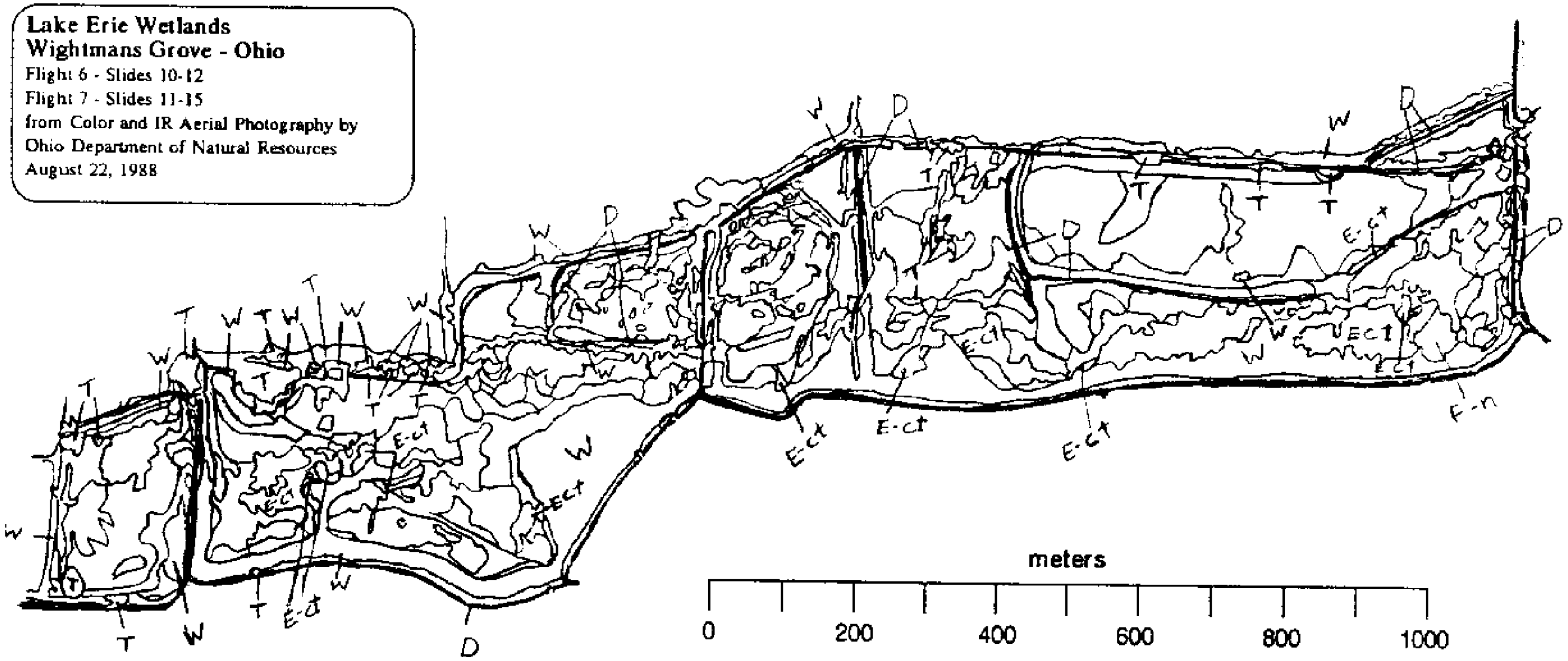


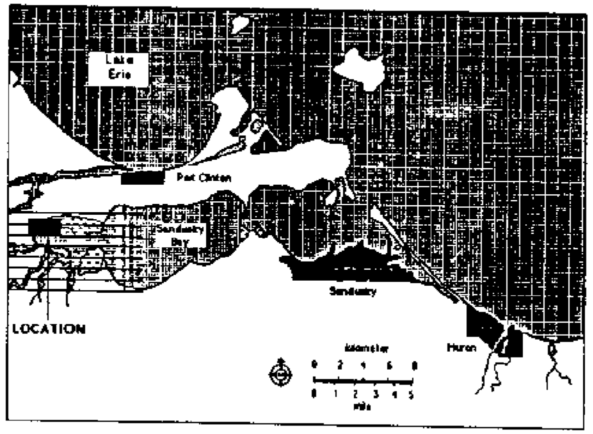


WETLANDS
W open water
E emergent wetlands
E-ct cattails
E-br bulrush
E-m millet
F floating-leaved wetland
F-n water lotus

OTHER LAND USES
T forests (trees)
X exposed land
A agricultural land
A-bw buckwheat
D dikes

Lake Erie Wetlands
Wightmans Grove - Ohio
Flight 6 - Slides 10-12
Flight 7 - Slides 11-15
from Color and IR Aerial Photography by
Ohio Department of Natural Resources
August 22, 1988





WETLANDS
W open water
E emergent wetlands
  E-ct cattails
  E-br bulrush
  E-m millet
F floating-leaved wetland
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T forests (trees)
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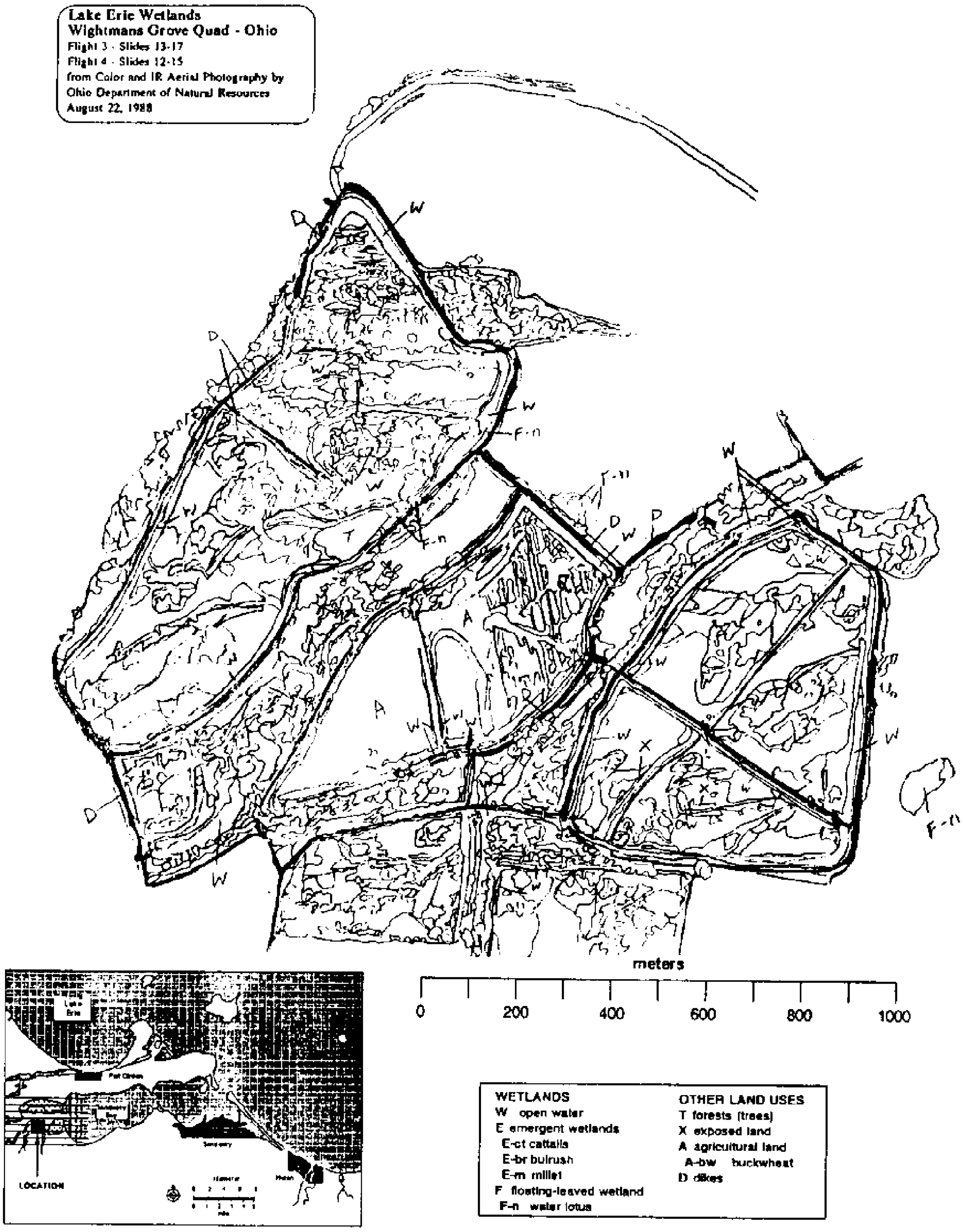
Lake Erie Wetlands
Wightmans Grove Quad - Ohio
Flight 3 - Slides 13-17
Flight 4 - Slides 12-15
from Color and IR Aerial Photography by
Ohio Department of Natural Resources
August 22, 1988
W
D
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LOCATION
WETLANDS
W open water
E emergent wetlands
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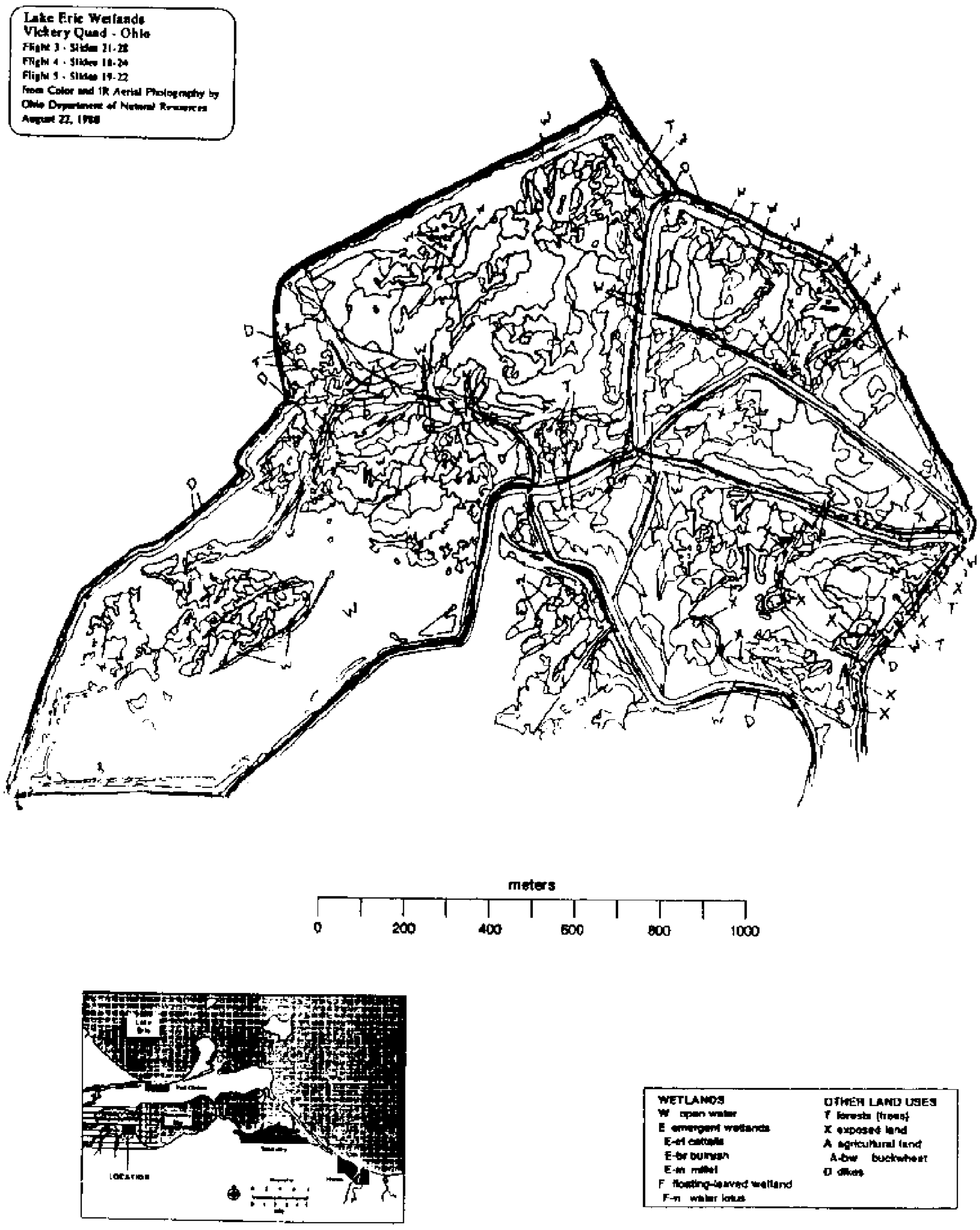
Lake Erie Wetlands
Vickery Quad - Ohio
Flight 3 - Slides 21-28
Flight 4 - Slides 18-24
Flight 5 - Slides 19-22
From Color and IR Aerial Photography by
Ohio Department of Natural Resources
August 22, 1988
meters
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LOCATION
WETLANDS
W open water
E emergent wetlands
E-ct cattails
E-br bulrush
E-m millet
F floating-leaved wetland
F-n water lotus
OTHER LAND USES
T forests (trees)
X exposed land
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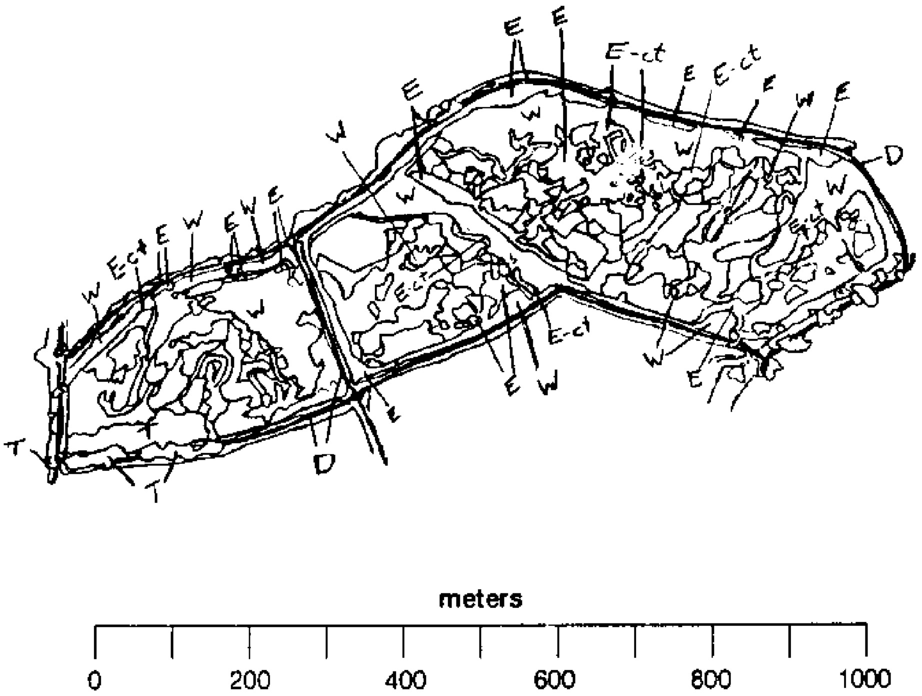
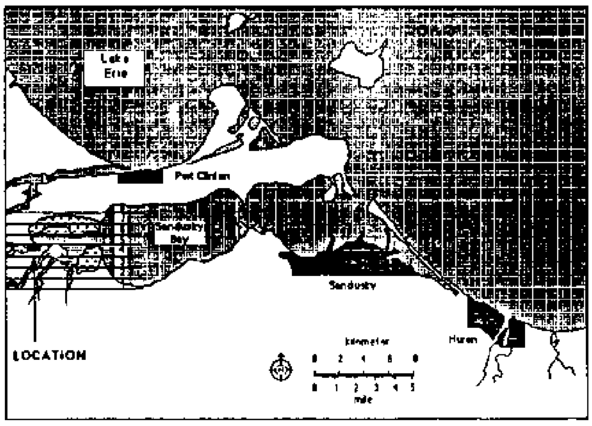
A-bw buckwheat
D dikes

