AQUATIC PLANT CONTROL RESEARCH PROGRAM

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LARGE-SCALE OPERATIONS MANAGEMENT TEST OF USE OF THE WHITE AMUR FOR CONTROL OF PROBLEM AQUATIC PLANTS

Report 2

FIRST YEAR POSTSTOCKING RESULTS

Volume IV

Nitrogen and Phosphorus Dynamics of the Lake Conway Ecosystem: Loading Budgets and a Dynamic Hydrologic Phosphorus Model

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P. O. Box 631, Vicksburg, Miss. 39180

LARGE-SCALE OPERATIONS MANAGEMENT TEST OF USE OF THE WHITE AMUR FOR CONTROL OF PROBLEM AQUATIC PLANTS

Report 1: Baseline Studies

Volume I: The Aquatic Macrophytes of Lake Conway, Florida

Volume II: The Fish, Mammals, and Waterfowl of Lake Conway, Florida

Volume III: The Plankton and Benthos of Lake Conway, Florida

Volume IV: Interim Report on the Nitrogen and Phosphorus Loading Characteristics of the Lake Conway, Florida, Ecosystem

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An integrated nutrient budget for Lake Conway, Florida, was developed that integrated physical, chemical, and biological relationships. A hydrologic budget was constructed from measurements of stormwater runoff, subsurface seepage flows, and existing precipitation and evaporation data. It was determined that major sources of external nitrogen and phosphorus loadings were from atmospheric loadings, urban runoff, and subsurface seepage. Based upon a simulation model of

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the phosphorus dynamics of Lake Conway, it was concluded that sedimentation of phosphorus was occurring at higher than predicted rates, nutrient release by submerged macrophytes was salient to phosphorus dynamics, and release of phosphorus by sediments was not a significant internal source of this nutrient.

PREFACE

The work described in this volume was performed under Contract No. DACW39-76-C-0076-002 between the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., and the University of Florida, Gainesville, Fla. The work was sponsored by the U. S. Army Engineer District, Jacksonville, and by the Office, Chief of Engineers, U. S. Army, Washington, D. C.

This report describes research conducted on the nitrogen and phosphorus budget of the Lake Conway ecosystem and is part of the Large-Scale Operations Management Test (LSOMT) of the Aquatic Plant Control Research Program (APCRP) at the WES. A series of WES reports document the findings of this research. Report 1 presents baseline information, and Reports 2 and 3 contain data collected the first and second years, respectively, after stocking the lake with the white amur. The work reported herein is the fourth volume (of seven) in Report 2.

The work was performed and this volume was written by Dr. Eldon C. Blancher, II, and Mr. Charles R. Fellows of the University of Florida, Gainesville, Fla.

The work was monitored by the WES Environmental Laboratory (EL), Dr. John Harrison, Chief. The study was under the general supervision of Mr. Bob O. Benn, Chief, Environmental Systems Division (ESD), EL. Mr. J. Lewis Decell was Manager, APCRP. Principal investigators at WES for the study were Mr. Eugene G. Buglewicz and Dr. Andrew Miller of the ESD, EL.

Commanders and Directors of WES during the conduct of the study and preparation of the report were COL John L. Cannon, CE, COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

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FIRST YEAR POSTSTOCKING RESULTS

Nitrogen and Phosphorus Dynamics of the Lake Conway Ecosystem: Loading Budgets and a Dynamic Hydrologic Phosphorus Model

PART I: INTRODUCTION

1. The process of eutrophication or enrichment in natural waters is caused primarily by the increased availability of plant nutrients. In most lake systems, the elements usually responsible for the acceleration of this process are nitrogen and phosphorus. The high concentrations of these nutrients in eutrophic lakes may reflect either high loadings from external sources or alteration of nutrient cycles within a lake. Such enrichment modifies the character of a lake by increasing primary productivity and thus leads to problems associated with increased growth of vascular plants or algae. In order to fully understand these processes, it is necessary to develop nutrient budgets from which the supply, losses, and transformations of nutrients can be ascertained.

2. The work presented herein is part of the Large-Scale Operations Management Test (LSOMT) being conducted by the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., to test the efficacy of the white amur (*Ctenopharyngodon idella*) as an aquatic plant control agent in Lake Conway, Florida. In addition to an assessment of the impact of this fish on the aquatic macrophyte populations, data on physical and chemical parameters, as well as on nontarget biota, have been collected to identify additional effects of the white amur. The analyses in this report serve as a base from which the overall impact of this fish on the Lake Conway ecosystem can be ascertained.

3. The objectives of this investigation were to:

a. Assess external nitrogen and phosphorus loadings to the Lake Conway ecosystem.

b. Determine if and when nutrient limitation exists in the lake and, if so, which nutrient is limiting.

c. Develop a dynamic hydrologic--materials model for the Lake Conway system to determine if the budgets are reasonably accurate.

d. Assess the importance of internal nutrient loadings.

Objectives *a* and *b* were met and presented in a preliminary report (Blancher et al. 1978). The work reported herein presents the revised nutrient budgets and the dynamic model that were subsequently developed to complete the objectives *c* and *d*.

4. A number of additional studies recently have been published on the Lake Conway LSOMT. These studies include a general description of the Lake Conway area (Theriot 1977) and studies of its fishes (Guillory, Land, and Gasaway 1977), aquatic macrophytes (Nall, Mahler, and Schardt 1977) (Nall, Schardt, and Burkhalter 1978), plankton and benthos (Fox et al. 1977; Conley et al. 1978), and water quality (Sawicki 1977), as well as system modeling (Ewel and Fontaine 1977; Fontaine and Ewel 1978), zooplankton and trophic state (Blancher 1979), seepage flows (Fellows 1978), and a study of the nitrogen cycle (Sompongese 1978). The reader is referred to these articles for additional discussion of these topics.

PART II: METHODS AND MATERIALS

Hydrology

5. Lake and watershed areas were calculated from U. S. Geological Survey (USGS) topographical maps with an electronic planimeter (Hewlett Packard 9810A-9864A). Extent of catchment area was determined from topographic features and by consulting area tax assessment maps at the Orange County Public Works Office for street drainage patterns. Land use and development patterns for the watershed were estimated from recent (1975) aerial photographs supplied by county engineers (Orange County Public Works, Orlando, Fla.).

6. A bathymetric map was produced using both depth profiles obtained with a recording depth meter and an existing bathymetric map.* The area of each metre-depth interval was determined with an electronic planimeter, and lake volumes were calculated by summing the volumes at each 1-m interval. Mean depths of the pools were computed by dividing their volumes by their respective surface areas.

7. Monthly rainfall and evaporation data were obtained from U. S. Weather Bureau climatological data reports (National Oceanographic and Atmospheric Agency (NOAA) 1972-1978). Rainfall data reported by the Orlando weather station at McCoy Air Base were used because of the close proximity of the airport to the lake. Averages of evaporation pan data from the Lisbon and Lake Alfred stations (within a 50-mile (80.5-km) radius of Lake Conway) were assumed to be representative of the Lake Conway area. Coefficients for estimating evaporation from the lake surface were those determined for Lake Okeechobee by Kohler (1954).

8. The volume of direct runoff was calculated by the Department of Agriculture Soil Conservation Service (SCS) method and the rational method (Chow 1964). The SCS method is based on an empirical model that relates the amount of direct runoff to land use and hydrologic soil

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* Schardt, J., Unpublished bathymetric map of Lake Conway, Department of Natural Resources, Tallahassee, Fla.

characteristics. A weighted curve number (CN) is developed from tabularized values for the different soil groupings and the expected direct runoff is obtained from the model. The rational method is based on the assumption that a certain percentage of the rainfall for a given area will contribute to the direct runoff. By measuring the amount of direct runoff during a storm event, a runoff coefficent can be calculated by dividing the runoff by the total volume of rainfall in the basin.

9. To calibrate these methods, a 128-ha area of the drainage basin was identified from topographic maps and confirmed with Orange County engineers for street drainage patterns. During an intense thunderstorm in August 1976, flow through an open channel draining into Lake Conway from this area was measured. Flow rate was measured with a Gurley flow meter at 15-min intervals, and water samples were collected for turbidity, specific conductance, and nutrient determinations. Rainfall was simultaneously collected and measured. Additional hydrographs were obtained during March, May, and June 1978. Continuous measurements of flow rates during these periods were performed using an ISCO bubble flow meter and automatic recorder in conjunction with a 45-deg V notch weir used as the primary device. During each storm event water samples for nutrient analysis were obtained with a flow-actuated ISCO automatic sampler.

10. Subsurface seepage into Lake Conway was measured by Fellows (1979), using the methods of Lee (1972, 1977), and Lock and John (1978). Drums enclosing 0.255 m^2 of lake bottom were pushed (open end down) 10 to 15 cm into the sediments. The closed ends were vented by 0.9-cm-diam plastic tubing into either a 0.180- or 3.5-ℓ bag. Flow was calculated by dividing the volume of water collected by the measured time. Water samples were collected from the individual drum ends for subsequent nutrient analysis. Drum collectors were placed on transects perpendicular to the shoreline since seepage flow decreases with increasing distance from shore (Lichtler, Anderson, and Joyner 1968). Flow as a function of distance from shore was then plotted and integrated and expressed as flow per metre of shoreline per unit time (m^3/m-day).

Nutrients

11. Dry fallout and rainfall for nutrient analyses were collected initially (August 1976-September 1976) using large (4-ℓ) nalgene beakers. After October 1977, collection of these samples was accomplished using an automatic wet-dry precipitation collector (Aerochem Metrics Inc., Miami, Fla.). This collector consisted of two large buckets with a servo-operated lid and a precipitation sensor.

12. Beginning in June 1976, monthly water samples were collected for nutrient analysis at all stations in the Conway system at a depth of 1 m. Additional samples were obtained at 4 and 7 m at the deeper stations in the center of each pool. After March 1977, sampling was continued at the deep stations only with samples collected at each metre interval. Supplemental nutrient data covering the period January 1976-March 1978 were obtained from the Orange County Pollution Control Department.* All water samples were analyzed for nitrogen $\left(NH_4^+, NO_2^-, NO_3^-, \text{and total Kjeldahl nitrogen (TKN)}\right)$ and phosphorus (ortho and total phosphate) using methods described in Standard Methods (American Public Health Association (APHA) 1975) and the U. S. Environmental Protection Agency Methods Handbook (1974).

13. Bioassay methods including algal assay procedure (U. S. Environmental Protection Agency 1971), alkaline phosphatase assay (Fitzgerald and Nelson 1966) and nitrogen fixation (Stewart, Fitzgerald, and Burris 1968) were used to determine nutrient limitation in the Conway system.

14. A hydrologic and phosphorus model was developed using a linear systems model similar to one described by Rich (1973). The model was simulated, using the Continuous System Modeling Program (CSMP) (Speckhart and Green 1976) on the Northeast Regional Data Center's Amdahl 460 computer. Functions for rainfall and evaporation were derived using data from the National Weather Service (NOAA 1972-1978), and lake height function was developed from the USGS (1977-1978). Data used for

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* Personal Communication, 1978, Raymond T. Kaleel, Orange County Pollution Control Department, Orlando, Fla.

developing functions of phosphorus release from both vascular aquatic plants and sediments were obtained from Fontaine (1978).

PART III: RESULTS AND DISCUSSION

Development of the Hydrologic Budget

15. Nutrient inputs to a lacustrine system are closely related to the hydrologic budget of the system. Therefore, the construction of an accurate water budget is necessary for the development of a realistic materials budget.

16. The hydrologic budget of a lake can be expressed by the following equation:

$$\Delta V = Q_i + P - E - Q_o \pm Q_g \quad (1)$$

where

ΔV = change in water storage*
Q_i = surface inflows
P = precipitation
E = evaporation
Q_o = surface outflows
Q_g = groundwater input or output

17. Monthly precipitation, evaporation, and pan coefficients for the 1976 water year are presented in Table 1. The volume of direct precipitation onto the Lake Conway surface was 8.87 × $10^6 m^3$. An annual evaporation volume of 9.75 × $10^6 m^3$ was determined by multiplying the monthly pan coefficients (Kohler 1954) by the lake surface area (7.39 km) and the monthly pan evaporation and then summing the evaporation volumes.

18. Surface and subsurface inflows to the lakes were divided into two major components each: stream inflow and surface stormwater runoff, and subsurface seepage and groundwater inflows. Stream inflow to the Conway system is primarily by small ditches that drain the surrounding watershed. Consequently, inflow from these ditches was considered as a

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* All units were 10^6 cubic metres per month.

part of stormwater runoff. Total runoff was calculated from stormwater runoff and seepage. Stormwater runoff is that water which enters stream channels associated with storms and contributes directly to the runoff hydrograph. Seepage is that portion of total runoff which enters the lake following infiltration of soils in the watershed. Groundwater inflows include those flows into the lake from the confined aquifer.

19. To adequately assess these inflows, it was necessary to calculate them using appropriate methods, combine them to determine total inflows, and then evaluate how they compared to expected total inflows calculated from changes in lake stage. Thus, a check of the accuracy of the measured inflows could be made. The volume of stormwater runoff can vary considerably within a drainage basin. Soil type, vegetative cover, and extent of impervious surfaces as well as frequency, intensity, and duration of rainfall play major roles in determining the amount of runoff. It is therefore necessary to obtain hydrographs of stormwater flows for the basin also, using standard empirical methods for determining direct runoff.

20. Stormwater hydrographs for the Conway basin were calculated from data collected in August 1976 and March, May, and June 1978, and are summarized in Table 2. An example is given in Figure 1, and the remaining hydrographs of these storms are presented in Appendix A. Measurements of stormwater flows during 1977 were not possible because of the paucity of rainfall. Of the precipitation that fell during those storms, 3.5 percent on an average entered the lake as stormwater runoff. Initiation of runoff and time interval to peak flow and return to base flow were generally rapid.

