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

Report 1

BASELINE STUDIES

Volume IV

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

By Eldon C. Blancher II and Charles R. Fellows

Department of Environmental Engineering Sciences
University of Florida
Gainesville, Fla. 32601

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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

Volume V: The Herpetofauna of Lake Conway, Florida

Volume VI: The Water and Sediment Quality of Lake Conway, Florida

Volume VII: A Model for Evaluation of the Response of the Lake Conway, Florida, Ecosystem to Introduction of the White Amur

Volume VIII: Summary of Baseline Studies and Data

Report 2: First Year Poststocking Results

Report 3: Second Year Poststocking Results

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Preliminary estimates of external nutrient loadings to the three lakes that comprise the Lake Conway system showed nitrogen inputs (3.88 $g/m^2/yr$) that exceeded established critical levels for lakes. Phosphorus loadings (0.214 $g/m^2/yr$) were slightly below the range of critical loadings for the system. These loadings would indicate that the Lake Conway system should exhibit a mesotrophic character. Loading levels established for the individual lakes showed higher loadings to the northern lakes of the system (Continued)

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20. ABSTRACT (Continued)

which received drainage from a more extensive residential area. Experimental evidence indicates that phosphorus became a limiting factor in the lake briefly during spring and early summer of 1977.

PREFACE

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

This is the fourth of eight volumes that constitute the first of a series of reports documenting a large-scale operations management test of use of the white amur for control of problem aquatic plants in Lake Conway, Florida. Report 1 presents the results of the baseline studies of Lake Conway; subsequent reports will present the annual poststocking results.

This volume was written by Messrs. Eldon C. Blancher II and Charles R. Fellows of the Department of Enviornmental Engineering Sciences of the University of Florida.

The authors wish to acknowledge Drs. T. L. Crisman, J. L. Fox, P. L. Brezonik, and J. F. Heaney for their helpful comments during the preparation of this report. Special thanks go to Miss Diane Sompongse, and Messrs. F. M. Kooijman and R. A. Conley for their help during the field operations.

The work was monitored at WES in the Mobility and Environmental Systems Laboratory (MESL) by Mr. R. F. Theriot under the general supervision of Mr. W. G. Shockley, Chief, MESL, and Mr. B. O. Benn, Chief, Environmental Systems Divison (ESD), and under the direct supervision of Mr. J. L. Decell, Chief, Aquatic Plant Research Branch (APRB), ESD. The ESD and APRB are now part of the recently organized Environmental Laboratory of which Dr. John Harrison is Chief.

Director of WES during the period of the contract was COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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

BASELINE STUDIES

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

PART I: INTRODUCTION

1. It is now commonly accepted that increased availability of nutrients, notably nitrogen and phosphorus, speeds the eutrophication of lakes. This excessive availability of nutrients may be due to either increased loading 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.

2. Of prime importance in the understanding of the eutrophication process is the nutrient budget, a fundamental concept of theoretical and applied limnology (Vollenweider 1969). General theories of nutrient supply, losses, and concentration, as well as the qualitative relationships between nutrients and biological productivity, are well known. Quantitative relationships between these parameters have not yet been fully understood.

3. The need for a quantitative method of predicting the response of a lake to increased nutrient supply was expressed by Edmondson et al. (1961) in a study of Lake Washington. Since then, several workers have proposed models predictive of eutrophication rates. The most important are those of Biffi (1963), Piontelli and Tonolli (1964), Vollenweider (1965), and Dillon (1974). Improvement of these simple models led to the development of Vollenweider's (1969) critical loading concept. Over the past few years, this concept has been used, critically reviewed (Dillon 1974), and constantly refined (Vollenweider 1975 and 1976).

4. The construction of a nutrient loading model requires an

analysis of the sources and sinks of nutrients for a particular lake (Table 1). When constructing a nutrient budget, sources and sinks generally refer to the flow of nutrients to and from the water column. Figure 1 shows a simple model of nutrient pathways to and within a lake. Nutrient inputs may be either natural or cultural in origin and flow into the lake directly or indirectly as either surface or subsurface runoff from the watershed. These materials are then recycled between the water, biota, and sediments, and are ultimately lost in the outflowing waters or buried in sediments. Although there is a constant exchange between the sediments and the other components, in most lake systems the net flow is to the sediments. Thus lakes act as traps by storing more nutrients in the sediments than are released to the water column.

5. The purpose of this study was to assess the inputs and outputs of nitrogen and phosphorus to and from the Lake Conway system. The major flows of these nutrients were identified and measured and a

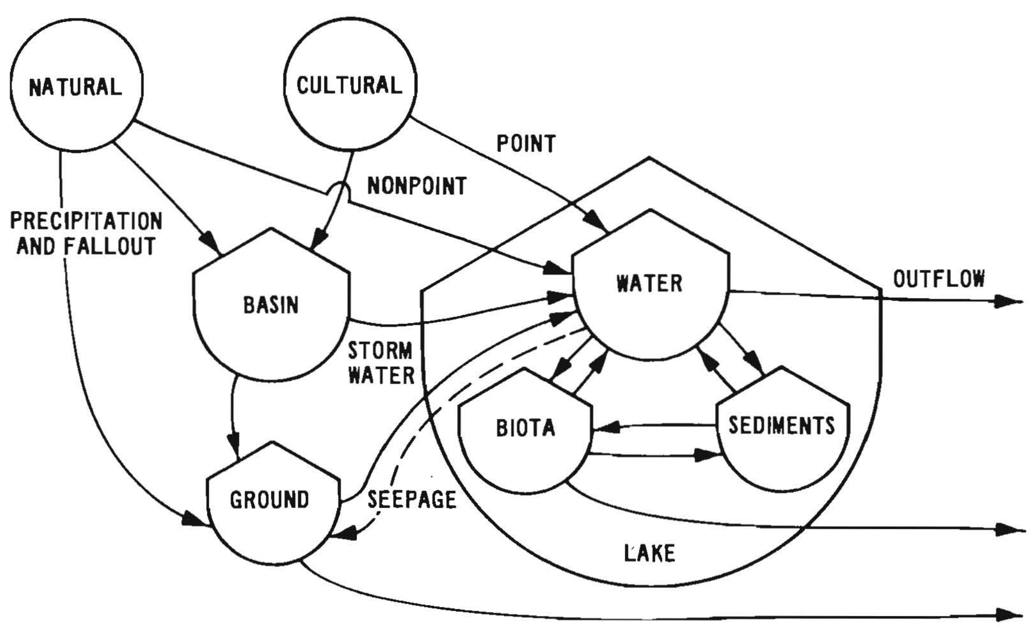

Figure 1. Simplified model of nutrient pathways in a lake ecosystem (symbols after Odum 1971)

general loading model was constructed. Additionally, bioassay techniques were used to indicate the extent of nutrient limitation within the lake. This information will be useful in determining whether the future feeding activities of the white amur or grass carp (_Ctenopharyngodon idella_) will have a significant impact on the nutrient loading of the lake by internal nutrient cycling.

PART II: MATERIALS AND METHODS

6. Lake and watershed areas were calculated from U. S. Geological Survey (USGS) topographical maps by electronic planimetric methods. Extent of the 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.

7. A bathymetric map was produced using both depth profiles obtained with a recording depth meter and an existing bathymetric map produced by J. D. Schardt, Florida Department of Natural Resources. The area of each metre-depth interval was determined with an electronic planimeter, and lake volumes were calculated by summing the volumes of each 1-m interval. Mean depths were computed by dividing lake volumes by their respective area.