Lake Erie Wetlands
Wightmans Grove Quad - Ohio
Flight 4 - Slides 9-11
Flight 5 - Slides 9-12
from Color and IR Aerial Photography by
Ohio Department of Natural Resources
August 22, 1988





WETLANDS
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OTHER LAND USES
T forests (trees)
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D dikes

Part III. Systems Approaches

10

Ecosystem Modelling of a Lake Erie Coastal Wetland

Wiliam J. Mitsch
Brian C. Reeder

Introduction

Wetlands are ecosystems and, as such, have interconnected parts that depend on or drive other parts of the system. A modelling approach is appropriate to integrate many data bases and describe the interconnections. For Old Woman Creek wetland, we have described in some detail the hydrology, phosphorus conditions, and productivity of this coastal wetland. Simulation modelling provides an opportunity to tie these pieces together, to examine if they are in the appropriate scale, and to make predictions for conditions other than those for which the model is calibrated.

Wetland modelling is relatively new, compared to modelling of other types of ecosystems. Some aspects of wetland modelling can be borrowed from the more developed lake and estuary modelling techniques (see Kremer and Nixon 1978, Reckhow and Chapra 1983, Straskraba and Gnauck 1985, Henderson-Sellers 1984, Jørgensen 1989). Other aspects can be derived from terrestrial models (Phipps 1979, Pearlstein et al. 1985, Mitsch 1988b). Reviews of the state of the art of modelling in wetlands are presented by Mitsch et al. (1982, 1988), Mitsch (1983), and Costanza and Sklar (1985). Recent models of wetlands include one of a freshwater wetland receiving wastewater (Kadlec and Hammer 1988).

Our intent in this chapter is to introduce a wetland model of hydrology, productivity, and phosphorus calibrated from data collected at Old Woman Creek wetland. The model emphasizes the role of ecosystem metabolism in the cycling and retention of nutrients and is used, through the calibration process, to estimate the role and importance of sedimentation and resuspension on the nutrient dynamics of the wetland.

Methods

The model is developed with the software STELLA™, a high-level, symbol-based programming language. The model is assumed to be a spatially-lumped, non-linear set of ordinary differential equations described in submodels on hydrology, phosphorus, and productivity. The model is calibrated and initially run for a simulated 274 day period, assumed to be from March 1 through November 30, 1988, at Old Woman Creek wetland. A time step of 0.1 days is used although experimentation with time steps up to 0.5 days show no appreciable differences in the simulations. The integration method is 4th order Runge Kutta. Calibration is done in a step-wise method by first calibrating the hydrologic submodel, then the productivity submodel, and finally the phosphorus submodel. Calibration is accomplished with each submodel by comparing field data with model results and adjusting selected parameters until there is an adequate fit of data and model results. An emphasis is on re-creating the appropriate seasonal patterns as well as the appropriate magnitudes of the field data by the model.

Results and Discussion

The Model

A conceptual diagram of the simulation model of Old Woman Creek wetland is shown in Figure 10.1. There are