21. Estimates of stormwater runoff by the SCS (1975) method resulted in a CN of 56 for the Conway basin. Using the SCS empirical model, this means that approximately 4.6 cm of rainfall is necessary before any surface runoff can be detected. For a 6.35-cm rainfall (2.5 in.), approximately 0.15 cm of runoff, or 2.4 percent of rainfall, would result.

22. Since both the rational and SCS methods gave comparable runoff coefficients, the annual volume of stormwater runoff was calculated

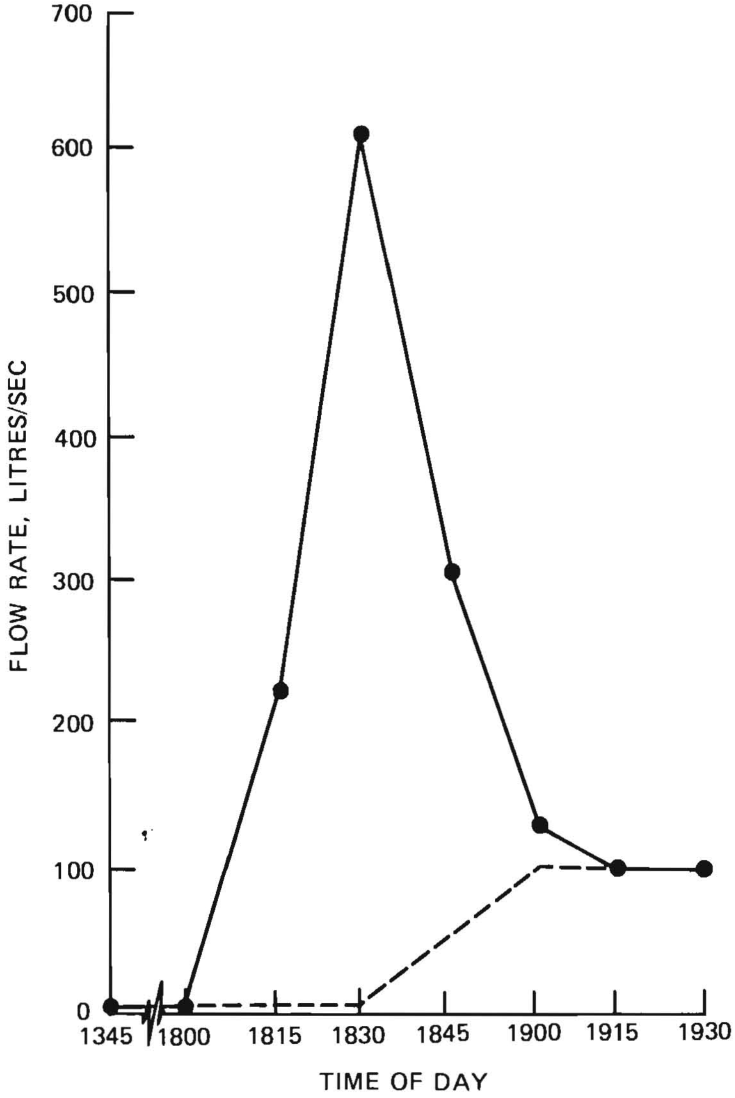

Figure 1. Hydrograph of stormwater runoff on 21 August 1976 at the corner of Gatlin Ave. and Bumby Dr., Orlando, Fla.

by multiplying the annual amount of precipitation in the basin by 0.035, the average runoff coefficient determined from the hydrographs.

23. Seepage flows into Lake Conway were measured for a period of 12 months and plotted against the dates they were obtained (Figure 2). This annual seepage graph is intended to reflect the total seepage input to both lakes. The total seepage reflects not only the steady seepage flows but also some seepage that pulsed into these lakes following rain events.

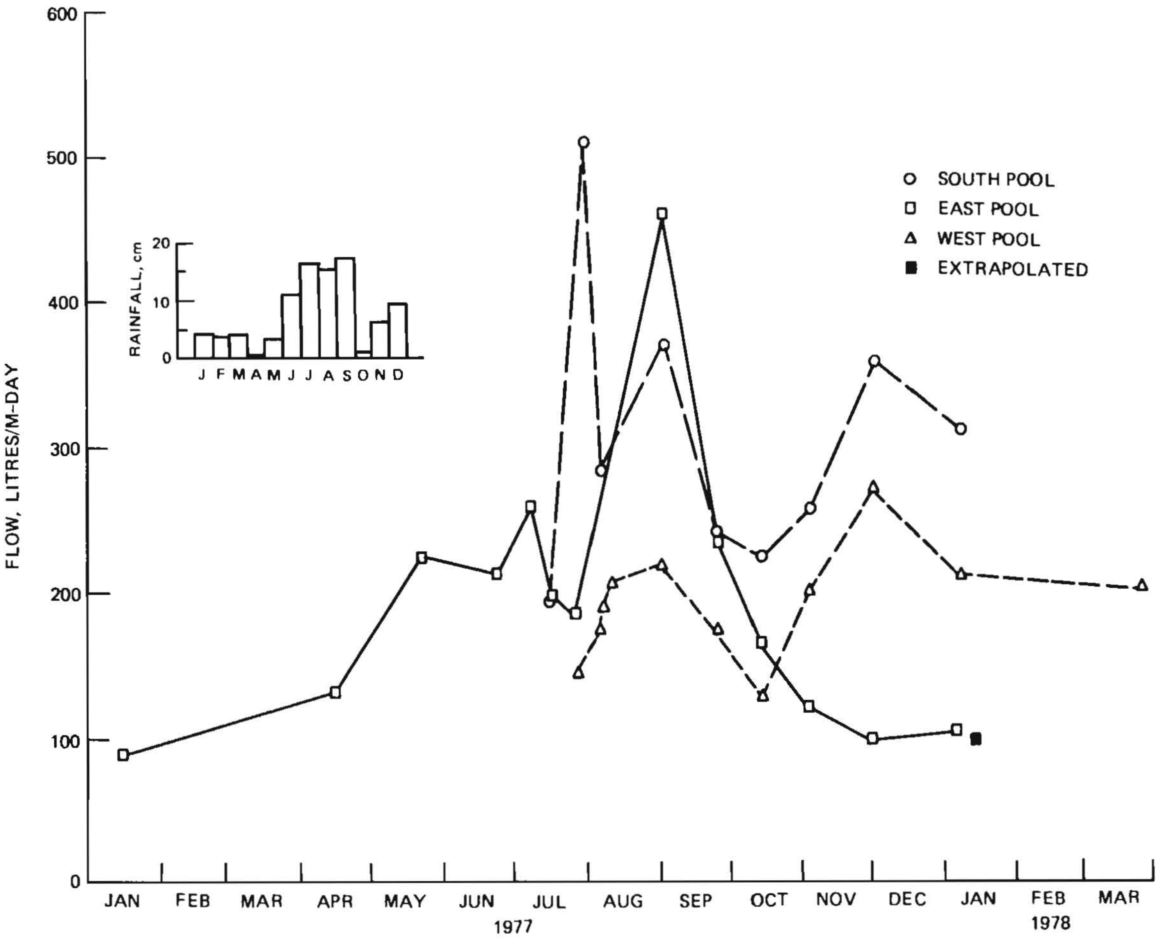

Figure 2. Seepage flows plotted against time for the three Lake Conway sites during 1977-1978. Inset histogram shows monthly rainfall values during study period

24. Seepage measurement scheduling was usually arranged 2 or 3 weeks in advance, and sampling was conducted regardless of the prevailing weather conditions. The seepage obtained during this study is believed to be unbiased with respect to weather conditions, and all measurements were represented on the annual seepage graphs either directly or as an averaged value for replicate measurements of the same or consecutive dates.

25. An annual seepage input value for the East Pool site was calculated by first averaging the initial and final flow values and multiplying this by the 9 days not included in the 356-day measurement period. This product (0.9 m^3/m) was then added to the integrated 356-day

input (63.9 m^3/m shoreline). The annual East Pool input was 64.8 m^3/m shoreline.

26. The annual seepage values for the remaining two Lake Conway sites were calculated by use of a seepage quotient. This quotient was the annual East Pool seepage, 64.8 m^3/m shoreline (integrated for 1 year), divided by that amount of East Pool seepage which occurred during the time period that each site was measured. For the South Pool, the integrated seepage value (Figure 2) and the calculated annual inputs were 53.1 and 98.3 m^3/m shoreline, respectively. At the West Pool these values were 32.3 and 64.2 m^3/m shoreline.

27. To determine the average seepage value for the five-lake system, the numerical average of these three values, 75.8 m^3/m shoreline (integrated for 1 year), was used. This average was chosen since this area was classified by Leighty et al. (1957) to be a "good" recharge area for the Floridan Aquifer and because poor correlations of flow with land use and watershed area were made. From this value and the length of shoreline for the five pools, the total seepage input for the Lake Conway system was calculated to be $2.15 \times 10^6 m^3$/yr, which is equivalent to 30.3 cm of lake stage per year.

28. The occurrence of a high intensity, short duration rain event during a routine sampling trip to Lake Conway on 1 December 1977 afforded an opportunity to construct a seepage hydrograph. An undetermined amount of rain fell during a 10-min period immediately after the routine sampling of the East Pool site. A histogram of integrated flow versus time shows a rapid change in flow and the subsequent decay in rate to near prerain flow (Figure 3). Groundwater table heights, at the times indicated (Figure 3), show a change that corresponds to the change in seepage flow. The integrated seepage input due only to the rain (i.e., with the initial seepage rate subtracted) was 13.8 ℓ/m shoreline, or 7.3×10^{-2} mm lake stage. To approximate the amount of rainfall, a soil porosity of 25 percent was assumed. Since it was known that the maximum change in groundwater height was 5.2 cm, rainfall was then estimated to be about 1.3 cm. Seepage input from the rain was equal to 0.56 percent of what fell directly onto the lake surface.

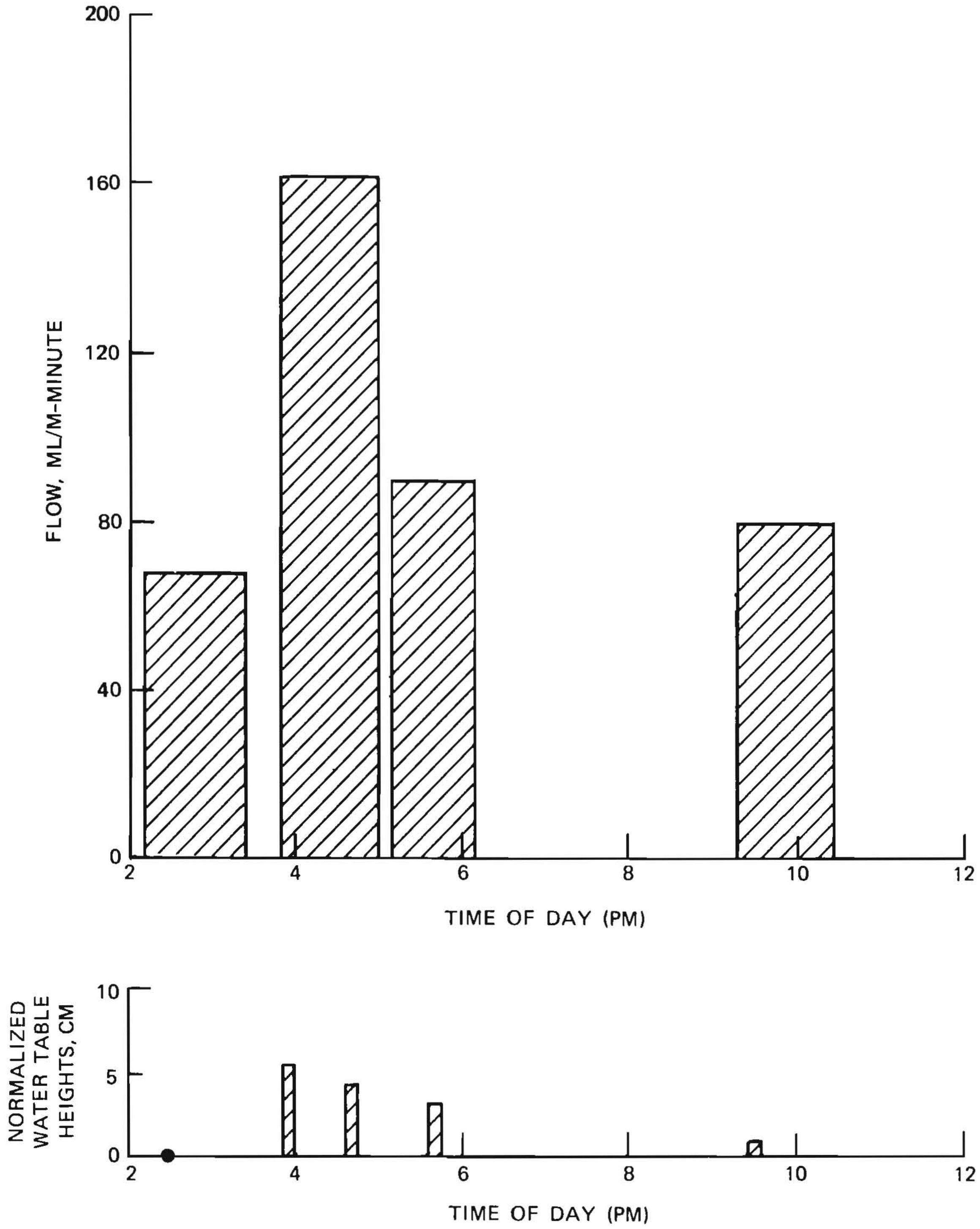

Figure 3. Seepage histogram and corresponding water table height before and after a rain event at the East Pool site

29. Estimation of the accuracy of the values for the total runoff components was based on several methods of determining total runoff. For the first of these, it was assumed that correlation of total rainfall in the basin with subsequent rise in lake level would provide an additional estimate of total runoff. Months that contained well-defined storm events following a dry period were determined from the rainfall record, and subsequent changes in lake storage and estimates of total runoff were calculated (Table 3). From these calculations, it was determined that an average of 12.7 percent of the precipitation that fell in the watershed (excluding the lake) entered the lake. Secondly, information from the USGS (1972-1978) indicates that the average annual outflow via Boggy Creek is 17.8 cm. Considering that average total rainfall for the area is 132.1 cm, runoff is approximately 13.5 percent of total rainfall. Variations in rainfall-runoff for Boggy Creek (Figure 4) indicate that, when total rainfall was 120 cm, approximately 12 to 13 percent of the rainfall that fell in the basin contributed to total runoff.

