Ohio Sea Grant College Program

A Method for Estimating Fluxes from Coastal Wetlands into the Great Lakes, with an Example from Lake Erie

Kenneth A. Krieger, Ph.D.

Water Quality Laboratory
Heidelberg College
Tiffin, Ohio

**Technical Bulletin
OHSU-TB-025-93**

#2

January 1993 – The Ohio State University

OHIO SEA
GRANT
COLLEGE
PROGRAM

Ohio Sea Grant College Program
The Ohio State University
1314 Kinnear Road
Columbus, OH 43212-1194
TEL 614/292-8949
FAX 614/292-4364

Sea Grant, a unique partnership with public and private sectors combining research, education, and technology transfer for public service, is the national network of universities meeting changing environmental and economic needs of people in our coastal, ocean and Great Lakes regions.

Ohio Sea Grant College is one of 29 programs in the National Sea Grant College Program (grant NA90AA-D-SG132, project R/ES-4) of the National Oceanic and Atmospheric Administration (NOAA). Funding support is provided by National Sea Grant, Ohio Board of Regents, The Ohio State University, Ohio State University Extension, and participating universities, agencies and businesses. Ohio Sea Grant is administered by The Ohio State University.

Additional copies of this technical bulletin (TB-025) are available from the Columbus office of Ohio Sea Grant for $2.00 (includes tax, postage and handling).

Suzanne Abbati......*Designer*

A Method for Estimating Materials Fluxes from Coastal Wetlands into the Great Lakes, with an Example from Lake Erie

Kenneth A. Krieger, Ph.D.
Water Quality Laboratory, Heidelberg College, Tiffin, Ohio 44883

Abstract

A method is presented in detail for the quantitative estimation of the flux of water and dissolved or suspended materials through coastal wetlands of the Great Lakes where the juncture of the wetland and lake is constricted by a narrow opening. Application of the method requires frequent (e.g., hourly or daily) data on atmospheric deposition, precipitation, evaporation, upstream discharges from tributaries, wetland water level changes, and water chemistry data at upstream and downstream locations, as well as a detailed knowledge of wetland depth-area and depth-volume relationships. Data collected during October 1989 are used to demonstrate the method.

Table of Contents

List of Tables

List of Figures

List of Appendices

A Method for Estimating Materials Fluxes from Coastal Wetlands into the Great Lakes, with an Example from Lake Erie

INTRODUCTION

The need to understand the water quality functions of wetlands has long been recognized (Zedler and Kentula 1985, International Joint Commission 1986, Mitsch and Gosselink 1986), and within the past two decades, models have been generated to advance this understanding for various types of wetlands (Mitsch et al. 1988). Along the shores of the Laurentian Great Lakes, coastal wetlands are believed to play an important role in the amelioration of pollution. The riverine wetlands at the flooded mouths of Great Lakes tributaries (so-called "Great Lakes estuaries"; Brant and Herdendorf 1972, Herdendorf 1990, Dyer 1990, Odum 1990) may be especially important in reducing the loadings of pollutants received from agricultural watersheds. Mass balance studies of pollutants entering and leaving tributary coastal wetlands of the Great Lakes have not been conducted. Sager et al. (1985) approached this type of study when they related carbon, nitrogen and phosphorus concentrations at the mouth of a Green Bay, Lake Michigan, coastal marsh to water levels measured during ebb and flood phases of seiches.

The intent of this paper is to describe a method for the quantitative estimation of the flux of water and dissolved or suspended materials through Great Lakes coastal wetlands, especially those surrounding tributary mouths. The environmental parameters that must be measured simultaneously, the order of the steps that must be followed to calculate the loads, the equations that are used in the calculations, and some loads computed using the method are presented in detail.

Background

Wetlands along the shores and extending up the tributaries of the Laurentian Great Lakes are thought to function as sinks for a variety of materials, including suspended sediments and sediment-bound pollutants, such as pesticides, toxic metals and organic chemicals (Klarer and Millie 1989, MacCrimmon 1980). Buchanan (1982) estimated that the Old Woman Creek wetland on the shore of Lake Erie has been accumulating sediment from its agricultural watershed at the rate of approximately one centimeter per year. It is thought that such wetlands also transform some pollutants from more biologically active forms to forms that have less impact on the receiving lake. For example, orthophosphate, which derives from natural sources as well as from treated sewage effluent and agricultural runoff, can cause undesirable algal growth in the Great Lakes. The uptake of orthophosphate by algae in the coastal wetlands, which intercept surface runoff from Great Lakes tributaries, transforms the orthophosphate into organic phosphorus within the algae. The algae in the wetland are transported into the lake during high rates of tributary flow (Klarer 1989), but the phosphorus is no longer available directly to stimulate algal growth in the lake. Depending on their individual chemical and physical properties, materials moving into and through coastal wetlands follow most or all of the hydrologic pathways shown in Figure 1.

Substantiation of the ameliorating effects of coastal wetlands on the pollutant loads carried down rivers from Great Lakes watersheds has been lacking, except by the application of indirect evidence from differences in pollutant concentrations between the upstream and downstream ends of wetlands (Klarer and Millie 1989, MacCrimmon 1980). In order to use chemical concentrations (mg L^{-1}) as surrogates to determine mass transport (usually reported in kilograms or metric tons of material), such estimates have necessarily assumed that the instantaneous discharge (flow rate, $m^3 s^{-1}$) of water into a wetland is equal to that discharging from the wetland into the lake, which probably is rarely the case because the water levels of the wetland and lake do not maintain an equilibrium. This is illustrated by Figure 2, which compares the constantly changing levels of the Old Woman Creek coastal wetland in northern Ohio and contiguous Lake Erie.

The only valid estimation of the differences between input and output of materials in a wetland is derived by measuring both concentration and discharge at each end of the system. With that information, the estimated load of a substance during a selected interval of time is calculated as:

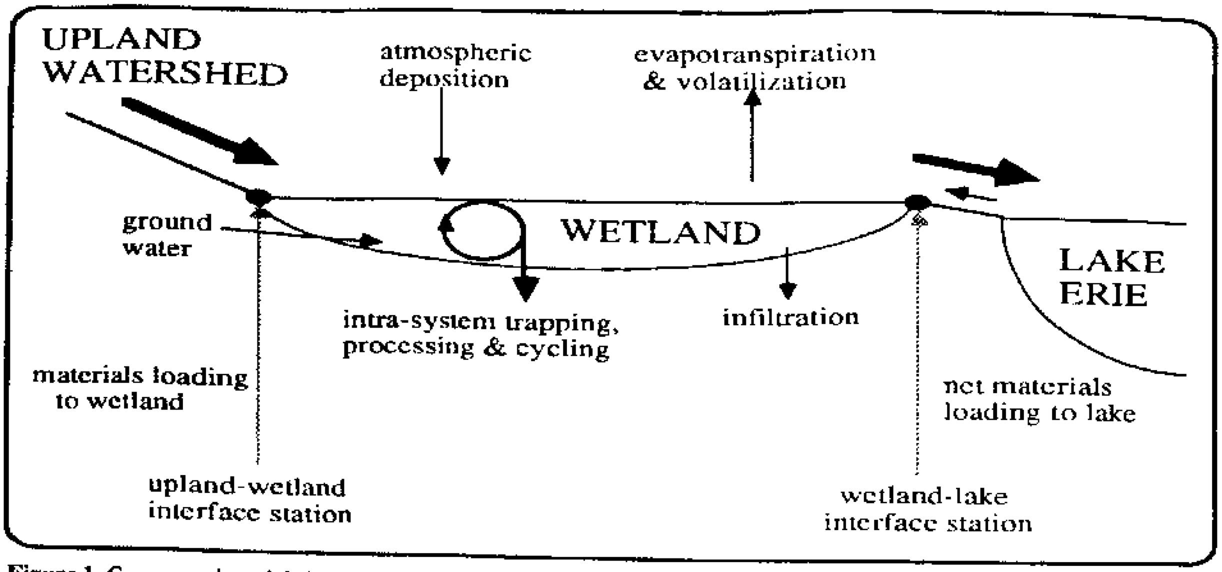

Figure 1 *Conceptual model showing the routes of movement of water and materials through a Great Lakes coastal wetland. The thickness of the arrows is an approximate indication of the expected relative importance of each pathway. The dashed arrows indicate that flow between the wetland and lake is sometimes interrupted by a barrier beach. The present study examines the loading of materials into a coastal wetland and Lake Erie by means of discharge and concentration measurements acquired at an upland site and a site near the juncture of the wetland and the lake.*

$$\text{Load} = \text{Concentration} \times \text{Discharge} \times \text{Time} = \text{kg/m}^3 \times \text{m}^3\text{/sec.} \times \text{sec.} \qquad (1)$$

In estimating loading in free-flowing streams, the time interval represented by each chemical sample in a series of samples is typically determined by calculating the midpoint in time between it and the previous sample and the midpoint between it and the following sample. Thus, for a series of samples that were collected at equal intervals, the time at which the sample was collected lies at the midpoint of the interval represented by that sample. For a series where the samples were collected at unequal intervals, the time of sample collection will not coincide with the midpoint. (Refer to Baker (1988) for a more detailed discussion.)

At discharge measurement sites on upland streams, such as most of the gaging stations operated by the U.S. Geological Survey (U.S.G.S.) (see, for example, Shindel et al. 1990), discharge is a function of the river stage (water depth); the higher the stage, the greater the amount of discharge. At such sites, the U.S.G.S. develops a "rating curve" that plots the discharge at each stream stage. Rating tables are produced that list the discharge (in ft^3/s) for each stage in increments of 0.01 foot (0.305 cm). A rating table (Appendix A) has been produced for discharge in the most downstream free-flowing reach of Old Woman Creek, a second-order tributary to Lake Erie in northern Ohio. On the basis of the rating curve and a record of the stream stage gathered at 15-minute intervals, the U.S.G.S. annually publishes the computed mean daily discharges (in ft^3/s) for each year. The mean daily discharges published for Old Woman Creek for October 1989 are shown in Appendix B.

The downstream reaches of most, if not all, Great Lakes tributaries possess a much more complex hydrology than the upstream, free-flowing reaches. The complexity arises from the interaction of stream and lake hydrologic processes in the stream reach which lies at or below the lake stage. In these regions, the discharge is no longer proportional to stream stage; therefore, the discharge cannot be calculated in the same manner as for free-flowing streams. The hydrology of these "flooded" stream reaches (and their associated wetlands) is controlled by six primary interacting processes, one or more or more of which dominates at any given time. They include (1) upland stream discharge; (2) seiches and storm surges, which irregularly raise and lower the lake stage and thus fill and drain the wetland and stream channel, much as the regular ocean tides do in estuaries; (3) periodic and somewhat seasonal "fill-and-drain" cycles in small tributaries, whereby a barrier beach develops from lake surf action and dams the tributary mouth, followed by a rising wetland water level behind the dam and eventual breaching of the dam, which allows the water level to drop suddenly (see Figure 2A); (4) direct precipitation on the wetland water surface; (5) evapotranspiration; and (6) seasonal, as well as long-term, oscillations in lake level, which affect the extent of downstream tributary flooding. Seiches and storm surges frequently reverse the normal flow of the tributary into the lake, instead forcing an intrusion of lake water up the channel and into the surrounding wetland. The rapid and ephemeral events involving the fill-and-drain cycles and storm surges, seldom observed by most visitors to Great Lakes tributary mouths, have been documented on videotape (Krieger and Wright 1990).