8. Rainfall and evaporation data were obtained from U. S. Weather Bureau climatological data reports. Rainfall data reported by the Orlando weather station at McCoy Air Base was used because of the close proximity of the airport to the lake. Averages of evaporation pan data from the Lisbon and Lake Alfred stations were assumed to be representative of the Lake Conway area. Coefficients used for estimating evaporation from the lake surface were those determined for Lake Okeechobee by Kohler (1954).

9. A 2-litre plastic beaker was placed out immediately preceding a storm to collect rainfall for nutrient analysis. In addition, beakers for the collection of dry fallout were placed out for 24-hour periods.

10. The volume of direct runoff was calculated by the U. S. Department of Agriculture Soil Conservation Service (SCS) method (1975) and the rational method (Chow 1964). The SCS method is described in detail in a technical publication "Urban Hydrology for Small Watersheds" (Technical Release No. 55, 1975). The method requires developing a weighted curve number from land use and hydrologic soil groupings and determining the amount of direct runoff from an empirical model. The

rational method consists of measuring the amount of direct runoff during a storm event in order to calculate a runoff coefficient. To this end 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 was measured. Flow rate was measured with a Gurley flow meter at 15-minute intervals and water samples were collected for turbidity, conductivity, and nutrient determinations. Rainfall was simultaneously collected and measured.

11. Subsurface seepage into Lake Conway was measured using the methods of Lee (1972, 1977). 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-diameter plastic tubing into either a 0.180- or 3.5-litre bag. Flow was calculated by dividing the volume of water collected by the collection time. Water samples were collected from the individual drum ends for subsequent nutrient analysis. Drum collectors were placed on a transect perpendicular to the shoreline since seepage flow decreases with increasing distance from the shore (McBride and Pfannkuch 1975). Flow versus distance from shore was then calculated in order to express flow per metre of shoreline when integrated.

12. Beginning in February 1977, monthly water samples for nutrient analysis were collected at 1-m intervals from the center of each pool of the Conway system. Additional nutrient data on the lakes were obtained by the U. S. Army Engineer Waterways Experiment Station (WES).

13. All water samples were analyzed for nitrogen (NH_4^+, NO_2^-, NO_3^-, and total Kjeldahl nitrogen or TKN) and phosphorus (PO_4^-, TP) using methods described in Standard Methods (American Water Works Association 1975) or the U. S. Environmental Protection Agency Methods handbook (1976). Loading rates were calculated by multiplying the yearly volumes of combined inflows by the respective nutrient concentration and dividing by the surface area. The mass balance-loading models used in this report are essentially those of Vollenweider (1968, 1975).

14. The nitrification capacity of sediments from the West Pool of Lake Conway was evaluated. Suspended and unsuspended sediment-water

systems consisting of 750 ml each of sediments and deionized water were incubated in the dark at 10°C and 23°C. Samples were obtained from these experimental systems at intervals of 0.3, 1, 2, 5, and 7 days and analyzed for nitrate (NO_3^-) and ammonia (NH_4^+).

15. Bioassay methods including Algal Assay Procedure (U. S. Environmental Protection Agency 1971), alkaline phosphatase assay (Fitzgerald 1968) and nitrogen fixation (Stewart et al. 1968) were used to determine nutrient limitation.

PART III: THE STUDY AREA

16. Three lakes consisting of five pools comprise the Lake Conway system (Figure 2). From north to south the pools are Lake Gatlin, the West and East Pools of Little Lake Conway, and the Middle and South Pools of Lake Conway proper. Located in the central portion of Orange County directly south of the City of Orlando, these lakes form the upper portion of the Boggy Creek drainage basin. Average elevation of the lakes is 26.2 m above mean sea level (msl). Lake level is controlled by a concrete and wooden dam at the southeast corner of the South Pool. Outflow from the system is into Lake More Prairie and eventually to Boggy Creek via a canal.

17. Comprised of a series of fused dolines, the basins of the Conway system exhibit a diversity of shapes and sizes. A bathymetric map of the system is given in Figure 3 and morphometric features of the individual pools are described in Table 2.

18. Soils of the surrounding watershed are of the Blanton, Charlotte, and Orlando units and are composed of moderately to excessively drained fine sands (Soil Conservation Service 1960 and 1973). Infiltration of rainfall into these soils is immediate and complete, resulting in little or no surface runoff.

19. Orange County is underlain by marine limestone, dolemite, shale, and sand (Lichtler et al. 1968). Surficial undifferentiated sediments of Pleistocene age are underlain by the discontinuous Hawthorne formation of Eocene age. Porous limestones underlie the Hawthorne formation and constitute the upper portion of the Floridian aquifer.

20. The piezometric surface of the Floridian aquifer averages 16.8 m above mean sea level around Lake Conway (Lichtler et al. 1968). Since lake level never falls below the piezometric surface of the aquifer, flow from the aquifer to the lake is unlikely. However, seepage of groundwater into the aquifer is probable. The clay-rich sands of the Hawthorne formation usually retard vertical movement of water between the water table and the limestones of the Floridian aquifer below. Since this layer is discontinuous in Orange County, and the area is