30. By combining the estimated surface runoff and seepage input and dividing by the precipitation in the watershed ((2.24 + 1.62)/ 46.28 m^3), a total runoff of 8.3 percent is obtained. Compared to the average calculated total runoff above of 12.7 percent (Table 3), this value is considerably lower than what would be expected for this area.

31. An estimate of groundwater flow (from the confined aquifer) was determined by considering the fall in lake stage during an extended dry period and correlating this value with losses estimated from evaporation alone. During three such periods, the drop in lake levels could be predicted by evaporation alone, showing no net inflow or outflow from groundwater and seepage.

32. This method does not distinguish groundwater (confined aquifer) flow from subsurface seepage. Seepage of this latter type was not monitored during these extended dry periods but, during this study, was always found to flow into the system in large amounts (usually >100 ℓ/m shoreline-day i.e., >0.4 mm/day). Consequently, groundwater flows might be expected to be outflows from the system since evaporation alone accounted for fall in lake stage. These observations, however, do

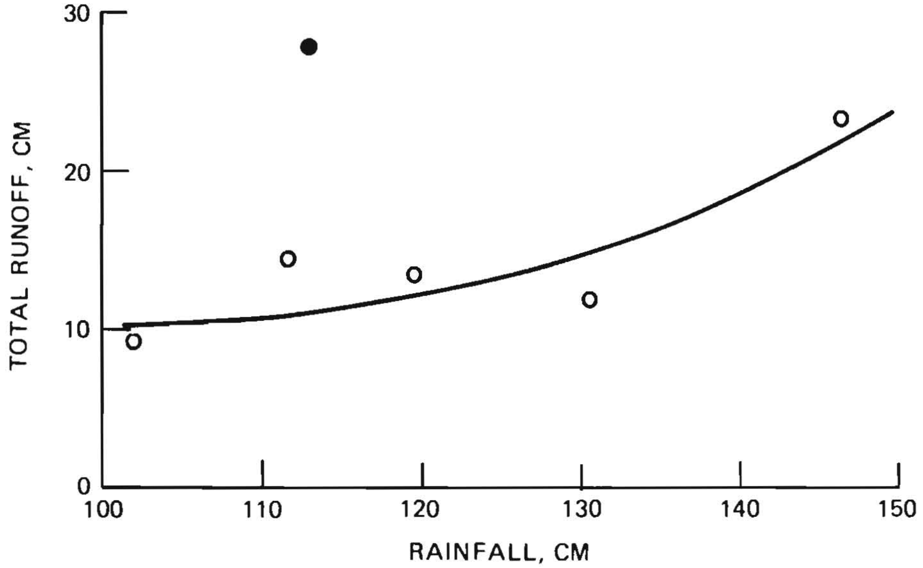

Figure 4. Precipitation-total runoff relationship for Boggy Creek. Closed circle (●) is the datum point for 1974, a year when the rainfall record was incomplete, possibly explaining the apparent discrepancy

not preclude the possibility of subsurface seepage from the system, especially in the area near the only surface outflow. These observations do support the hypothesis that groundwater flows (from the confined aquifer) into the Conway system are insignificant.

33. Surface outflow through the outlet during the study occurred only during August, September, and October 1976. From three measurements obtained during these months, it was determined that annual surface outflow was approximately $1.87 \times 10^6 m^3$. Additional outflows from the lakes might occur via groundwater recharge, seepage, evapotranspiration losses, and domestic pumpage. No attempt to measure these flows was made, and it was assumed that these flows constituted the difference between calculated inputs and outputs.

34. From lake height information for the years 1974-1975 and 1975-1976, it was determined that the net change in storage in the system for the water year 1976 was $-0.53 \times 10^6 m^3$. This amount was added to the outputs as additional seepage, i.e. groundwater recharges, out of the lake.

35. Utilizing all this information, a hydrologic budget for the Conway system was constructed (Table 4). It is evident that the hydrologic cycle of this system is dominated by precipitation-evaporation events. Other significant inflows are stormwater runoff and seepage, with the latter being the most important. Hydrologic budgets calculated for the individual pools in the Conway system are presented in Table 5.

Development of Dynamic Hydrologic Model

36. The calculated flows were used in a dynamic model to predict change in storage within the lake system. An information flow diagram for the model was prepared (Figure 5). The model was simulated for the period from December 1972 through March 1978 on a monthly basis. Simulation of the model from the measured flows resulted in a large, unrealistic increase in lake storage (i.e., the model was unstable). Two possibilities could explain this discrepancy: (a) either the outflows were too small or (b) the inflows were too large. Since no reasonable arguments could be presented to justify additional outflow from the lake, it was assumed that the inflows to the lake were too large. The controlling factors in the inflow equation left only two possibilities where errors could exist: (a) either the seepage and runoff coefficients were too large or (b) the basin area was too large. Since earlier arguments indicated that the total runoff measured was already too small, the most likely place of error was the basin area. Even though the area is well defined by drainage patterns and sewers, the effective drainage area is probably smaller because of high infiltration and depression storage in the area. Therefore, the basin area was determined to be 29.2 percent less, and was reduced from 35.6 to 25.2 km^2. As a result of this change, the model provided more realistic predictions.

37. Additional refinement of the model was accomplished by incorporating a factor that changed the runoff and seepage coefficients to reflect (simulate) moisture conditions in the water table aquifer. During dry periods (low rainfall), this factor decreased these coefficients and conversely increased them during wet seasons (high rainfall).

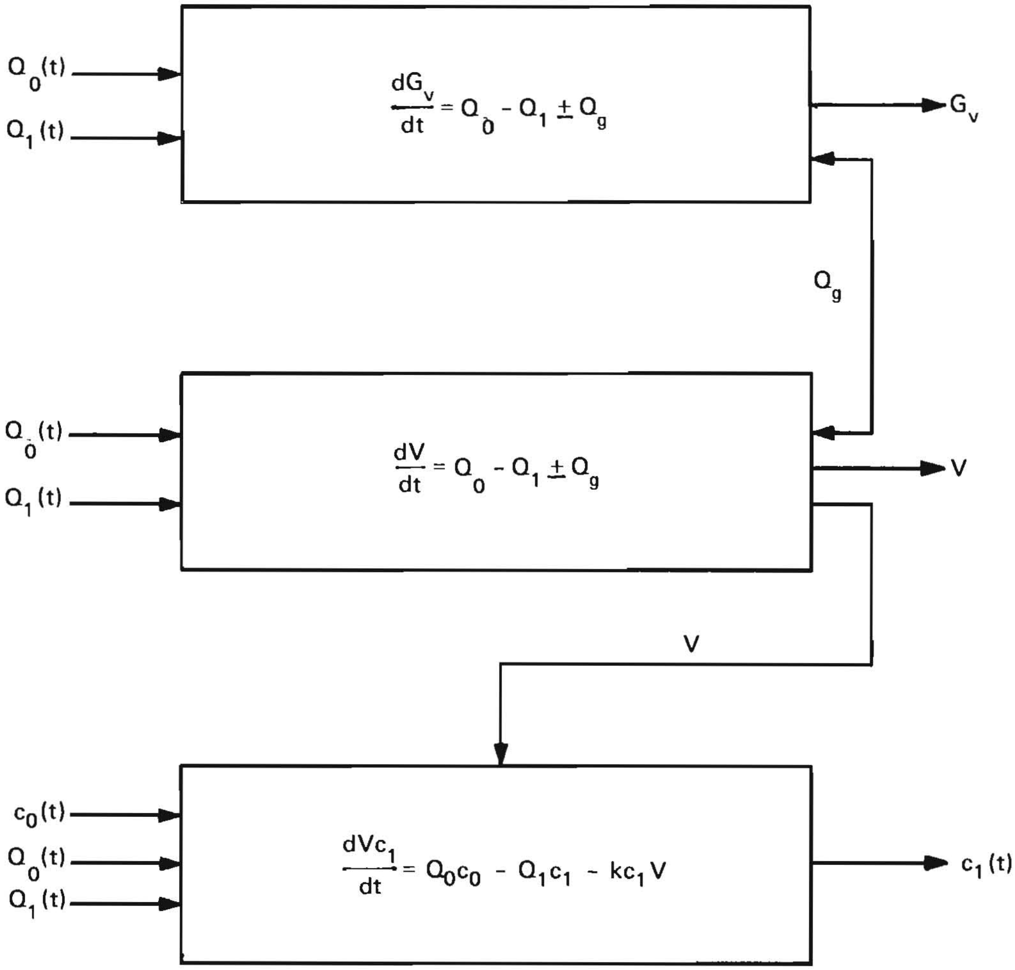

Figure 5. Flow diagram for the dynamic hydrologic--materials systems model. Q_0 = inflow volume at time zero, Q_1 = outflow volume at time 1, c_0 = inflow concentration, c_1 = average lake concentration, V = lake volume, G_v = groundwater volume, Q_g = groundwater flow

Also, minor changes in the coefficients were necessary to obtain the best simulation. These adjustments resulted in a model that simulated the observed lake height accurately for the period December 1972 to June 1977. After this period, the model showed an increase in lake height that was not observed. Repeated ajustments of the important coefficients did not improve the response of the model. Since a realistic simulation was desired, an additional drain (approximately 3 percent of inflows) was added to reduce the levels to those observed in the lake. The explanation that this discrepancy was due to unpredictable changes in outflow characteristics or recharge characteristics of the basin during an exceedingly dry year is plausible.

38. The results of the model are compared with the actual changes in lake height in Figure 6. A listing of the computer program is included as Appendix B. Differences between the simulated and observed changes in lake height are within 5 percent on a volume basis.

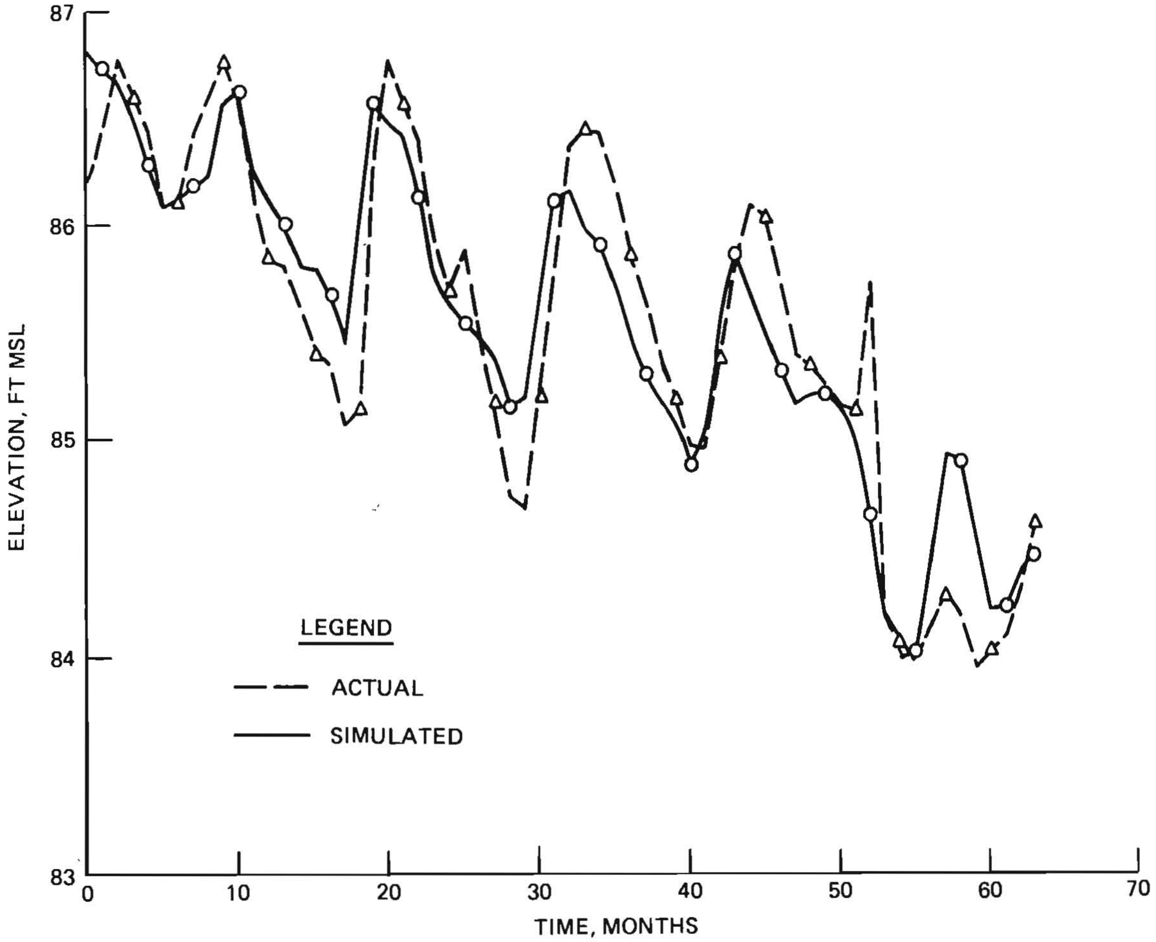

Figure 6. Comparison of the actual variations in lake height of the Lake Conway system and the simulated height from the hydrologic model for the period December 1972 (month 0) through March 1978 (month 63)

PART IV: NUTRIENT LOADING AND PHOSPHORUS DYNAMICS OF THE LAKE CONWAY SYSTEM

39. The trophic dynamics of lake systems are the integration of incoming allochthonous materials with the lake's biota. The first step in elucidating factors affecting trophic structure is to quantify some of these inputs, and this is most effectively accomplished by the development of a nutrient budget.

