Water Quality Models for Understanding Potential Eutrophication in Lake Okeechobee

Center For Wetlands, Gainesville, Florida

A report to the Division of State Planning for the special project to prevent the eutrophication of Lake Okeechobee

DSP-BCP-59-76

WATER QUALITY MODELS FOR UNDERSTANDING POTENTIAL EUTROPHICATION IN LAKE OKEECHOBEE, FLORIDA

Principal Investigators

H. T. Odum
F. G. Nordlie

Center for Wetlands
University of Florida
Gainesville, Florida

This report is one of the research reports commissioned by the Florida Division of State Planning and the Florida Department of Environmental Regulation as part of the Special Project to Prevent the Eutrophication of Lake Okeechobee. This research and others commissioned by the participating agencies form the basis for the Special Project final report and management plans.

State of Florida
Department of Administration
Division of State Planning
Bureau of Comprehensive Planning

December, 1976

TABLE OF CONTENTS

I. REGIONAL ANALYSIS OF ALTERNATIVE MANAGEMENT SCHEMES FOR THE KISSIMMEE RIVER BASIN AND LAKE OKEECHOBEE

T. Fontaine and M. Brown

Introduction

The study region includes the Kissimmee basin, Lake Okeechobee, and the Agricultural Area as shown in Figs. 1-3. Ecosystems that developed throughout the region and attracted large-scale economic activity are shown in Fig. 1. The patterns of man and nature that developed as a result of abundant natural energies and a diversity of lakes, rivers, swamps, and uplands are shown in Figs. 2 and 3. The purchased energy attracted by the free resident energy of the region is summarized in the energy budget diagram in Fig. 4.

Energy flows into the region from the sun, wind, and rain, and with the development of agricultural and urban areas, additional energy enters the region in the form of oil, natural gas, goods, and materials. Some energy, such as incident sunlight and wind, is of low quality (in its ability to do work) and some, such as water and the fuels that support man's activity, is of high quality. The effective use of all available energy in a partnership of man and nature appears to lead to maximum economic vitality.

In the Kissimmee-Okeechobee region, purchased fossil fuel energies are complimented by lower quality energies of the natural system to produce exports and locally consumable goods. Current energy theory indicates that the greater the energy flows from natural systems, the more economic activity based on outside fuel energies can be "attracted" and sustained. Effective "energy trades" of exports for imports depend on the amount of nature's free energies that can be used to subsidize production and life support processes. If, for example, the energy content of produced goods is higher than competing regions, economic competitiveness and the resultant ability to attract and purchase additional energy may suffer. Thus, the energy content of exported goods may act as a limiting factor on economic activity sustained by the region.

The combination of resident and purchased energy that best maximizes the total flow of high quality energy maximizes the economy of man and sets guidelines for interfacing subsystems of the total environment. Thus, the best strategy for long term value and vital economic functioning recognizes the contribution of free energy flows generated from natural systems and maximizes the total flow with higher quality fossil fuel energies.

The caloric work value of energy flows in ecological systems can be converted into equivalent fossil fuel calories. The unit used is the <u>fossil fuel equivalent</u>. This enables the free natural work of ecological systems to be compared directly to the work of the economic sector so that the relative value of both sectors can be evaluated.

An energy diagram of the aspects of the systems of man and nature together shows their interplay in ways not usually understood when examined separately. Flows of money, materials, goods, and fuels can be converted to an equivalent basis so that true energetic relationships can be shown. The resultant model can then be examined in relation to questions of resource protection and management to provide insight for maximizing value and making good use of man-dominated and natural subsystems.

This report recommends alternative management of the Kissimmee-Okeechobee basin based on calculations that indicate several proposed alternatives maximize total energy flow through the area better than the present regime. Principal recommendations concern natural hydroperiods instead of regulated ones, the spreading of water over a wider area to amplify the regional value of natural systems and maintenance of shallow ground water levels at higher than present levels.

Carrying capacities of the region for several possible future conditions are also suggested. Carrying capacity is defined as the level of economic activity and settlements that competes economically by maximizing energy from all sources to the life support system. The optimal mix of land, water, and energy-use differs according to the availability of external fuel supplies. Since the latter is indeed changing, so must carrying capacity.