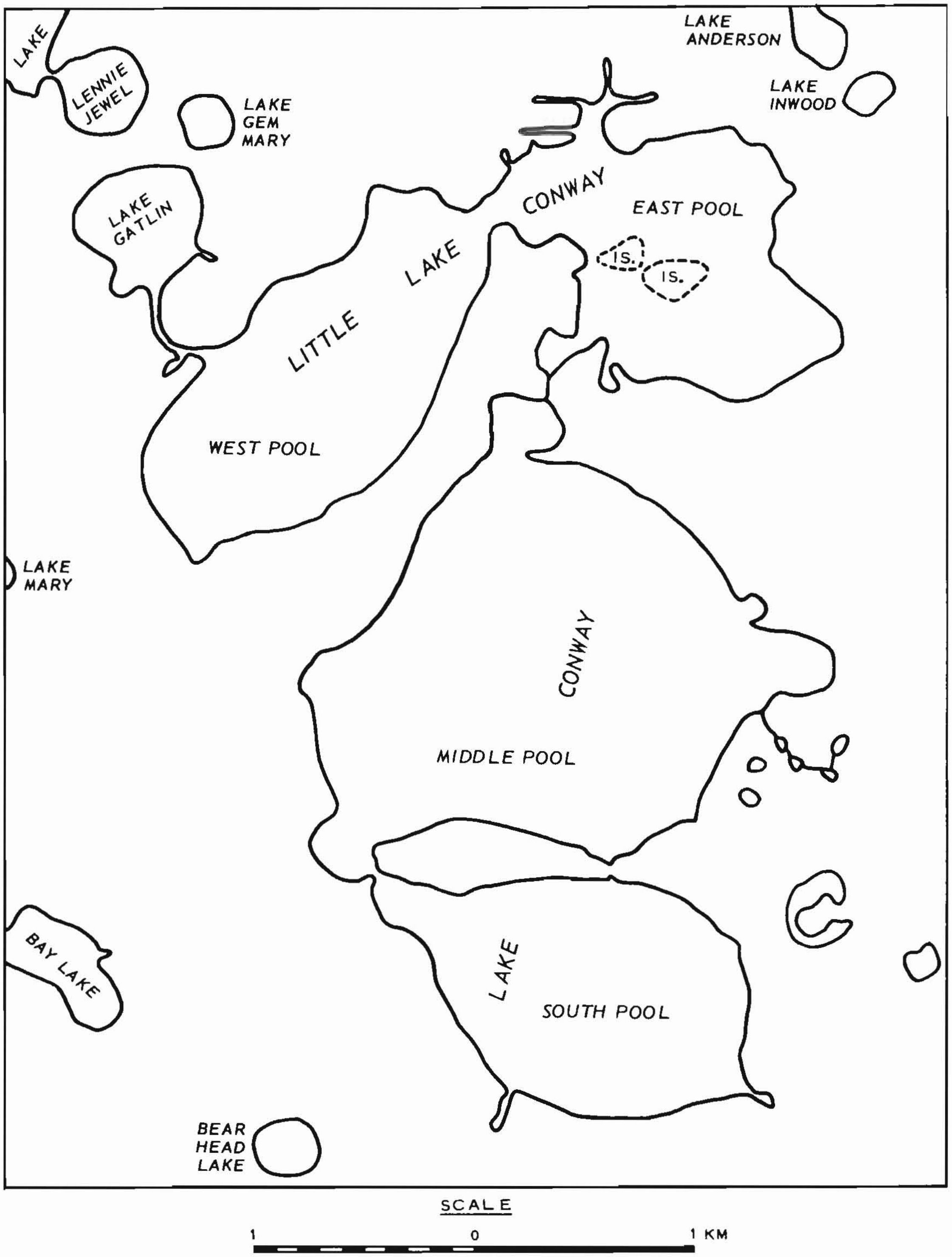

Figure 2. Lake Conway system

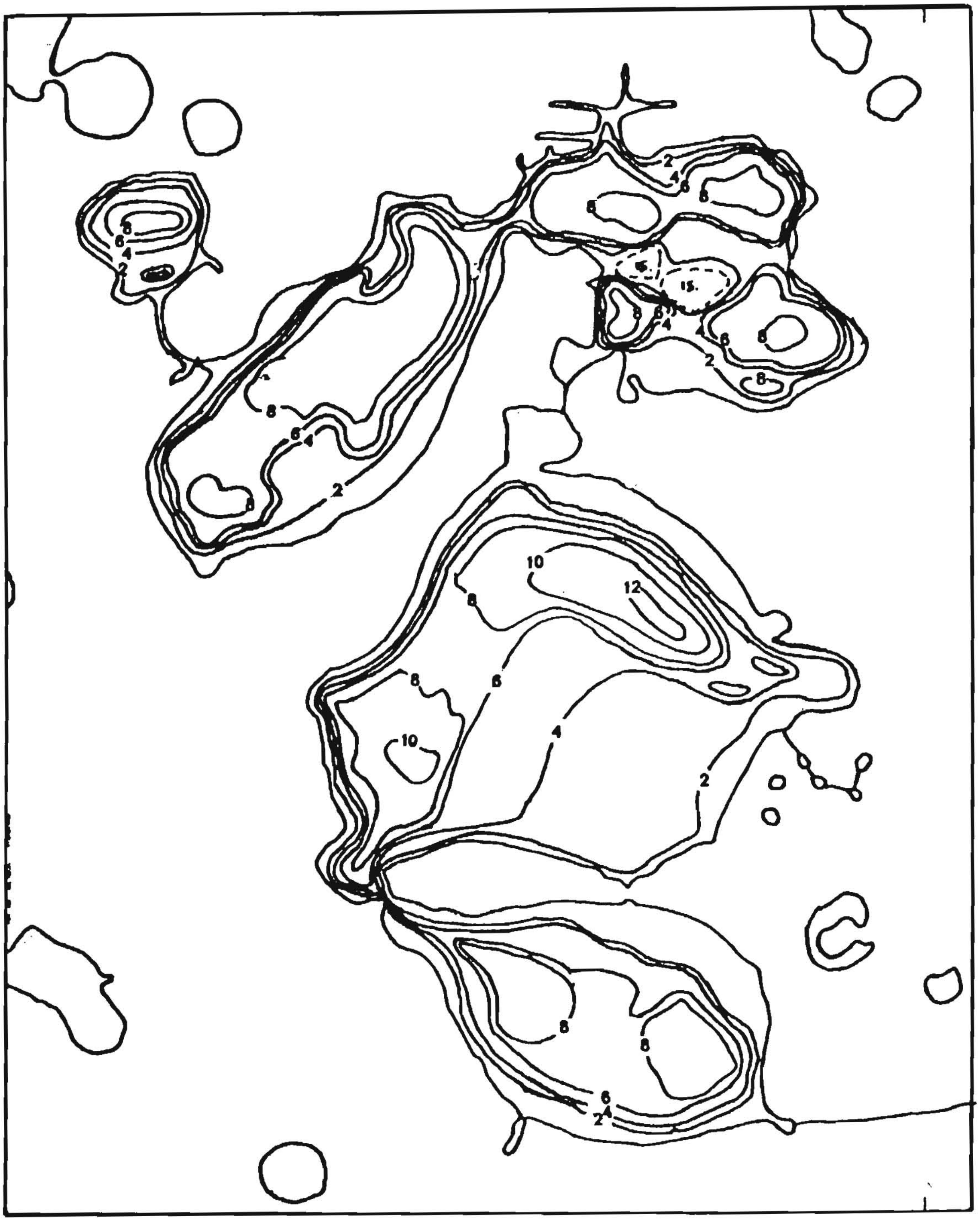

Figure 3. Bathymetric map of Lake Conway system
(contours are at 2-m intervals)

considered to be an area of good recharge for the aquifer (Lichtler et al. 1968), the possibility of groundwater flow out of the lake is great.

21. Land use patterns for the Lake Conway watershed are presented in Table 3. Urban to suburban development dominates the surrounding drainage basin, replacing areas previously allocated to agriculture.

PART IV: RESULTS AND DISCUSSION

Hydrology

22. Nutrient inputs to a lacustrine system are closely related to the hydrologic budget of the system. Thus, critical to the development of any realistic materials budget is the construction of an accurate water budget.

23. The hydrologic budget of a lake may be expressed by the following equation

$$S = (P_l - E_l)A_l + {}^{i}V_i - {}^{o}V_o \pm G$$

where

S = change in water storage

P_l = precipitation on lake surface

E_l = evaporation from lake surface

A_l = surface area of the lake

${}^{i}V_i$ = sum of inputs (influent streams and runoff)

${}^{o}V_o$ = sum of outputs (effluent streams)

G = groundwater flow

24. Monthly rainfall and evaporation for the 1976 water year are presented in Table 4. The volume of direct precipitation onto the Lake Conway surface was 8.87×10^6 m^3. An annual evaporation volume of 9.30×10^6 m^3 was determined by multiplying the annual pan coefficient (0.78) (Kohler 1954) by the lake surface area (7.39 km^2) and the height of pan evaporation (161.42 cm).

25. Inflows to the lakes were divided into four major components: stream inflows, surface runoff, subsurface seepage, and groundwater. Each of these components was assessed to determine its significance in the overall hydrological budget.

26. Stream inflow to the Conway system is produced primarily by small ditches that drain the surrounding watershed. Inflow from these ditches was considered as a part of total runoff. Total runoff was

calculated from stormwater runoff and seepage. Stormwater runoff is that water which enters stream channels associated with storms and forms a runoff hydrograph. Seepage is that portion of total runoff which enters the lake following infiltration of soils in the watershed.

27. The volume of stormwater runoff can vary considerably within a drainage basin. Soil type, vegetation 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 in addition to using standard empirical methods for determining direct runoff.

28. A stormwater hydrograph for the Conway basin was calculated from data collected on 21 August 1976 (Figure 4). Of the precipitation that fell during that storm (1.98 cm), 3.6 percent entered the lake as stormwater runoff. Initiation of runoff and the time interval to peak flow were rapid. Return of flow to slightly above base flow was also rapid.