40. Depending on the type of information desired, two approaches for developing budgets are available: the net budget method (Johnson and Owen 1971) and the mass balance approach (Burns 1976). Net budgets are based on the concentration of the input sources entering a system and can have an input with a negative effect (i.e. if it has a dilution effect on the system). Net budgets are preferable when the nature of the input sources is being investigated. In the case of the mass budget, the quantity of materials is considered independent of the concentration and is always positive. Mass budgets are appropriate when the behavior of the individual nutrients within the lake is the prime consideration (Vollenweider 1975). For purposes of this investigation, the mass budget is the best approach.

Atmospheric Sources

41. Atmospheric inputs of phosphorus and nitrogen originate from a variety of sources including fertilizer mining, manufacturing, soils, and combustion of various types (fuels, agricultural burning, and forest fires) (Barkdoll, Overton, and Betson 1977). Eventually these materials are removed from the atmosphere as dry fallout or scavenged by precipitation. Much of the material that falls on land surfaces can potentially be resuspended into the atmosphere. Fallout onto water surfaces is essentially irreversible. In these cases, open bodies of water receive a disproportionate share of atmospheric particulate matter (Murphy 1974).

42. Based on the rainfall and dry fallout samples collected (Table 6), annual loadings of 0.048 g P/m^2-yr and 0.36 g N/m^2-yr for

rainfall and 0.080 g P/m^2-yr and 0.57 g N/m^2-yr for dry fallout have been calculated. The resulting bulk loadings (0.128 g P/m^2-yr and 0.93 g N/m^2-yr) compare well with similar loadings of 0.105 g P/m^2-yr and 1.0 g N/m^2-yr for Gainesville, Fla. (Hendry and Edgerton 1978, unpublished data, Department of Environmental Engineering, University of Florida, Gainesville, Fla.).

Nutrients From Stormwater Runoff and Seepage

43. The accumulation of particulate materials in urban areas and its subsequent runoff into water bodies have been investigated recently (Fruh et al. 1966; Mattraw and Sherwood 1977; Field, Curtis, and Bowden 1976). An early study by Weibel (1969) showed that runoff can contain suspended solids at concentrations that exceed those in raw domestic wastewaters. Seven probable sources of contaminants in urban runoff were listed by Sartor and Boyd (1972): pavement, vehicles, atmosphere, vegetation, litter, domestic and industrial spills, and antiskid compounds. Transport of these contaminants into nearby waters often results in significant nutrient loadings and subsequent water quality degradation.

44. Analysis of nitrogen and phosphorus concentrations in stormwater runoff from the small catchment in the Lake Conway watershed, described in Part III, yielded average concentrations of 3.25 and 0.39 mg/ℓ for nitrogen and phosphorus, respectively (Table 7). These compare well to published values that range from 1.93 to 4.45 mg/ℓ for N and from 0.19 to 0.98 mg/ℓ for P (Weibel 1969; Cowen and Lee 1976; Rast and Lee 1978). Multiplying the hydrologic loadings from stormwater runoff in the watershed (Table 4) by the measured concentrations and dividing by the surface area of the lake resulted in areal loadings of 0.069 g P/m^2-yr and 0.84 g N/m^2-yr.

45. During the period July 1977 through March 1978, seepage nutrient fluxes were measured from three to five times at each of the sites in Lake Conway. Table 8 summarizes the results and shows the daily fluxes of each nutrient and the seepage flow rates by site and date.

46. The West and South Pool fluxes for August 1977 were estimated

from incomplete data sets. After nutrient flux patterns had been established for these sites, the nutrient fluxes measured on this date were recalculated using graphical extrapolation to include the additional area from the fourth seepage meter to the outermost meter. The estimated nutrient flux values probably still underestimated the true fluxes.

47. Significant underestimations of seepage nutrient fluxes probably also occurred when nutrient fluxes in the meter furthest from shore were relatively large. Occurrences of this type are indicated in Table 8. The fluxes of ammonium at all sites were initially similar, and they tended to decline after about a 2-month period of constant or increasing flux. The fluxes of ammonium plus total organic nitrogen (i.e. Kjeldahl nitrogen flux) remained elevated for 3 to 3-1/2 months after meter installation because the flux organic nitrogen was initially low and it increased as the ammonium flux declined.

48. Total Kjeldahl nitrogen (TKN), which accounted for most of the nitrogen in the seepage water, remained relatively constant at each of the three sites in Lake Conway until after November 1977. The decline in TKN flux was probably caused by lack of sedimenting input to the area under the seepage meter, i.e., it was an artifact of the seepage meter. An average daily flux of total nitrogen was calculated for each site in the East and the South Pools from the data up to and including the November sampling date. Similar calculations were conducted on the ammonium and total organic nitrogen data from the West Pool site; however, the nitrate plus nitrite values were not included with this analysis. The elevated oxidized nitrogen (NO_2 and NO_3) values were probably caused by an atypically heavy fertilizer application to an adjacent citrus grove. The average of these three site averages was 0.62 g N/m shoreline-day. This average daily flux was biased because it was generated from data obtained during the months of greatest seepage flow and highest water temperature. The effects of temperature on the annual nutrient flux could not be compensated for with the limited data collected during this study. The effects of the seepage cycle were better known and were used to generate an annual average daily flux value.

49. A seepage quotient, similar to the quotients used in the water

budgeting section, was employed to calculate the annual average daily flux of nitrogen into Lake Conway. This ratio was generated from the flow data of the East Pool site, and it consisted of the average daily hydraulic loading for the year divided by the average daily hydraulic loading for the 110-day period during which the nutrient flux data were obtained. The product of the average flux (0.62 g N/m shoreline-day) and the seepage quotient (0.693) is an estimate of the annual average daily flux; this value was 0.430 g N/m shoreline-day. The total annual loading of nitrogen from seepage was calculated by multiplying the latter figure by the shoreline length of the five pools (2.95×10^4m) and by 365 (days per year). The result, 4640 kg N/yr, was divided by the surface area of the five lakes ($7.39 \times 10^6 m^2$) to yield an annual areal nitrogen loading of 0.628 g N/m^2-yr for the Lake Conway system.

50. The phosphorus loading to Lake Conway was calculated from the mean of the three site averages for flux measurements of total phosphorus up to and including the 3 November 1977 date. The seepage quotient procedure was then employed to minimize the effects of the annual seepage flow cycle. The total phosphorus seepage input to Lake Conway was 180 kg P/yr, or 24.4 mg P/m^2-yr.

51. Since undeveloped land in the watershed surrounding Lake Conway has a high infiltration rate, virtually no surface runoff should originate from these areas. These types of areas are interspersed throughout the "urban" area in the drainage basin. Consequently, they are included in the previous calculations for residential sources.

52. Surface runoff from agricultural areas is also considered negligible for several reasons. Urban encroachment into these areas is very evident, and their classification as agricultural is questionable. Few active citrus farms remain. Infiltration in these areas is also great because of the paucity of impermeable surfaces.

Additional Sources of Nutrients to Lake Conway

53. Other inputs of nutrients to lake systems occur in the form of internal loadings: nutrient regeneration from the sediments by

chemical and biological processes (burrowing insects and mixing by fishes); nutrient "pumping" by vascular aquatic plants; and nitrogen fixation by blue-green algae (and possibly by sediment bacteria). Inputs from the sediments and aquatic plants are not considered for purposes of the annual budget, but they will be discussed in the phosphorus modeling section. Detectable rates (up to 30 ng N/g dry weight-hr) of nitrogen fixation occurred during August 1977 in Lake Gatlin and in the East Pool of Little Lake Conway associated with benthic algal mats. Since nitrogen fixation only occurred at that particular time and since heterocystic blue-green algae were not common in the plankton, it was concluded that fixation of nitrogen represented an insignificant portion of the total nitrogen budget.

Outputs

54. Discharge of nutrients through the outlet of Lake Conway accounted for only a small portion of total nutrient loss. It was assummed that outflow nutrient concentrations were equal to average surface concentrations (Figure 7), which were 0.87 mg/ℓ for nitrogen and 0.024 mg/ℓ for phosphorus. Multiplying by the total outflow (Table 4) and converting to annual areal rates of loss yields values of 0.22 g/m^2-yr for nitrogen and 0.006 g/m^2-yr for phosphorus.

55. Losses by fish and weed removal, volatilization, and evaporation were not assessed. However, losses via these routes would probably represent only a minor portion of the total. Groundwater recharge as a nutrient sink for the Lake Conway system is considered to be insignificant, which follows from the conclusion of insignificant flow reached in Part III. Even if this conclusion were in error, nutrients being carried out via this pathway would end up in the sediments of the lake as either particulates or adsorbed to clay and organic matter.

56. Subtraction of nutrient outputs from total inputs yields a value that is considered to be a representative nutrient loss by sedimentation. Although this loss does not represent complete removal from the system, sedimentation does eliminate a significant portion of nutrients

from biological or chemical cycling within the lakes.

57. Annual nitrogen and phosphorus budgets for the Lake Conway system were prepared and are presented in Table 9. The atmosphere was the major external source of both nitrogen and phosphorus to Lake Conway, accounting for 37 and 56 percent of the total, respectively. Urban runoff was the second most important source of both nitrogen and phosphorus. Monthly nitrogen and phosphorus loadings (Table 10) reflected differences in the hydrologic loadings to the system.

Phosphorus Loading Model

58. If volumetric flow rates into and out of the system are unequal and time varying, and a completely mixed situation exists, the budget for a conservative substance (not transformed chemically or biologically or removed by sedimentation) entering a lake would follow a fundamental mass balance equation as follows:

$$\frac{d(Vc_i)}{dt} = Q_i c_i - Q_o c_o \tag{2}$$

where

V = volume of lake at time t*

c_i = average concentration in inflow

Q_i = inflows to lake

Q_o = outflows to lake

c_o = average concentration in lake

For a nonconservative substance such as phosphorus, the basic equation could be rewritten as:

$$\frac{d(Vc_i)}{dt} = Q_i c_i - Q_o c_o - kc_o V \tag{3}$$

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* All units were 10^6 cubic metres per month.

where k is a first-order rate constant or a term for the loss of substances other than through the outlet (i.e., reaction and/or sedimentation).

59. Equation 3 can be solved with the restrictive assumptions that outflow concentration is equal to the mean lake concentration and that sedimentation is a function of the mass of material under consideration in the lake. Vollenweider (1968) obtained the solution:

$$(m_w) = \frac{L_m}{q_s} \frac{1}{1 + \sigma_m (\overline{z}/q_s)} \tag{4}$$

where

(m_w) = mean lake concentration at steady-state
L_m = yearly areal loading of substance m
q_s = discharge height, m
σ_m = sedimentation coefficient
$\overline{z}$ = mean depth, m

Generally, mean lake concentration is a function of residence time, areal loading, and sedimentation characteristics. Using this relationship for phosphorus in a number of Swiss and North American lakes, Vollenweider (1975) developed empirical limits of critical loadings for lakes of various flushing characteristics. He found that these limits were 0.1 to 0.3 g P/m^2-yr and 1.0 to 2.0 g N/m^2-yr in temperate lakes. Brezonik and Shannon (1971) found higher limits of 0.28 to 0.49 g P/m^2-yr and 2.0 to 3.4 g N/m^2-yr for Florida lakes using a different approach, and suggested that subtropical lakes may be able to assimilate somewhat larger nutrient loadings. Phosphorus loadings to Lake Conway fall below Vollenweider's ranges of critical loadings, whereas loadings for nitrogen exceed the acceptable loadings of Vollenweider and are in the critical range according to Brezonik and Shannon.

60. Two terms in the Vollenweider input-output model must be carefully considered before utilizing Vollenweider's model: the water residence time τ_w and the phosphorus sedimentation coefficient σ_p. Water residence time has been recently shown to be one of the most important factors in empirical loading models (Yeasted and Morel 1978).

Hence, critical to any application of such models is the definition of residence time. Although τ_w appears to be a straightforward concept, defined as the lake volume divided by the outflow, care must be taken on what "outflow" means in terms of the models. As this term represents the flushing characteristics of a lake, outflow (especially in cases of lakes whose hydrology is dominated by precipitation evaporation events) should be defined as total outflow less the losses caused by evaporation. In this way an "effective" residence time that represents the true flushing characteristics of the system is obtained. All subsequent calculations were performed using this "effective" residence time.

61. The second factor that must be critically examined is the phosphorus sedimentation coefficient σ_ρ (equivalent to k in Equation 2). Realizing its importance in his relationship and the reality that it must be calculated from the model itself, Vollenweider (1975, 1976) provided several ways to calculate this coefficient. The first of these, derived from observations on lakes in his earlier studies, is as follows:

$$\ln \sigma_\rho = \ln 5.5 - 0.85 \ln \bar{z} \tag{5}$$

Equation 5 results in $\sigma_\rho = 1.34$ for Lake Conway. Use of this value to predict the mean lake concentration $[\bar{P}]$ from Equation 3 results in a value of 0.034 mg/ℓ which is considerably higher than the observed value of 0.024 mg/ℓ. Working backwards from the observed concentration, a value of 1.8 for σ_ρ was found, indicating that Vollenweider's equation can underestimate σ_ρ for Florida lakes.

62. Another relationship which can be used to calculate σ_ρ is the equation (Vollenweider 1976):

$$\sigma_\rho = \frac{F_\rho(z)}{\bar{z} \cdot [\bar{P}]_\lambda} \tag{6}$$

where

$[\bar{P}]_\lambda$ = average lake concentration over depth $\bar{z}$, mg P/m^3

$F_\rho(z)$ = the flux of P through z , mg P/m^2-yr

The major drawback to this equation is that $F_\rho(z)$ is unavailable for Lake Conway and most lakes that Vollenweider studied.

63. Vollenweider (1976) then defined sedimentation velocity as $F_\rho\left(z/[P]_\lambda^{sp}\right)$ and, by working backwards from Equation 6 using a sedimentation coefficient from this model, he obtained an apparent settling velocity of approximately 10 m/yr. As Vollenweider points out, the value obtained from this model is considerably below experimentally obtained values because it is a net sedimentation velocity. Burns and Pashley (1974) measured actual settling velocities in Lake Ontario and found that they ranged from -0.4 to 2.0 m/day. Taking an average of their results calculated for a year, a value of 240 m/yr is obtained.