Methods are available for estimating discharge in backwater areas subject to reversing flows with the use of various types of multidirectional velocity meters, including mechanical, electromagnetic and acoustic velocity meters. The characteristics of each

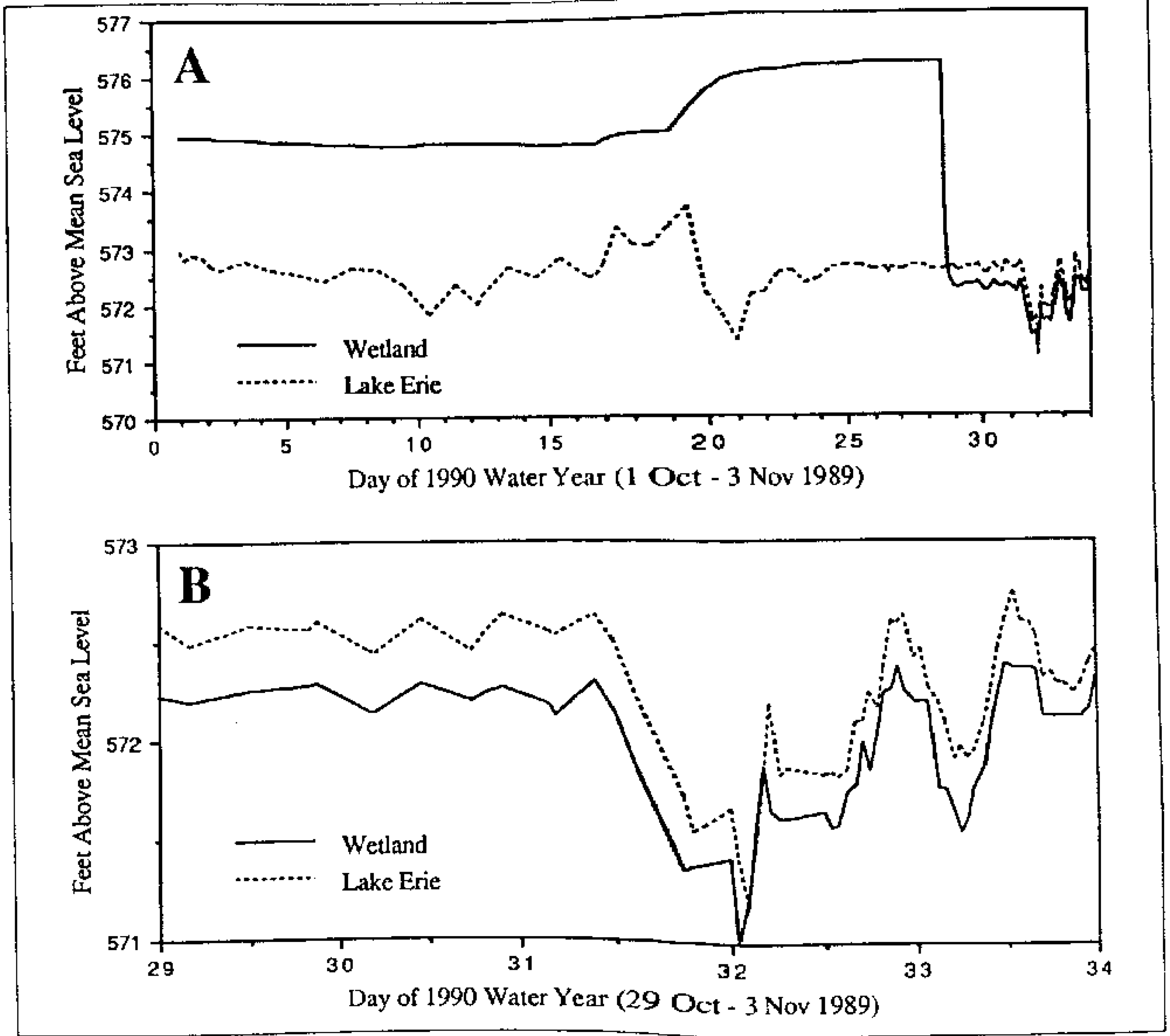

Figure 2 *Water level changes in the Old Woman Creek wetland (U.S.G.S. Station 04199165) and adjacent Lake Erie (Ruggles Beach, U.S.G.S. Station 04199175) during October and early November 1989.* ***Fig. 2A*** *shows the higher water level in the wetland, which broke through the barrier beach beginning at about 1100 hours on 28 October 1989 and quickly fell to the level of Lake Erie.* ***Fig. 2B*** *shows detail of Fig. 2A for the period 29 October to 3 November 1989. The graph shows from five to seven data points each day on 29, 30 and 31 October and hourly data points on 1 and 2 November (days 32 and 33) in order to demonstrate the greater number of rising and falling stages which are detected with more detailed data sets. The lake stage appears to be calibrated at a slightly higher elevation.*

type of meter and the complexities of their use are described by Kennedy (1984).

Difficulties have been encountered in the use of single meters for measuring discharge at the drowned mouths of tributaries and in the outlets of coastal wetlands. Adequate measurement in some circumstances may require that multiple meters be employed at several points horizontally and vertically within a cross-section of the outlet. During periods of low flow, the velocity is highly variable over time and space, and flow may simultaneously be in opposite directions at different points in the cross-section. Such flow reversals are only detectable by a battery of velocity meters strategically placed in the cross-section. These requirements make the measurement of stream discharge at lake level expensive and computationally complex.

Because of the difficulties and expense in estimating discharge with velocity meters in areas under the influence of lake stage, and when meters are not available, it is desirable to employ an alternative approach that is independent of velocity measurements. One approach that has been attempted makes use of the differences, at any given point in time, in the stages at three geographic points—one located in the wetland a few hundred meters upstream of the discharge point, another at the discharge point—and the third a few hundred meters offshore in the lake. The slope of the differences is used to calculate the expected flow rate of water due to gravitation past the discharge point, taking into account frictional forces and other factors.

The present report describes an alternative method for estimating discharge and materials fluxes between a coastal wetland and a lake. The method relies on a detailed knowledge of the bathymetry of the wetland and changes in area and volume of the wetland as described by hypsographic (depth-area) and depth-volume curves. The method was developed specifically to determine the loads of sediment, nutrients and pesticides moving through the Old Woman Creek wetland into Lake Erie (Figure 3). The downstream loads estimated by this method were subtracted from the upstream loads estimated by the standard approach described above for free-flowing streams. The difference was the amount estimated to be retained within the wetland or changed to other chemical states before leaving the wetland.

Methods of Data Collection for Discharge and Water Chemistry

The data were collected at two instrumented stations on Old Woman Creek, one located upstream above the influence of Lake Erie and the other downstream at a constriction near the mouth, where fluctuating lake levels and the shifting barrier beach continuously modify flows and water exchange between the wetland and lake (Figure 3). At the upstream site (Berlin Road, U.S.G.S. station 04199155), where the creek drains 83 percent of the total watershed, stream stage was recorded and water samples were collected. Electrical service to a winterized building permitted the year-round operation of automated, refrigerated water samplers (Isco Model 2700) for the collection of samples for sediment, nutrient and pesticide analysis. A submersible pump was permanently anchored in the creek and pumped water into a plastic washtub continuously for about one hour before and after each water sample was scheduled to be collected by the autosampler. The autosampler was timed to collect a water sample from the washtub every eight hours (0400, 1200, 2000 hours). From April through August, a second autosampler collected pesticide samples from the same washtub. Details of the collection, analytical and quality control procedures are described by Baker (1988).

An identical sampling protocol was followed at the downstream site, where samples were collected from the middle of a wetland constriction about 30 meters upstream of the U.S. Highway 6 bridge (Figure 3). An intake pipe with a submersible pump at the end was suspended in the water column by a large float, which kept the pump above the bottom and about 0.5 meters below the surface.

It was not desirable nor feasible to analyze all of the samples, since three were collected each day. During low flow periods at both sites, only a single sample per day (usually at 1200 hours) was analyzed, and when no surface flow was present at a site, several days were often allowed to elapse between analyzed samples. When storm runoff was present upstream, as demonstrated by increased

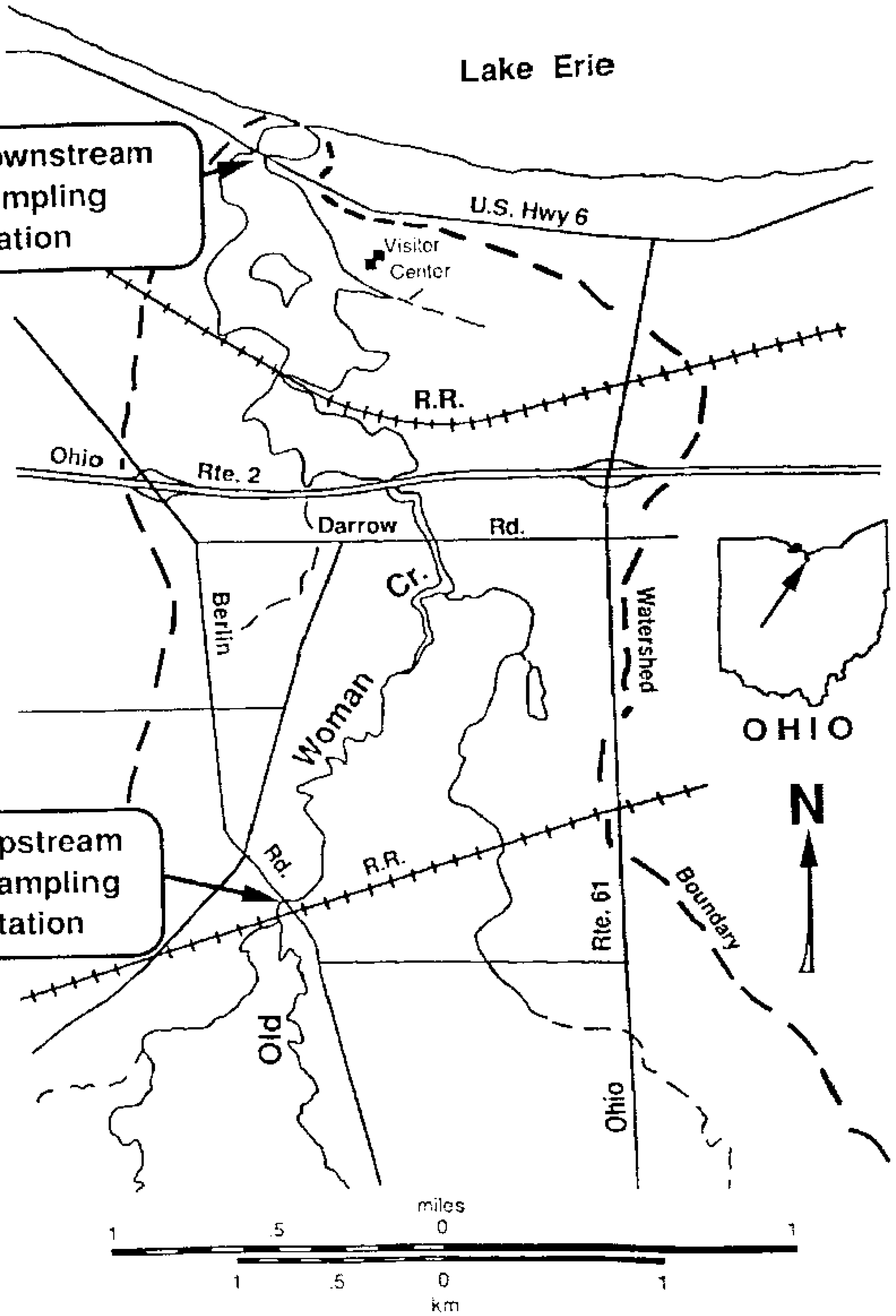

Figure 3 *Lower end of the 68.9* km^2 *Old Woman Creek watershed, Erie County, Ohio. The two arrows show the locations of the upstream and downstream transport stations.*

turbidity in the samples, all three samples taken each day were analyzed to the point where turbidity returned to background levels; afterwards, analysis of one sample per day was resumed until the next storm event.

Conductivity (specific conductance), as an indirect indicator of the ionic content of water, is a sensitive marker of water masses from different sources. For instance, groundwater entering Old Woman Creek is rich in dissolved minerals, and during low flow, the conductivity of the creek water sometimes exceeds 100 mS m^{-1} (1,000 µmhos cm^{-1}) at 25°C. During storm runoff events, groundwater is diluted by rain water, occasionally yielding creek water conductivities below 40 mS m^{-1}. The conductivity of Lake Erie water is almost always below 35 mS m^{-1}, with a western basin mean of 28.2 mS m^{-1} (Krieger 1989). By contrast, the conductivity of Old Woman Creek wetland water has varied from 17.6 to greater than 100 mS m^{-1} (Krieger 1989; Krieger, unpublished Ohio Sea Grant data).