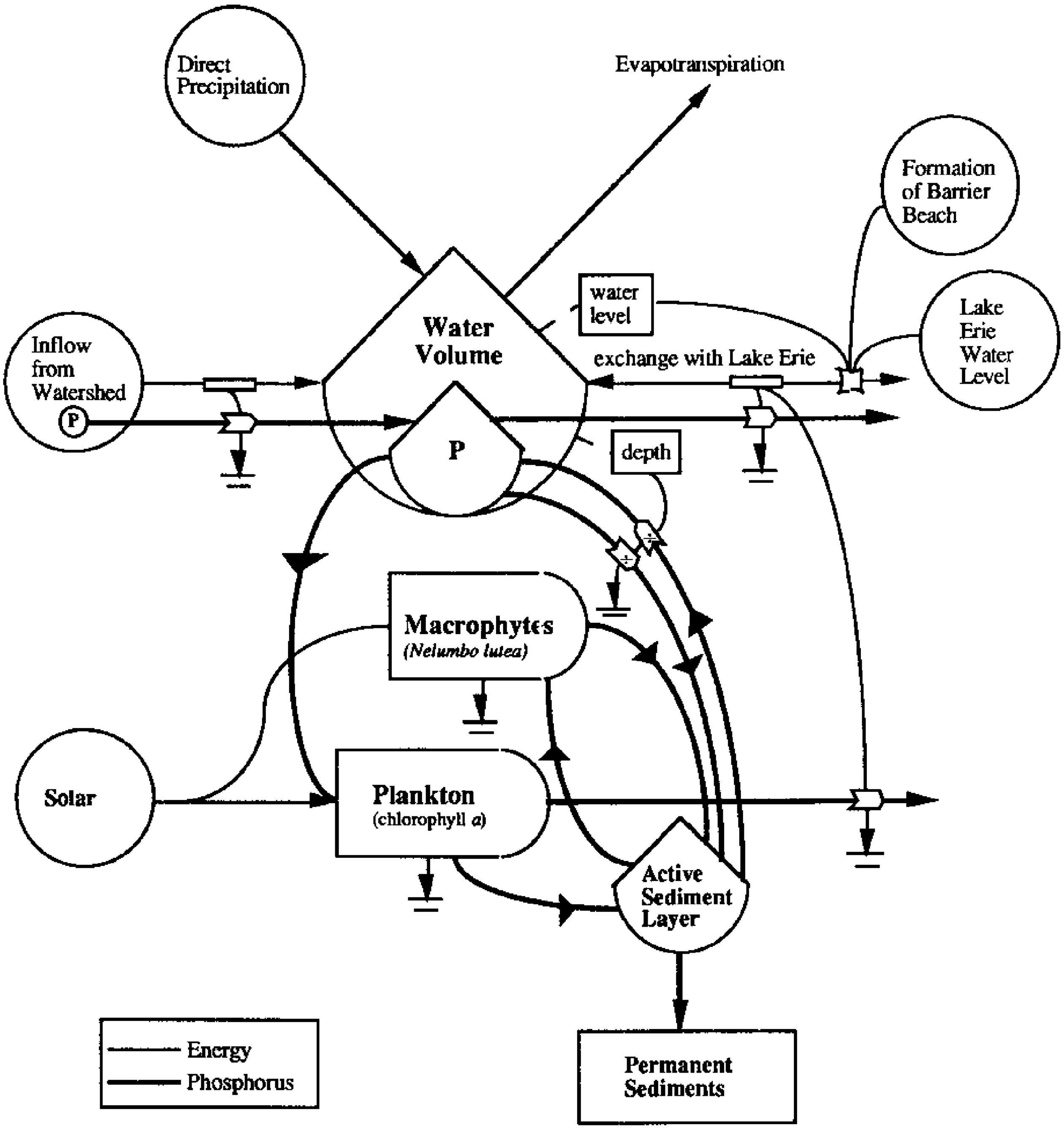


Figure 10.1 Generalized conceptual model of Old Woman Creek wetland

Table 10.1 State variables and differential equations for Old Woman Creek wetland model

---

Water, Q

$dQ / dt = Pd(t) + Q_i(t) - ET(t) - k1Q$ (when $b = 1$ and $L > L_E$) $+ (L_E - L)A$ (when $b = 1$ and $L_E > L$)

where,

Q = water volume in wetland, m3   Pd(t) = direct precipitation, m3/day

$Q_i(t)$ = surface inflow, m3/day

ET(t) = evapotranspiration, m3/day

k1 = outflow coefficient, day-1

b = 1 (when outflow is open); = 0 (when outflow is closed)

L = wetland water level, m = f(Q)

L_E = Lake Erie water level, m

A = wetland area, m2

Plankton Biomass, Pl

$d P_l / dt = k2I - k3P_l - spP_l - k1P_l$

where,

P_l = plankton biomass, kcal/m2

k2 = GPP coefficient

I = solar radiation, kcal/m2-day

k3 = respiration coefficient, day-1

sp = plankton sedimentation coefficient, day-1

Macrophytes, M

$dM / dt = k4\,I\,\% - k5M - k6(t)\,M$

where,

M = macrophyte biomass, kcal/m2

k4 = GPP coefficient for macrophytes

% = percent cover by macrophytes = f(depth)

k5 = macrophyte respiration coefficient, day-1

k6(t) = macrophyte sedimentation coefficient, day-1 = f(time of year)

Total Phosphorus, P

$dP / dt = C(Qi)\,Q_i(t) - k1P - (s1/d)\,P - a\,(k2I - k3P_l)\,A + (s2/d)\,A$

where,

P = total phosphorus, g

C(Qi) = phosphorus concentration of inflow, g/m3 = f (inflow)

s1 = sedimentation velocity, m/day

s2 = resuspension velocity, m/day

d = wetland depth = f(water volume)

a = phosphorus/kcal ratio in plankton, gP/kcal

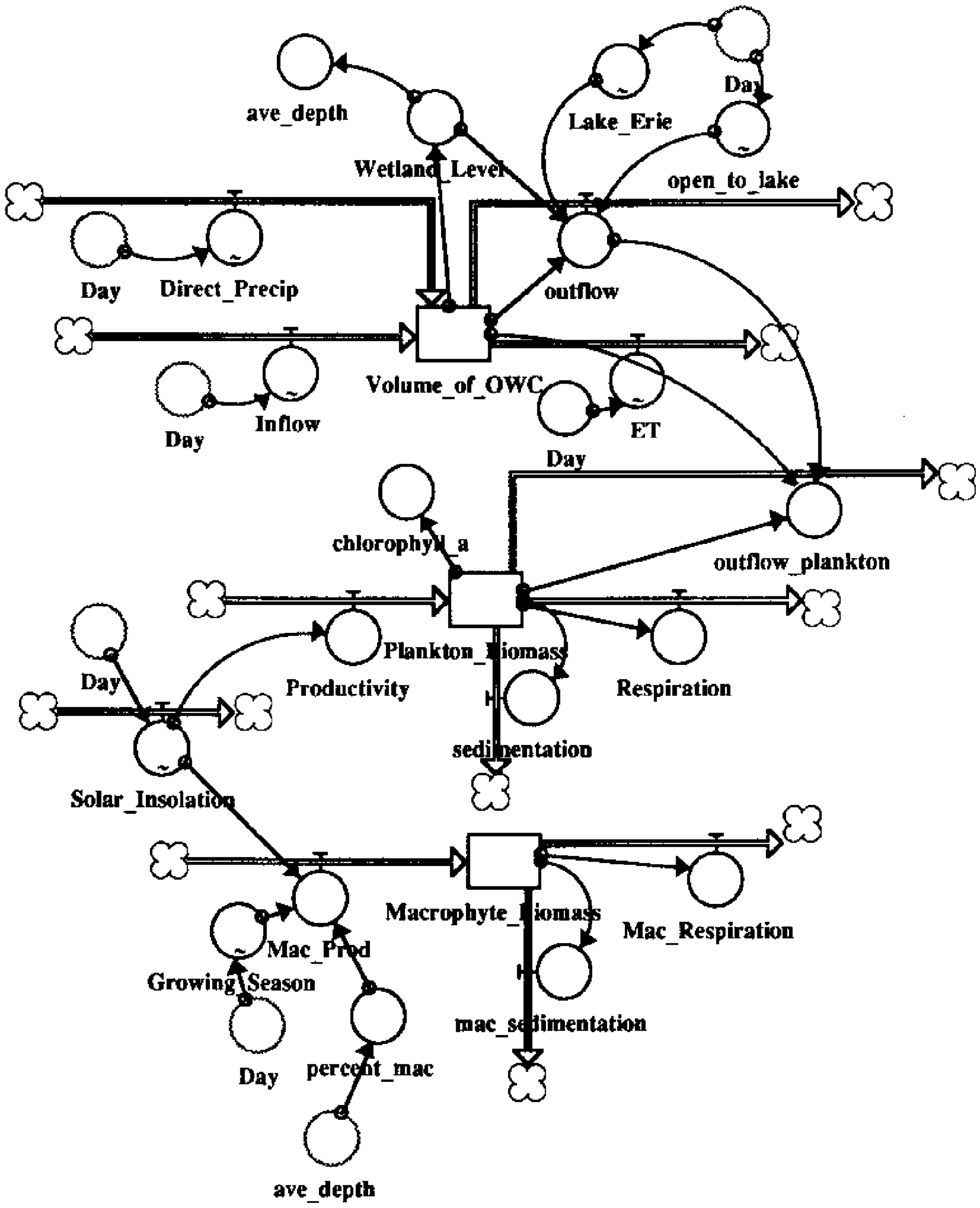
Phosphorus in Sediments, S

$dS / dt = a\,(k2I - k3P_l)\,A - (s2/d)\,A + a\,sp\,P_l\,A + \beta\,k6(t)\,M\,A + \beta\,(k4I\,\% - k5M)\,A$

where,

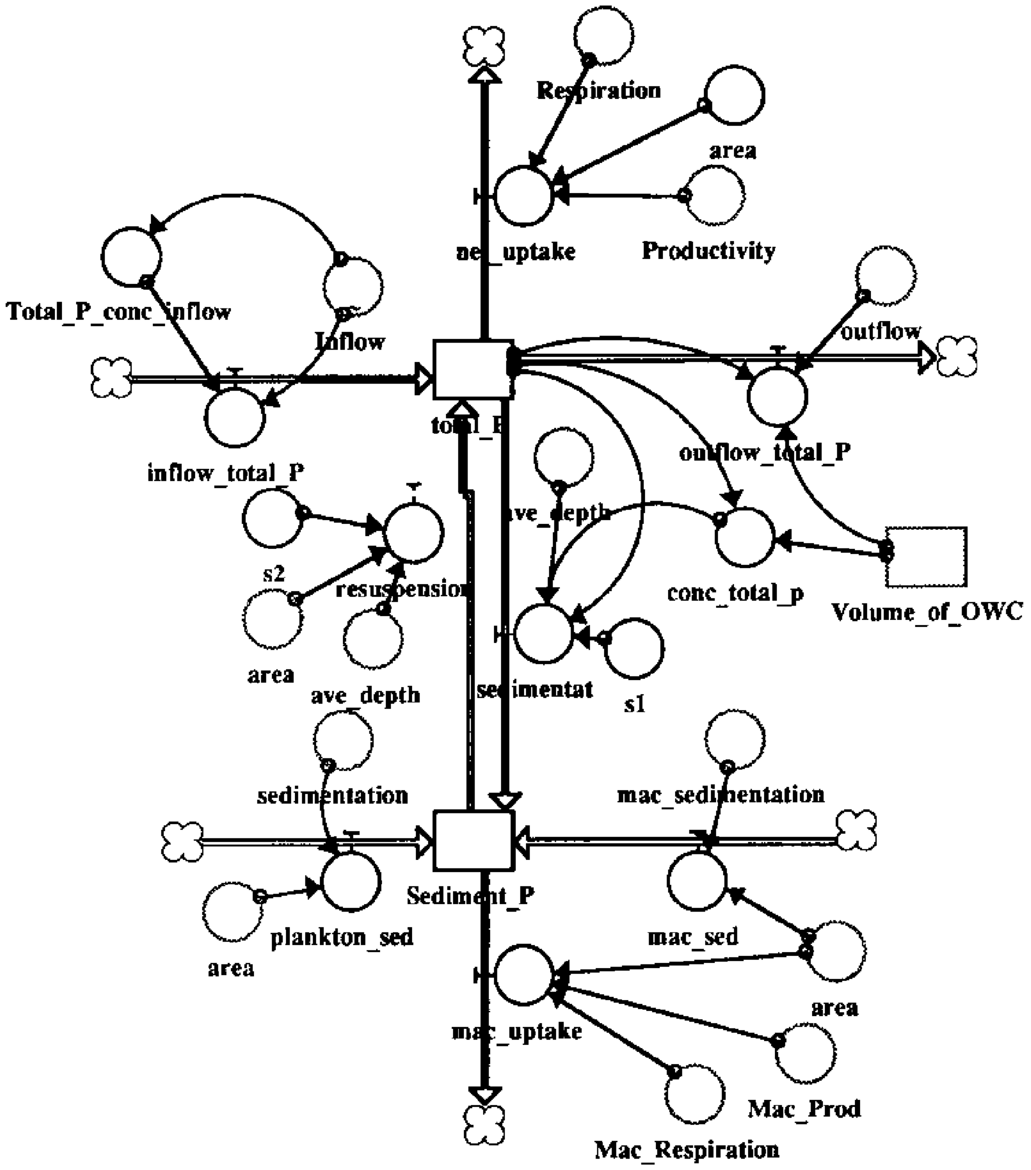
S = phosphorus in sediments, gP

ß = phosphorus/kcal ratio in macrophytes, gP/kcal



a)