A Dynamic Model of Phosphorus in Lake Conway

64. Equation 3 in the preceding section was used in the systems model to simulate the change in total phosphorus concentration over time (see Figure 7). Although the model was simulated for a period of over 5 years, total phosphorus concentrations were available only for the period January 1976 through December 1977, and for comparative purposes only those results are presented (Figure 7). The 5-year simulation, however, was used to test the model's stability.

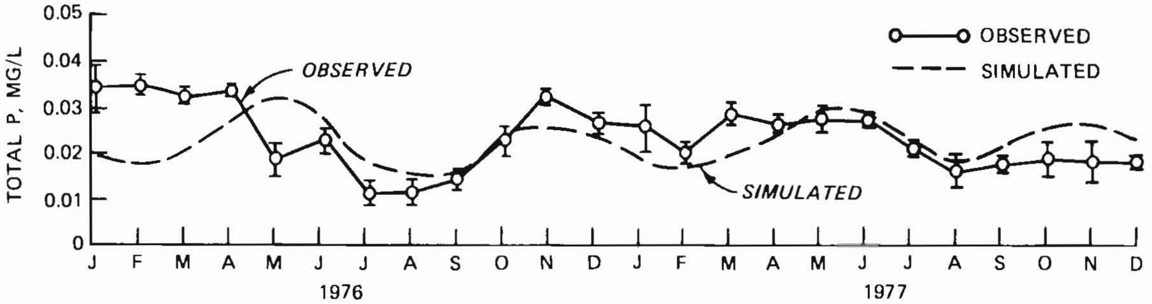

Figure 7. A comparison of the final simulation of the materials model to total phosphorus concentrations in the lake. Bars represent the standard error of the mean

65. Using only external inputs and a sedimentation coefficient derived from Vollenweider's (1975) model, the model yielded phosphorus levels that are representative of conditions in the lake on an annual

basis, but the simulations did not fit the observed seasonal trends of total phosphorus concentrations. This was expected because of the simplifying assumptions used in Vollenweider's derivation, i.e. that a constant σ_ρ can be used to represent the net sedimentation coefficient for the system. While the assumption of a constant loss coefficient may be adequate for an annual cycle, it is an oversimplification for a dynamic model. Other factors must be considered to explain the seasonal events observed.

66. Functions* were obtained for phosphorus loadings from vascular plants and the sediments from Fontaine (1978). He estimated these functions from productivity measurements and sediment leaching experiments performed during 1976. Since these functions represent maximal expected inputs from these sources, their actual contribution to the lake is considered as a fraction of the total. As an initial estimate these functions were run at half of their potential loadings. Reduction of the loadings was continued until the simulated phosphorus concentrations fit the observed seasonal trends. This occurred when the plants were reduced to 20 percent, and the sediments were reduced to 1 percent of their respective maximal loadings. In order to obtain an optimal fit, the sedimentation coefficient from Vollenweider's model had to be increased from 0.15 to 0.70. While some justification of using a higher sedimentation coefficient was presented previously in the discussion of loading models, it is necessary to examine the relationship more closely. Using Vollenweider's relationship to compute a settling velocity for Lake Conway using the sedimentation coefficient from the dynamic model, a value of 44.1 m/yr is obtained. Although this is still well below the values reported by Burns and Pashley (1974), it is probably realistic for a lake system with an averaged mean depth of only 5 m.

67. As an additional reference parameter to check the calculations of the loading model, Vollenweider (1976) also introduced the concept of relative phosphorus residence time π_r defined as:

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* See Appendix B, ***Functions*** of the model. For time = 0.0, phosphorus (g/m^2) = 0.00102; for time = 2.0, phosphorus = 0.00108, etc.; time = 0.1 of a year.

$$\pi_r = \frac{\tau_\rho}{\tau_w{}^{*}} = \frac{\frac{1}{\tau_w}}{\frac{1}{\tau_w} + \sigma_\rho} \simeq \frac{1}{1 + \tau_w} \qquad (7)$$

The third term of Equation 7 is developed from the steady-state model and the fourth term is a statistical approximation. For Lake Conway, π_r calculated from the third term is 0.053, but if calculated from the fourth term it is 0.231. According to Vollenweider, this may indicate that accumulation of phosphorus in the sediments of Lake Conway must occur at a greater rate than in the lakes he used in his study. This corroborates both the results of the dynamic model and the previous calculations, as well as the findings of Brezonik and Shannon (1971). Shallow subtropical lakes, such as those found in Florida, may be able to assimilate more nutrients than would be expected for temperate lakes, justifying the increase in the sedimentation coefficient.

68. The final simulation is presented in Figure 7 along with observed trends in total phosphorus concentrations. A correlation coefficient (r = 0.25) was calculated for the two curves, indicating a weak fit of the model to the observed data. When the first 5 months of 1976 are not included in the comparison, a reasonable fit is observed (r = 0.63). The observed high phosphorus concentrations in early 1976 may have been caused by a large amount of phosphorus being recycled in the lake system because of extensive herbicide treatment of the aquatic plants the preceding fall.

69. Contributions of total phosphorus of the lake from the three major input sources are shown in Figure 8 and in the following tabulation:

Year	1976	1977
External		
All sources	0.24	0.25

(Continued)

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* "w" refers to water. For example, τ_ρ/τ_w is the residence time for phosphorus in the lake.

Year	1976	1977
Internal		
Macrophytes	0.66	0.68
Sediments	0.02	0.02
Total	0.92	0.95

Note: Determined by balancing the dynamic model; grams per square metre per year.

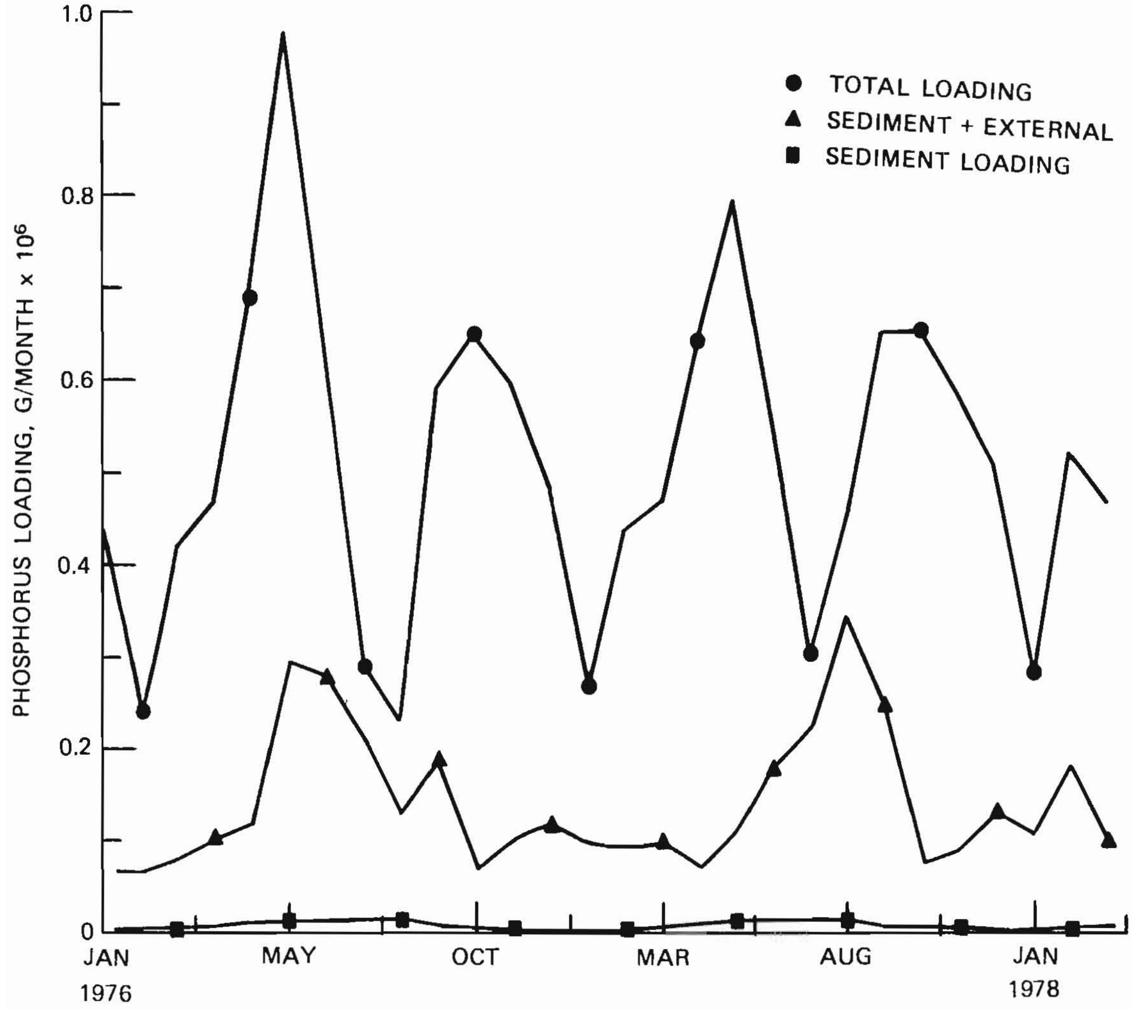

Figure 8. Phosphorus loadings to the Lake Conway system from sediments, external sources, and macrophytes. The area between the top and middle curves represents loading from macrophytes, and the area between the middle and bottom curves represents loading from external sources

The relatively small contribution of phosphorus from the sediments and the dominance of macrophyte pumping in the model give some insight into the role of these components, at least for the Conway system. The simulation suggests that phosphorus released from the sediments during anoxic conditions in the summer does not become entrained during overturn in the fall. This hypothesis has been suggested previously by Fitzgerald (1970), who observed that adsorbtion of phosphorus by lake muds is rapid enough to remove most of the phosphorus before it can be used to support algal growth. An alternate hypothesis that the amount of phosphorus from the plants is too high and the sediments are actually supporting the observed concentrations of phosphorus cannot be ruled out entirely. However, the mass balance of phosphorus determined by use of the dynamic model does not support the hypothesis that sediment release is an important source of phosphorus for Lake Conway.

PART V: SUMMARY AND CONCLUSIONS

70. This report summarized and integrated some of the physical, chemical, and biological data that were collected from the Lake Conway system during the period April 1976 through March 1978. The purpose of this work was to clarify some of the relationships between external nutrient loadings and internal nutrient cycling in this subtropical ecosystem.

71. Measurements were made of stormwater runoff and subsurface seepage flows to the lake. Using the collected data and existing precipitation and evaporation data, a hydrologic budget was constructed. The budget was refined and verifed by use of a dynamic systems model. The hydrologic model accurately predicted the change in lake level for the period December 1972 through March 1978.

72. Based on the flows determined from the hydrologic investigation, inputs of nutrients to Lake Conway were calculated. The major sources of external nitrogen and phosphorus loadings were from atmospheric loadings, urban runoff, and subsurface seepage. Estimates of nutrient inputs showed that both nitrogen (2.53 g N/m^2-yr) and phosphorus (0.224 g P/m^2-yr) loadings were in the range of "critical" loading for the system.

73. A simulation model of the phosphorus dynamics of Lake Conway was developed to determine the relative importance of external inputs and internal nutrient cycling. From the results of the model, the following conclusions were drawn:

- *a*. The sedimentation of phosphorus in Lake Conway occurs at a rate higher than would be predicted from Vollenweider's analyses on temperate lakes.
- *b*. Nutrient release by submerged macrophytes is an important process in the phosphorus dynamics of Lake Conway.
- *c*. Release of phosphorus by sediments is not a significant internal source of this nutrient for Lake Conway.

REFERENCES

American Public Health Association. 1975. Standard Methods for the Analysis of Water and Wastewater, 14th ed., New York.

Barkdoll, M. P., Overton, D. E., and Betson, R. P. 1977. "Some Effects of Dustfall on Urban Stormwater Quality," Journal of the Water Pollution Control Federation, Vol 49, pp 1976-1984.

Blancher, E. C. et al. 1978. "Nitrogen and Phosphorus Loading Characteristics of the Lake Conway, Florida, Ecosystem," Preliminary Report, Department of Environmental Engineering Sciences, University of Florida, Gainesville, Fla.

Blancher, E. C. 1979. Lake Conway, Florida: Nutrient Dynamics, Trophic State, Zooplankton Relationships, Ph.D. Dissertation, University of Florida, Gainesville, Fla.

Brezonik, P. L., and Shannon, E. E. 1971. "Trohpic State of Lakes in North Central Florida," Water Resources Research Center Publication No. 13, University of Florida, Gainesville, Fla.

Burns, N. M. 1976. "Nutrient Budgets for Lake Erie," Journal of the Fisheries Research Board of Canada, Vol 33, pp 520-536.

Burns, N. M., and Pashley, A. E. 1974. "In Situ Measurement of the Settling Velocity Profile of Particulate Organic Carbon in Lake Ontario," Journal of the Fisheries Research Board of Canada, Vol 31, pp 291-297.

Chow, V. T. 1964. Handbook of Hydrology, McGraw-Hill, New York.

Conley, R. A. et al. 1978. "The Plankton, Periphyton and Benthic Invertebrates of Lake Conway, Florida," Department of Environmental Engineering Sciences, University of Florida, Gainesville, Fla.

Cowen, W. F., and Lee, G. F. 1976. "Phosphorus Availability in Particulate Materials Transported by Urban Runoff," Journal of the Water Pollution Control Federation, Vol 48, pp 580-591.

Ewel, K. C., and Fontaine, T. D., III. 1977. "Proposed Relationships Between White Amur and the Aquatic Ecosystem at Lake Conway, Florida," Proceedings, Research Planning Conference on the Aquatic Plant Control Program, 19-22 October 1976, Atlantic Beach, Fla., Miscellaneous Paper A-77-3, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 159-176.