At the downstream site, the conductivity of every sample collected throughout the year was analyzed. Abrupt differences in conductivity between two adjacent samples indicated a change in water masses due to changing water levels or the influx of upland storm water. Thus, two or three samples per day were analyzed as indicated by conductivity changes and storm events.

Method for Calculating Materials Fluxes

Determination of Stage Intervals The approach used at the free-flowing upstream site to calculate the time interval represented by each sample, in which the midpoints in time between the previous and following samples delimit the interval, cannot be applied to the downstream site at lake level. During the time between samples at the lake level site, the wetland stage may rise and fall several times, usually reflecting short-term intrusions of lake water into the wetland. Water sampled at that site derives from the lake or the wetland, depending on whether flow is directed into or out of the wetland at the time of sampling. Because the sampling site is situated about 100 meters upstream of the mouth, water flowing upstream past the sampling point could be wetland water rather than lake water, which may not yet have traveled that far upstream. However, the identity of the water mass sampled can be determined because the wetland and lake water masses have different conductivities, as noted above. In calculating materials loading, a sample can represent only the water mass from which it was taken; the alternate water mass must be represented by a different sample. Thus, it is necessary to know all the time intervals when the stage was rising and falling (hereafter called "stage intervals") and to apply the correct water chemistry data to each stage interval.

Two questions must be answered before water samples can be assigned to stage intervals. First, because the sampling site is slightly inland from the mouth of the wetland (Figure 3), was the magnitude of the stage change sufficient for the water mass previously sampled at the end of the pump intake line to be replaced by a different water mass? For example, during a rising stage, was the wetland water mass displaced by a mass of incoming lake water at the intake point? Second, what resolution is desirable for recording stage changes? Over a period of several days, a greater number of rising and falling stage intervals will be observed in stage data recorded every 15 minutes than in stage data recorded hourly. Likewise, hourly data will yield more stage intervals than will daily data (Figure 2B). The largest stage changes will usually be apparent in the daily data. Because water samples for this project were collected every eight hours, it makes little sense to be concerned with changes occurring during intervals as short as 15 minutes. Many stage changes observed even in hourly data are small (<0.10 ft.) and of less than three hours duration (see sample stage data sheet, Appendix C). In the computations that follow, only stage oscillations of at least 0.10 foot (30.5 cm) as recorded in the hourly data were used. Even so, five or more stage intervals may be found within some 24-hour periods. The stage intervals of at least 0.10 foot for October 1989, as recorded in the hourly data shown in Appendix C, are characterized in Table 1 and appear in Figure 2.

Assignment of Chemical Samples to Intervals Once the stage intervals have been determined, it is necessary to assign a water sample to each interval so that sediment and chemical fluxes can be calculated. Because the number of analyzed samples varies from less than one to three per day, it is often necessary to apply a particular sample to more stage intervals than the one during which it was collected. Table 2 lists the dates and times when samples were collected in October 1989.

A protocol for assigning samples to stage intervals has been developed to ensure consistency of the process. This protocol is presented in Figure 4 in a form similar to a dichotomous key. That is, at each step, or couplet, a decision about the stage interval or the sample, if one was collected during the interval, must be made. This protocol was followed in the flux calculations, which are presented later in this report. An explanation of each step is provided here.

Step 1 requires knowing whether a water sample was collected during the interval under consideration. If so, then it may be possible for that sample to be used for the flux calculations for that interval, as determined in steps 2, 3 and 4. If not, a sample taken during another interval must be applied to this interval in order to provide concentration data for computing fluxes.

In **Step 2,** the direction of the stage oscillation must be determined. If the water sample was collected while the stage was *falling*, the sample invariably will represent water that has passed through the wetland. Thus, that sample can be used to calculate materials flux. On the other hand, if the stage was *rising*, the sample may have been taken from either a lake water mass or a wetland water mass (because the sampling point is slightly upstream of the mouth).

Step 3 provides for determining whether the water sample can be used to calculate the flux of materials entering from the lake. Water may be flowing out into the lake, despite the fact that the wetland stage is rising in response to a rising lake stage. This occurs when the total water input into the wetland from precipitation and discharge from the upland tributaries exceeds the change in volume resulting from the rising stage, after accounting for evaporation. An example of this is seen in the last stage interval for the month of October 1989 in Table 1. In such instances, the water sample collected during the interval should be used to calculate materials flux, and the flux should be added to the total loading to the lake.

If water was flowing into the wetland from the lake, as determined by the calculation in Step 3, then the identity of the water mass (lake or wetland) at the time of sampling must be determined before a decision can be made whether to use the water sample taken during that interval. This decision is made in **Step 4** by observing the conductivity of the sample, since this property provides a "signature" for lake water. Values below about 35 mS m^{-1} in the wetland result either from the intrusion of lake water or from the influx of low-conductivity storm water from upstream. If the sample conductivity is less than 35 mS m^{-1} during a rising stage with water flowing in from Lake Erie, the sampled water mass is assumed to be lake water. If higher conductivity values are encountered under that set of conditions, it is assumed that a wetland water mass was sampled and that lake water was entering the wetland but had not yet progressed to the sample intake line. Therefore, the present sample represents wetland water, not lake water, and it cannot be used to calculate materials flux into the wetland from the lake. **Step 5** then requires that the concentration values of the nearest sample to that interval (either before or after) with a conductivity less than 35 mS m^{-1} during an inflow from the lake be used to characterize the fluxes during that interval.

Under circumstances when the upstream tributaries are discharging through the wetland at a high rate after a rainstorm, the conductivity of the wetland water sometimes drops to values below 35 mS m^{-1} as a result of the dilution of high-conductivity groundwater with rainwater. The water mass is unmistakably wetland or creek water under those circumstances because of the strong outflow of water into the lake.

In those instances when no water sample was collected during a stage interval (Step 1), it is necessary to use a surrogate water sample. In **Step 6** it is determined whether the stage rose or fell during the interval. If the stage fell, the values of the last sample taken with a conductivity greater than 35 mS m^{-1} are used (**Step 7a**), since the wetland was discharging to the lake. If it was a rising stage, once again the direction of flow must be determined (**Step 7b**). If the discharge was into Lake

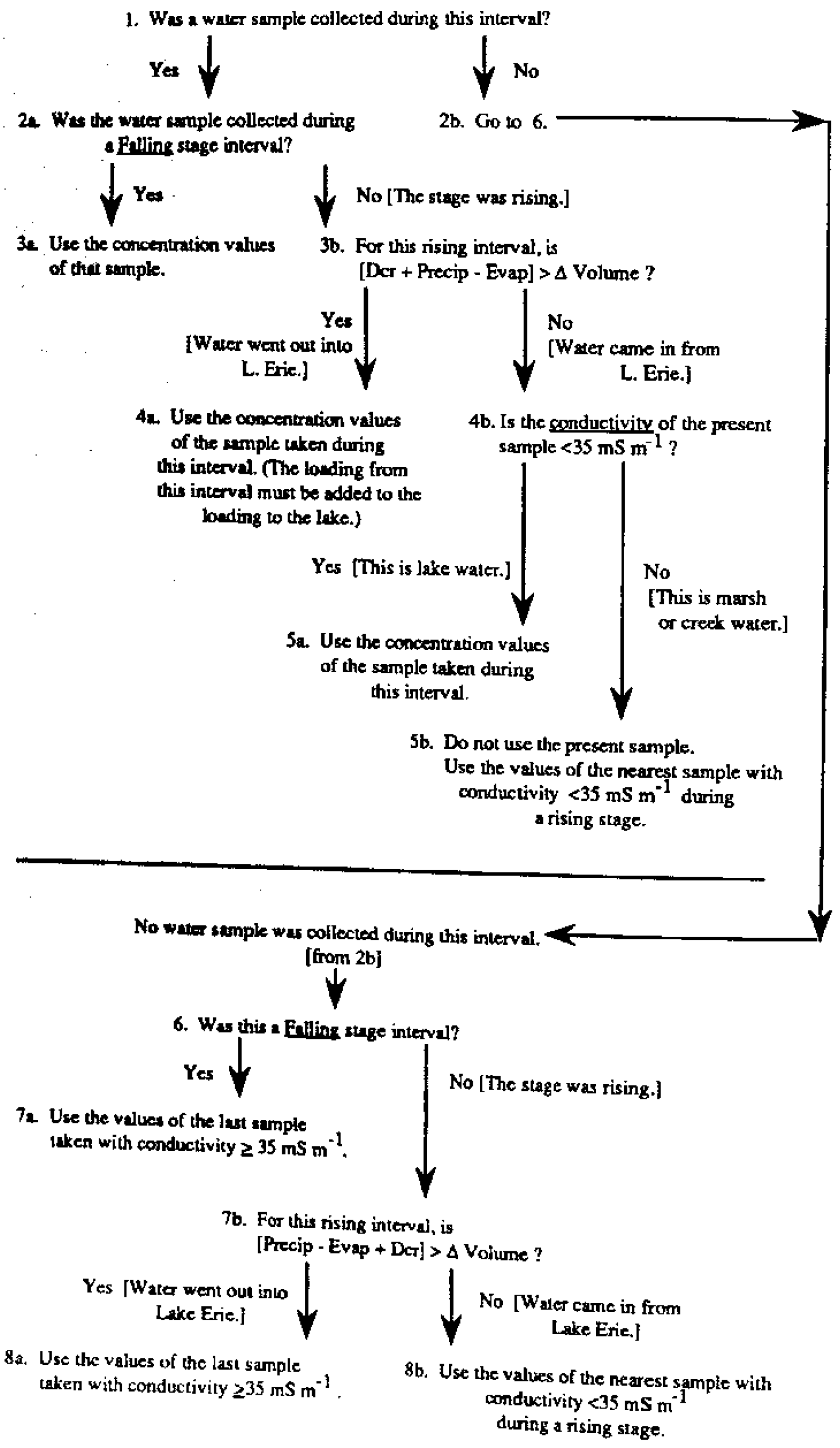

Figure 4 *Protocol for assignment of samples to stage intervals.*

Erie, the values of the last sample taken with a conductivity greater than or equal to 35 mS m^{-1} are used (**Step 8a**). If the discharge was from Lake Erie, the values of the nearest sample with a conductivity less than 35 mS m^{-1} during a rising stage are used (**Step 8b**). The results of this protocol for the month of October 1989 are shown in the far right column for each interval in Table 1.

Calculation of Discharge for Each Stage Interval In order to complete the protocol discussed above for rising stage intervals (steps 3b and 7b), and to compute fluxes for all intervals, data are needed on precipitation, evaporation, surface discharge into the wetland from its watershed, groundwater exchange, and the change in volume of the wetland. In essence, a water budget must be calculated for each stage interval, and it must take into account each of the pathways in the conceptual model shown in Figure 1.

Discharge for falling stages is calculated differently than discharge from rising stages, although the same parameters are used. The following equations assume negligible groundwater interaction in the model (Figure 1). An equation similar to Eq. (2) below was constructed independently by Mitsch et al. (1989), who also disregarded groundwater interchange in their computations.

During a *falling stage interval*, discharge through the mouth of the wetland is calculated by the equation:

$$D = \Delta V - \text{Evap.} + \text{Precip.} + D_{cr} \qquad (2)$$

where:

D = discharge from the wetland during the interval (in m^3)

$\Delta V = |V_b - V_e|$; V_b = volume of water in the wetland at beginning of the interval and V_e = volume at end of the interval

Evap = evaporation during the interval (in m^3)
= total evap (in m) times mean area (in m^2) of wetland during the interval; beginning and ending areas are determined from the hypsographic table (Appendix D)

Precip = precipitation during the interval (in m^3)
= total precip (in m) times mean area (in m^2) of wetland during the interval

D_{cr} = discharge from the total watershed via the tributaries (in m^3 sec^{-1})
= $D_{Berlin} + D_{other} = 1.187(D_{Berlin})$, where
D_{Berlin} = mean hourly discharge at the Berlin Road gaging station, based on the hourly stages reported by U.S.G.S. during the interval, and
D_{other} = discharge from the remainder of the watershed, extrapolated from D_{Berlin}.