29. Estimates of stormwater runoff by the Soil Conservation Service method resulted in a curve number of 56 for the Conway basin. This means that approximately 7.6 cm of rainfall is necessary before any surface runoff can be detected.

30. The volume of stormwater runoff was calculated by multiplying the amount of precipitation in the basin by 0.036, a runoff coefficient determined from the hydrograph. Additional measurements of stormwater flows were not possible due to the paucity of rainfall during spring and early summer of 1977.

31. In situ seepage measurements provide direct measurement of seepage flow. Prior to the development of this technique, seepage flow was estimated by subtracting the measurable outputs from the inputs. The seepage-meter method used in this study has provided integrated values (per m shoreline values) with an error margin of ± 20 percent.

32. Annual seepage volumes have been generated by extrapolation of the preliminary data. Utilizing samples from a single site during a 193-day period, the annual increase in lake level due to seepage has been calculated for each pool (Table 5). Recent samples from two other

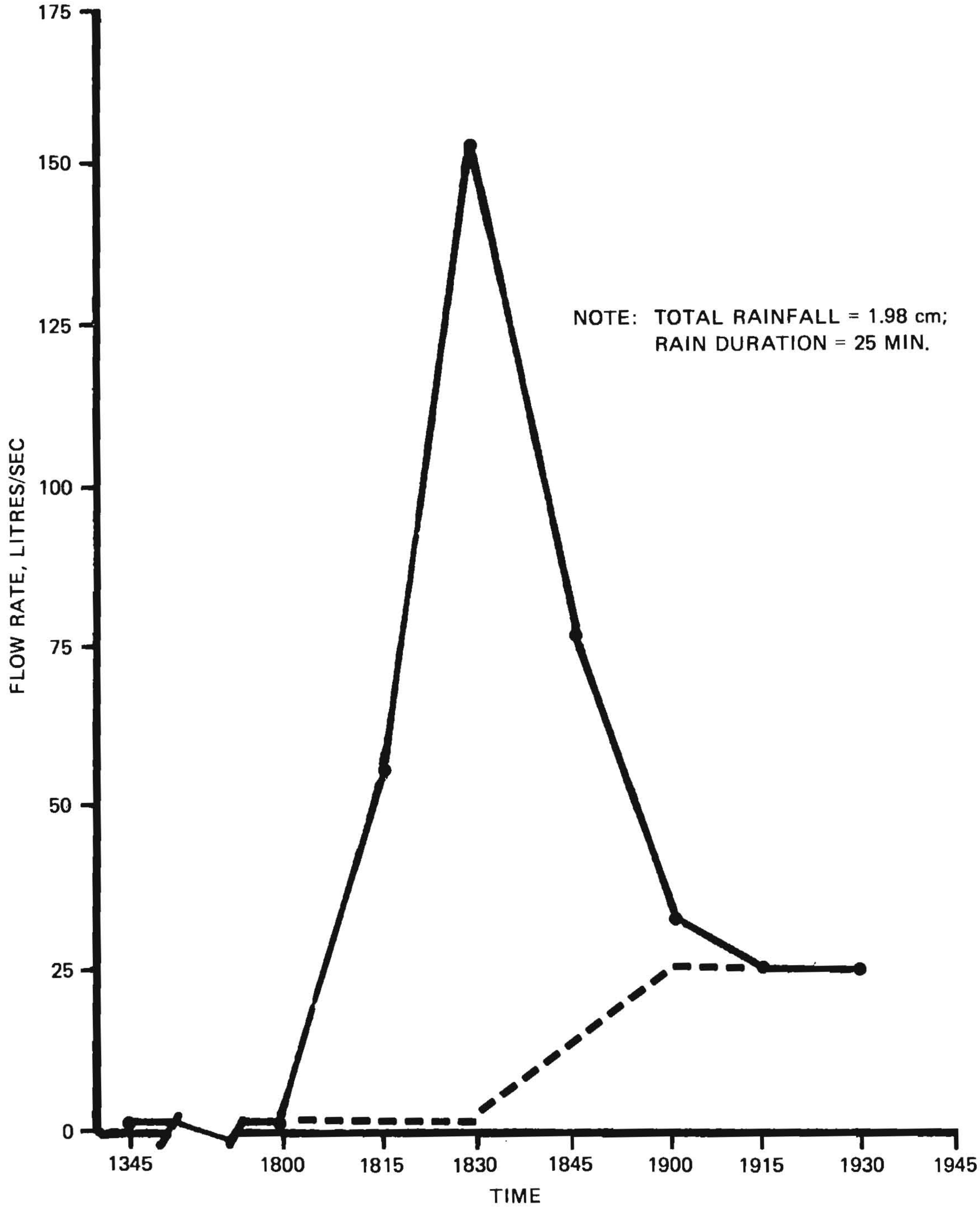

Figure 4. Runoff hydrograph of 21 August 1976 at Gatlin Avenue and Bumby Drive for Lake Conway basin

sites not considered here add credibility to these early estimates.

33. Estimation of the accuracy of the values for the runoff components was based on another method of determining total runoff. 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. Well-defined storm events following a dry period were determined from rainfall data, and subsequent changes in lake storage and estimates of total runoff were calculated (Table 6). From these calculations it was determined that of the total precipitation that fell in the watershed an average of 12.6 percent entered the lake. Additionally, information from the USGS indicates that the average annual outflow via Boggy Creek is 17.8 cm. Considering that total rainfall for the area is 120 cm, runoff is approximately 14.8 percent of total rainfall.

34. By combining surface runoff and seepage and dividing by the precipitation in the watershed $((2.15 + 1.66)/45.44)$ a total runoff coefficient of 8.4 percent is obtained. This value is considerably lower than other estimates; however, the estimate was determined from data obtained primarily during a dry year. Furthermore, seepage measurements may be low due to frictional resistance in the sampling apparatus. Additional measurements and experimentation will improve the accuracy of these estimations.

35. An estimate of groundwater inflow (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. These observations support the hypothesis that groundwater flows to the Conway system are insignificant.

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

37. Utilizing all this information, hydrologic budgets for both the Conway system and its individual pools were constructed (Tables 7 and 8). It is evident that the hydrodynamic cycle of this system is dominated by precipitation-evaporation events. Other significant inflows are stormwater runoff and seepage, with seepage the more important.

38. In order to verify the accuracy of this budget, the calculated flows will be used in a model to predict change in storage within the lake system. The results of this model will subsequently be compared with actual changes in lake level recorded for the Conway system.

Nutrient Budget

39. One of the most effective ways to begin a quantitative study of a lake is by developing a nutrient budget. Depending on the type of information desired, two approaches for developing budgets are available: the mass balance approach (Vollenweider 1975; Imboden 1972) and the net budget method (Johnson and Owen 1971). Net budgets are preferable when the nature of the input sources is being investigated, whereas mass budgets are more appropriate when the behavior of the individual nutrients within the lake is the prime consideration (Burns 1976). In the case of the mass budget, the quantity of materials is considered independent of the concentration and is always positive. For purpose of this investigation the mass budget is the appropriate choice of approach.

Inputs

40. Atmospheric inputs of phosphorus (P) and nitrogen (N) originate from a variety of sources. These include fertilizer mining and manufacture, soils, and combustion of various types (fuels, agricultural burning, and forest fires). Eventually these materials are removed from the atmosphere as dry fallout or scavenged by precipitation. It should be noted that much of the material that falls on land surfaces may potentially be resuspended into the atmosphere. If this is the case and significant re-entrainment does occur, then open bodies of water would receive a disproportionate share of atmospheric particulate matter (Murphy 1974).