Fellows, C. R. 1978. The Significance of Seepage in the Water and Nutrient Budgets of Selected Florida Lakes, M.S. Thesis, College of Engineering, University of Florida, Gainesville, Fla.

Fellows, C. R. 1979. Hydrologic Seepage Flows in Some Selected Florida Lakes, M.S. Thesis, College of Engineering, University of Florida, Gainesville, Fla.

Field, R., Curtis, J., and Bowden, R. 1976. "Urban Runoff and Combined Sewer Overflow," Journal of the Water Pollution Control Federation, Vol 48, pp 1191-1206.

Fitzgerald, G. P. 1970. "Aerobic Muds for the Removal of Phosphorus from Lake Waters," Limnology and Oceanography, Vol 15, pp 550-555.

Fitzgerald, G. P., and Nelson, T. C. 1966. "Extractive and Enzymatic Analyses for Limiting or Surplus Phosphorus in Algae," J. Phycol., Vol 2, pp 32-37.

Fontaine, T. D. 1978. An Ecological Systems Model for Lake Conway, Florida, Ph.D. Dissertation, College of Engineering, University of Florida, Gainesville, Fla.

Fontaine, T. D., and Ewel, K. C. 1978. "Baseline Studies for Evaluating the Response of an Ecosystem to the Introduction of White Amur," Second Annual Report to the U. S. Army Engineer Waterways Experiment Station, Center for Wetlands, University of Florida, Gainesville (mimeo).

Fox, J. L. et al. 1977. "Biological Baseline Studies of the Lake Conway, Florida, System," Proceedings, Research Planning Conference on the Aquatic Plant Control Program, 19-22 October 1976, Atlantic Beach, Fla., Miscellaneous Paper A-77-3, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 123-145.

Fruh, E. G. et al. 1966. "Measurement of Eutrophication and Trends," Journal of the Water Pollution Control Federation, Vol 38, pp 1237-1258.

Guillory, V., Land, R., and Gasaway, R. 1977. "Baseline Data Report--Lake Conway Grass Carp Projects. Fishes," Proceedings, Research Planning Conference on the Aquatic Plant Control Program, 19-22 October 1976, Atlantic Beach, Fla., Miscellaneous Paper A-77-3, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 97-112.

Johnson, M. G., and Owen, G. E. 1971. "Nutrients and Nutrient Budgets in the Bay of Quinte, Lake Ontario," Journal of the Water Pollution Control Federation, Vol 43, pp 836-853.

Kohler, M. A. 1954. "Lake and Pan Evaporation in Water-Logs Investigations--Lake Heffner Studies," U. S. Geological Survey Professional Paper 269.

Lee, D. R. 1972. Septic Tank Nutrients in Groundwater Entering Lake Shallie, Minnesota, M.S. Thesis, University of North Dakota, Grand Forks, N. D.

Lee, D. R. 1977. "A Device for Measuring Seepage Flux in Lakes and Estuaries," Limnology and Oceanography, Vol 22, pp 140-147.

Leighty, C. M. et al. 1957. "Soil Survey of Orange County, Florida," U. S. Department of Agriculture Soil Conservation Service, Gainesville, Fla.

Lichtler, W. F., Anderson, W., and Joyner, B. F. 1968. "Water Resources of Orange County, Florida," State of Florida, State Board of Conservation, Tallahassee.

Lock, M. A., and John, P. H. 1978. "The Measurement of Groundwater Discharge Into a Lake by a Direct Method," Internationelen Revue gesamte Hydrobiologie Hydrographie, Vol 63, pp 271-275.

Mattraw, H. C., and Sherwood, C. B. 1977. "Quality of Storm-Water Runoff from a Residential Area, Broward County, Florida," *Jour. Research U. S. Geol. Survey.,* Vol 5, pp 823-834.

Murphy, T. J. 1974. "Sources of Phosphorus Inputs from the Atmospheres and Their Significance to Oligotrophic Lakes," WRC-74-0092, Report #92, University of Illinois, Urbana, Ill.

Nall, L. E., Mahler, M. J., and Schardt, J. D. 1977. "Aquatic Macrophyte Sampling in Lake Conway," *Proceedings, Research Planning Conference on the Aquatic Plant Control Program, 19-22 October 1976, Atlantic Beach, Fla.,* Miscellaneous Paper A-77-3, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 113-122.

Nall, L. E., Schardt, J. D., and Burkhalter, A. P. 1978. "The Effect of the White Amur on the Aquatic Vegetation of Lake Conway, Florida," First Annual Report, Baseline Data, Florida Department of Natural Resources, Tallahassee, Fla.

National Oceanographic and Atmospheric Administration. 1972-1978. *U. S. Climatological Reports, Florida Section,* Washington, D. C.

Rast, W., and Lee, G. 1978. "Summary Analysis of the North American (U. S. Portion) OECD Eutrophication Project," EPA-600/3-78-008, U. S. Environmental Protection Agency, Corvallis Environmental Research Lab., Corvallis, Oreg.

Rich, L. 1973. *Environmental Systems Engineering,* McGraw-Hill, New York.

Sartor, J. D., and Boyd, G. S. 1972. "Water Pollution Aspects of Street Surface Contaminants," EPA-R2-72-081.

Sawicki, A. T. 1977. "Background Water Quality Analysis of Lake Conway," *Proceedings, Research Planning Conference on the Aquatic Plant Control Program, 19-22 October 1976, Atlantic Beach, Fla.,* Miscellaneous Paper A-77-3, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 146-158.

Soil Conservation Service. 1975. "Urban Hydrology for Small Watersheds," SCS Engineering Division Technical Release No. 55, Upper Darby, Pa.

Sompongese, D. 1978. *A Study of the Nitrogen Cycle in the Lake Conway, Florida, Ecosystem,* M.S. Thesis, College of Engineering, University of Florida, Gainesville, Fla.

Speckhart, F. H., and Green, W. L. 1976. "A Guide to Using CSMP--The Continuous System Modeling Program," Prentice-Hall, New Jersey.

Stewart, W. D. P., Fitzgerald, G. P., and Burris, W. D. 1968. "Acetylene Reduction by Nitrogen Fixing Blue-Green Algae," *Archiv Mikrobiologie,* Vol 62, pp 336-348.

Theriot, R. F. 1977. "The Large-Scale Operations Management Test (LSOMT) With the White Amur at Lake Conway, Orlando, Florida," *Proceedings, Research Planning Conference on the Aquatic Plant Control Program, 19-22 October 1976, Atlantic Beach, Fla.,* Miscellaneous Paper A-77-3, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 87-96.

U. S. Environmental Protection Agency. 1971. "Algal Assay Bottle Test," National Eutrophication Research Program, Pacific Northwest Water Laboratory, Corvallis, Oreg.

U. S. Environmental Protection Agency. 1974. "Methods for Chemical Analysis of Water and Wastes," Environmental Monitoring and Support Laboratory, Cincinnati, Ohio.

U. S. Geological Survey. 1972-1978. "Water Resources Data for Florida Water, Years 1972-1978," Washington, D. C.

Vollenweider, R. A. 1968. "Scientific Fundamentals of the Eutrophication of Lakes and Flowing Waters With Particular Reference to Phosphorus and Nitrogen as Factors in Eutrophication," OECD Technical Report DAS/CS1/68.27.

Vollenweider, R. A. 1975. "Input-Output Models, With Special Reference to the Phosphorus Loading Concept in Limnology," Schweizereich Zeitschrift fur Hydrologie, Vol 37, pp 53-84.

Vollenweider, R. A. 1976. "Advances in Defining Critical Loading Levels for Phosphorus in Lake Eutrophication," Memoir ist Italien Idrobiol., Vol 33, pp 53-65.

Weibel, S. R. 1969. "Urban Drainage as a Factor in Eutrophication," Eutrophication: Causes, Consequences and Correctives, National Academy of Sciences, Washington, D. C.

Yeasted, J. G., and Morel, F. M. M. 1978. "Empirical Insights into Lake Response to Nutrient Loadings, with Application to Models of Phosphorus in Lakes," Environmental Science and Technology, Vol 12, pp 195-201.

Table 1

Precipitation, Evaporation, and Pan Coefficients for Water Year 1976 (October 1975 through September 1976)

Month	Precipitation* cm	Evaporation** cm	Pan Coefficient†
October 1975	12.04	12.70	0.76
November	1.68	8.95	0.71
December	1.29	7.07	0.83
January 1976	0.94	7.54	0.77
February	2.11	10.23	0.69
March	4.37	14.93	0.73
April	5.49	17.09	0.84
May	26.31	17.01	0.82
June	25.22	16.34	0.85
July	17.90	17.61	0.91
August	8.26	17.25	0.91
September	14.91	14.70	0.85
Total	120.52	161.42	

---

* For Orlando Weather Station, McCoy Air Base station.

** Average for Lisbon and Lake Alfred stations.

† Kohler (1954).

Table 2

Summary of Stormwater Runoff Hydrographs Collected at Gatlin Avenue and Bumby Drive, Orlando, in 1976 and 1978

Date	Total Flow m^3	Rainfall cm	Basin Area ha	Volume of Rainfall in Basin m^3	Rain Duration hr	Antecedent Conditions (Time Since Last Rain)	Base Flow m^3/sec	Runoff Coefficient
21 August 1976	986.30	1.98	128	25,344	0.42	24 hr	0.0	0.039
23 March 1978	45.43	0.18	43	774	1.25	24 hr	0.0	0.059
4 May 1978	665.88	3.68	43	15,824	2.00	24 hr	0.0	0.042
16 June 1978	45.75	0.33	43	1,419	0.90	48 hr	0.0	0.032
21 June 1978	4.58	0.58	43	2,494	0.33	5 days	0.0	0.002
Average coefficient								0.035

Table 3

Estimation of Total Precipitation, Evaporation, and Runoff in the Conway System ($m^3 \times 10^6$)

Date	Total Rainfall in Basin	Δ Volume in Lake	Precipitation on Lake	Evaporation From Lake	Net Precipitation	Total Runoff	Total Runoff/ Total Rainfall in Basin Expressed as a Percentage
April 1973	0.686	+0.112	0.131	0.120	0.011	0.100	15
March 1974	3.35	+0.896	0.638	0.113	0.524	0.371	11
May 1975	7.63	+1.299	1.167	0.782	0.385	0.914	12
Average							12.7

Table 4

Annual Hydrologic Budget for the Lake Conway System for the Water Year 1976*

	Volume ($m^3 \times 10^6$)
Sources	
Precipitation	8.87
Influent streams	NS
Stormwater	1.66
Seepage in	2.15
Groundwater (from confined aquifer)	NS**
Total in	12.68
Sinks	
Evaporation	9.27
Surface outflow	1.87
Seepage out	NS
Groundwater and pumpage	2.07†
Total out	13.21
Change in storage	-0.53

---

* In millions of cubic metres.

** NS = not significant.

† Obtained by difference.

Table 5

Hydrological Budget for Each Pool in the Conway System*

Pool	Precipitation	Stormwater	Seepage In	Total In	Evaporation	Outflows**	Groundwater Out	Total Out
South	1.64	0.076	0.395	2.11	1.72	0.18	0.21	2.11
Middle	3.59	0.136	0.669	4.40	3.75	0.20	0.44	4.39
East	1.52	0.626	0.488	2.63	1.59	0.78	0.26	2.63
West	1.78	0.629	0.433	2.84	1.86	0.70	0.28	2.84
Gatlin	0.34	0.197	0.164	0.70	0.35	0.28	0.07	0.70

---

* In millions of cubic metres.
** Obtained by difference.

Table 6

Loadings of Nitrogen and Phosphorus to Lake Conway From Atmospheric Sources

Date	Total Nitrogen Dry mg/m^2-day	Total Nitrogen Wet mg/mm Rainfall	Total Phosphorus Dry mg/m^2-day	Total Phosphorus Wet mg/mm Rainfall
18 August 1976*	--	0.30	--	0.080
19 November-1 December 1977	--	0.25	--	0.030
1 December-15 December 1977	--	0.37	--	0.004
15 January-11 February 1978	1.11	0.17	0.10	0.007
19 March-3 May 1978	1.91	0.24	0.40	0.023
3 May-23 May 1978	1.58	0.35	0.18	0.093
23 May-12 June 1978	2.19	0.34	0.22	0.030
12 June-12 July 1978	1.32	0.32	0.28	0.018
12 July-30 July 1978	1.29	0.30	0.15	0.041
Mean value	1.56	0.30	0.22	0.036

---

* One rain event only.

Table 7

Nitrogen and Phosphorus Concentrations in Stormwater Runoff Entering Lake Conway

	Number of Samples	Total Nitrogen*	Total Phosphorus*	Total Flow m^3
21 August 1976	9	2.3	0.33	986.3
23 March 1978	27	4.7	0.45	45.5
4 May 1978	28	4.6	0.47	665.8
16 June 1978	12	4.0	0.42	45.8
21 June 1978	8	5.1	0.63	4.6
Mean values	--	3.25	0.39	--

---

* Concentrations are flow-weighted averages expressed as milligrams per litre.

Table 8

Nutrient Flux Values for the Three Study Sites in Lake Conway During the 1977-78 Study Period

Site and Installation Date	Date	Flow*	NH_4^+-N**	Total Organic Nitrogen**	NO_3^--N† NO_2^--N	Total Phosphorus†	Ortho-P†
East Pool	7/16	196	0.470	--	2.57	11.8	2.9
Some meters repositioned	11/3	120	0.054	0.269	--	6.1	0.3
	1/6	103	0.030	0.038	0.024	4.4	0.8
West Pool	8/7	189	0.562††	0.0	2.78††	23.6††	12.3††
7/27	9/1	217	0.490‡	0.099‡	688	23.2	14.5
	11/3	198	0.112	0.378	2952	16.1	8.5
	1/6	209	0.047	0.125	5120	14.0	9.6
	3/24	200	0.015	0.208	3286	10.7	4.4††
South Pool	8/7	283	0.525††	0.246††	2.25††	56.5††	42.0††
7/15	9/1	368	0.652	0.327	2.45	34.9	30.9
	11/3	256	0.359	0.641	--	35.6	24.6
	1/6	310	0.154	0.069	0.309	61.9	43.3

---

* Amounts in litres per metre of shoreline per day.