Figure 10.2 STELLA™ diagram for Old Woman Creek wetland showing a) hydrology and productivity submodels, and b) phosphorus submodel



b)

Figure 10.2 (continued)

Table10.2 Model parameters, definitions, values and sources for Old Woman Creek wetland model

Symbol	Name	Values/Units	Source
State Variables			
Q	water volume in wetland	m^3	field data
P	total phosphorus	g	field data
P_l	plankton biomass	kcal/m^2	chlorophyll data
M	macrophyte biomass	kcal/m^2	biomass data
P	total phosphorus in water	gP	field data
S	phosphorus in sediments	gP	field data
Forcing Functions			
Pd(t)	direct precipitation	m^3/day	field data
$Q_i(t)$	surface inflow	m^3/day	USGS data
ET(t)	evapotranspiration	m^3/day	field data
L_E	Lake Erie water level	m	USGS data
I	solar radiation	kcal/m^2-day	field data
Parameters and Coefficients			
k1	outflow coefficient	1.0 day^{-1}	calibration
b	wetland water level	m	field data
A	wetland area	m^2	field data
s1	sedimentation velocity	0.03 m/day	Henderson-Sellers 1984
s2	resuspension velocity	0.0025 gP/m-day	calibration
d	wetland depth	m	field data
k2	GPP/solar	0.005	field data
k3	respiration coefficient	1.0 day^{-1}	field data
sp	plankton sedimentation coefficient	0.25day^{-1}	calibration
k4	GPP/solar for macrophytes	0.0025	estimate
%	percent cover by macrophytes = f(depth)		variable
k5	macrophyte respiration coefficient	0.015 day^{-1}	calibration
k6(t)	macrophyte sedimentation coefficient	0.01 day^{-1} $t<288$	estimate
		0.1 day^{-1} $t>288$	estimate
$C(Q_i)$	phosphorus concentration of inflow	g/m^3	Baker 1988
d	wetland depth	m	field data
a	phosphorus/kcal ratio in plankton	0.001 gP/kcal	Jørgensen 1982
ß	phosphorus/kcal ratio in macrophytes	0.00075 gP/kcal	field data
c	chlorophyll/energy ratio	3.7 mg cha/kcal	Vollenweider 1974

several assumptions implicit in the model:

- There is no built-in phosphorus limitation on productivity in the model. This appears to be a valid assumption based on the work of Heath (1987) and others;
- one active layer of sediments is considered with linear pathways of sedimentation and resuspension;
- phosphorus is lumped as total phosphorus, rather than partitioning it as available and unavailable phosphorus. This is consistent with the assumption of no phosphorus limitation;
- phosphorus discharges into Lake Erie when the water level in the wetland is higher than Lake Erie and the barrier beach is open;
- auto-catalytic reactions of plankton and macrophytes are initially left out of the model to increase model stability;
- macrophyte dynamics are based on productivity measurements of *Nelumbo lutea*, the dominant macrophyte presently in Old Woman Creek wetland; and
- plankton biomass is converted from energy units to chlorophyll a with a constant ratio of 3.7 mg chlorophyll *a* / kcal for populations not limited by nutrients (Vollenweider 1974).

The STELLA program model is shown in Figure 10.2 and differential equations are given in Table 10.1. Model parameters are defined and given in Table 10.2. The hydrology submodel in Figure 10.2a balances direct precipitation, evapotranspiration, inflow and outflow. The first three terms are included in the model as forcing functions based on data from the 1988 water budget. Significant inflow was limited to March and April of that year (Figure 10.3). The productivity submodel, also shown in Figure 10.2a, includes estimates of planktonic biomass (expressed as kcal/ m^2 and mg chlorophyll/m^2) and macrophyte biomass (expressed as kcal/m2). Plankton is transported from the wetland when there is flow out of the wetland and the barrier beach is open. Both plankton and macrophytes are assumed to contribute to sedimentation in the wetland. The phosphorus submodel (Figure 10.2b) includes one storage of phosphorus in the water and one in the active sediment layer. The exchange of phosphorus with the sediments includes sedimentation based on the standard velocity model (Henderson-Sellers 1984). A review of sedimentation velocity coefficients by Kamp-Nielsen (1983) suggests an average of 10 m/yr (0.3 m/day) for small lakes. This value was used in the initial calibration of the model. Inflow of phosphorus to Old Woman Creek assumes that the concentration of phosphorus is a function of the flow, as determined from previous data collected from similar small watersheds that drain to Lake Erie (Figure 10.4).

Model Calibration

A step-wise calibration procedure is used to determine several of the coefficients in the model. The hydrology submodel is developed from hydrologic budget data described in Chapter 4 with the outflow coefficient of the wetland as the primary unknown. An outflow coefficient of the wetland of 1.0/day reproduces the water levels as measured in the wetland in 1988 (Figure 10.5). The days in which the wetland was open to Lake Erie and the simulated outflow from Old Woman Creek are also shown in Figure 10.5. When the flow is negative, water is flowing from Lake Erie to the wetland. The model indicates that this reverse flow occurred several times in March through May when the barrier beach to Lake Erie was opened. The model assumes a closed beach from the middle of May through the end of the year, eliminating exchange between the wetland and Lake Erie during this time.

The second step in model calibration involves the productivity submodel. The calibrated hydrology submodel is coupled to the productivity submodel for this second calibration step. The productivity submodel, which includes plankton and macrophytes, is developed from extensive field data described in Chapters 3 and 5. Patterns of gross primary productivity, as measured on several occasions through 1988, are effectively reproduced by the model, with the primary calibration factor being the plankton gross primary productivity coefficient, k2 (Figure 10.6a). A further check of the plankton dynamics was made possible as a result of the availability of chlorophyll a data (Figure 10.6b). Because of shade adaptation and the great variability of the chlorophyll/biomass ratio in natural aquatic systems (Vollenweider 1974), we are not as confident of the pattern of chlorophyll suggested by the model, but the field data and the model give the same general seasonal pattern and are clearly in the same range. The model overpredicts chlorophyll in May and June, after which the field data pattern are closely reproduced.

There are few data on macrophytes in the wetland, but calibration of the macrophyte component of the productivity submodel, especially for productivity and respiration coefficients, developed a pattern that generally fit the sparse available data (Figure 10.7a). These calibration estimates are for *Nelumbo lutea*, the predominant macrophyte in Old Woman Creek wetland, and assume 100% coverage by the plant with peak biomass of approximately 600 kcal/m^2. Later calibration simulations decreased the percent cover of macrophytes to be a linear function of water depth to predict

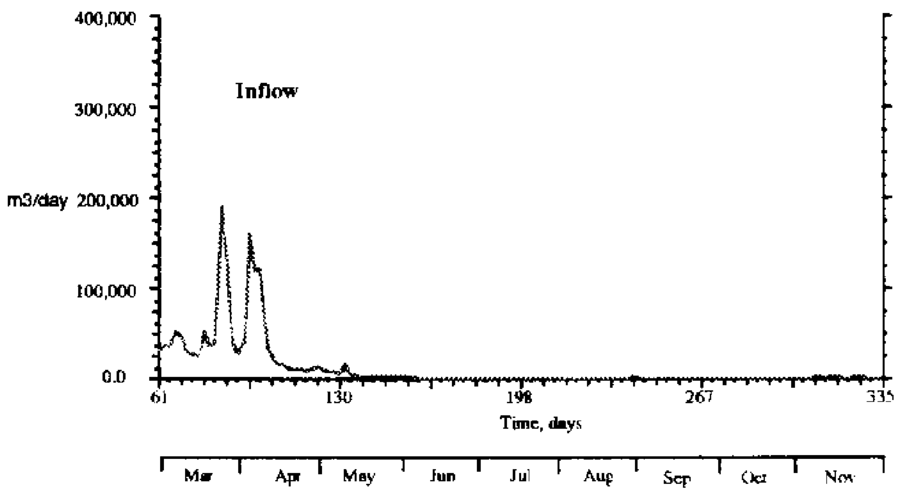


Figure 10.3 Inflow of water to Old Woman Creek wetland as programmed by the model for March through November, 1988

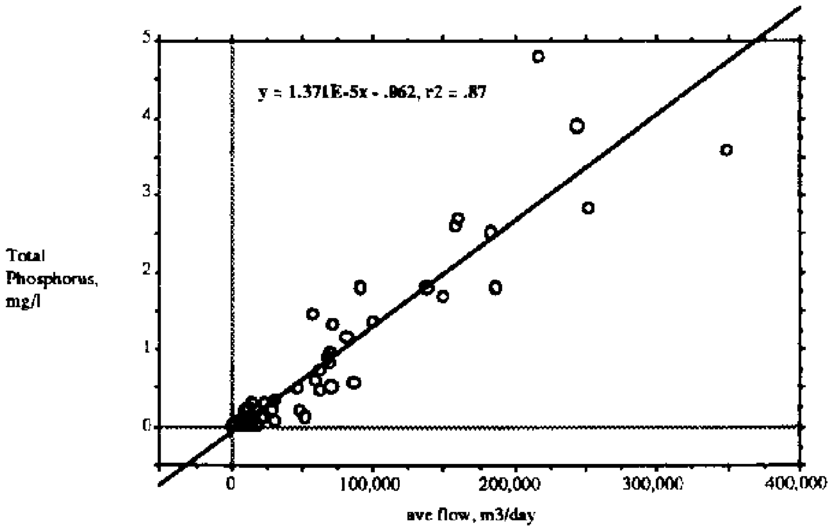


Figure 10.4 Relationship between total phosphorus concentration and flow for two small watersheds draining to Lake Erie (data from Baker, 1988). This relationship was used to calculate phosphorus concentrations of inflow in Old Woman Creek wetland model