41. Based on a limited number of rainfall/dry fallout samples, annual loadings of 0.104 $g/m^2/yr$ P and 2.33 $g/m^2/yr$ N for rainfall and 0.008 $g/m^2/yr$ P and 0.42 $g/m^2/yr$ N for dry fallout have been calculated. These values are correspondingly high for rainfall and low for dry fallout when compared with similar data for Gainesville, Florida (C. Hendry, personal communication). However, when these two inputs are combined, the resulting loadings (0.112 $g/m^2/yr$ P and 2.75 $g/m^2/yr$ N) compare well with similar loadings of 0.105 $g/m^2/yr$ P and 2.58 $g/m^2/yr$ N for Gainesville.

42. The accumulation of matter in urban areas and its subsequent runoff into water bodies have recently been investigated (Cowen and Lee 1976; Field et al. 1976; Barkdoll et al. 1977). An early study showed that runoff contains concentrations of suspended solids that exceed concentrations in raw domestic wastewaters (Weibel 1969). Seven probable sources of contaminants listed by Sartor and Boyd (1972) were (a) pavement, (b) vehicles, (c) atmosphere, (d) vegetation, (e) litter, (f) domestic and industrial spills, and (g) antiskid compounds. Transport of these contaminants into nearby waters often results in significant nutrient loadings and subsequent water quality degradation.

43. Analysis of nitrogen and phosphorus concentrations in stormwater runoff from the small watershed mentioned previously yielded average concentrations of 2.3 mg/ℓ and 0.33 mg/ℓ for nitrogen and phosphorus, respectively. These compare closely with published values of 3.1 mg/ℓ for N and 0.36 mg/ℓ for P (Weibel 1969). Calculations of areal loading rates for the Conway system were based on the above nutrient concentrations and resulted in loadings of 0.079 $g/m^2/yr$ for P and 0.269 $g/m^2/yr$ for N.

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

45. Surface runoff from agricultural areas is considered negligible for several reasons. Urban encroachment in these areas is very evident,

and its classification as agricultural is questionable. Few active citrus farms exist. Infiltration in these areas is also very great due to the paucity of impermeable surfaces. Most of the impact in these areas would be to the subsurface drainage or seepage to the lake.

46. Groundwater nutrient input to lakes is a product of flow and nutrient concentration. In the past this contribution was calculated by determining the seepage input by subtraction and analyzing groundwater from wells for nutrient concentrations. McBride and Pfannkuch (1975) developed a model with supportive evidence from Lee (1972), which correlated decreased seepage into lakes with increasing distance from the shore. In an investigation of the fate of septic tank nutrients near lakes, Lee (1972) showed that groundwater may not be homogeneous with respect to nutrient concentration. Furthermore, Chen and Keeney (1974) reported that lake sediments act as nitrate sinks (assimilatory nitrate reduction and denitrification) as groundwater flows through them and into a lake.

47. Nutrient input via subsurface seepage, generally, is poorly understood. Annual seepage loading rates are reported in Table 9. Combined seepage for nitrate and nitrite nitrogen was found to range from 0.5-2.5 times the concentrations found in the lake. Due to greater NH_4^+-N input, NO_3-NO_2 nitrogen was considered to be of small consequence. Single-day NH_4^+-N loadings ranged from 1.35-2.48 mg/day for three stations. Extrapolations were made using the largest value since 6 months of hydrological data were available for this site (Figure 5). Similar extrapolations for total phosphorus are given in Figure 6.

48. Detectable rates of nitrogen fixation occurred during August 1977 in Lake Gatlin and the East Pool of Little Lake Conway but represented an insignificant portion of the total nitrogen budget.

<u>Outputs</u>

49. Discharge of nutrients through the outfall accounted for only a small portion of total nutrient loss. It was assumed that outflow nutrient concentrations were equal to average surface concentrations, which were 0.87 mg/ℓ for nitrogen and 0.043 mg/ℓ for phosphorus. Multiplying by the total outflow and converting to annual areal rates of loss