During a *rising stage interval*, discharge is calculated with the equation:

$$D \text{ (in } m^3) = -[\Delta V + \text{Evap.} - \text{Precip.} - D_{cr}] \qquad (3)$$

Several points should be noted in regard to performing the calculations. First, it is of interest to know the total inflows into the wetland from Lake Erie, as well as the total outflows from the wetland into the lake. By adding the inflows and outflows for a period of time, the net water budget for the wetland is derived. Therefore, Eq. (3) results in a negative discharge value when water flows in from Lake Erie and a positive discharge value when water flows out into Lake Erie.

Second, change in volume of the wetland is determined from the depth-volume table by subtracting the volume represented by the stage reading at the beginning of the interval from the volume represented by the stage reading at the end of the interval. The depth-volume table, expanded from one developed by Herdendorf and Hume (1991), is presented in Appendix D.

Third, precipitation and evaporation data add a degree of complexity to the calculations, in that these data are measured on a daily basis, not synchronized with the timing of stage intervals. Although it is possible to extract detailed, continuous data from the chart recordings, the manual effort involved makes this option prohibitive. Thus, when several stage intervals fall within a single day, which is often the case, the daily evaporation and precipitation values must be subjectively apportioned among the intervals. Furthermore, evaporation is measured from the evaporation pan directly as *net* evaporation, rather than total evaporation. Total evaporation (in mm) is calculated as:

Table 1 *Stage intervals, volume changes, precipitation, evaporation and total discharge at the Old Woman Creek wetland during October 1989.*

Inter-val	Date	Interval (seconds) Began - Ended	Stages (feet) Begin.	End	Rose/ Fell	Vol. (10^3m^3) Begin.	End	Δ	Mean Area (m^2)	Precip. mm	10^3m^3	Evap. mm	m^3	D_{cr}	Total Discharge 10^3m^3
1	10/01 - 10/28	1300		6.11	R				MOUTH CLOSED						0*
2	10/29	28/1300-29/0400 (54,000)	6.11	2.19	F	647.6	41.2	-606.4	429.4	0	0	1.27	0.55	4.08	+ 609.9
3	10/29	0400 - 2100 (61,200)	2.19	2.28	R	41.23	49.60	+ 8.37	231.3	0	0	2.5	0.58	4.41	- 4.53
4	10/30	2100-0500 (28,800)	2.28	2.14	F	49.60	38.27	- 11.33	224.2	0	0	0	0	2.08	+ 13.41
5	10/30	0500 - 1100 (21,600)	2.14	2.28	R	38.27	49.60	+ 11.33	224.2	0	0	2.24/3	0.17	1.49	- 10.01
6	10/30	1100 - 1600 (18,000)	2.28	2.13	F	49.60	37.91	- 11.69	223.0	0	0	2.24*2/3	0.34	1.24	+ 12.59
7	10/30	1600 - 2200 (21,600)	2.13	2.26	R	37.91	47.74	+ 9.83	219.9	0	0	0	0	1.56	- 8.27
8	10/31	2200 - 0500 (25,200)	2.26	2.12	F	47.74	37.55	- 10.19	218.6	0	0	0	0	1.82	+ 12.01
9	10/31	0500 - 1000 (18,000)	2.12	2.29	R	37.55	50.53	+12.98	223.3	0	0	0	0	1.30	- 11.68
10	10/31	1000-1900 (32,400)	2.29	1.35	F	50.53	13.83	- 36.70	144.6	4.57	0.66	1.55	0.22	2.56	+ 39.70
11	10/31	1900 - 2400 (18,000)	1.35	1.42	R	13.83	14.57	+ 0.74	42.49	0	0	0	0	1.55	+ 0.81

* Some wetland water seeped through the sand barrier beach into Lake Erie.

$$E_T = \text{Precip.} + \text{Net Evap.} \quad (4)$$

Precipitation and pan evaporation data for October 1989 at the Old Woman Creek wetland are presented in Table 3. Of course, it is not necessary to separate precipitation from evaporation in the water budget model (Figure 1), but instead those two components can be combined into a single net evaporation term in the equations. When precipitation exceeds total evaporation, the net evaporation value will be negative.

To apply precipitation and evaporation to the discharge equations, the measurements (in meters rather than the original inches) must be converted to volumes (m^3) by multiplying them by the mean surface area (m^2) of the wetland during the interval (Table 3). The mean surface area is derived from the hypsographic table (Appendix D) by adding the areas of the beginning and ending stages and dividing by two.

Fourth, discharge from the entire watershed via tributaries to the wetland (D_{cr}) includes the mainstem of Old Woman Creek and perennial and intermittent streams that enter the wetland directly around its perimeter. Old Woman Creek, at the gaging station where discharge is measured at Berlin Road (D_{Berlin}), drains 83 percent of the total watershed. Another 15.5 percent of the watershed is drained by tributaries below the gaging station, and the surface of the wetland, when full, accounts for 1.5 percent of the watershed. Thus, all discharge values from the gaging station are multiplied by 1.187 (98.5%/83.0%) to estimate the total surface discharge into the wetland. An additional factor should be built into the equation in the future to account for periods of very low flow in the mainstem of Old Woman Creek, when there may be no surface flow into the wetland from any other tributaries (i.e., $D_{cr} = D_{Berlin}$). However, only a small error in the total loading probably results from the lack of inclusion of this factor because a great majority of the discharge, and therefore pollutant and nutrient inputs, occurs during high flow events, when the smaller tributaries, especially the one draining 7.5 percent of the watershed east of Berlin Road, are flowing.

The rating tables provided by the U.S.G.S. report discharge in cubic feet per second. To obtain a discharge for the equations, an average creek stage at Berlin Road is computed for the wetland stage interval by dividing the sum of all hourly creek stages by the number of hourly readings. The average creek stage is converted to cubic feet per second. The total cubic meters of water discharged is then:

$$m^3 = ft^3/sec. \times 0.0283\ m^3/ft^3 \times sec. \quad (5)$$

The discharges of Old Woman Creek at Berlin Road in October 1989 are listed in Table 4 for each sample interval at that site.

Fifth, no direct measurements of exchanges between groundwater and surface water were made during this study. The net groundwater exchange for all intervals is assumed to be zero. Matisoff and Eaker (1989, 1992) showed that diffusional fluxes of solutes between Old Woman Creek wetland sediments and the overlying water were insignificant in comparison to seepage fluxes, and that the seepage fluxes composed an insignificant proportion of the total solute flux values obtained using flux chambers. They found that groundwater input occurred around the perimeter of the wetland, varying in their studies from zero cubic feet per second during a prolonged summer drought to 2.4 cubic feet per second after the drought subsided. They also measured discharge through the barrier beach, which ranged from 0.076 cubic feet per second to 0.42 cubic feet per second for the period of June through December. Thus, it appears that the maximum groundwater input rates could have accounted for a significant proportion of total water exchange in the wetland during some periods of very low surface water input, but that groundwater input is probably insignificant when compared to the very large volumes of water transported through the wetland during high-flow periods (Table 4).

Table 2 *Conductivity and concentrations of total phosphorus, soluble reactive phosphorus, and total suspended solids in water samples collected near the mouth of Old Woman Creek wetland from 17 October (891017) through 3 November 1989 (891103). Conductivity was read on all but one of the samples collected; a "-" indicates that the parameter was not measured in that sample. Letters to the left of sample dates are used to designate those samples discussed in the text.*

	Date	Time	Total P mg L^{-1}	Soluble Reactive P mg L^{-1}	Total Suspended Solids, mg L^{-1}	Conductivity mS m^{-1}
	891017	0400	0.163	0.002	50	53.5
	891017	1200	0.156	0.006	51	52.8
	891017	2000	-	-	-	53.0
	891018	0400	-	-	-	52.9
	891018	1200	0.157	0.007	53	52.9
	891018	2000	-	-	-	53.1
	891019	0400	-	-	-	44.4
	891019	1200	0.118	0.007	87	35.2
	891019	2000	-	-	-	41.5
	891020	0400	-	-	-	43.5
	891020	1200	0.113	0.015	34	45.8
	891020	2000	-	-	-	47.2
	891021	0400	-	-	-	48.3
	891021	1200	0.100	0.011	24	48.9
	891021	2000	-	-	-	48.6
	891022	0400	-	-	-	48.2
	891022	1200	0.087	0.006	17	48.6
	891022	2000	-	-	-	49.2
	891023	0400	-	-	-	50.3
	891023	1200	0.100	0.003	13	51.9
	891023	2000	-	-	-	50.1
	891024	0400	-	-	-	51.8
	891024	1200	0.078	0.001	10	51.2
	891024	2000	-	-	-	52.4
	891025	0400	-	-	-	51.9
	891025	1200	0.078	0.001	11	52.2
	891025	2000	-	-	-	52.9
	891026	0400	-	-	-	52.2
	891026	1200	0.076	0.001	12	52.1
	891026	2000	-	-	-	52.3
	891027	0400	-	-	-	52.4
	891027	1200	0.086	0.001	14	-
	891027	2000	0.274	0.007	190	58.4
	891028	0400	0.237	0.013	74	60.2
	891028	1200	0.242	0.012	44	60.0
A	891028	2000	0.257	0.006	64	61.0
B	891029	0400	0.287	0.006	77	61.5
C	891029	1200	0.253	0.007	65	61.2
D	891030	2000	0.258	0.029	75	65.0
	891031	0400	-	-	-	62.2
	891031	1200	-	-	-	59.3
E	891031	2000	0.314	0.022	155	65.3
	891101	0400	-	-	-	68.0
	891101	1200	-	-	-	69.1
F	891101	2000	0.160	0.019	50	61.0
G	891102	0400	0.138	0.020	48	54.0
H	891102	1200	0.096	0.023	26	38.2
I	891102	2000	0.135	0.018	64	45.9
J	891103	0400	0.075	0.014	40	26.4
	891103	1200	0.118	0.015	54	56.4
	891103	2000	0.075	0.014	38	32.8

Table 3 *Measured amounts and calculated volumes of precipitation and evaporation during October 1989 at the Old Woman Creek wetland.*

Date	Mean Stage (ft)	Mean Area 10^3m^2	PRECIPITATION Measured mm	Vol. 10^3m^3	EVAPORATION Net mm	Total mm	Vol. 10^3m^3
1	574.92	569.0	0	0	2.6	2.6	1.48
2	574.91	568.6	0	0	3.86	3.86	2.19
3	574.88	567.2	0	0	4.04	4.04	2.29
4	574.86	566.3	0	0	3.23	3.23	1.83
5	574.85	565.8	0	0	4.22	4.22	2.39
6	574.84	565.8	0	0	2.49	2.49	1.41
7	574.81	564.0	0	0	3.12	3.12	1.76
8	574.80	563.5	0	0	1.61	1.61	0.91
9	574.78	562.6	0	0	1.61	1.61	0.91
10	574.80	563.5	13.2	7.44	-10.72	2.48	1.40
11	574.82	564.4	0	0	3.35	3.35	1.89
12	574.82	564.4	0	0	2.95	2.95	1.66
13	574.81	564.0	0	0	3.75	3.75	2.12
14	574.80	563.5	0	0	3.75	3.75	2.11
15	574.79	563.0	0	0	3.75	3.75	2.11
16	574.79	563.0	25.1	14.13	-24.22	0.88	0.50
17	574.93	569.5	10.2	5.81	-4.66	5.54	3.16
18	574.97	571.3	2.03	1.16	0	2.03	1.16
19	575.34	588.4	33.3	*	-23.57	*	*
20	575.82	620.4	1.27	*	-0.91	*	*
21	575.95	629.9	0.25	*	-1.81	*	*
22	576.02	635.0	0	0	0	0	0
23	576.07	638.7	0	0	1.70	1.70	1.09
24	576.10	640.8	0	0	1.19	1.19	0.76
25	576.11	641.6	0	0	1.80	1.80	1.15
26	576.11	641.6	0	0 1.32	1.32	1.32	0.85
27	576.11	641.6	0	0	1.45	1.45	0.93
28	574.77	562.1	0	0	1.78	1.78	1.00
29	572.24	232.5	0	0	2.49	2.49	0.58
30	572.21	223.3	0	0	2.24	2.24	0.50
31	571.90	143.8	4.57	0.66	-3.02	1.55	0.22
		Totals	**89.92**	**50.54**	**+10.61**	**79.31**	**43.59**

*The data collection times varied between precipitation and evaporation on these dates, yielding incongruent data. Totals for the period 19-21 October 1989 were precipitation 34.82 mm, volume of precipitation 21.34 10^3 m^3, net evaporation -26.29 mm, total evaporation 8.53 mm, volume of evaporation 5.23 10^3 m^3. Mean area for the period was 612.9 10^3m^2.