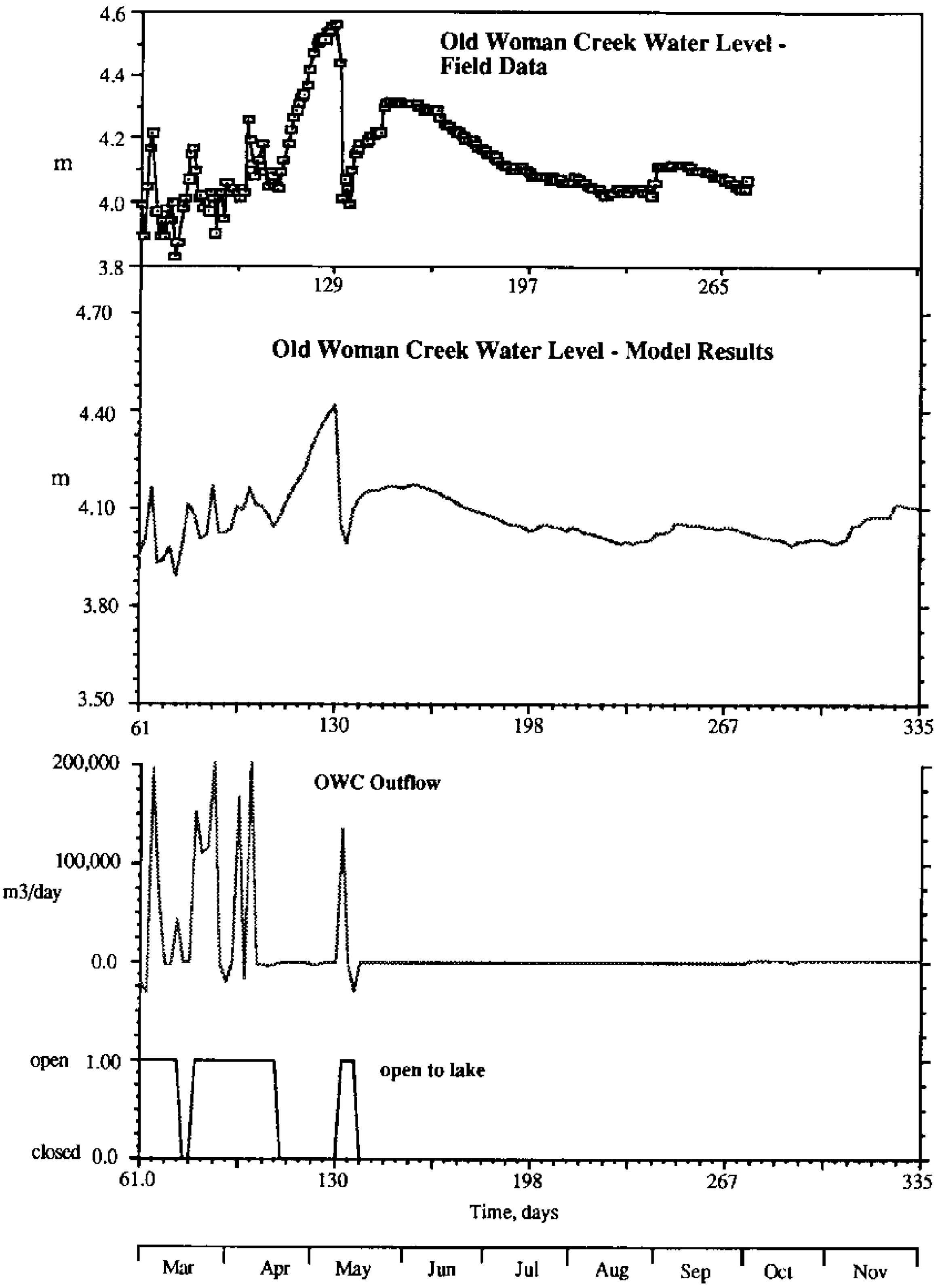


Figure 10.5 Actual water level in Old Woman Creek wetland in 1988 compared to simulated water level, simulated surface outflow and simulated period of the wetland being open to Lake Erie

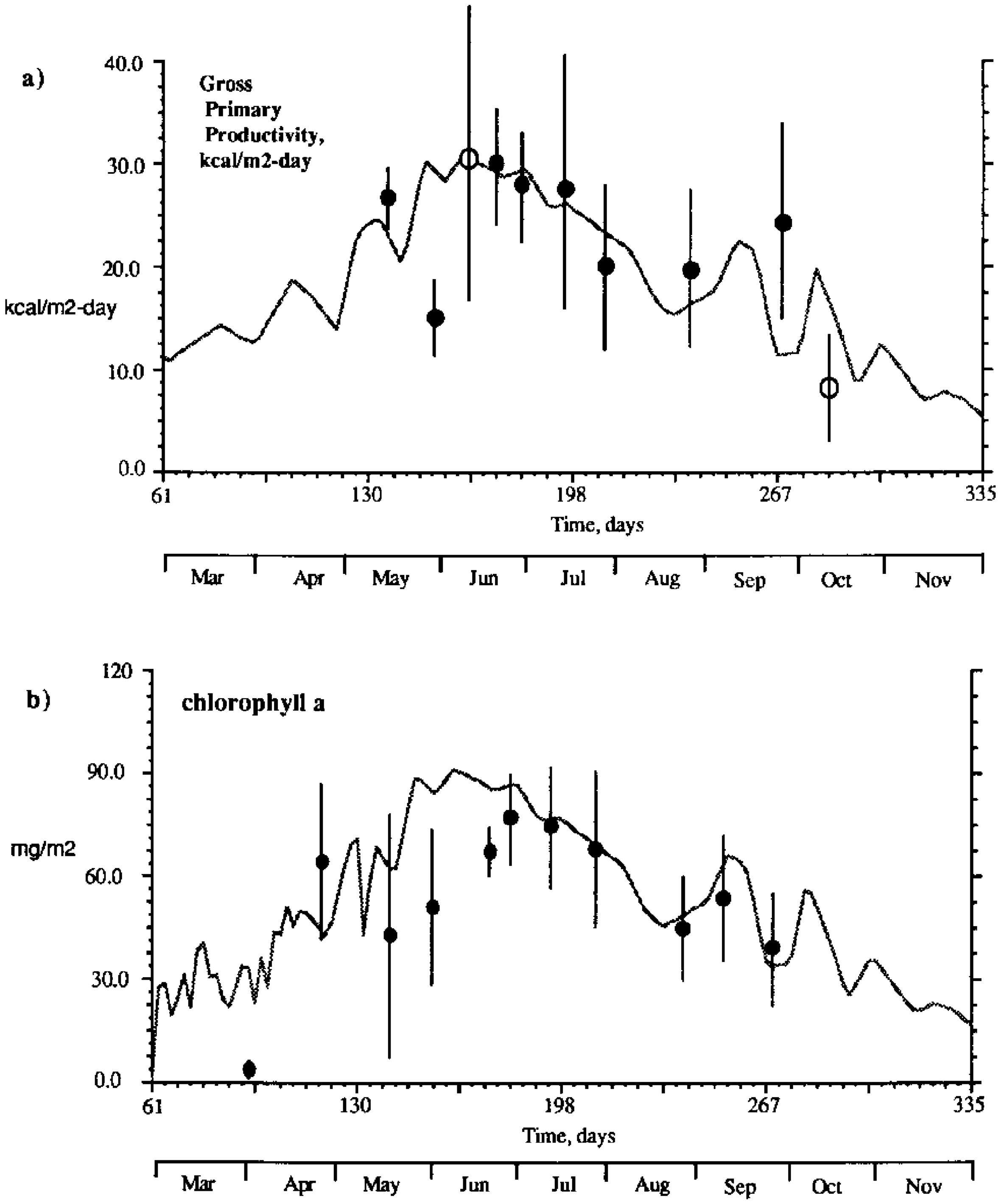


Figure 10.6 Model simulations compared to field data of Old Woman Creek wetland for 1988 for a) gross primary productivity of open water, and b) chlorophyll *a*. Range bars indicate one standard deviation of field data. Open circles on a) indicate full dissolved oxygen diurnals