** Amounts in grams per metre of shoreline per day.

† Amounts in milligrams per metre of shoreline per day.

†† Estimated from established flux patterns using incomplete data.

‡ Possible underestimation.

Table 9

Annual Nitrogen and Phosphorus Budgets for the Lake Conway System for the Water Year 1976*

	Nitrogen	Phosphorus
Inputs		
Airborne		
Combined wet and dry precipitation	0.93	0.125
Surface		
Urban stormwater	0.84	0.069
Agricultural runoff	NS	NS
Undeveloped land runoff	NS	NS
Subsurface		
Groundwater inflow	NS	NS
Seepage	0.63	0.024
Septic tanks**	0.10	0.006
In situ		
Nitrogen fixation	NS	--
Sediment leaching	(?)	(?)
Nutrient recycling (vascular plants)	(?)	(?)
Total in	2.50	0.224
Outputs		
Surface outfalls	0.22	0.006
Groundwater recharge	NS	NS
Fish and weed removal	NS	NS
Volatilization and evaporation	(?)	--
Denitrification	(?)	--
Sedimentation	2.28†	0.218†
Total out	2.50	0.224

Note: NS = not significant.

* Loadings are reported in grams per square metre of lake surface area per year (g/m^2-yr).

** Determined by calculation.

† Obtained by difference.

Table 10

Monthly Loadings of Nitrogen and Phosphorus to the Lake Conway System for the Water Year 1976*

Date	Storm-water	Seepage	Atmo-spheric	Outflow	Storage	Net Sedimentation**
			Nitrogen			
October 1975	0.643	0.487	0.612	0.00	37.07	-8.44
November	0.075	0.067	0.382	0.00	28.00	+9.66
December	0.059	0.052	0.374	0.00	35.29	-6.74
January 1976	0.042	0.037	0.366	0.00	11.86	+23.94
February	0.094	0.086	0.392	0.00	18.65	-6.156
March	0.296	0.176	0.442	0.00	23.01	-3.48
April	0.347	0.221	0.467	0.00	22.14	+1.87
May	1.386	1.063	0.928	0.00	29.49	-4.11
June	1.138	1.029	0.904	0.00	30.77	+1.85
July	0.906	0.722	0.742	0.00	26.38	+6.72
August	0.480	0.333	0.538	0.38	42.68	-14.61
September	0.773	0.603	0.676	0.22	26.05	+18.80
			Phosphorus			
October 1975	0.049	0.018	0.080	0.00	0.716	-0.133
November	0.014	0.002	0.053	0.00	1.08	-0.251
December	0.012	0.002	0.051	0.00	0.87	+0.275
January 1976	0.009	0.001	0.051	0.00	1.09	-0.159
February	0.013	0.003	0.054	0.00	1.13	+0.030
March	0.021	0.006	0.060	0.00	1.04	+0.177
April	0.026	0.008	0.063	0.00	1.06	+0.077
May	0.101	0.039	0.118	0.00	0.60	+0.718
June	0.092	0.037	0.115	0.00	0.75	+0.094
July	0.071	0.026	0.096	0.00	0.38	+0.287
August	0.030	0.013	0.070	0.003	0.37	+0.122
September	0.060	0.022	0.088	0.004	0.47	+0.070

---

* All loadings are reported in grams × 10^6.

** Septic tank inputs were treated as a constant inflow for these calculations. Positive sedimentation represents a loss from storage to the sediments.

APPENDIX A: STORMWATER HYDROGRAPHS

Stormwater hydrographs for storms were measured at the corner of Gatlin Avenue and Bumby Drive, Orlando, Fla., on the following dates: 23 March 1978, 4 May 1978, 16 June 1978, and 21 June 1978 (Figures A1-A4, respectively).