Table 4 *Sample times, discharge intervals, total discharge per interval and fluxes of materials in Old Woman Creek at Berlin Road in October 1989.*

Date	Sample Time	Interval Beg.	Interval End	Interval Hrs	Stage Beg.	Stage End	Stage Mean	Mean Disch. cfs	Total Discharge $10^3 m^3$	kg of materials SRP	kg of materials TP	kg of materials TSS
890930	1200	2400										
891001	1200	2400	2400	24	2.51	2.51	2.51	0.635	1.55	0.0140	0.043	10.9
891002	1200	2400	2000	20	2.51	2.53	2.52	0.672	1.37	0.0096	0.037	6.9
891003	0400	2000	0800	12	2.53	2.50	2.51	0.635	0.78	0.0070	0.023	5.5
891003	1200	0800	2400	16	2.50	2.49	2.49	0.562	0.92	0.0092	0.027	15.6
891004	1200	2400	2400	24	2.49	2.47	2.48	0.525	1.28	0.0124	0.037	12.8
891005	1200	2400	2400	24	2.47	2.46	2.47	0.491	1.20	0.0084	0.031	9.6
891006	1200	2400	2400	24	2.46	2.45	2.46	0.459	1.12	0.0090	0.034	15.7
891007	1200	2400	2400	24	2.45	2.42	2.43	0.372	0.91	0.0055	0.031	9.1
891008	1200	2400	2400	24	2.42	2.41	2.42	0.347	0.85	0.0026	0.027	7.7
891009	1200	2400	2000	20	2.41	2.41	2.41	0.323	0.66	0.0026	0.022	6.6
891010	0400	2000	0800	12	2.41	2.41	2.41	0.323	0.39	0.0016	0.012	3.9
891010	1200	0800	2400	16	2.41	2.76	2.65	1.333	2.17	0.0087	0.150	60.8
891011	1200	2400	2400	24	2.76	2.67	2.71	1.783	4.36	0.1134	0.458	34.9
891012	1200	2400	2400	24	2.67	2.61	2.64	1.268	3.10	0.0372	0.161	18.6
891013	1200	2400	2400	24	2.61	2.59	2.60	1.034	2.53	0.0152	0.111	15.2
891014	1200	2400	2400	24	2.59	2.56	2.58	0.931	2.28	0.0160	0.096	9.1
891015	1200	2400	2400	24	2.56	2.53	2.54	0.751	1.84	0.0184	0.083	7.4
891016	1200	2400	2000	20	2.53	2.65	2.53	0.710	1.45	0	0.080	8.7
891017	0400	2000	0800	12	2.65	3.13	3.06	7.554	9.24	1.3213	3.142	304.9
891017	1200	0800	1600	8	3.13	3.01	3.07	7.843	6.39	0.1981	2.307	581.5
891017	2000	1600	2400	8	3.01	2.91	2.96	5.169	4.21	0.1810	0.960	168.4
891018	0400	2400	0800	8	2.91	2.87	2.89	3.936	3.21	0.1380	0.523	70.6
891018	1200	0800	2400	16	2.87	2.85	2.86	3.474	5.66	0.0906	0.657	67.9
891019	1200	2400	1600	16	2.85	4.54	3.55	28.23	46.02	1.9328	15.509	6396.8
891019	2000	1600	2400	8	4.54	4.17	4.37	76.81	62.60	2.5040	14.148	3818.6
891020	0400	2400	0800	8	4.17	3.59	3.84	43.75	36.66	1.6130	6.929	1099.8
891020	1200	0800	2400	16	3.59	3.16	3.30	16.46	26.83	0.8854	3.783	697.6
891021	1200	2400	2400	24	3.16	3.06	3.11	9.091	22.23	0.3335	1.867	155.6
891022	1200	2400	2400	24	3.06	2.99	3.02	6.485	15.86	0.3172	0.936	63.4
891023	1200	2400	2000	20	2.99	2.93	2.96	5.169	10.53	0.0632	0.432	42.1
891024	0400	2000	0800	12	2.93	2.89	2.91	4.264	5.21	0.0365	0.234	36.5
891024	1200	0800	2400	16	2.89	2.86	2.88	3.777	6.16	0.0246	0.222	18.5
891025	1200	2400	2400	24	2.86	2.82	2.84	3.193	7.81	0.0156	0.250	23.4
891026	1200	2400	2400	24	2.82	2.79	2.81	2.805	6.86	0.0069	0.103	6.9
891026	1300	mouth opened										
891027	1200	2400	2400	24	2.79	2.77	2.78	2.458	6.01	0.0120	0.180	18.0
891028	1200	2400	2400	24	2.77	2.76	2.76	2.246	5.49	0.0165	0.165	11.0
891029	1200	2400	1600	16	2.76	2.75	2.75	2.146	3.50	0.0070	0.102	3.5
891030	2000	1600	0800	16	2.75	2.74	2.74	2.050	3.34	0.0301	0.137	16.7
891031	2000	0800	0800	24	2.74	2.78	2.76	2.246	5.48	0.6521	1.052	43.8
891101	2000	0800			2.76							
					Total Discharge for October 1989				323.61 x $10^3 m^3$			
Through 10/26	1200									9.9525	53.465	13,811.5
After 10/26	1300									0.7246	1.739	99.9
Total 10/89										10.6771	55.204	13,911.4

Example of Materials Flux Calculations

This method for calculating fluxes of materials through wetlands was developed in order to specifically characterize the functioning of the Old Woman Creek wetland as a sink, source or modifier of the major pollutants entering it. As an example, the fluxes of total phosphorus, soluble reactive phosphorus and total suspended solids in the samples collected from Old Woman Creek at Berlin Road in October 1989 are listed in Table 4, and the concentrations from which those fluxes were derived are shown in Table 5. The fluxes of water and materials through the wetland are shown in Table 6. Eleven stage intervals were recorded during the month. The first interval represented the period 1-28 October at 1300 hours, when the mouth of the wetland was closed and there was no interchange of surface water between the wetland and Lake Erie, except for some unmeasured seepage through the barrier beach into the lake and perhaps some overtopping of surf over the beach. Stage intervals 2 through 11 represented alternating periods of falling and rising water levels (also shown in Table 1), beginning with the opening of the mouth at 1300 hours on 28 October and ending at 2400 hours on 31 October.

The volume of precipitation and surface inflow from upstream are shown in Table 6 for interval 1. Upstream inflow is not shown for the remaining intervals because the individual upstream sample intervals did not correspond with the downstream stage intervals. The ultimate objective was to obtain flux estimates for the entire month, rather than for individual sample or stage intervals. Total upstream inflow is shown in the bottom part of Table 6 for the two periods before and after 28 October at 1300 hours.

Discharge at the wetland mouth is shown in Table 6 for each stage interval, negative values indicating inflow from Lake Erie. Water flowed from the wetland into the lake during the last rising stage interval in October 1989 (interval 11) because the volume of upstream discharge into the wetland exceeded the volume of evaporation plus the increase in volume of the wetland during the interval.

The samples used to calculate materials fluxes during each stage interval are shown in Table 2. Two samples were collected during interval 2, both representing the wetland water mass. Thus, the average concentrations of the two samples (A and B) were used. No samples were collected during the next three falling stage intervals, so it was necessary to use samples A and B again to calculate fluxes during those intervals. Sample C (Table 2) was never used because it was collected during a rising stage while lake water was entering the wetland, yet it was taken from the wetland water mass, as indicated by its high conductivity. Sample D, collected during falling interval 10, represented wetland water, and so was applied to fluxes for that interval. Sample E also represented wetland water but was collected during a rising stage (interval 11). However, because water was flowing out of the wetland into the lake during the interval, it was appropriate to use sample E for interval 11. During the first four rising stage intervals after 28 October (Table 1), water entered the wetland from Lake Erie (Table 6); however, no samples collected during those intervals represented lake water (as judged by their conductivities), so the next lake water sample encountered in the data (Table 2, sample J on 3 November 1989) was applied to each of those intervals.

The movement of soluble reactive phosphorus, total phosphorus and total suspended solids into and out of the wetland and the percentage loss of each material between the upstream and downstream ends are shown in Table 6. During the entire month of October 1989, 11.29 kilograms of soluble reactive phosphorus entered the Old Woman Creek wetland via atmospheric deposition or surface flow, while 4.58 kilograms (net) moved out of the wetland into Lake Erie, equivalent to a loss of 41 percent of the input amount. The lost SRP (Soluble Reactive Phosphorus) was either stored in that form somewhere in the wetland ecosystem or it was changed to another form of phosphorus, such as intracellular phosphorus in algae. The fate of the lost SRP should be the subject of additional investigation. Unlike the case for SRP, much (322 %) more total phosphorus left the wetland than entered it during October 1989. The difference, which far

Table 5 *Conductivity and concentrations of total phosphorus soluble reactive phosphorus and total suspended solids in water samples collected from Old Woman Creek at Berlin Road, October through early November 1989.*

Date	Time	Total P mg L^{-1}	Soluble Reactive P mg L^{-1}	Total Suspended Solids, mg L^{-1}	Conductivity mS m^{-1}
891001	1200	0.028	0.009	7	88.9
891002	1200	0.027	0.007	5	88.1
891003	0400	0.029	0.009	7	89.0
891003	1200	0.029	0.010	17	88.5
891004	1200	0.029	0.008	10	88.7
891005	1200	0.026	0.007	8	89.1
891006	1200	0.030	0.008	14	89.3
891007	1200	0.034	0.006	10	90.1
891008	1200	0.032	0.003	9	90.5
891009	1200	0.033	0.004	10	91.0
891010	0400	0.031	0.004	10	91.3
891010	1200	0.069	0.004	28	82.1
891011	1200	0.105	0.026	8	97.1
891012	1200	0.052	0.012	6	90.5
891013	1200	0.044	0.006	6	90.3
891014	1200	0.042	0.007	4	91.5
891015	1200	0.045	0.001	4	91.9
891016	1200	0.055	0.000	6	92.4
891017	0400	0.340	0.143	33	88.9
891017	1200	0.361	0.031	91	76.0
891017	2000	0.228	0.043	40	79.1
891018	0400	0.163	0.043	22	83.0
891018	1200	0.116	0.016	12	86.2
891019	1200	0.337	0.042	139	58.6
891019	2000	0.226	0.040	61	54.7
891020	0400	0.189	0.044	30	54.6
891020	1200	0.141	0.033	26	55.7
891021	1200	0.084	0.015	7	65.1
891022	1200	0.059	0.020	4	70.4
891023	1200	0.041	0.006	4	75.2
891024	0400	0.045	0.007	7	74.2
891024	1200	0.036	0.004	3	76.9
891025	1200	0.032	0.002	3	77.8
891026	1200	0.030	0.002	2	79.1
891027	1200	0.030	0.002	3	80.5
891028	1200	0.030	0.003	2	81.6
891029	1200	0.029	0.002	1	82.5
891030	2000	0.041	0.009	5	81.9
891031	2000	0.192	0.119	8	84.7
891101	2000	0.042	0.016	5	83.3
891102	2000	0.034	0.011	5	82.2
891103	2000	0.035	0.013	5	83.9

Table 6 *Water and material fluxes through the Old Woman Creek wetland calculated for October 1989.*

Stage Interval	Precip. $10^3 m^3$	Surface Inflow $10^3 m^3$	Discharge $10^3 m^3$	Sample Used*	FLUXES, kg: Soluble Reactive Phosphorus			Total Phosphorus			Total Suspended Solids		
					In	Out	% Loss	In	Out	% Loss	In	Out	% Loss
1	49.9	296.4	0†	-†	0.59 p@ 9.95 s@	0	0%	1.9 p 53.5 s	0	0%	150 p 13,812 s	0	0%
2			+ 609.9	(A+B)/2		+ 3.66			+ 165.9			+ 42,998	
3			- 4.5	J		- 0.06			- 0.3			- 181	
4			+ 13.4	(A+B)/2		+ 0.08			+ 3.7			+ 945	
5			- 10.0	J		- 0.14			- 0.8			- 400	
6			+ 12.6	(A+B)/2		+ 0.08			+ 3.4			+ 888	
7			- 8.3	J		- 0.12			- 0.6			- 331	
8			+ 12.0	(A+B)/2		+ 0.07			+ 3.3			+ 847	
9			- 11.7	J		- 0.16			- 0.9			- 467	
10	0.7		+ 39.7	D	0.02 p	+ 1.15		0.1 p	+ 10.2		6 p	+ 2,978	
11			+ 0.8	E		+ 0.02			+ 0.3			+126	
Before† 10/28 1300	49.9	296.4	0		10.54	0	0%	55.4	0	0%	13,962	0	0%
After 10/28 1300	0.7	27.3	Net 653.9		0.74	+4.58	619%	1.8	+184.2	10,233%	106	47,403	44,720%
Total for Oct. '89	50.6	323.7	Out 688.4 <u>In - 34.5</u> Net +653.9		0.61 p <u>10.68 s</u> 11.29 total	+4.58	41%	2.0 p <u>55.2 s</u> 57.2 total	+184.2	322%	156 p <u>13,912 s</u> 14,068 total	+47,403	337%

*See Table 2 for sample characteristics.