Alternatives

Five management alternatives which may promote more effective regional interactions are evaluated. Increasing use of nature's free energy to subsidize economic production, especially during times of declining fossil fuel availability, makes a more competitive system that can produce goods more cheaply. Evaluations include calculations of the following:

(1) Productivity of natural and managed ecosystems.

(2) Cost of flood control project operation and maintenance.

(3) Regional economic flow.

(4) Flood protection.

All flood protection alternatives considered would deliver the same overall degree of flood protection as presently exists where the alternative specifically calls for land inundation.

Reestablishment of the Kissimmee River Floodplain

Partial or complete reestablishment of the prechannelization hydroperiod and associated vegetational patterns in the Kissimmee River basin was evaluated as an alternative which may promote more energy flow through the region. Possible effects which might result are: (1) increased energy flow through photosynthetic production in reestablished wetlands, (2) removal of nutrients by wetlands from non-point sources such as improved pasture. Use of created marshland to substitute for improved pasture may be particularly economical as the cost of energy to subsidize cow-calf operations continues to rise. Created marshlands could also help keep fertilizer nutrients on the land, thus making fertilizer application less necessary and costly.

Changes in hydroperiod resulting from this alternative would keep more water stored on the land and reduce regulatory discharges of water with a high energy value to the sea (200,000 acre-ft per year, Gayle, 1975). It should also allow more water storage in Lake Okeechobee during drought years (Gayle, 1975). During drought years this water could generate more agricultural and natural energy flow than under present hydroperiod regulation.

Water Table Elevation in the Everglades Agricultural Area (EAA)

This alternative may provide additional years of agriculture in the EAA by using elevated water tables to retard oxidation of muckland soils. Elevated water tables to retard oxidation would use free energy from nature and could reduce subsidance rates to levels equal to or greater than present practices that involve inundation of lands by pumping. Some crop losses would be inherent. Long term economic profit may increase, however, despite crop losses. The need for backpumping would also decrease since less water would have to be moved. The amount of land in sugarcane production could remain the same.