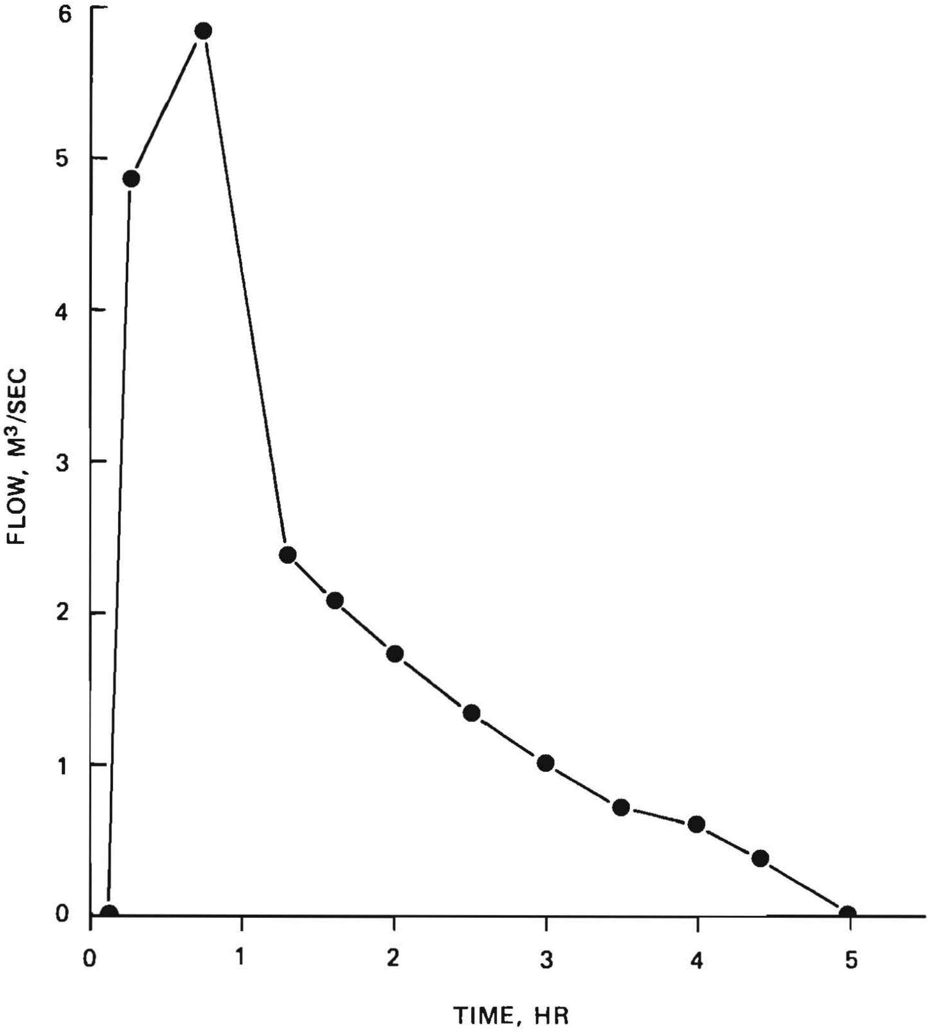

Figure A1. Stormwater hydrograph, 23 March 1978

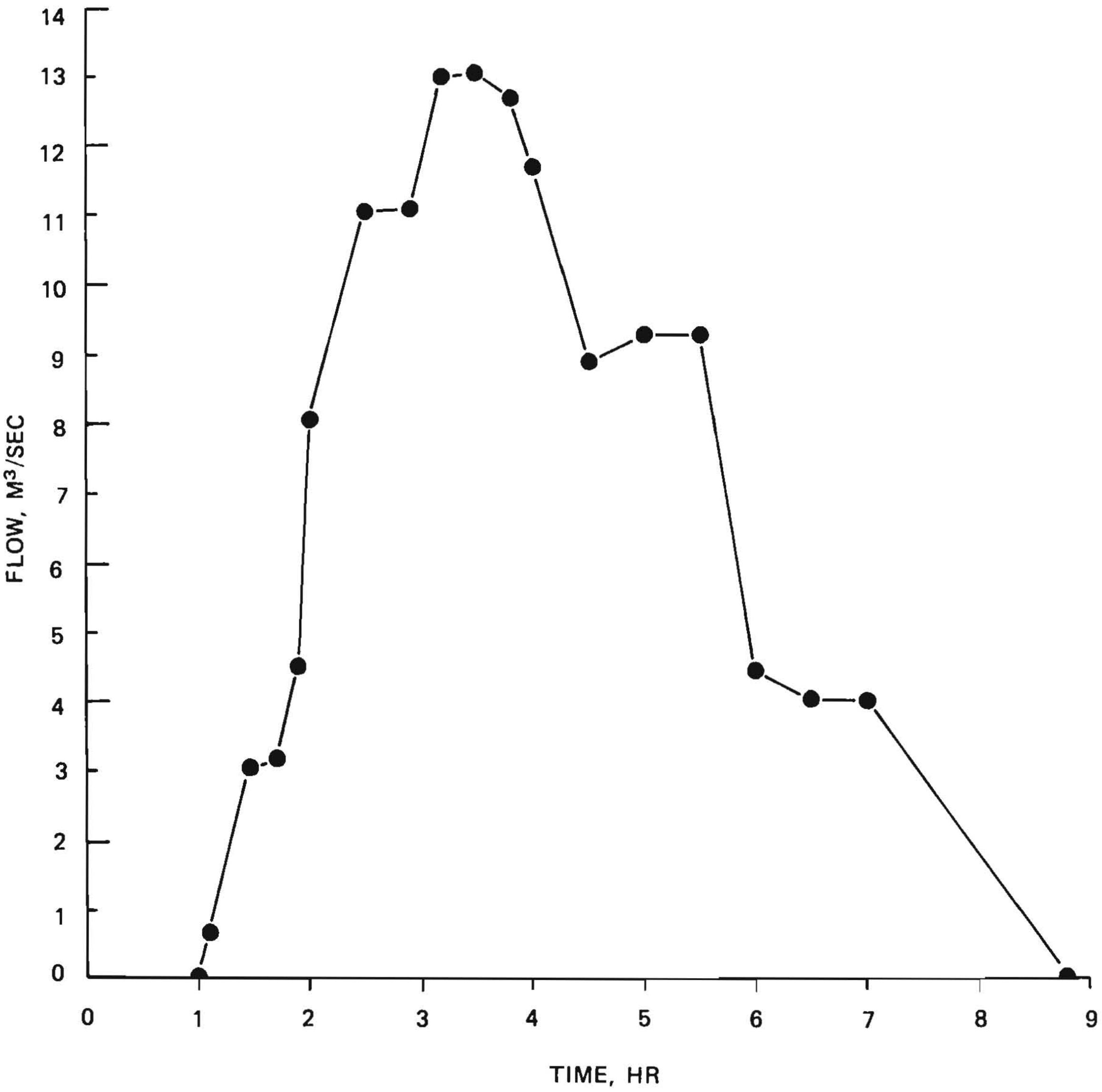

Figure A2. Stormwater hydrograph, 4 May 1978

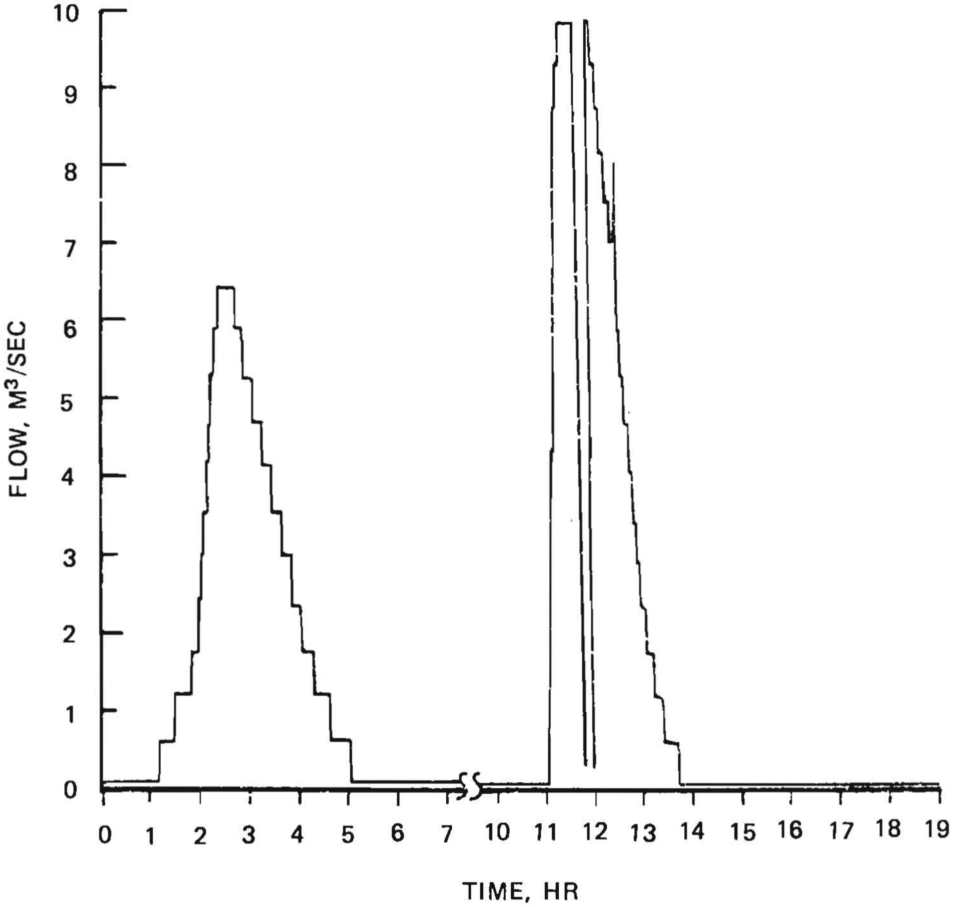

Figure A3. Stormwater hydrograph, 16 June 1978

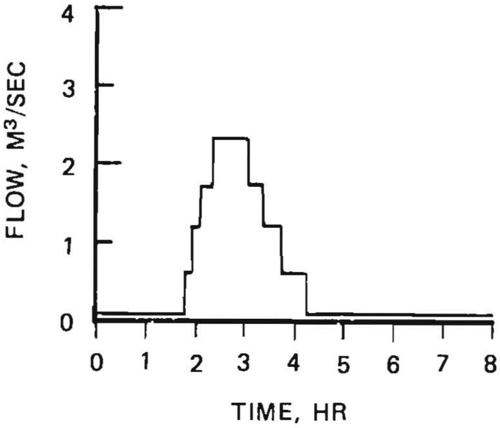

Figure A4. Stormwater hydrograph,
21 June 1978

APPENDIX B: COMPUTER LISTINGS

The following is a listing of the hydrologic--materials systems model written in the Continuous Systems Modeling Program (CSMP) Language. Also included is the Job Control Language (JCL) for coupling CSMP to the Gould plotter, using a program in the Northeast Regional Data Center's systems library.

```
//PMODEL   JOB (1006,3448,10,10,0),'***** BLANCHER ',CLASS=M
// EXEC PGM=DEJCSMP3
//STEPLIB DD DSN=A0011301.S1.LOADLIB,DISP=SHR
//        DD DSN=GATOR.CSMPV103,DISP=SHR
//        DD DSN=GRAPHICS.GOULD.LIBRARY,DISP=SHR
//PLOTLIB DD DSN=A0011301.S1.LOADLIB3,DISP=SHR
//SYSLIB DD DSN=GATOR.CSMPV103,DISP=SHR
//       DD DSN=SYS1.FORTLIB,DISP=SHR
//COMPRINT DD SYSOUT=A
//SYSPRINT DD DUMMY
//FT01F001 DD DDNAME=SYSIN
//FT02F002 DD SYSOUT=B,DCB=(RECFM=F,BLKSIZE=80)
//FT04F001 DD UNIT=SYSDA,DCB=(RECFM=VBS,BLKSIZE=1024,LRECL=204),
//        SPACE=(TRK,(3,2))
//FT05F001 DD UNIT=SYSDA,SPACE=(TRK,(2,2)),
//         DCB=(RECFM=FB,BLKSIZE=1600,LRECL=80)
//FT06F001 DD SYSOUT=A
//FT07F001 DD UNIT=SYSDA,SPACE=(TRK,(4,4)),
//         DCB=(RECFM=FB,BLKSIZE=1600,LRECL=80)
//FT13F001 DD UNIT=SYSDA,SPACE=(TRK,(8,8)),
//         DCB=(RECFM=VBS,BLKSIZE=1024,LRECL=204)
//FT14F001 DD UNIT=SYSDA,SPACE=(TRK,(8,8)),
//         DCB=(RECFM=VBS,BLKSIZE=1024,LRECL=204)
//FT15F001 DD UNIT=SYSDA,SPACE=(TRK,(3,2)),
//         DCB=(RECFM=VBS,BLKSIZE=1024,LRECL=204)
//SYSLIN DD UNIT=SYSDA,SPACE=(TRK,(4,2)),
//       DCB=BLKSIZE=3120
//SYSLINK DD DSN=*.SYSLIN,VOL=REF=*.SYSLIN,DISP=(OLD,PASS)
//        DD DSN=GATOR.CSMPCTRL,DISP=SHR
//SYSLMOD DD DSN=&&CSMPXEQ(DEJEXE),UNIT=SYSDA,
//        SPACE=(TRK,(10,4,1))
//LINKUT1 DD UNIT=SYSDA,SPACE=(TRK,(8,2))
//SYSVECTR DD DSN=&&VECT,UNIT=SYSDA,SPACE=(TRK,(15,10),RLSE),
//       DCB=BLKSIZE=2400,DISP=(MOD,DELETE)
//SYSPOUT DD SYSOUT=A
//SYSUT1 DD UNIT=SYSDA,SPACE=(26600,(100),,CONTIG,ROUND)
//SYSPLOT DD UNIT=SYSDA,SPACE=(26600,(100,25),RLSE,,ROUND)
//FT18F001 DD DUMMY
//SYSIN DD *
//
```

```
                ****CONTINUOUS SYSTEM MODELING PROGRAM****

                           *** VERSION 1.3 ***

TITLE LAKE CONWAY HYDROLOGIC-PHOSPHORUS MODEL
*                                                                      *
INITIAL
************************************************************************
*                                                                      *
*                                                                      *
********  STATE  VARIABLES  ******************
*                                                                      *
*                                                                      *
***********************************************************************
INCON  VCIN = 1000000
INCON VIN = 36500000.
INCON GVIN = 36500000.
*CONSTANTS USED IN HYDROLOGIC EQUATION (GMS UNITS EXCEPT ZEROHT)
CONST FF= 1.0
CONST  KDRAIN = 1.5E 05
CONST DRAIN=0.00
CONST AREABS = 25220000.
CONST AREALK = 7390000.
CONST KIVSUM = 0.0
CONST ZEROHT = 85.50
CONST CVMET = 0.0254
CONST KUNCO= 0.037
CONST KCPOT = 0.11
CONST CPCO= 0.10
CONST KGOUT = 0.92
CONST KREL=1.0
CONST KPERC = 0.08
CONST  KGFLOW=0.1
*  CONSTANTS USED IN MATERIALS EQUATION  GMS UNITS
CONST  KSED = 0.7
CONST K2 = 0.2
CONST K3 = 0.2
CONST K1 = 0.01
CONST KSEEPI = 0.058
CONST  KRAINI = 0.040
CONST KRUNIN = 0.39
CONST KFALIN = 0.007
CONST KFLOUT = 583130.0
```

```
*********************************************************************************
*                                                                               *
*      ***FUNCTIONS***                                                          *
*                                                                               *
*           RAIN/MONTH   =   'RAIN'                                             *
*                                                                               *
*       EVAP/MONTH=    'AVAP'                                                   *
*                                                                               *
*         EVAP/MONTH=   'BVAP'                                                  *
*                                                                               *
*  FULLOWING FUNCTIONS SUPPLIED BY THOMAS D. FONTAINE                            *
*          PHOSPHORUS RELEASE FROM VASCULAR PLANTS                              *
*      PHOSPHURUS RELEASE BY SLOUGHING ='VPPSED'                                *
*      PHOSPHURUS RELEASE BY LEACHING= 'VPPLCH'                                 *
*          PHOSPHORUS RELEASED FROM SEDIMENTS    = 'SEDPRL)                     *
*                                                                               *
*********************************************************************************
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                10.,.0846,11.,.0690,12.,.0575,13.,.0479,14.,.0561,...
                15.,.0808,16.,.1610,17.,.1750,18.,.1880,19.,.2030,...
                  20.,.1840,21.,.0993,22.,.0846,23.,.0690,24.,.0575,...
                25.,.0479,26.,.0561,27.,.0808,28.,.1610,29.,.1750,...
                30.,.1880,31.,.2030,32.,.1840,33.,.0993,34.,.0846,...
                35.,.0690,36.,.0575,37.,.0479,38.,.0561,39.,.0808,...
                40.,.1610,41.,.1750,42.,.1880,43.,.2030,44.,.1840,...
                45.,.0993,46.,.0846,47.,.0690,48.,.0575,49.,.0479,...
                50.,.0561,51.,.0808,52.,.1610,53.,.1750,54.,.1880,...
                55.,.2030,56.,.1840,57.,.0993,58.,.0846,59.,.0690,...
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              13.,.18,14.,.63,15.,3.67,16.,1.17,17.,2.69,18.,15.28,...
              19.,6.01,20.,6.56,21.,5.78,22.,.48,23.,.31,24.,1.62,...
              25.,.98,26.,1.49,27.,1.10,28.,1.36,29.,7.52,30.,9.70,...
              31.,9.26,32.,4.75,33.,4.97,34.,4.74,35.,.66,36.,.51,...
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              7.41,8.,6.98,9.,6.21,10.,5.63,11.,4.64,12.,3.05,13.,...
              3.35,14.,4.42,15.,5.50,16.,8.09,17.,8.03,18., 6.87,19.,...
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              3.10,38.,4.34,39.,6.25,40.,7.13,41.,7.90,42.,6.40,43.,...
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           3.13,26.,3.13,27.,4.90,28.,6.40,29.,7.07,30.,6.51,31.,...
           6.18,32.,6.66,33.,4.81,34.,4.64,35.,3.18,36.,2.71,37.,...
           2.84,38.,3.68,39.,5.65,40.,6.20,41.,6.05,42.,6.02,43.,...
           6.55,44.,5.81,45.,5.04,46.,4.50,47.,2.68,48.,2.19,49.,...
           2.87,50.,3.43,51.,4.88,52.,6.80,53.,7.68,54.,6.67,55.,...
           7.20,56.,5.91,57.,5.32,58.,4.29,59.,3.30,60.,4.20,61.,...
           3.43,62.,2.88,63.,5.41
FUNCTIUN AKOE = 0.0,.83,...
            1.,.77,2.,.69,3.,.73,4.,.84,5.,.82,6.,.85,7.,.91,8.,...
           .91,9.,.85,10.,.76,11.,.71,12.,.83,13.,.77,14.,.69,...
           15.,.73,16.,.84,17.,.82,18.,.85,19.,.91,20.,.91,21.,...
           .85,22.,.76,23.,.71,24.,.83,25.,.77,26.,.69,27.,.73,...
           28.,.84,29.,.82,30.,.85,31.,.91,32.,.91,33.,.85,34.,...
           .76,35.,.71,36.,.83,37.,.77,38.,.69,39.,.73,40.,.84,...
           41.,.82,42.,.85,43.,.91,44.,.91,45.,.85,46.,.76,47.,...
           .71,48.,.83,49.,.77,50.,.69,51.,.73,52.,.84,53.,.82,...
           54.,.85,55.,.91,56.,.91,57.,.85,58.,.76,59.,.71,60.,...
           .83,61.,.77,62.,.69,63.,.73
FUNCTIUN LKHT = 0.0,86.2,...
            1.,86.44,2.,86.76,3.,86.59,4.,86.44,5.,86.07,...
              6.,86.10,7.,86.42,8.,86.60,9.,86.76,10.,86.55,...
             11.,86.12,12.,85.84,13.,85.82,14.,85.60,15.,85.39,...
             16.,85.35,17.,85.06,18.,85.14,19.,86.35,20.,86.77,...
             21.,86.56,22.,86.39,23.,85.94,24.,85.68,25.,85.89,...
             26.,85.44,27.,85.17,28.,84.74,29.,84.68,30.,85.20,...
             31.,85.79,32.,86.36,33.,86.44,34.,86.42,35.,86.19,...
             36.,85.85,37.,85.63,38.,85.35,39.,85.18,40.,84.96,...
             41.,84.95,42.,85.37,43.,85.80,44.,86.08,45.,86.03,...
             46.,85.71,47.,85.39,48.,85.34,49.,85.26,50.,85.16,...
             51.,85.13,52.,85.73,53.,84.21,54.,84.06,55.,83.96,...
             56.,84.12,57.,84.28,58.,84.19,59.,83.95,60.,84.02,...
             61.,84.09,62.,84.29,63.,84.61
***************************************************************
```

```
************************************************************************
*     ****LAKE VOLUME EQUATION ****                                    *
************************************************************************
       V= INTGRL(VIN,QIN-QOUT)
       QIN=RAININ+RUNOFF+FLOWIN+GFLOW + CPIN
       QOUT=EVAP+FLOUT+CPOUT+DRAIN
************************************************************************
*     ***GROUNDWATER EQN *****                                         *
************************************************************************
       GV  = INTGRL ( GVIN , GIN - GOUT)
       GIN = GRAIN - GFLOW
       GOUT = KGOUT * GRAIN
       GRAIN = RAINT*CVMET*AREABS*KPERC
       GFLOW=-KGFLO2*((KREL*V)-GV)
************************************************************************
*     **** MATERIALS EQN ****                                          *
************************************************************************
      VC1  =  INTGRL(VCIN,INFLUX-OUTFLX-SEDMNT)
       INFLUX = RAININ*KRAINI + RUNOFF*KRUNIN + CPIN*KSEEPI ...
       + AREALK*KFALIN + PFMVAP*AREALK  +  PFMSED*AREALK + GFLOW*KSEEPI
       OUTFLX    = (CPOUT*VC1/V)+(FLOUT*VC1/V)
       SEDMNT = KSED * VC1
        PCONC= VC1/V
       DELTHT = ((V/AREALK)/CVMET)/12 +  70.6
       PLANTI = PFMVAP*AREALK
       SEDIN = PFMSED*AREALK
       NEWIN = INFLUX-(PLANTI + SEDIN)
       PCNTVP = (PLANTI/INFLUX)* 100.
       PCNTSD = ( SEDIN/INFLUX)*100.
       PCNTIN =(NEWIN /INFLUX)*100.
************************************************************************
TERMINAL
TIMER DELT=1.E-3,FINTIM=63.,OUTDEL=1.0,PRDEL=1.0
METHOD RECT
PRTPLT PLANTI ,SEDIN,NEWIN  , PCONC
PREPAR DELTHT, HEIGHT
END
STOP
```

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Blancher, Eldon C.
Large-scale operations management test of use of the white amur for control of problem aquatic plants : Report 2 : First year poststocking results : Volume IV : Nitrogen and phosphorus dynamics of the Lake Conway ecosystem : Loading budgets and a dynamic hydrologic phosphorus model / by Eldon C. Blancher, II, Charles R. Fellows (Department of Environmental Engineering Sciences, University of Florida). -- Vicksburg, Miss. : U.S. Army Engineer Waterways Experiment Station ; Springfield, Va. : available from NTIS, 1982.
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1. Aquatic biology. 2. Aquatic weeds. 3. Conway, Lake (Fla.) 4. Weed control--Biological control. I. Fellows, Charles R. II. United States. Army. Corps of Engineers. Jacksonville District. III. United States. Army. Corps of Engineers. Office of the Chief of Engineers. IV. U.S. Army Engineer Waterways Experiment Station. Environmental Laboratory. IV. Title V. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; A-78-2, Rept.2, Vol. 4.
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