†Mouth was closed throughout the interval 1-28 October 1989 at 1300 hours, with some unmeasured see page through barrier beach.

@p = precipitation and other atmospheric deposition; s = surface flow exceeds the amount of the lost SRP, most likely represents phosphorus stored within plankton and adsorbed to particulate matter during the course of the summer, which was exported primarily during the opening of the mouth of the wetland (interval 2, Table 6).

Summary and Conclusions

A method has been presented for the estimation of the fluxes of water and materials between lakes and their coastal wetlands where the two are separated by a constricted passage or "mouth." The method was developed specifically to determine annual and seasonal fluxes at the mouth of the Old Woman Creek wetland on the south shore of Lake Erie, but it should be equally applicable to large lakes throughout the world possessing similar types of coastal wetlands. A quantitative knowledge of the capacities of such wetlands to store, modify and release various materials, especially sediment, nutrients and toxic pollutants, is essential to our progress in understanding the functional values of these shallow aquatic ecosystems and the nature of their interactions with the receiving lakes.

To calculate a water budget and materials fluxes for a single month is a very time-consuming and tedious task. Before the method can be applied efficiently to estimate seasonal and annual mass balances, it will be necessary to computerize the database and the mathematical calculations. This should be the next step in the further development and refinement of the method.

Acknowledgments

The work presented here would not have been possible without a great amount of field assistance from Dr. David M. Klarer, Scott Hoffman, Gary Obermiller and Gene Wright of the Old Woman Creek National Estuarine Research Reserve and State Nature Preserve, who helped construct instrumentation houses, monitored the sampling equipment and collected precipitation and evaporation data. A detailed bathymetric map and hypsographic and depth-volume curves for the wetland were developed by Drs. Charles E. Herdendorf of The Ohio State University and Terry M. Hume of the National Institute of Water and Atmospheric Research Ltd of New Zealand. Drs. Herdendorf and Hume, as well as Dr. Sharon Fitzgerald of the U.S. Geological Survey, Madison, Wisconsin, critically reviewed an earlier version of this report. The U.S.G.S. provided continuous stage data at the upstream and downstream sites and developed a discharge rating curve for the upstream site through a cooperative agreement with the Ohio Department of Natural Resources, Division of Natural Areas and Preserves. This work is a result of research sponsored in part by the Ohio Sea Grant College Program, project R/ES-4 under grant NA89AA-D-SG132 of the National Sea Grant College Program, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, as well as with funding from the Ohio Department of Natural Resources, Division of Natural Areas and Preserves and additional grants to the Water Quality Laboratory of Heidelberg College.

Literature Cited

Baker, D.B. 1988. *Sediment, nutrient and pesticide transport in selected lower Great Lakes tributaries.* U.S. Environ. Protect. Agency, Chicago, Illinois. EPA-05/4-88-001. 225 pp.

Brant, R.A., and C.E. Herdendorf. 1972. Delineation of Great Lakes estuaries. *Proc. 15th Conf. Great Lakes Res.* 1972:710-718. Internat. Assoc. Great Lakes Res.

Buchanan, D.B. 1982. *Transport and deposition of sediment in Old Woman Creek Estuary, Erie County, Ohio.* M.Sc. Thesis, The Ohio State Univ., Columbus, Ohio.

Dyer, K. 1990. The rich diversity of estuaries. *Estuaries* 13:504-505.

Herdendorf, C.E. 1990. Great Lakes estuaries. *Estuaries* 13:493-503.

Herdendorf, C.E., and T.M. Hume. 1991. *Morphometry and water storage in Old Woman Creek: a freshwater estuary in western Lake Erie.* OWC Tech. Rept. No. 7. Ohio Dept. Natural Resources, Div. Natural Areas and Preserves, Columbus, Ohio. 22 pp. + 5 app.

Internat. Joint Comm. 1986. *Great Lakes international surveillance plan (GLISP).* Vols. I and II. Windsor, Ontario.

Kennedy, E.J. 1984. Discharge ratings at gaging stations. Ch. A10, Book 3, *Applications of hydraulics. Techniques of water-resources investigations of the United States Geological Survey.* Washington, D.C.: Dept. Interior, U.S. Geological Survey. 59 pp.

Klarer, D.M. 1989. Plankton and macroinvertebrates. In: *Lake Erie and its estuarine systems (issues, resources, status, and management).* K.A. Krieger (ed.), pp. 177-189. Washington, D.C.: U.S. Dept. Commerce, NOAA, Estuarine Programs Office.

Klarer, D.M., and D.F. Millie. 1989. Amelioration of storm-water quality by a freshwater estuary. *Arch. Hydrobiol.* 116:375-389.

Krieger, K.A. 1989. Chemical limnology and contaminants. In: *Lake Erie and its estuarine systems (issues, resources, status, and management).* K.A. Krieger (ed.), pp. 149-175. Washington, D.C.: U.S. Dept. Commerce, NOAA, Estuarine Programs Office.

Krieger, K.A., and E. Wright. 1990. *Currents of change: physical processes in Great Lakes coastal wetlands.* Video documentary. Heidelberg College, Tiffin, Ohio. 20 min.

MacCrimmon, H.R. 1980. Nutrient and sediment retention in a temperate marsh ecosystem. *Int. Revue Ges. Hydrobiol.* 65:719-744.

Matisoff, G., and J.P. Eaker. 1989. *The importance of groundwater advection on sediment-water chemical exchange at Old Woman Creek freshwater estuary.* NOAA Final Report #NA88AA-D-CZ-012.

Matisoff, G., and J.P. Eaker. 1992. Summary of sediment chemistry research at Old Woman Creek, Ohio. *J. Great Lakes Res.* 18(4).

Mitsch, W.J., and J.G. Gosselink. 1986. *Wetlands.* Van Nostrand Reinhold Co., New York, New York. 537 pp.

Mitsch, W.J., B.C. Reeder, and C. Carlson. 1989. Hydrology of a freshwater coastal wetland during severe drought conditions. In: *Wetlands of Ohio's coastal Lake Erie: a hierarchy of systems.* W.J. Mitsch (ed.), pp. 69-79. Columbus, Ohio: The Ohio State Univ., School of Natural Resources.

Mitsch, W.J., M. Straskraba, and S.E. Jørgensen. (eds.). 1988. *Wetland modelling.* Developments in Environmental Modelling, 12. Elsevier, New York. 227 pp.

Odum, W.E. 1990. The lacustrine estuary might be a useful concept. *Estuaries* 13:506-507.

Sager, P.E., S. Richman, H.J. Harris, and G. Fewless. 1985. Preliminary observations on the seiche-induced flux of carbon, nitrogen and phosphorus in a Great Lakes coastal marsh. Chapter 4. In: Prince, H.H., and F.M. D'Itri (eds.). *Coastal Wetlands.* Lewis Publishers Inc., Chelsea, Michigan.

Shindel, H.L., J.H. Klingler, J.P. Mangus, and L.E. Trimble. 1990. *Water resources data Ohio water year 1989. Vol. 2. St. Lawrence River Basin statewide project data.* U.S. Geological Survey Water-Data Report OH-89-2. 226 pp.

Zedler, J.B., and M.E. Kentula. 1985. *Wetlands research plan.* U.S. Environ. Protect. Agency, Corvallis, Oregon. 118 pp.

Appendix A *Part of rating table published by U.S.G.S. for Old Woman creek at Berlin Road, U.S.G.S. Station 04199155, Erie County, Ohio.*

Gage Height (feet)	Discharge in Cubic Feet per Second .00	.01	.02	.03	.04	.05	(Expanded Precision) .06	.07	.08	.09
2.00	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
2.10	.000	.001	.001	.001	.001	.001	.001	001	.001	.001
2.20	.001	.002	.003	.005	.008	.013	.022	.036	.058	.094
2.30	.150	.161	.173	.186	.200	.214	.230	.246	.263	.281
2.40	.300	.323	.347	.372	.399	.428	.459	.491	.525	.562
2.50	.600	.635	.672	.710	.751	.793	.837	.883	.931	.982
2.60	1.034	1.089	1.146	1.206	1.268	1.333	1.401	1.471	1.544	1.621
2.70	1.700	1.783	1.868	1.957	2.050	2.146	2.246	2.350	2.458	2.569
2.80	2.685	2.805	2.930	3.059	3.193	3.331	3.474	3.623	3.777	3.936
2.90	4.100	4.264	4.434	4.609	4.790	4.976	5.169	5.367	5.572	5.783
3.00	6.000	6.239	6.485	6.740	7.003	7.274	7.554	7.843	8.140	8.448
3.10	8.764	9.091	9.428	9.774	10.13	10.50	10.85	11.22	11.59	11.97
3.20	12.37	12.77	13.19	13.61	14.05	14.50	14.88	15.26	15.65	16.05
3.30	16.46	16.88	17.30	17.73	18.17	18.62	19.08	19.55	20.02	20.51
3.40	21.00	21.43	21.87	22.32	22.77	23.23	23.70	24.17	24.66	25.14
3.50	25.64	26.14	26.65	27.17	27.69	28.23	28.76	29.31	29.87	30.43
3.60	31.00	31.47	31.95	32.43	32.92	33.41	33.91	34.41	34.92	35.43
3.70	35.95	36.47	37.00	37.53	38.07	38.61	39.16	39.72	40.28	40.84
3.80	41.41	41.99	42.57	43.16	43.75	44.35	44.95	45.56	46.17	46.79
3.90	47.42	48.05	48.69	49.33	49.98	50.64	51.30	51.96	52.64	53.32
4.00	54.00	54.55	55.11	55.67	56.23	56.80	57.37	57.94	58.52	59.10
4.10	59.69	60.27	60.86	61.46	62.06	62.66	63.26	63.87	64.49	65.10
4.20	65.72	66.34	66.97	67.60	68.23	68.87	69.51	70.16	70.81	71.46
4.30	72.11	72.77	73.44	74.10	74.77	75.45	76.12	76.81	77.49	78.18
4.40	78.87	79.57	80.27	80.97	81.68	82.39	83.10	83.82	84.54	85.27
4.50	86.00	86.62	87.24	87.87	88.49	89.12	89.75	90.39	91.03	91.66
4.60	92.31	92.95	93.60	94.24	94.90	95.55	96.20	96.86	97.52	98.19
4.70	98.85	99.52	100.2	100.9	101.5	102.2	102.9	103.6	104.3	104.9
4.80	105.6	106.3	107.0	107.7	108.4	109.1	109.8	110.5	111.2	112.0
4.90	112.7	113.4	114.1	114.8	115.5	116.3	117.0	117.7	118.5	119.2
5.00	119.9	120.7	121.4	122.2	122.9	123.7	124.4	125.2	125.9	126.7
5.10	127.5	128.2	129.0	129.8	130.5	131.3	132.1	132.9	133.7	134.4
5.20	135.2	136.0	136.8	137.6	138.4	139.2	140.0	140.8	141.6	142.4
5.30	143.2	144.0	144.9	145.7	146.5	147.3	148.2	149.0	149.8	150.7
5.40	151.5	152.3	153.2	154.0	154.9	155.7	156.6	157.4	158.3	159.1
5.50	160.0	160.8	161.6	162.4	163.2	164.0	164.8	165.6	166.5	167.3
5.60	168.1	168.9	169.7	170.6	171.4	172.2	173.1	173.9	174.7	175.6
5.70	176.4	177.2	178.1	178.9	179.8	180.6	181.5	182.3	183.2	184.0
5.80	184.9	185.8	186.6	187.5	188.4	189.2	190.1	191.0	191.8	192.7
5.90	193.6	194.5	195.4	196.2	197.1	198.0	198.9	199.8	200.7	201.6
6.00	202.5	203.4	204.3	205.2	206.1	207.0	207.9	208.8	209.8	210.7
6.10	211.6	212.5	213.4	214.4	215.3	216.2	217.2	218.1	219.0	220.0
6.20	220.9	221.8	222.8	223.7	224.7	225.6	226.6	227.5	228.5	229.4
6.30	230.4	231.4	232.3	233.3	234.3	235.2	236.2	237.2	238.1	239.1
6.40	240.1	241.1	242.1	243.0	244.0	245.0	246.0	247.0	248.0	249.0
6.50	250.0	251.0	252.0	253.0	254.0	255.0	256.0	257.0	258.1	259.1
6.60	260.1	261.1	262.1	263.2	264.2	265.2	266.3	267.3	268.3	269.4