On Site Storage and Recycle of Excess EAA Water

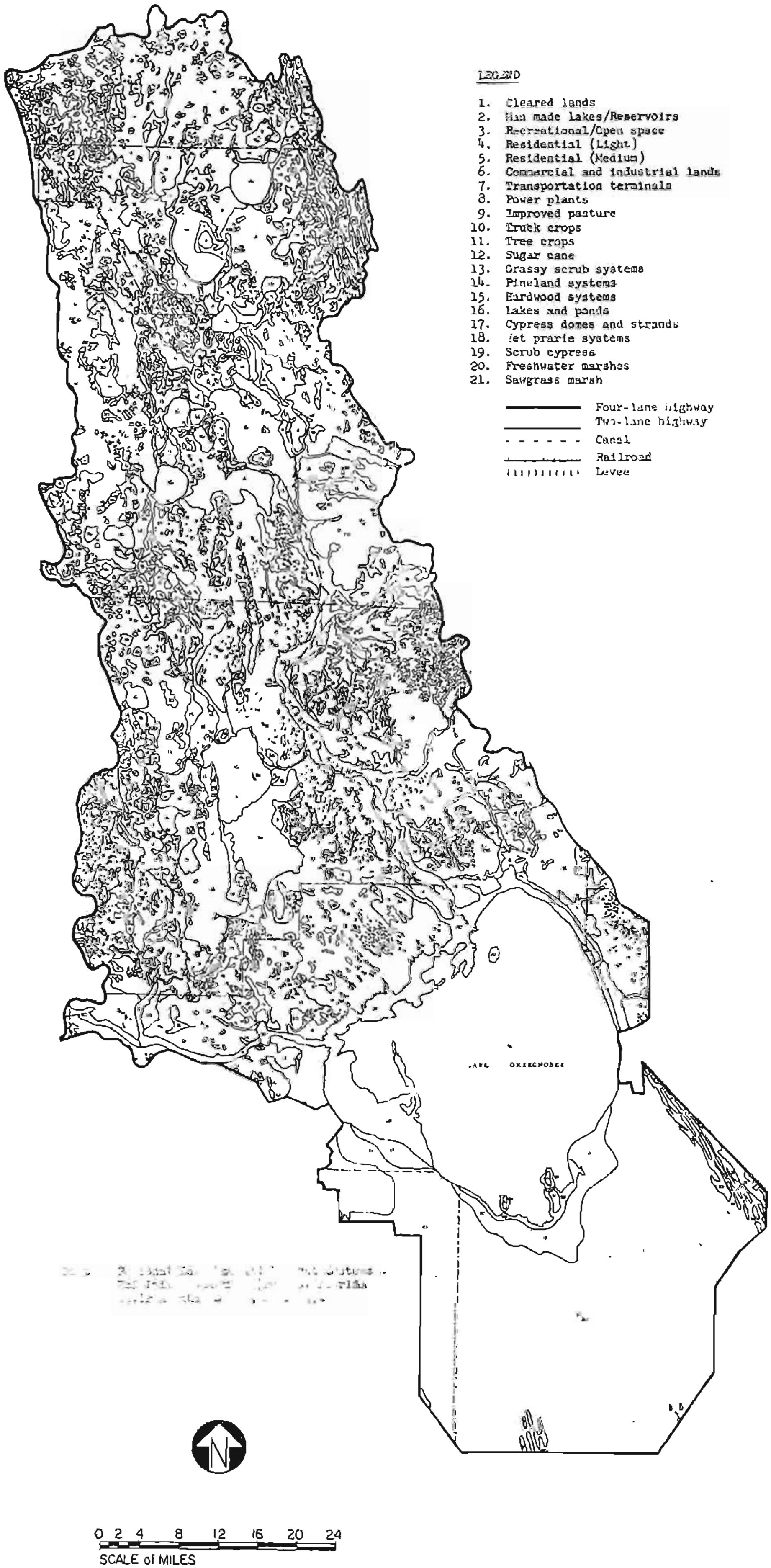
On site storage and recycle of excess agricultural water and nutrients presently backpumped to Lake Okeechobee would improve water quality in the lake. Water which flows from the EAA south to the conservation areas could also be treated in this manner. Deepening of the canal midsection water flow retardant known as the "hump" has been proposed as necessary for quick delivery of all water to treatment sites. Storage of additional water would have benefits during drought.

Elevation of Stage Level in Lake Okeechobee

Lake elevation may provide additional water storage of particular importance during drought. The photosynthetic amplifier value of additional water in the lake is calculated in addition to changes in energy resulting from head differences. The effect of raising the lake level on natural productivity within the lake's boundaries is also assessed.

Crop Rotation and Peat Deposition -- Steady State Agriculture

Since EAA soils are subsiding and estimates of the remaining years of agricultural products in these areas are at most thirty-five years, a proposal for rebuilding muck soils with hyacinth ponds is presented. A system of "crop rotation" could be set up so that a certain percentage of the area would remain in sugarcane production while others are flooded and seeded with hyacinths. After sufficient hyacinth deposition the crops would be rotated. This system would be one of steady state yields, instead of increasing ones.


LEGEND
1. Cleared lands
2. Mian made lakes/Reservoirs
3. Recreational/Open space
4. Residential (Light)
5. Residential (Medium)
6. Commercial and industrial lands
7. Transportation terminals
8. Power plants
9. Improved pasture
10. Truck crops
11. Tree crops
12. Sugar cane
13. Grassy scrub systems
14. Pineland systems
15. Eardwood systems
16. Lakes and ponds
17. Cypress domes and strands
18. ïet prarie systems
19. Scrub cypress
20. Freshwater marshes
21. Sawgrass marsh
Four-lane highway
Two-lane highway
Canal
Railroad
Levee
LAKE OKEECHOBEE
N
0 2 4 8 12 16 20 24
SCALE of MILES