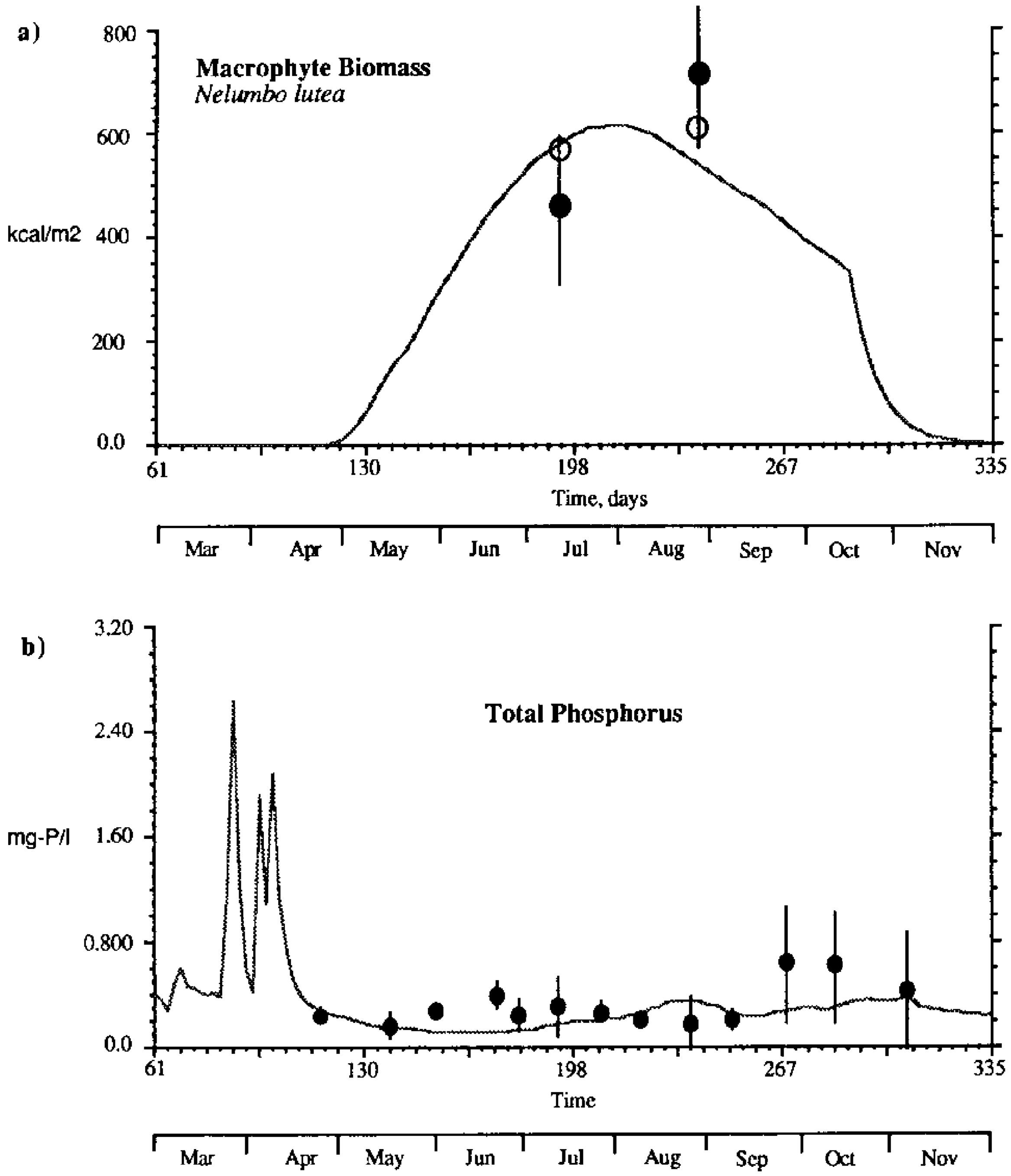


Figure 10.7 Model simulations compared to field data of Old Woman Creek wetland for 1988 for a) *Nelumbo lutea* biomass, and b) total phosphorus. Range bars indicate one standard deviation of field data. Open circles on a) indicate alternate biomass measurement method

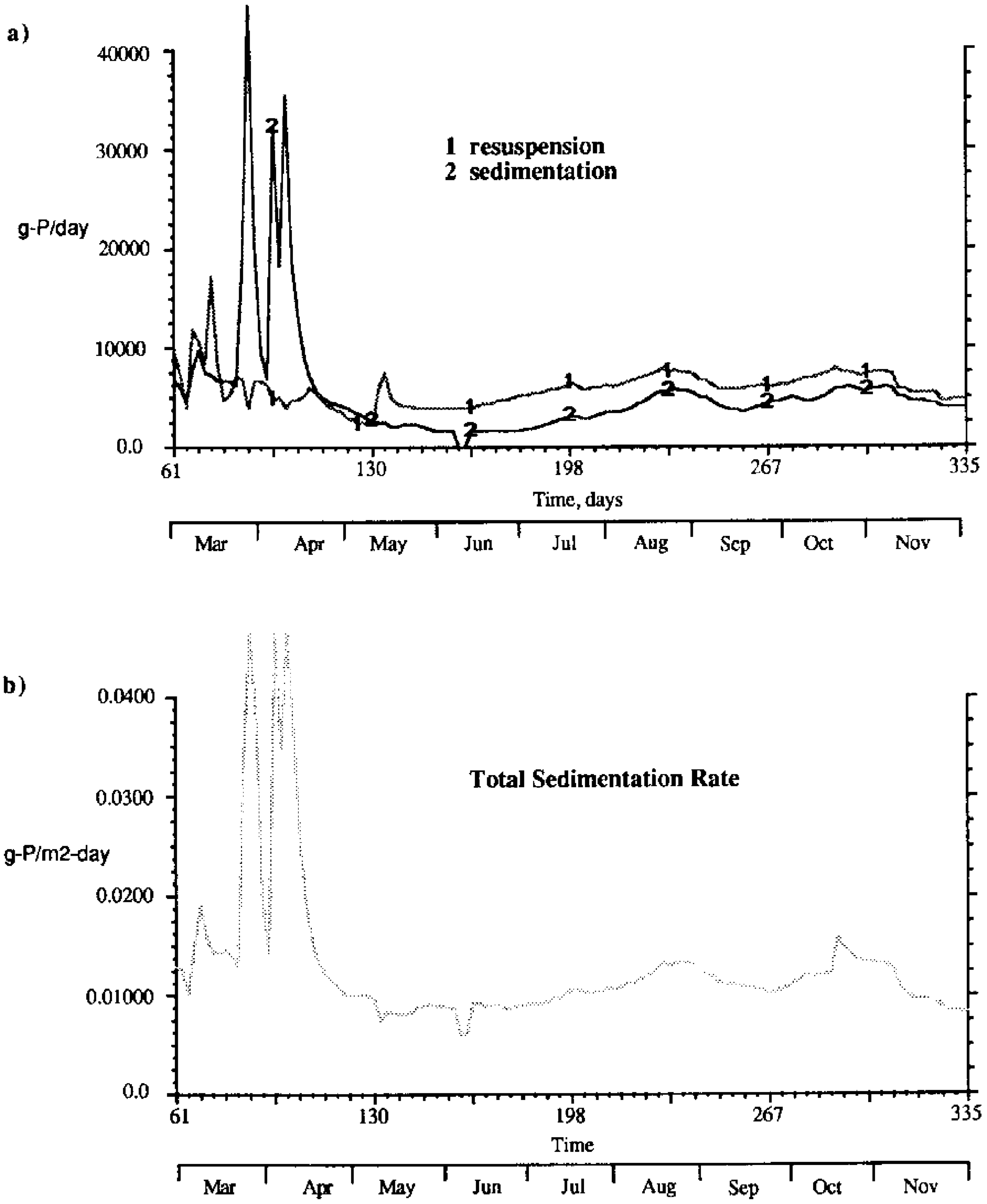


Figure 10.8 Simulations of Old Woman Creek wetland model for 1988 for a) resuspension and sedimentation of inorganic sediments, and b) total sedimentation rate including plankton and macrophytes.

more realistically the percent cover of the wetland by macrophytes as:

$$\% \text{ cover} = 1.00 - 7/2\, d \quad \text{for } d < 0.2857, \text{ and}$$
$$= 0.00 \quad \text{for } d \geq 0.2857$$

where,

d = average depth, m.

When water is deeper, the percent cover is low or zero; in shallow water, the cover is higher.

The third part of the calibration of the model involves the phosphorus submodel which is then coupled with the hydrology and productivity submodels (Figure 10.7b). Several estimates of sedimentation and resuspension coefficients are attempted, with the final determination using a literature average for sedimentation (s1 = 0.3 m/day) and a calibrated estimate of the resuspension coefficient. Because resuspension is a surface effect that is generally independent of the volume of sediments, it is assumed to be only dependent on depth. Shallower water generally leads to greater turbulence in the sediments and hence higher readings from field samples. The range of phosphorus in the wetland from May through November is generally reproduced by the simulation; data were not available from March and April when the highest loadings of phosphorus from the upstream watershed occurred.

Sedimentation

The use of hydrology, productivity, and nutrient calibrations from extensive field data enable preliminary estimations of the role of sedimentation and resuspension in the shallow wetland. The model's estimates of sedimentation (inorganic only) and resuspension are shown in Figure 10.8a. High levels of sedimentation occur in the early spring, with resuspension exceeding sedimentation through the remainder of the year. This excess of resuspension over sedimentation is surprising at first, but the productivity estimates throughout the year clearly illustrate that there is insufficient phosphorus in the inflow to support the high level of productivity and the generally high phosphorus concentrations experienced in the wetland from May through November. The model also predicts the total sedimentation rate, including contributions from plankton and macrophytes. High rates, often as high as 0.04 g-P/m^2-day, are simulated for the spring, while the rate for the remainder of the year, when very little allochthonous inflows are experienced, is around 0.01 g-P/m^2-day (Figure 10.8b). This rate translates to a total of 0.79 g-P/m^2 for the 9 month study period. Because the study year 1988 occurred during a significant drought year, we can expect the net sedimentation rate to be well below average. From data presented in Chapter 6 on sediment stratigraphy, an accumulation of phosphorus in the sediments is estimated to be 8 g-P/m^2-yr. It is not unreasonable to suggest that only 10 percent of the normal sedimentation occurred in the wetland during our calibration year of the extreme drought.

Nutrient Budgets

The model also allows calculations of nutrient budgets for the wetland (Figure 10.9). According to the model results, the wetland retained approximately 10 percent of the phosphorus during the study period. While this is less than the retention of 36 to 47 percent retention estimated in Chapter 5 from literature sources and field data, it is a reasonable estimate based on the hydrologic conditions for that particular year. Almost all of the inflow occurred when the wetland was open to Lake Erie and when the barrier beach closed at the outlet to the wetland, almost no additional streamflow entered the wetland. Cycling of nutrients from sediments to water column and back dominated the growing season.

Future Simulations

A calibrated model is only the first step to a completely validated model. The model needs to be checked with an independent data set from a different year with different hydrologic conditions. If validation proves successful, the model can then be used to predict nutrient dynamics of the wetland for a variety of scenarios, including high and low lake levels and differing inputs of water and nutrients from the upstream watershed. Prediction and hypothesis testing are the ultimate values of ecological modelling, but the entire effort of organizing the data of many research initiatives and many researchers is clearly valuable.