Appendix B *Mean daily discharges (ft^3/sec.) and hourly stages (ft.) published by the U.S.G.S. for October 1989 at Old Woman Creek at Berlin Road.*

DATE	MAX GH /DISCH <TIME>	MIN GH /DISCH <TIME>	MEAN GH	MEAN DISCH	SHIFT ADJ	DATUM CORR	STAGE, IN HUNDREDTHS OF FEET, AT INDICATED HOURS											
							0100 1300	0200 1400	0300 1500	0400 1600	0500 1700	0600 1800	0700 1900	0800 2000	0900 2100	1000 2200	1100 2300	1200 2400
10/01/89	2.51 .06 <0015>	2.50 .04 <0415>	2.51	.04	-0.23W	0.02	251 250	251 250	251 251	251 251	250 251	250 251	250 251	250 251	250 251	250 251	250 251	250 251
10/02/89	2.53 .09 <1845>	2.50 .02 <0800>	2.51	.05	-0.24W	0.02	251 251	251 251	251 252	251 252	251 252	250 252	251 253	251 253	251 252	251 252	251 252	251 252
10/03/89	2.52 .06 <0015>	2.49 .01 <1230>	2.50	.02	-0.24W	0.02	252 249	251 249	251 249	251 249	251 249	250 249	250 249	250 249	250 249	250 249	250 249	250 249
10/04/89	2.49 .01 <0015>	2.47 .00 <1400>	2.48	.01	-0.24W	0.02	249 248	248 247	248 248	248 248	248 248	248 248	248 248	248 248	248 247	248 247	248 247	248 247
10/05/89	2.47 .00 <0015>	2.44 .00 <0500>	2.46	.00	-0.24W	0.02	247 246	247 246	247 246	247 246	246 246	247 247	246 247	246 246	246 246	246 246	246 245	247 246
10/06/89	2.46 .00 <0015>	2.45 .00 <0415>	2.45	.00	-0.24W	0.02	246 245	246 245	246 245	246 245	245 245	246 245	246 245	246 245	246 245	245 245	245 245	245 245
10/07/89	2.45 .00 <0030>	2.42 .00 <2100>	2.43	.00	-0.24W	0.02	244 243	244 243	244 243	244 243	244 243	244 243	244 243	243 243	244 242	243 242	243 242	243 242
10/08/89	2.42 .00 <0015>	2.41 .00 <1000>	2.41	.00	-0.24W	0.02	242 241	242 241	242 241	242 241	242 241	242 241	242 241	242 241	242 241	241 241	242 241	241 241
10/09/89	2.41 .00 <0015>	2.40 .00 <0900>	2.41	.00	-0.24W	0.02	241 240	241 240	241 241	241 240	241 241	241 241	241 241	241 241	240 240	241 241	241 240	240 240
10/10/89	2.80 1.7 <1615>	2.40 .00 <0015>	2.57	.55	-0.19W	0.02	240 256	240 257	240 263	240 279	240 280	240 279	240 277	241 277	242 276	244 275	247 277	252 275
10/11/89	2.76 1.3 <0015>	2.67 .40 <2215>	2.71	.86	-0.15W	0.02	275 270	274 270	274 270	273 270	273 270	273 269	273 269	272 269	272 268	272 268	271 267	271 267
10/12/89	2.67 .40 <0015>	2.61 .32 <1900>	2.64	.44	-0.18W	0.02	267 263	267 263	267 262	266 262	265 262	266 262	265 261	265 261	265 261	265 261	264 261	264 261
10/13/89	2.61 .32 <0015>	2.59 .26 <2230>	2.60	.30	-0.20W	0.02	261 260	261 260	261 260	260 260	260 260	260 260	260 260	260 260	260 260	260 260	260 259	260 259
10/14/89	2.59 .26 <0015>	2.56 .20 <2400>	2.58	.24	-0.21W	0.02	259 258	259 258	259 259	259 258	258 258	258 258	258 258	258 257	258 257	258 257	258 257	256 256
10/15/89	2.56 .20 <0015>	2.53 .09 <2030>	2.55	.14	-0.23W	0.02	256 255	256 255	256 254	256 254	255 254	255 254	255 254	255 254	255 253	255 253	255 253	255 253
10/16/89	3.14 10 <2315>	2.52 .06 <0245>	2.59	.88	-0.21W	0.02	253 252	253 252	253 252	252 253	252 252	252 253	252 253	252 265	252 287	252 281	252 313	252 309
10/17/89	3.15 10 <0715>	2.91 3.5 <2315>	3.04	7.1	-0.01W	0.02	312 306	305 304	301 302	314 301	312 299	312 299	314 296	313 295	312 293	311 292	309 292	306 291
10/18/89	2.91 3.5 <0015>	2.84 2.2 <1300>	2.86	2.6	-0.07W	0.02	290 285	289 285	289 284	289 284	288 284	288 284	288 284	287 284	287 284	287 284	286 284	286 285
10/19/89	4.56 90 <1700>	2.84 2.2 <0015>	3.79	46	-0.01W	0.02	285 420	286 428	288 444	291 454	296 456	305 452	325 446	335 437	347 431	370 430	393 425	406 417
10/20/89	4.16 43 <0015>	3.16 11 <2400>	3.50	27	0.00W	0.02	410 336	405 333	396 331	388 328	380 327	370 325	365 323	359 321	353 320	347 319	343 318	339 316
10/21/89	3.16 11 <0015>	3.06 7.4 <2230>	3.10	8.9	0.00W	0.02	315 309	314 309	314 309	313 309	312 308	312 308	312 307	311 307	311 307	310 307	310 306	310 306
10/22/89	3.06 7.6 <0015>	2.99 5.6 <2245>	3.02	6.6	0.00W	0.02	306 302	305 302	305 302	305 301	304 301	304 301	304 301	303 300	303 300	303 300	303 299	302 299
10/23/89	2.99 5.6 <0015>	2.91 3.5 <2300>	2.95	4.5	-0.03W	0.02	299 294	298 294	298 294	297 294	297 293	297 293	296 293	296 293	296 292	295 292	295 291	295 291
10/24/89	2.91 3.5 <0015>	2.85 2.3 <2345>	2.88	3.0	-0.06W	0.02	291 288	291 288	290 288	290 288	290 287	289 287	289 287	289 287	289 286	288 286	288 286	288 286
10/25/89	2.85 2.3 <0015>	2.82 2.0 <2145>	2.84	2.2	-0.09W	0.02	285 283	285 283	285 283	285 283	285 283	284 283	284 283	284 283	284 283	284 282	283 282	283 282
10/26/89	2.82 2.0 <0015>	2.79 1.5 <2150>	2.80	1.7	-0.10W	0.02	282 280	282 280	281 280	281 280	281 280	281 280	281 280	280 280	280 280	280 279	280 279	280 279
10/27/89	2.79 1.5 <0015>	2.77 1.3 <1145>	2.78	1.4	-0.11W	0.02	279 277	278 278	278 278	278 278	278 278	278 278	278 278	278 278	278 277	278 277	278 277	277 277
10/28/89	2.77 1.3 <0015>	2.76 1.3 <0345>	2.76	1.3	-0.12W	0.02	277 276	277 276	277 276	276 277	276 277	276 277	276 277	276 277	276 277	276 276	276 276	276 276
10/29/89	2.76 1.3 <0015>	2.75 1.1 <0315>	2.75	1.2	-0.13W	0.02	276 275	276 275	276 275	275 275	275 275	275 275	275 275	275 275	275 275	275 275	275 275	275 275
10/30/89	2.75 1.1 <0015>	2.74 1.1 <0330>	2.74	1.1	-0.13W	0.02	275 274	275 274	275 274	274 274	274 275	274 274	274 275	274 275	274 275	274 275	274 275	274 275
10/31/89	2.80 --	2.74 --	2.76	1.3	-0.12W	0.02	275 276	275 277	275 277	275 277	274 278	275 278	275 277	274 280	275 277	275 279	275 279	275 279

Appendix C *Hourly stages (ft.) reported by the U.S.G.S. for October 1989 at the Old Woman Creek wetland at U.S. Highway 6, U.S.G.S. Station 04199165, Erie County, Ohio. Addition of 560.00 feet to the recorded stage yields the mean feet above sea level.*

DATE	MAX GH (TIME)	MIN GH (TIME)	MEAN GH
10-01	14.92 <0015>	14.92 <0015>	14.92
10-02	14.92 <0015>	14.90 <1930>	14.91
10-03	14.90 <0015>	14.87 <1430>	14.89
10-04	14.87 <0015>	14.86 <0415>	14.86
10-05	14.86 <0015>	14.85 <1015>	14.85
10-06	14.85 <0015>	14.82 <2230>	14.84
10-07	14.82 <0015>	14.80 <2400>	14.81
10-08	14.80 <0015>	14.79 <1300>	14.80
10-09	14.79 <0015>	14.76 <1115>	14.78
10-10	14.83 <1415>	14.78 <0015>	14.80
10-11	14.82 <0015>	14.81 <0015>	14.82
10-12	14.83 <0515>	14.81 <1300>	14.82
10-13	14.81 <0015>	14.80 <1230>	14.81
10-14	14.80 <0015>	14.80 <0015>	14.80
10-15	14.80 <0015>	14.78 <1600>	14.79
10-16	14.95 <2400>	14.78 <0015>	14.79
10-17	14.97 <2130>	14.95 <0015>	14.95
10-18	14.97 <0015>	14.97 <0015>	14.97
10-19	15.68 <2345>	14.97 <0015>	15.34
10-20	15.91 <2359>	15.68 <0015>	15.82
10-21	15.99 <2300>	15.91 <0015>	15.95
10-22	16.05 <2250>	15.99 <0015>	16.02
10-23	16.09 <2155>	16.05 <0015>	16.07
10-24	16.10 <1050>	16.09 <0015>	16.10
10-25	16.11 <1130>	16.10 <0015>	16.11
10-26	16.11 <0015>	16.11 <0015>	16.11
10-27	16.11 <0015>	16.11 <0015>	16.11
10-28	16.11 <0015>	12.22 <2400>	14.77
10-29	12.29 <2030>	12.14 <1415>	12.24
10-30	12.30 <2130>	12.13 <1400>	12.21
10-31	12.29 <1000>	11.22 <2315>	11.90
11-01	12.37	10.99	11.74