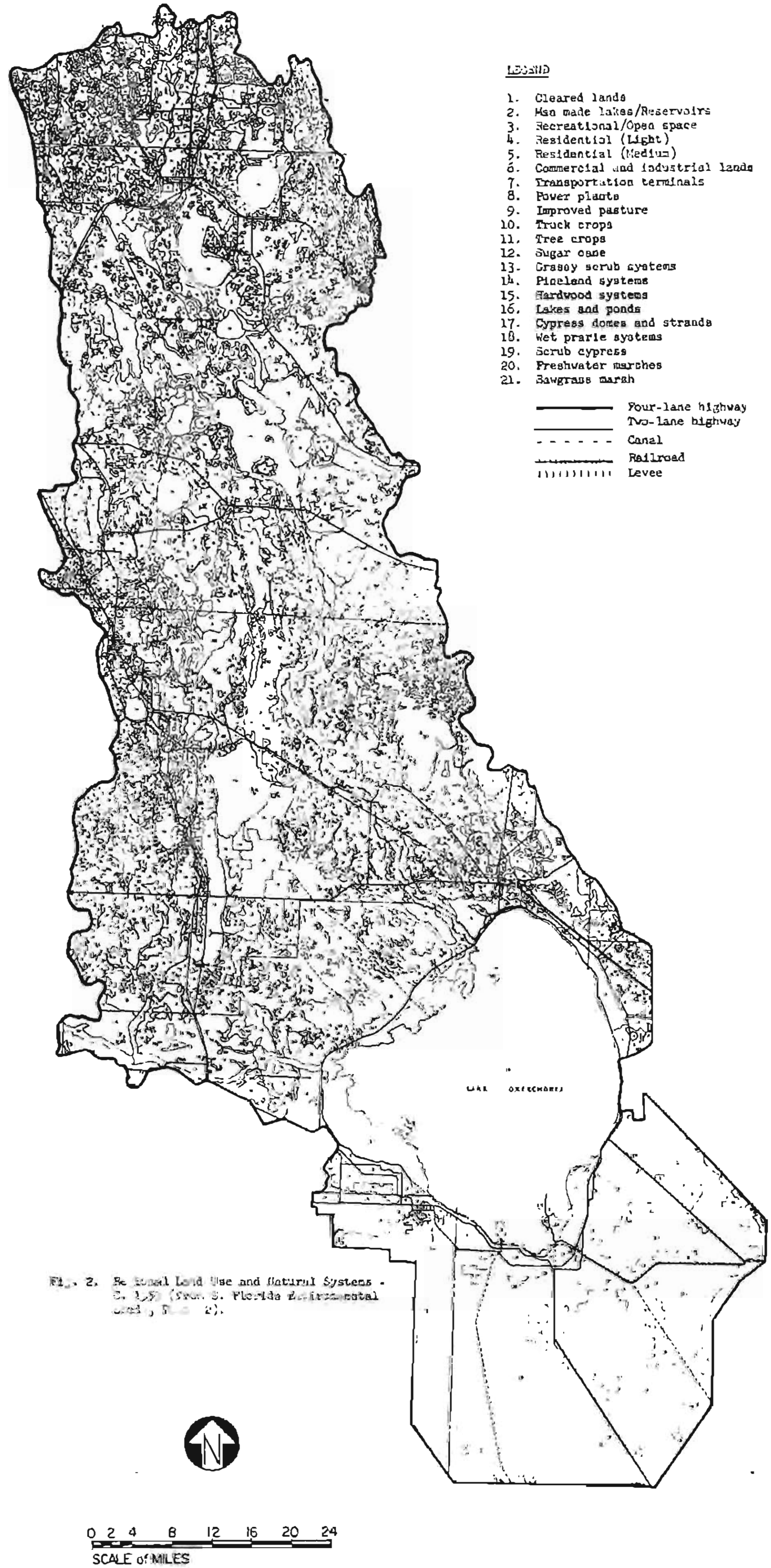