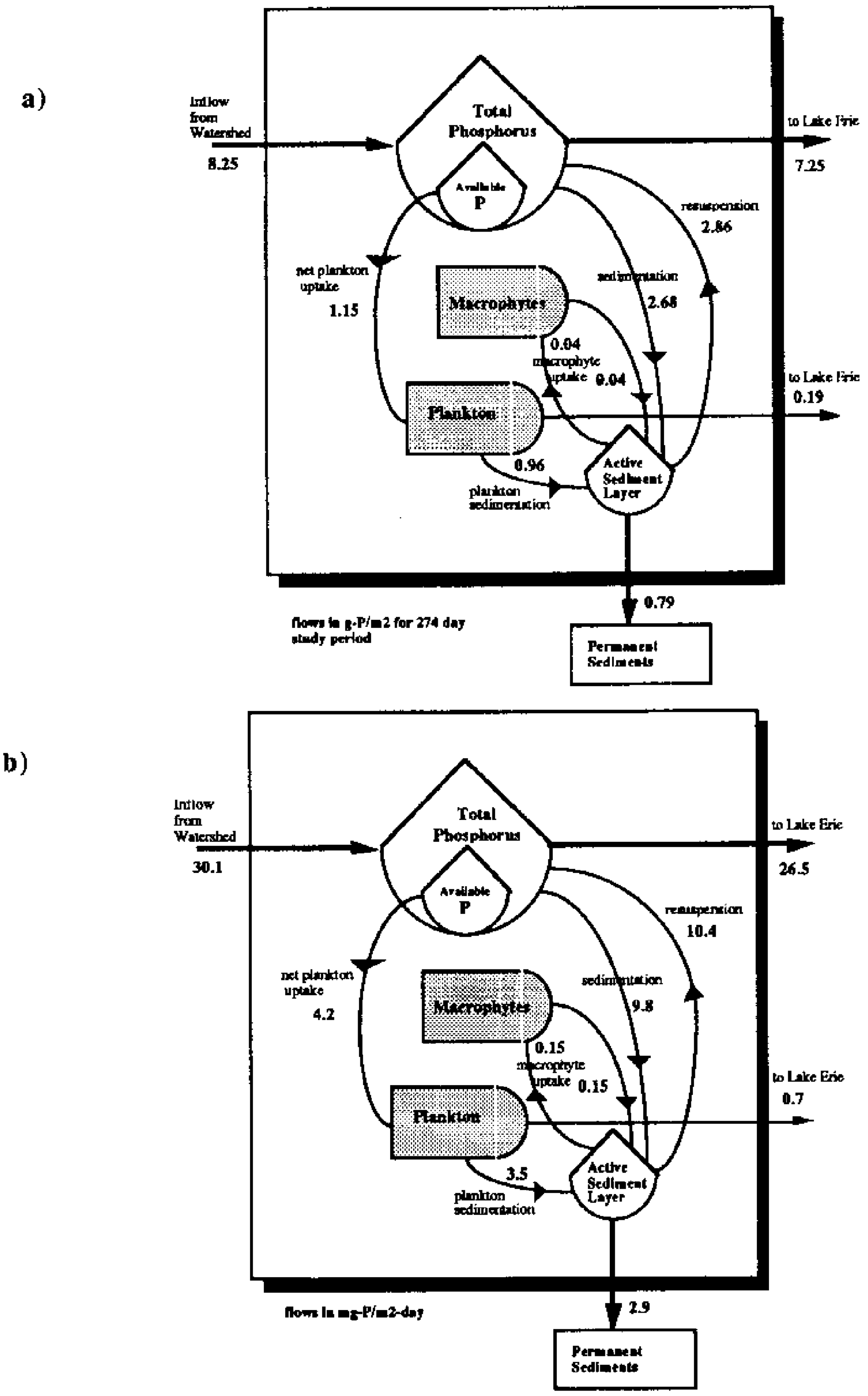


Figure 10.9 Nutrient budgets for Old Woman Creek wetland as calculated from Old Woman Creek model for units in a) g-P/m^2 for 9 month simulation period, and b) mg-P/m^2-day

Toward Dynamic Cartographic Modelling of Coastal Wetlands of Lake Erie

Gi-chul Yi
Dana Tomlin
William J. Mitsch

Introduction

Of all the Great Lakes, Lake Erie shows the greatest deterioration of water quality, in spite of the fact that 90 percent of the water source is good quality water from Lake Huron. Lake Erie is narrow and relatively shallow in comparison to other Great Lakes. Thus it is reasonable that an improvement of water quality should start from within its own drainage basin. One of the major problems facing Lake Erie is nonpoint pollution from agricultural watershed (Baker et al. 1985). Among nonpoint sources, soil loss has been recognized as one of the primary harmful components of water pollution (U.S. EPA 1985, Journal of Soil and Water Conservation 1985, OEPA 1983).

Recently the State of Ohio has tried to cooperate with various agencies to achieve the legistrated water quality goal (i.e. Clean Water Act, Federal Water Pollution Control Act). The strategies developed as a result of several discussion among different agencies resulted in agreements to focus on "problem" areas - portions of counties, watersheds or regions (OEPA 1983). Once critical areas have been identified, various control practices could be developed. Therefore, what is required at first is a convincing means of identifying critical erosive area and a means of evaluating various management policies (Yi 1987).

A number of previous studies have noted that the degree of water quality is very well correlated with the presence of wetlands (Mitsch and Gosselink 1986). Wetlands protect water bodies from sediments, nutrients, and other natural and man-made pollutants. Wetland vegetation filters sediments, organic matter, and chemicals while microorganisms utilize dissolved nutrients and break down organic matter. Wetlands have also been found to protect shorelines, to prevent floods, recharge ground water and serve as wildlife habitats. These values of wetlands vary from one wetland to another (space scale) and from one time to another (time scale). Because of this wide variation among individual wetlands, the significance of the values and benefits must be determined by different time (day, month, year, decade and century) and different space (individual, regional, national, international and global) scale basis.

The use of wetlands has become a controversial issue between those who wish to develop and those who wish to preserve. Developers regard wetlands as prime areas for residential, commercial and recreational development because of their typical proximity to water. Farmers drain or clear wetlands to plant crops in their rich organic soil. On the other hand, conservationists questions about the intrinsic values of numerous ecological services.

Wetland Data Management

Wetland resource management entails not only a data base describing the resource, its size, location, type, and important characteristics, but also planning, decision-making, monitoring, and even manipulation or use of the resource. Resource managers may require information for evaluation, such as the composition of the wetland and the surrounding land use.

Remote sensing has become an important tool in wetland management because it provides much of the needed data base information and a monitoring capability (see

Chapter 9). During the last two decades, legislation requiring wetland classification and inventory, concerns for wetland losses, the need for habitat evaluation, and the increased availability of aircraft and satellite data have rapidly expanded remote sensing research and technology related to wetlands. The use of this technology is concerned with various categories such as identification and classification, mapping and inventory, monitoring historical change and quantification. Due to the capability of remote sensing to provide synoptic views of large area, this technology can be applied efficiently and effectively the data implementation sources of digital cartographic data.

A "model", which can be a simplified verbal, graphic or mathematical description, is used to help understand a complex system. Many types of cartographic maps have also been developed to express and manage landscapes. Maps are good descriptors of the land, showing various landscape features. However, maps have one major limitation. They present a spatial characteristics of a landscape at one instant in time. A map representing a landscape feature stays the same until it is updated. However all biotic (animals, plants) and abiotic (air, water, soil) materials move over the landscape in a long time frame. Here models in the form of cartographic data can be used to describe how selected environmental qualities arise from a combination of existing conditions and even proposed alteration. Given the ability to analyze and to synthesize cartographic data, a variety of cartographic models can be developed to represent facts, to simulate processes, express judgment, or to otherwise provide for effective description of geographic phenomena (Tomlin 1989). Here the terms of "descriptive" and "prescriptive" models are used to describe the environmental quality and "cartographic modeling" is proposed for use in reference to the act of synthesizing geographic information as a part of decision-making process (Tomlin 1983). To move from description to prescription, however, a new set of techniques is required. These are techniques that broaden the role of cartographic modeling from relatively passive inquiry to much more active intent. Descriptive models answer questions; prescriptive models solve problems (Tomlin 1989).

Since the beginning of 20th century, a small number of scientists have utilized "systems analysis," the study of a complex system's behavior and its interaction among its components. This approach is quite amenable to ecological analysis when we review the landscape as a product of its past functioning. Throughout history, time and space have seldom been integrated into landscape analysis. Incorporating dynamic methods into landscape description and prescription will be very effective for better understanding of our environment. They incorporate movement and change through time and thus spatial dynamic methods can describe and evaluate natural and man-made systems as well as prescribe for future management. Thus the development of cartographic models in a dynamic system comprise the focus of this study. Geographic Information Systems(GIS) will be used for part of this study. GIS is a computerized spatial data handling system that is developed for the storage, manipulation and display of spatial data and it can transform, retrieve and output into usable information. Advantages of GIS are related to the effective linking capability of remote sensing, statistics, computer graphics, computer computation, and dynamic simulation.

Objectives

The main objective of this study is to develop dynamic cartographic model of a particular part of Lake Erie shoreline, including coastal wetlands. This main objective will be accomplished by understanding and replicating the behavior of the system and by developing the graphic display of several dynamic spatial models (i.e. soil erosion, sedimentation and wetlands) for supporting future management decisions. It will focus on the understanding of the form and function of various landscape patterns and how these patterns affect the movement and storage of some important natural materials such as abiotic (soil loss-sediment) and biotic(wetland vegetation) factors. The importance of this study is in developing a convincing tool which might useful to local officials in formulating resource management policies, especially for wetland management.

Methodology

The Site

Sandusky Bay is located on the southwest shore of Lake Erie, Ohio and is oriented from east to west direction. It is approximately 25.4 km long and its width varies from a value of 7.38 km to 5.06 km (U.S.G.S. 7.5 topographic maps). The maximum depth is approximately 3.0 meters and the mean depth is 1.2 m with a bottom slope of 1 percent (Lindsay 1976). Sandusky Bay receives water from Sandusky River, Muddy Creek and small tributaries. Sandusky River has a drainage basin of 3,680 km^2 and its land use is predominantly agricultural. Principal metropolitan areas in the Sandusky River basin are Bucyrus, Upper Sandusky, Tiffin and Fremont.