DATUM CORR		STAGE, IN HUNDREDTHS OF FEET, AT INDICATED HOURS 1	2	3	4	5	6	7	8	9	10	11	12
.00	AM	1492	1492	1492	1492	1492	1492	1492	1492	1492	1492	1492	1492
	PM	1492	1492	1492	1492	1492	1492	1492	1492	1492	1492	1492	1492
.00	AM	1492	1492	1492	1492	1492	1492	1492	1492	1492	1492	1492	1491
	PM	1491	1491	1491	1491	1491	1491	1491	1490	1490	1490	1490	1490
.00	AM	1490	1490	1490	1490	1490	1490	1489	1489	1489	1489	1489	1489
	PM	1488	1488	1487	1487	1487	1487	1487	1487	1487	1487	1487	1487
.00	AM	1487	1487	1487	1487	1486	1486	1486	1485	1485	1485	1485	1485
	PM	1486	1486	1486	1486	1486	1486	1486	1486	1486	1485	1486	1486
.00	AM	1486	1486	1486	1486	1486	1486	1486	1486	1486	1486	1485	1485
	PM	1485	1485	1485	1485	1485	1485	1485	1485	1485	1485	1485	1485
.00	AM	1485	1485	1485	1485	1485	1485	1485	1485	1484	1484	1483	1483
	PM	1483	1483	1483	1483	1483	1483	1483	1483	1483	1483	1482	1482
.00	AM	1482	1482	1482	1482	1482	1482	1481	1481	1481	1481	1481	1481
	PM	1481	1481	1481	1481	1481	1481	1481	1481	1481	1481	1481	1480
.00	AM	1480	1480	1480	1480	1480	1480	1480	1480	1480	1480	1480	1480
	PM	1479	1479	1479	1479	1479	1479	1479	1479	1479	1479	1479	1479
.00	AM	1479	1479	1479	1479	1479	1479	1479	1478	1478	1478	1478	1478
	PM	1476	1476	1476	1476	1476	1476	1476	1476	1478	1478	1478	1478
.00	AM	1478	1478	1478	1478	1478	1478	1478	1478	1478	1480	1481	1482
	PM	1482	1482	1483	1482	1482	1482	1482	1482	1482	1482	1482	1482
.00	AM	1482	1482	1482	1482	1482	1482	1482	1482	1482	1482	1482	1482
	PM	1482	1482	1482	1482	1482	1482	1482	1482	1482	1482	1482	1482
.00	AM	1482	1482	1482	1482	1482	1483	1483	1483	1482	1481	1481	1481
	PM	1481	1481	1481	1481	1481	1481	1481	1481	1481	1481	1481	1481
.00	AM	1481	1481	1481	1481	1481	1481	1481	1481	1481	1481	1480	1480
	PM	1480	1480	1480	1480	1480	1480	1480	1480	1480	1480	1480	1480
.00	AM	1480	1480	1480	1480	1480	1480	1480	1480	1480	1480	1480	1480
	PM	1480	1480	1480	1480	1480	1480	1480	1480	1480	1480	1480	1480
.00	AM	1480	1480	1480	1480	1480	1480	1480	1480	1480	1480	1480	1479
	PM	1480	1480	1480	1478	1478	1478	1478	1478	1478	1478	1478	1478
.00	AM	1478	1478	1478	1478	1478	1478	1478	1478	1478	1478	1478	1478
	PM	1478	1478	1478	1478	1478	1479	1478	1482	1483	1483	1483	1485
.00	AM	1485	1486	1487	1489	1490	1491	1492	1492	1493	1494	1494	1494
	PM	1495	1495	1495	1495	1495	1495	1496	1497	1497	1497	1497	1497
.00	AM	1497	1497	1497	1497	1497	1497	1497	1497	1497	1497	1497	1497
	PM	1497	1497	1497	1497	1497	1497	1497	1497	1497	1497	1497	1497
.00	AM	1497	1499	1504	1507	1508	1512	1517	1520	1528	1530	1533	1536
	PM	1538	1542	1544	1547	1550	1556	1556	1559	1561	1564	1556	1563
.00	AM	1569	1571	1573	1573	1576	1577	1579	1579	1580	1582	1583	1584
	PM	1585	1586	1586	1587	1587	1588	1588	1589	1589	1590	1590	1591
.00	AM	1591	1591	1592	1593	1593	1593	1594	1594	1594	1595	1595	1596
	PM	1596	1596	1597	1597	1597	1597	1598	1598	1598	1599	1598	1599
.00	AM	1599	1600	1600	1600	1600	1601	1601	1601	1601	1602	1602	1602
	PM	1603	1603	1603	1603	1603	1604	1604	1604	1604	1605	1605	1605
.00	AM	1605	1605	1605	1606	1606	1606	1606	1606	1606	1607	1607	1607
	PM	1607	1607	1607	1608	1608	1608	1608	1608	1608	1609	1609	1609
.00	AM	1609	1609	1609	1609	1609	1609	1609	1609	1609	1609	1610	1610
	PM	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610
.00	AM	1610	1610	1610	1610	1610	1610	1610	1610	1610	1610	1611	1611
	PM	1611	1611	1611	1611	1611	1611	1611	1611	1611	1611	1611	1611
.00	AM	1611	1611	1611	1611	1611	1611	1611	1611	1611	1611	1611	1611
	PM	1611	1611	1611	1611	1611	1611	1611	1611	1611	1611	1611	1611
.00	AM	1611	1611	1611	1611	1611	1611	1611	1611	1611	1611	1611	1611
	PM	1611	1611	1611	1611	1611	1611	1611	1611	1611	1611	1611	1611
.00	AM	1611	1611	1611	1611	1611	1611	1611	1611	1611	1611	1611	1611
	PM	1611	1549	1466	1364	1303	1265	1241	1237	1229	1227	1225	1222
.00	AM	1218	1221	1221	1219	1219	1223	1224	1226	1225	1224	1226	1223
	PM	1226	1226	1224	1214	1216	1215	1219	1219	1222	1225	1229	1227
.00	AM	1225	1223	1214	1214	1216	1215	1215	1222	1224	1226	1222	1220
	PM	1225	1225	1222	1213	1219	1219	1223	1227	1225	1228	1230	1228
.00	AM	1223	1218	1217	1217	1212	1211	1215	1217	1226	1229	1229	1224
	PM	1196	1200	1193	1188	1157	1151	1135	1137	1146	1134	1142	1144
.00	AM	1100	1119	1162	1117	1104	1161	1161	1161	1171	1159	1165	1161

Appendix D *Expanded hypsographic and depth-volume table for Old Woman Creek wetland*[†]

Deviation from IGLD[§] meters	IGLD feet	USGS[*] feet	Area 10^3 m^2	Volume 10^3 m^3
2.0	**575.16**	576.76	**650**	**777**
1.9	**574.84**	576.44	**646**	**712**
1.8	**574.51**	576.11	**642**	**648**
		576.10	641	646
		576.05	637	636
		576.00	634	627
		575.95	630	618
		575.90	626	608
		575.85	623	599
		575.80	619	590
1.7	**574.18**	575.78	**617**	**586**
		575.75	615	580
		575.70	612	571
		575.65	608	562
		575.60	604	552
		575.55	601	543
		575.50	597	533
1.6	**573.85**	575.45	**593**	**524**
		575.40	591	515
		575.35	589	507
		575.30	587	498
		575.25	584	489
		575.20	582	480
		575.15	580	472
1.5	**573.52**	575.12	**578**	**466**
		575.10	577	463
		575.05	575	454
		575.00	573	445
		574.95	570	437
		574.90	568	428
		574.85	566	419
		574.80	564	410
1.4	**573.19**	574.79	**563**	**408**
		574.75	561	402
		574.70	559	393
		574.65	556	385
		574.60	554	376
		574.55	551	368
		574.50	549	360
1.3	**572.86**	574.47	**547**	**354**
		574.45	547	351
		574.40	544	343
		574.35	542	334
		574.30	539	326
		574.25	537	318
		574.20	535	309
		574.15	532	301
1.2	**572.54**	574.14	**532**	**299**
		574.10	531	293
		574.05	530	285
		574.00	529	277
		573.95	528	269
		573.90	527	261
		573.85	526	253
1.1	**572.21**	573.81	**526**	**246**
		573.80	525	245
		573.75	524	237
		573.70	524	229
		573.65	523	221
		573.60	522	213
		573.55	521	205
		573.50	520	197
1.0	**571.88**	573.48	**519**	**194**
		573.45	515	190
		573.40	507	182
		573.35	498	175
		573.30	490	168
		573.25	482	161
		573.20	474	154
0.9	**571.55**	573.15	**466**	**147**
		573.10	458	139
		573.05	450	132
		573.00	442	125
		572.95	434	118
		572.90	426	111
		572.85	418	104
0.8	**571.23**	572.83	**414**	**101**
		572.80	405	98
		572.75	390	93
		572.70	374	89
		572.65	359	84
		572.60	343	79
		572.55	328	75
0.7	**570.90**	572.50	**313**	**70**
		572.45	297	65
		572.40	282	61
		572.35	266	56
		572.30	251	51
		572.25	236	47
		572.20	220	42
0.6	**570.57**	572.17	**211**	**39**
		572.15	206	39
		572.10	194	37
		572.05	181	35

Appendix D *Continued*

Deviation from IGLD[§] meters	**IGLD feet**	**USGS[*] feet**	**Area 10^3 m^2**	**Volume 10^3 m^3**
		572.00	169	33
		571.95	156	31
		571.90	144	30
		571.85	131	28
0.5	**570.24**	571.84	**129**	**27**
		571.80	119	26
		571.75	107	24
		571.70	94	22
		571.65	82	21
		571.60	69	19
		571.55	57	17
0.4	**569.91**	571.51	**47**	**16**
		571.50	46	15
		571.45	45	15
		571.40	43	14
		571.35	41	14
		571.30	39	13
		571.25	38	13
		571.20	36	12
0.3	**569.59**	571.19	**36**	**12**
		571.15	34	12
		571.10	32	11
		571.05	31	11
		571.00	29	10
		570.95	27	10
		570.90	25	9
0.2	**569.26**	570.86	**24**	**9**
0.0	**568.60**	570.20	**18**	**4**
-0.2	**567.94**	569.54	**7**	**2**
-0.4	**567.29**	568.89	**2**	**1**
-0.6	**566.63**	568.23	**1**	**0.8**
-0.8	**566.34**	567.94	**1**	**0.5**
-1.0	**565.32**	566.92	**1**	**0.3**
-1.2	**564.66**	566.26	**0.7**	**0.1**
-1.4	**564.01**	565.61	**0.3**	**0.03**

[§] International Great Lakes Datum

[*] USGS feet = IGLD feet + 1.60

[†] Bolded values were reported by Herdendorf and Hume (1991); other values were interpolated assuming linear change between the bolded values. Areas and volumes are rounded to 3 or fewer significant figures.

The Heidelberg College Water Quality Laboratory

The Water Quality Laboratory (WQL), founded in 1969, is an environmental research and education organization associated with the science departments of Heidelberg College. The WQL operates large scale, long term programs that (1) monitor impacts of agriculture on surface and ground water quality and (2) track progress associated with agricultural pollution abatement programs. The laboratory employs eight full time staff and several student technicians.

In its Lake Erie Tributary Monitoring Program, The WQL measures the concentration of pollutants in the major rivers draining into Lake Erie, including the Raisin, Maumee, Sandusky, Cuyahoga, and Grand Rivers. This program continues to provide the most detailed and longest term records available in the United State regarding the concentration of sediments, fertilizers and pesticides in rivers draining intensive row crop agriculture.

Through its Cooperative Private Well Testing Program, the WQL works with local county organizations to provide a low cost well testing program to residents who will allow data from their wells to be added to a local data base. Since most ground water pollution problems result from local causes, local data are essential to develop appropriate and effective ground water protection programs. Since 1987 the program has included 340 counties in 15 states, and 37,000 private wells.

The data collected by the WQL are used extensively by public and private organizations. In addition to the publication of reports and articles, the WQL operates an Environmental Extension Program, providing about 60 presentations per year to agricultural, environmental and general audiences throughout Ohio and the Midwest.

Financial support for WQL programs comes from state and federal agencies, industries, private foundations, and participants in the Cooperative Private Well Testing Program.