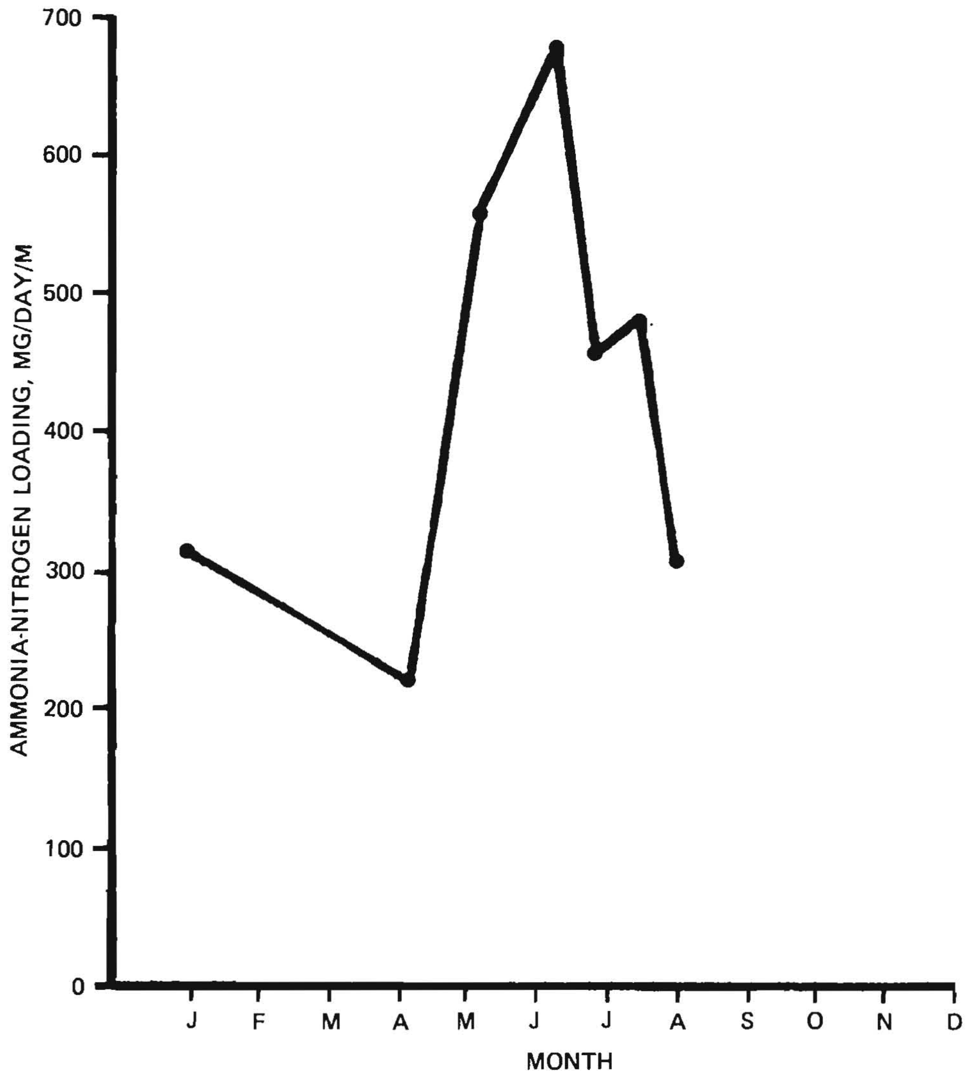

Figure 5. Ammonia-nitrogen seepage loading rates, Lake Conway system

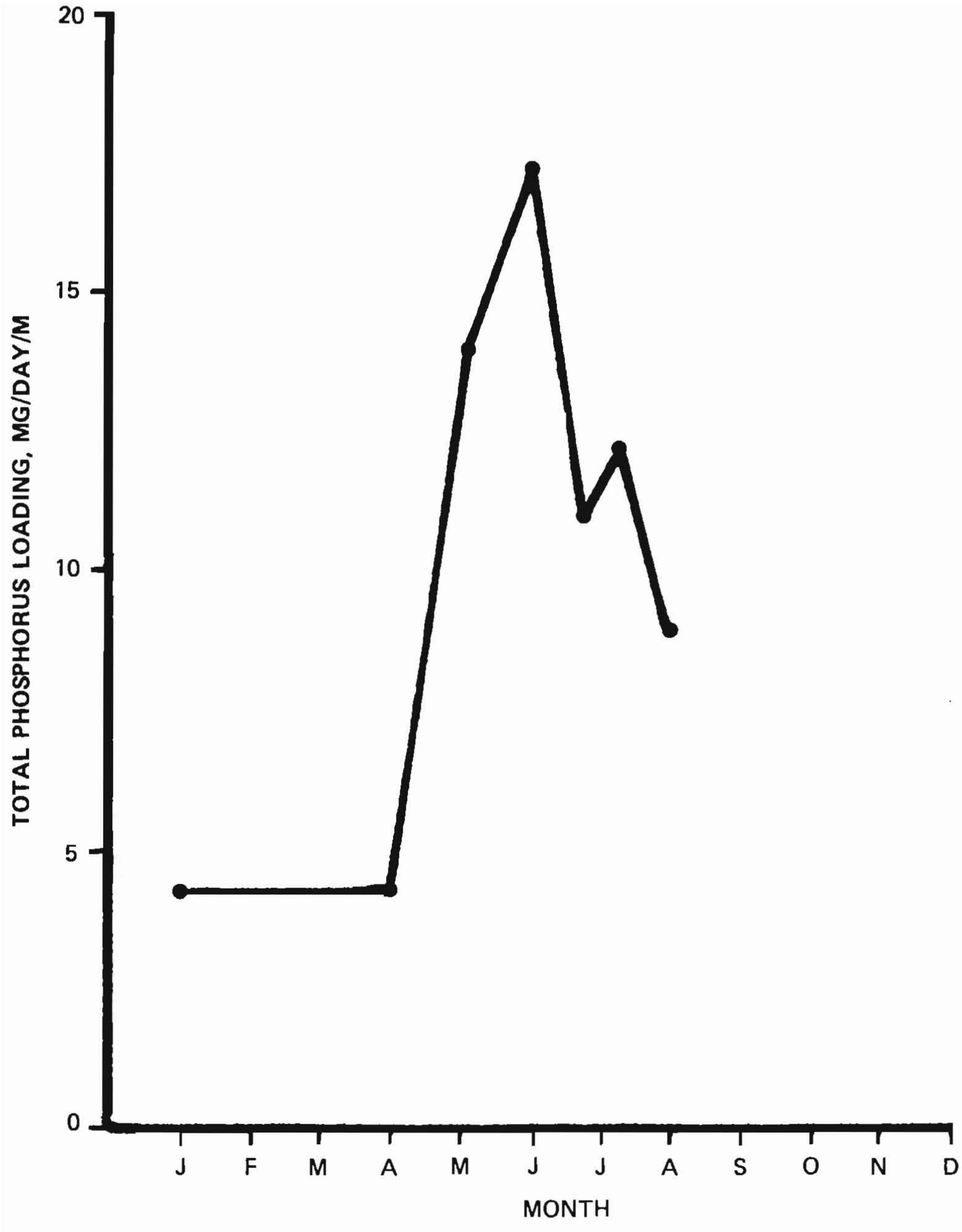

Figure 6. Total phosphorus seepage loading rates, Lake Conway system

gives figures of 0.22 $g/m^2/yr$ for nitrogen and 0.011 $g/m^2/yr$ for phosphorus.

50. Groundwater recharge as a nutrient sink for the Conway system was considered to be insignificant. Losses due to 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.

51. Subtraction of nutrient outputs from total inputs yields a value which is considered to be representative nutrient loss due to sedimentation. Although this loss does not represent complete removal from the system, it is a sink which eliminates nutrients from biological or chemical cycling within the lakes.

52. Preliminary nitrogen and phosphorus budgets for the Lake Conway system are presented in Table 10. Loadings from aerial sources represent the major external sources of both nitrogen and phosphorus to Lake Conway and represent 71 percent and 52 percent of the total, respectively. The second largest source of nitrogen loading was seepage. Urban runoff was the second most important source of phosphorus.

Loading Model

53. If steady state conditions prevail, the budget for a conservative (not transformed) substance in a lake would follow the following relationship

$$\text{INPUT} - \text{OUTPUT} = 0$$

or

$$\text{INPUT} = \text{OUTPUT}$$

This is the fundamental mass balance equation. Expressed in differential form

$$\sum^{i} m_i - \sum^{o} m_o - \frac{d\,m_w}{dt} = 0$$

where

$\sum^{i} m_i$ = sum of inputs

$\sum^{o} m_o$ = sum of outputs

m_w = total mass in the lake

For nonconservative (undergo transformation) substances, the basic equation could be written

$$\sum^{i} m_i - \sum^{o} m_o - \sum^{s} m_s - \frac{d\, m_w}{dt} = 0$$

where $\sum^{s} m_s$ equals the sedimentation or transformation term for substances in the lake (i.e. losses other than through the outlet). The above equation can be solved with the restrictive assumptions that mean lake concentration (m_w) is equal to the outflow concentration, and sedimentation is a function of mean lake concentration. Vollenweider (1975) solved the equation and obtained

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

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

54. Vollenweider (1968 and 1969) applied this equation in an investigation of Swiss lakes. Generally, mean lake concentration is a function of flushing (represented by mean depth and discharge height), areal loading, and sedimentation characteristics.

55. Using this relationship for phosphorus in a number of lakes in Switzerland and North America, Vollenweider (1975) developed empirical

limits for acceptable and dangerous loadings for lakes of various flushing characteristics. Figure 7 illustrates this relationship as applied to the Lake Conway system. Using the criteria of Vollenweider, the Conway system would be characterized as mesotrophic. When individual pools are considered, a trend of increasing nutrient loading from south to north in the system occurs.