The soils of the area are mostly poorly drained clays. The shallowness of the bay allows even the slightest wind to create a highly turbulent condition with heavy sedimentation of the drainage basin. According to a previous Lake

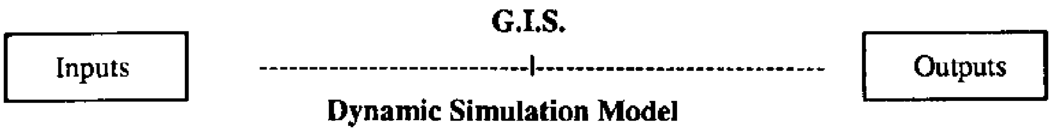


Figure 11.1 Basic approach to cartographic modelling

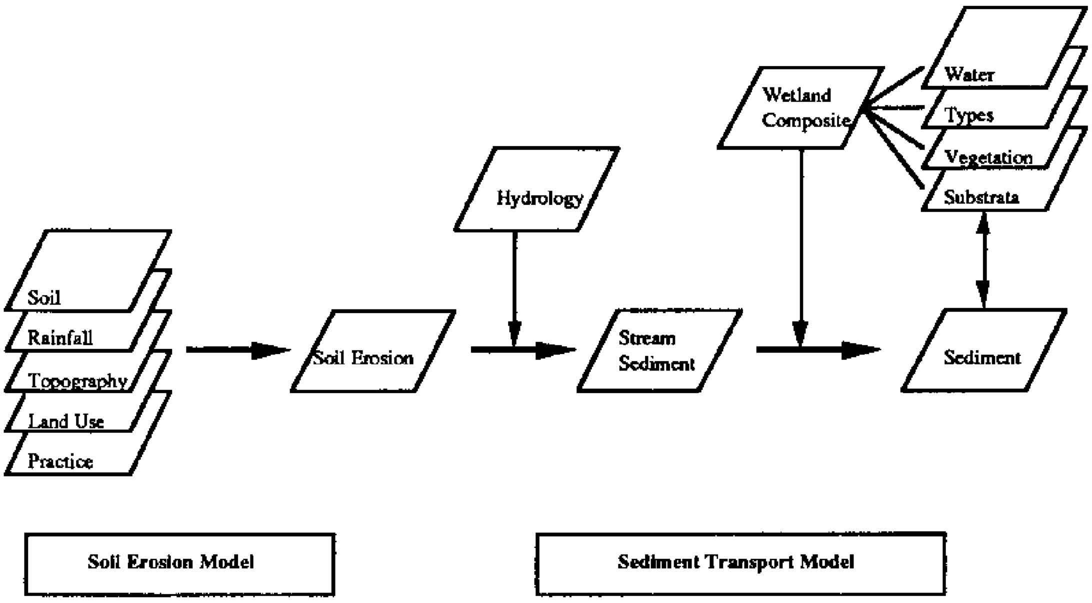


Figure 11.2 Descriptive GIS sub-models

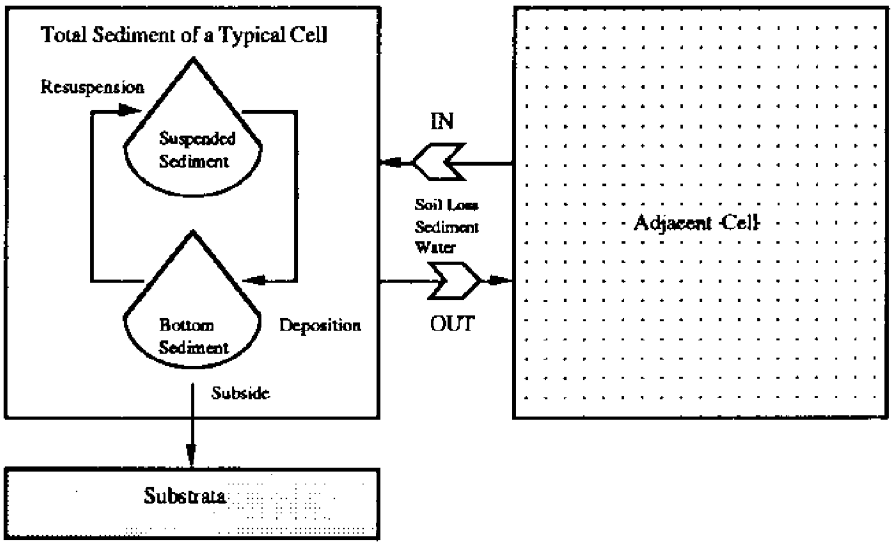


Figure 11.3 Example of dynamic spatial wetland model (from Costanza et al. 1986, 1988)

Erie Pollution Study (Northwest Ohio Water Development Plan 1967), the average sediment load in the Sandusky River is 408 thousand tons and the sediment composition is approximately 61 percent clay, 37 percent silt, and 2 percent sand.

Before settlement, most of the area around Sandusky Bay was a poorly drained swamp called the Black Swamp (Sampson 1930). This area has undergone considerable change in the past decade. Shaffer (1951) indicated that the south shoreline was about 371 meters farther north in 1900 than in 1950. Shore loss along the south shore of the eastern bay averaged 1.7 meters per year. The greatest shore loss was 3.0 meters per year along the south shore of the western bay. Shaffer (1951) suggested that this erosion was due primarily to northeast storms.

Modelling

Traditionally, time and space have not been integrated together in modeling. Maps are most effective in describing a landscape but, as one quick view of landscapes, they fail to express the dynamic nature of land and its systems. Thus this research presents a way of incorporating time and space, a core concepts of dynamic spatial landscape modeling, applications of implemented models and some thoughts for future possibilities.

1. Structure of Model

The basic structure of model comprised two different structure approach (Figure 11.1).

The first part include three descriptive GIS submodels which are Soil Erosion Model, Sediment Transport Model and Wetland Model (Figure 11.2). These models are constructed by overlaying several layers of GIS and connected in the spatial landscape model. The implemented model can describe the behavior of system. For example, the Soil Erosion Model can account for soil erosion on every parcel of watershed, the Transport Model can account for transported sediment from soil erosion, and the Wetland Model can account for wetland change over long term (several decades) and short terms(days).

The second part of the model is a dynamic simulation model. Compared to first spatial situation of GIS model, each cell of GIS contains a dynamic movement to connected each adjacent cell. In this model, how different landscape variables influence these exchanges and flow will be determined and the balance of inputs and outputs in a cell is a critical question of this model. For example, Figure 11.3 shows diagrammatically how the storage and flows of water can be interconnected within a typical cell (Costanza et al. 1986, 1988). The volume of water crossing from one cell to another carries a specified sediment or soil loss. Then this sediment can be deposited, resuspended or subsided in a cell. Plants and animals within each cell can also influence these exchange.

A implemented dynamic spatial model can account how different forcing function variables affect the state variables of the system. Example variables are:

Forcing Function
Climate(Rainfall,Wind)
Topography
LandUse(Cover)
Hydrology
Nutrients and Sediments in Runoff

State Variables
Water Level
Plants Distribution(Ecosystem types)
Soil and Sediments
Nutrients
Water Volume

Forcing functions are specified in the form of time series over long range period. Then the simulated output of state variables can be output as maps, figures and tables with varying time scale.

2. Prescriptive Cartographic Modelling

The implemented dynamic spatial model can output the past and current data. This will determine the functioning of the presently remaining wetlands. The future data will be predicted by simulation. The effects of different management scenarios can be analyzed in the model. These scenarios will cover:

1) the impacts of human management (i.e. various land management, erosion control, water level control, dredging, artificial wetland construction);

2) the impacts of various natural power (i.e. water level changes, runoff from watershed); and

3) the impacts of site specific manipulation (i.e. critical erosive area control, undiked - diked wetland types).

Data Preparation

The data entry into for this study will include several ways. Table 11.1 is a summary of available data sources and its implementation. The first method is by image processing (which include conversion and rectification) from several satellite imagery such as SPOT, LANDSAT and AVHRR. The second method is by converting digital computer data which can be acquirable from federal agency

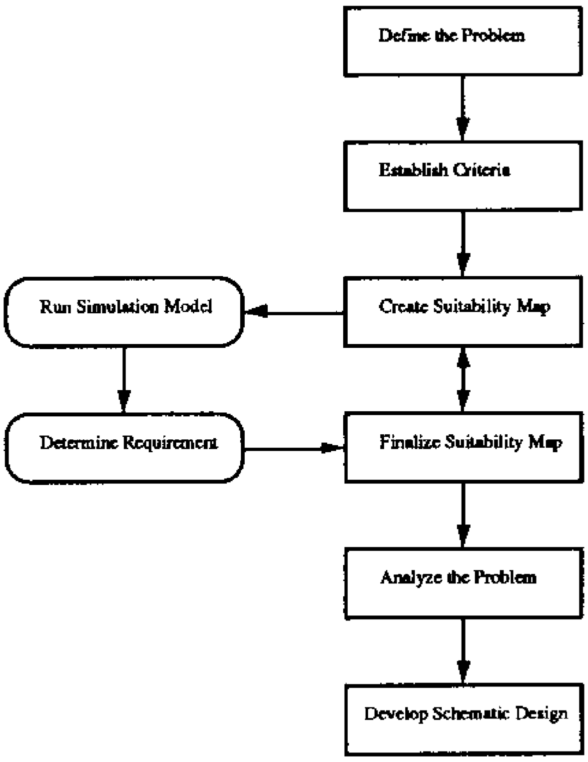


Figure 11.4 Design process of overall methodology for this study

Table 11. 1 Data sources for cartographic modelling

Data Sources	Date	Ways of implementation	Characteristics(Use)
SPOT	?	Image processing	Land Use, Wetland types, Sediment
LANDSAT	?	Image processing	Land Use, Wetland types, Sediment
AVHRR	?	Image processing	Sediment
LRIS	1975	Conversion	Soil, Drainage, Land Cover
OCAP	?	Conversion	Soil, Drainage, Land Cover
DEM	?	Transformation	Slope, Aspect
Aerial Slides (Color/CIR)	8/88	Visual Checking and Digitizing	Wetlands

SPOT: French Satellite Probatoire pour l'Observation de la Terre (10 meter cell width)
LANDSAT: MSS(79meter cell width), TM(30 meter cell width)
AVHRR: Advanced Very High Resolution Radiometer(1.1km cell width)
LRIS: Lake Erie Land Resources Information System(200 meter cell width)
OCAP: Ohio Capability Analysis Program
DEM: Digital Elevation Model

(i.e. U.S. Army Corp Engineers, U.S.G.S). The third way include digitizing of standard map outputs which is done by retracing the component categories on a digitizing tablet. Finally aerial photointerpretation is another way of data entry. Aerial photo can be digitized by using a video camera and then process to rectify (removal of distortion in aerial photographs).

Work Plan

The detailed steps of our work plan include the following:

1. Collect the existing data sources and check availability.
2. Collect (order) satellite data when cloud cover is absent and on-site sampling is available.
3. Preprocess (convert) the data into available digital format (i.e. ASCII).
4. Process and analyze the relationship between digital data and levels of system variables (i.e. satellite - sediment, land use, wetland loss)
5. Develop the model. This involves the sensitivity test of the model and the analysis of the result of model calibration.
6. Discuss and outline the use and implications of the model to provide solutions to pressing coastal management problems.

Expected Results

By linking GIS and dynamic simulation models, the automated prescriptive process can be devised. Figure 11.4 shows the design process of the overall methodology. Various management issues can be questioned in this stage (i.e. wetland loss - water level management, suitable artificial wetland construction, critical soil erosive control). Then, based on management criteria, suitability maps can be developed. By controlling the order of model process, the output of a suitability map can be used as input to the simulation model. This process can be continued until it satisfy management requirements (i.e. sediment concentration, optimum wetland distribution). If artificial wetlands are suggested, schematic design can be developed on the basis of GIS data.

The overall value of this spatial modelling approach will be a better understanding and management of Lake Erie's coastal wetlands.

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