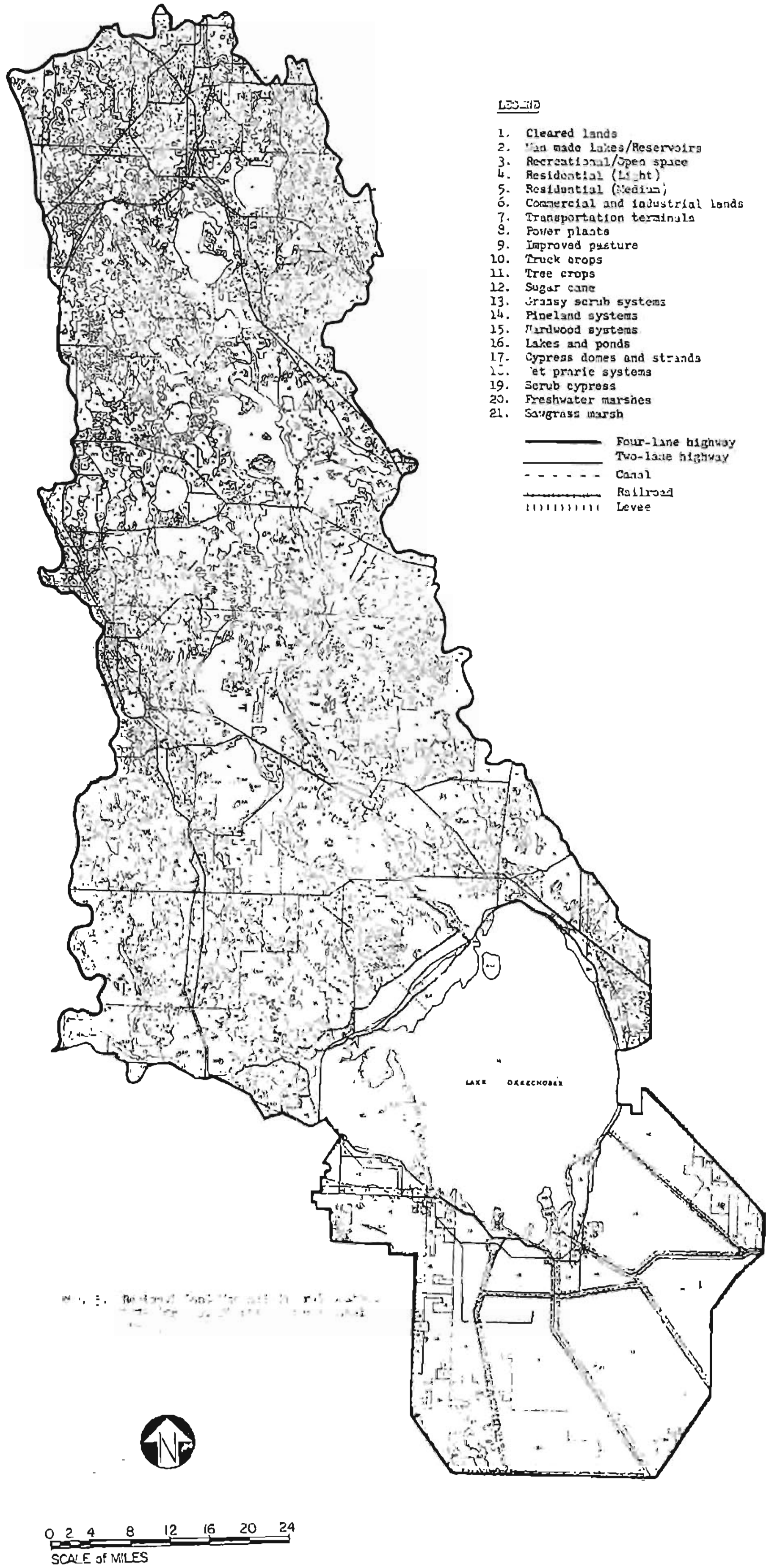