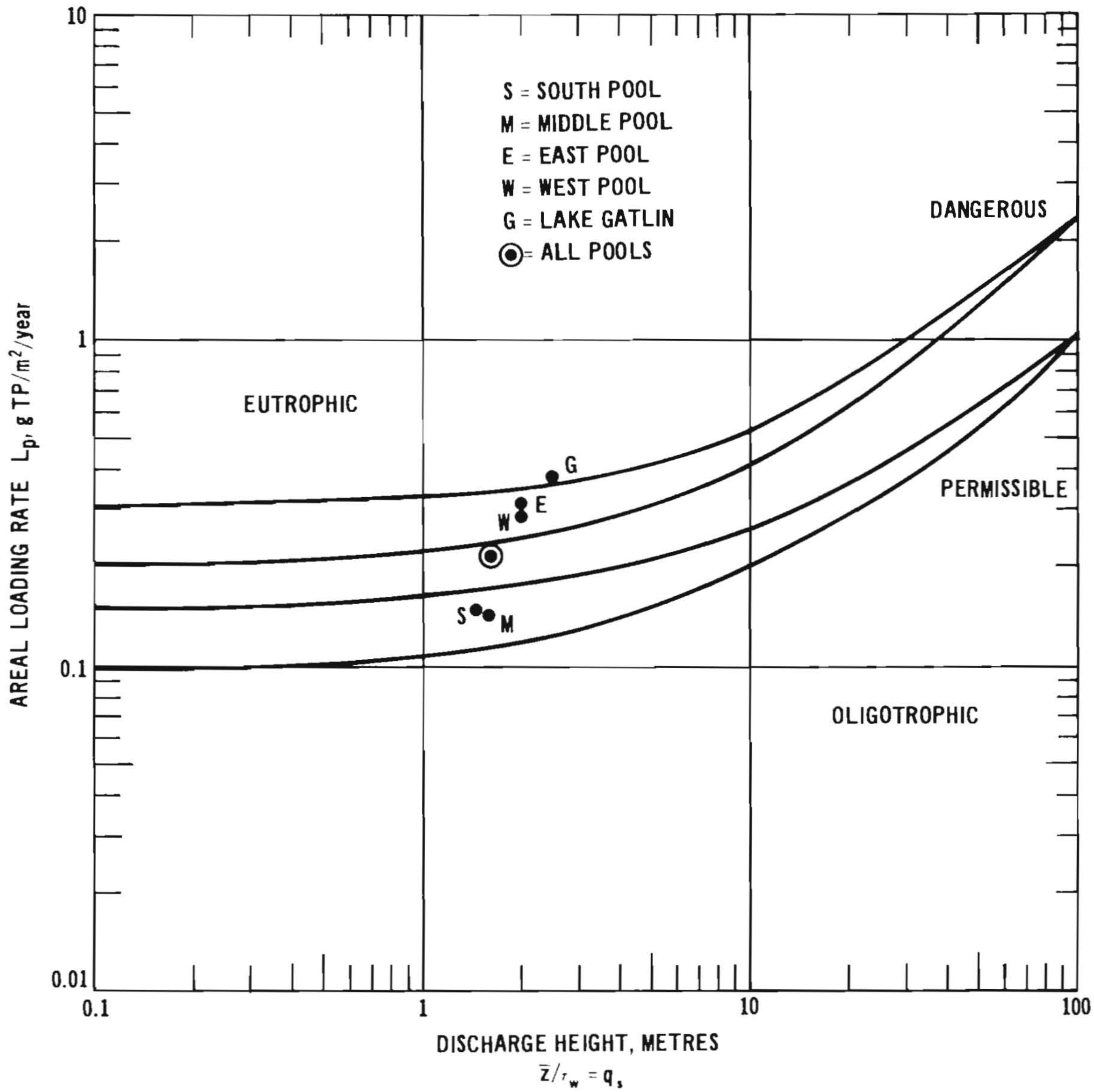

Figure 7. Areal phosphorus loadings of Lake Conway system

56. Vollenweider found that critical loading levels are 0.1-0.3 $g/m^2/yr$ for phosphorus and 1.0-2.0 $g/m^2/yr$ for nitrogen in temperate lakes. However, Brezonik and Shannon (1971) found that these levels may be somewhat higher for Florida lakes (0.28-0.49 $g/m^2/yr$ P and 2.0-3.4 $g/m^2/yr$ N), indicating that Florida lakes may be able to assimilate more nutrients and still retain a relatively "oligotrophic" appearance. Lake Conway's phosphorus loadings fall within the range of critical loadings, whereas loadings for nitrogen exceed the "dangerous" loadings indicated by both Vollenweider and Brezonik. Nitrogen supply to the lakes appears to be more than adequate to promote eutrophic conditions.

Other Considerations

57. External nutrient loadings are often considered to be the major factors controlling lake enrichment. However, mechanisms of nutrient cycling such as sedimentation, nutrient recycling, and fixation (N_2) play an important role in lacustrine nutrient cycles. Knowledge of limiting nutrients in a system is essential when making decisions as to which source is most important.

58. Results of algal bioassay experiments of April 1977 indicated that phosphorus became limiting during April in Lake Gatlin. Spikes of nitrogen and phosphorus combined and phosphorus alone caused significant increases in algal growth.

59. Alkaline phosphatase activity measures the ability of plants to utilize organically bound phosphorus. Enzyme activity increases when inorganic orthophosphate becomes scarce. Results from May and June 1977 show significant levels of activity for various algal species throughout the system (Table 11). Fitzgerald and Nelson (1966) demonstrated that phosphorus-limited algae exhibit activities of 2,400 to 28,000 enzyme units, or 5 to 25 times those of unlimited algae. Activities in June indicated phosphorus limitation in all pools. By July, however, alkaline phosphatase activities of all species tested were below the levels indicative of limitation.

60. Limitation of algal growth by nitrogen could not be demonstrated in Lake Conway. Neither algal bioassay nor nitrogen fixation

indicated limitation for N for the period tested.

61. Nitrification is a process whereby ammonia is oxidized to NO_2^- and NO_3^- by a select group of aerobic autotrophic bacteria. Although nitrification rates of up to 5.4 mg/ℓ/day were obtained in the experiments, preliminary studies indicate that Lake Conway sediments do not add appreciable amounts of NO_3^--N to water except in well-oxidized, stirred situations such as might be occurring in shallow areas or during lake turnover.

62. Although these results did show that phosphorus was briefly limiting during spring and early summer of 1977, it may not be a common occurrence. Aerial loadings (52.3 percent) and urban runoff (36.9 percent) are major sources of allochthonous phosphorus to the system. Since this was an extremely dry year, a significant portion of P loadings was lost even if one assumes that bulk aerial loadings remained constant. Thus, the fact that phosphorus did become limiting is not surprising. What may be of more significance, however, is the rapid response of the system to a change in loadings, indicating rapid assimilation and elimination of phosphorus entering the system.

PART V: CONCLUSIONS

63. Preliminary studies in the Lake Conway ecosystem have resulted in estimates of nitrogen and phosphorus loadings of 3.88 $g/m^2/yr$ and 0.214 $g/m^2/yr$, respectively. Major external sources of nitrogen were from aerial inputs and subsurface seepage flows, while phosphorus inputs were dominated by aerial loadings and urban runoff. The magnitudes of nitrogen loadings exceed the dangerous loading levels indicated by both Vollenweider (1968) for North American and Swiss Lakes, and Brezonik and Shannon (1971) for Florida lakes. Phosphorus inputs lie between permissible and dangerous levels, indicating that the lake system should exhibit mesotrophic conditions.

64. Due to decreased loadings during the spring and early summer of 1977 because of a scarcity of rainfall, the lake briefly exhibited symptoms of phosphorus limitation. This observation was supported by evidence from algal bioassay and alkaline phosphatase experiments. No indications of nitrogen limitation were found.

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Table 1

Possible Sources and Sinks for Nitrogen and Phosphorus for Lakes*

Natural	Cultural
Sources	
Precipitation on lake	Wastes, domestic and industrial
Soil erosion	Agricultural runoff
Forest runoff	Urban runoff
Meadow runoff	Septic tanks
Swamp runoff	Landfill leachates and runoff
Groundwater influx	
Nitrogen fixation**	
Deposition of plant litter	
Animal wastes	
Sediment recycling	
Sinks	
Outflow	Volatilization**
Groundwater recharge	Aquatic plant removal
Denitrification recharge	Fish removal
Sediment losses	

* After Brezonik et al. (1969).