Fig. 2. Regional Land Use and Natural Systems - C. 1[illegible] (from S. Florida Environmental Study, Plate 2).


LEGEND
1. Cleared lands
2. Man made Lakes/Reservoirs
3. Recreational/Open space
4. Residential (Light)
5. Residential (Medium)
6. Commercial and industrial lands
7. Transportation terminals
8. Power plants
9. Improved pasture
10. Truck crops
11. Tree crops
12. Sugar cane
13. Grassy scrub systems
14. Pineland systems
15. Hardwood systems
16. Lakes and ponds
17. Cypress domes and strands
18. Wet prarie systems
19. Scrub cypress
20. Freshwater marshes
21. Sawgrass marsh
Four-lane highway
Two-lane highway
Canal
Railroad
Levee
LAKE OKEECHOBEE
N
0 2 4 8 12 16 20 24
SCALE of MILES

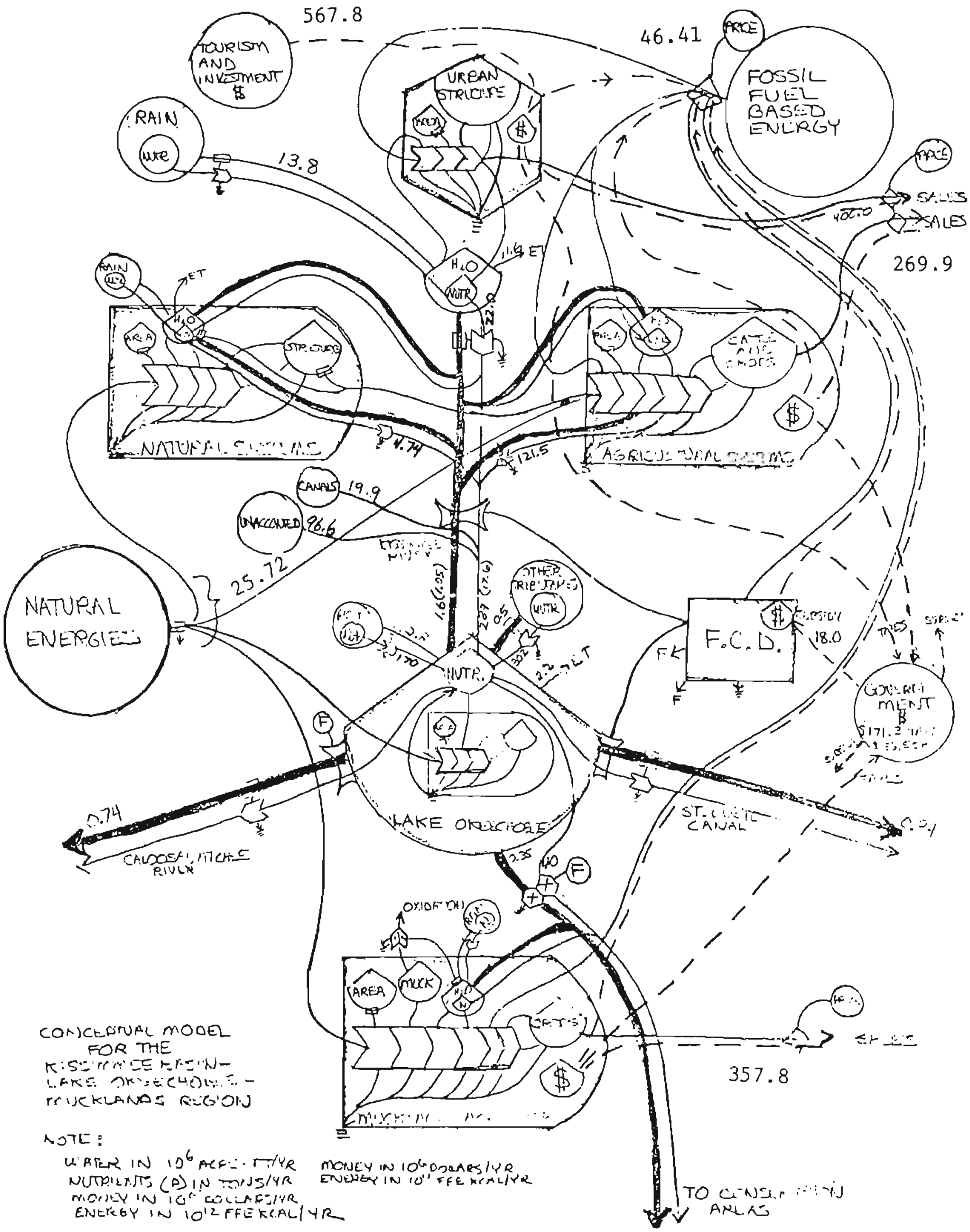


Fig. 4. Regional model for Kissimmee Basin - Lake Okeechobee - Mucklands area.