** Applies to nitrogen alone.

Table 2

Morphometric Features of the Lake Conway System

	Area km^2	Volume 10^6 m^3	Mean Depth m	Maximum Depth m
South Pool	1.37	8.24	6.01	9.0
Middle Pool	2.99	17.90	5.98	13.0
East Pool	1.27	5.76	4.54	8.2
West Pool	1.48	8.46	5.72	9.8
Lake Gatlin	0.28	1.18	4.18	8.0
All pools	7.39	41.54	5.29	13.0

Table 3

Features of the Lake Conway Drainage Basin

	Total Watershed Area, km^2	Lake Area km^2	Watershed Area (Less Lake) km^2	Percent Urban	Percent Citrus
South Pool	3.12	1.37	1.75	77.3	22.6
Middle Pool	6.14	2.99	3.15	68.2	31.8
East Pool	15.76	1.27	14.49	44.3	50.0
West Pool	16.04	1.48	14.56	69.3	14.3
Lake Gatlin	4.85	0.28	4.57	74.8	11.1
All pools	45.91	7.39	38.52	60.9	29.2

Table 4

Precipitation and Pan Evaporation Data (cm) for the Water Year 1976*

Month	Precipitation**	Evaporation†
Oct 1975	12.04	12.70
Nov	1.68	8.95
Dec	1.29	7.07
Jan 1976	0.94	7.54
Feb	2.11	10.23
Mar	4.37	14.93
Apr	5.49	17.09
May	26.31	17.01
Jun	25.22	16.34
Jul	17.90	17.61
Aug	8.26	17.25
Sep	14.91	14.70
Total	120.52	161.42

* October 1975-September 1976.
** For Orlando Weather Station Office, McCoy Air Base.
† Average for Lisbon and Lake Alfred Stations.

Table 5

Estimated Annual Seepage Inputs

	Seepage Inflow cm/yr
Lake Gatlin	48.4
West Pool	24.1
East Pool	31.6
Middle Pool	18.4
South Pool	23.7
All pools	24.0

Table 6

Estimation of Total Runoff in the Lake Conway System

Date	Total Rainfall in Basin 10^6 m^3	Change in Volume in Lake 10^6 m^3	Precipitation on Lake 10^6 m^3	Evaporation from Lake 10^6 m^3	Net Precipitation 10^6 m^3	Total Runoff 10^6 m^3	Percent of Total Rainfall in Basin That Is Runoff
Apr 1973	0.686	0.112	0.131	0.120	0.011	0.101	14.7
Mar 1974	3.350	0.896	0.638	0.113	0.525	0.371	11.1
May 1975	7.630	1.299	1.167	0.782	0.385	0.914	12.0

Table 7

Hydrological Budget for the Lake Conway System

		Volume 10^6 m^3
Sources		
Precipitation on lake		8.87
Surface inflows		NS*
Stormwater runoff		1.66
Seepage in		2.15
Groundwater inflows		NS
	TOTAL IN	12.68
Sinks		
Evaporation from lake surface		9.30
Surface outflows		1.87
Groundwater outflows		NS
Evapotranspiration		**
Seepage out		1.51†
Pumpage		**
	TOTAL OUT	12.68

* Not significant.
** Not measured.
† Obtained by difference.

Table 8

Hydrological Budget for Each Pool in the Lake Conway System

	Precipitation 10^6 m^3	Inflows	Storm Water 10^6 m^3	Seepage 10^6 m^3	Groundwater	Total In 10^6 m^3	Evaporation 10^6 m^3	Outflows** 10^6 m^3	Seepage	Total Out 10^6 m^3
South Pool	1.64	NS*	0.076	0.395	NS	2.11	1.73	(0.38)	NS	2.11
Middle Pool	3.59	NS	0.136	0.669	NS	4.40	3.76	(0.64)	NS	4.40
East Pool	1.52	NS	0.626	0.488	NS	2.63	1.60	(1.03)	NS	2.63
West Pool	1.78	NS	0.629	0.433	NS	2.84	1.86	(0.98)	NS	2.84
Lake Gatlin	0.34	NS	0.197	0.164	NS	0.70	0.35	(0.35)	NS	0.70

* Not significant.
** Obtained by difference.

Table 9

Estimated Annual Seepage Inputs

	NH_3-N g/m^2/yr	Total P g/m^2/yr
Lake Gatlin	1.154	0.026
West Pool	0.574	0.013
East Pool	0.753	0.017
Middle Pool	0.439	0.010
South Pool	0.565	0.013
All pools	0.753	0.017

Table 10

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

		Nitrogen	Phosphorus
	Inputs		
Airborne			
Combined wet and dry precipitation		2.750	0.112
Surface			
Urban storm water		0.269	0.079
Agricultural runoff		(?)	(?)
Undeveloped land runoff		NS**	NS
Domestic wastes		NS	NS
Industrial wastes		NS	NS
Subsurface			
Groundwater inflow		NS	NS
Seepage		0.753	0.017
Septic tanks		0.108	0.006
In situ			
Nitrogen fixation		NS	--
Sediment leaching		(?)	(?)
Nutrient recycling		(?)	(?)
	TOTAL IN	3.88	0.214
	Outputs		
Surface outfalls		0.22	0.011
Groundwater recharge		NS	NS
Fish and weed removal		(?)	(?)
Volatilization and evaporation		(?)	--
Denitrification		(?)	--
Sedimentation		(3.66)	(0.203)†
	TOTAL OUT	3.88	0.214

* Loadings are reported in grams per square metre of lake surface area per year.

** Not significant.

† Obtained by difference.

Table 11

In Situ Alkaline Phosphatase Activity of Various Plant Materials from the Lake Conway System*

		Month		
Location	Test Materials	May**	June	July
Lake Gatlin	Phytoplankton (Net)	+	7,000	--
	Lyngbya	+	10,222	--
East Pool	Phytoplankton (Net)	+	2,500	1,200
	Oedogonium	+	10,285	--
	Hydrilla	+	--	428
	Vallisneria	0	239	--
	Potamogeton	0	--	200
	Nitella	-	3,530	810
Middle Pool	Phytoplankton (Net)	+	23,636	591
	Nitella	-	1,356	1,466
	Potamogeton	0	--	345

* Activity reported in Alkaline Phosphatase units per milligram dry weight of dry material.

** Due to improper sample fixation, rates could not be established for this month. (+) indicates a positive response, (0), a negative response; (-) indicates no sample was taken.

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 1: Baseline studies; Volume IV: Interim report on the nitrogen and phosphorus loading characteristics of the Lake Conway, Florida, ecosystem / by Eldon C. Blancher II and Charles R. Fellows, Department of Environmental Engineering Sciences, University of Florida, Gainesville, Fla. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1979.

30, [9] p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; A-78-2, Report 1, v.4)

Prepared for U. S. Army Engineer District, Jacksonville, Jacksonville, Fla., and Office, Chief of Engineers, U. S. Army, Washington, D. C., under Contract No. DACW39-76-C-0076.

References: p. 28-30.

1. Aquatic plant control. 2. Lake Conway. 3. Nitrogen.

(Continued on next card)

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Large-scale operations management test of use of the white amur for control of problem aquatic plants; Report 1: Baseline studies: Volume IV: Interim report on the nitrogen and phosphorus loading characteristics ... 1979. (Card 2)

4. Nutrients. 5. Phosphorus. 6. White amur. I. Fellows, Charles R., joint author. II. Florida. University, Gainesville. Dept. of Environmental Engineering Sciences. III. United States. Army. Corps of Engineers. IV. United States. Army. Corps of Engineers. Jacksonville District. V. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; A-78-2, Report 1, v.4.
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