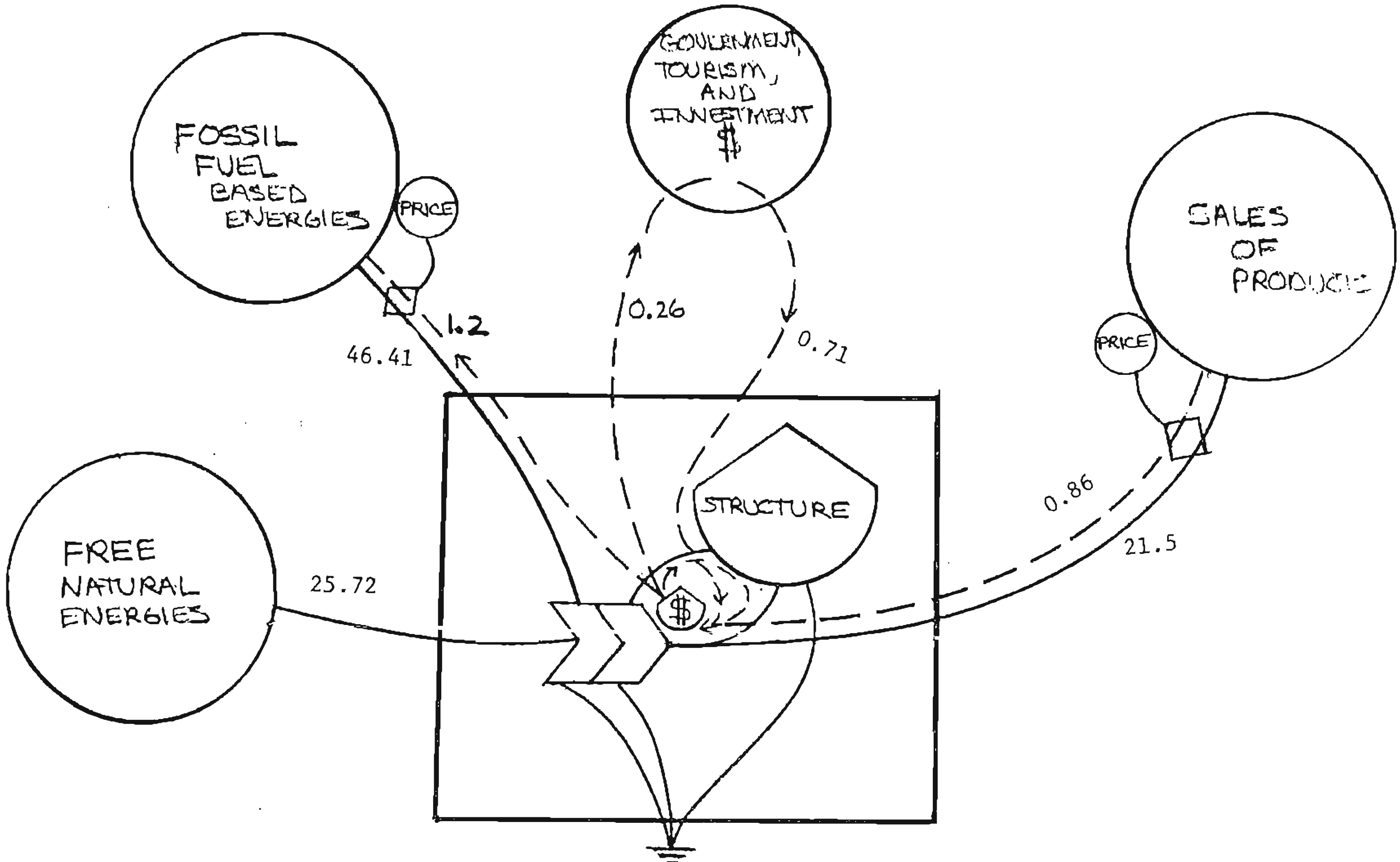


Fig. 5. Diagram showing gross relationships of regional energy and money flows. Money (dashed lines) expressed as $\$10^9$/yr; energy (solid lines) expressed as $\times 10^{12}$ FFE kcal/yr.

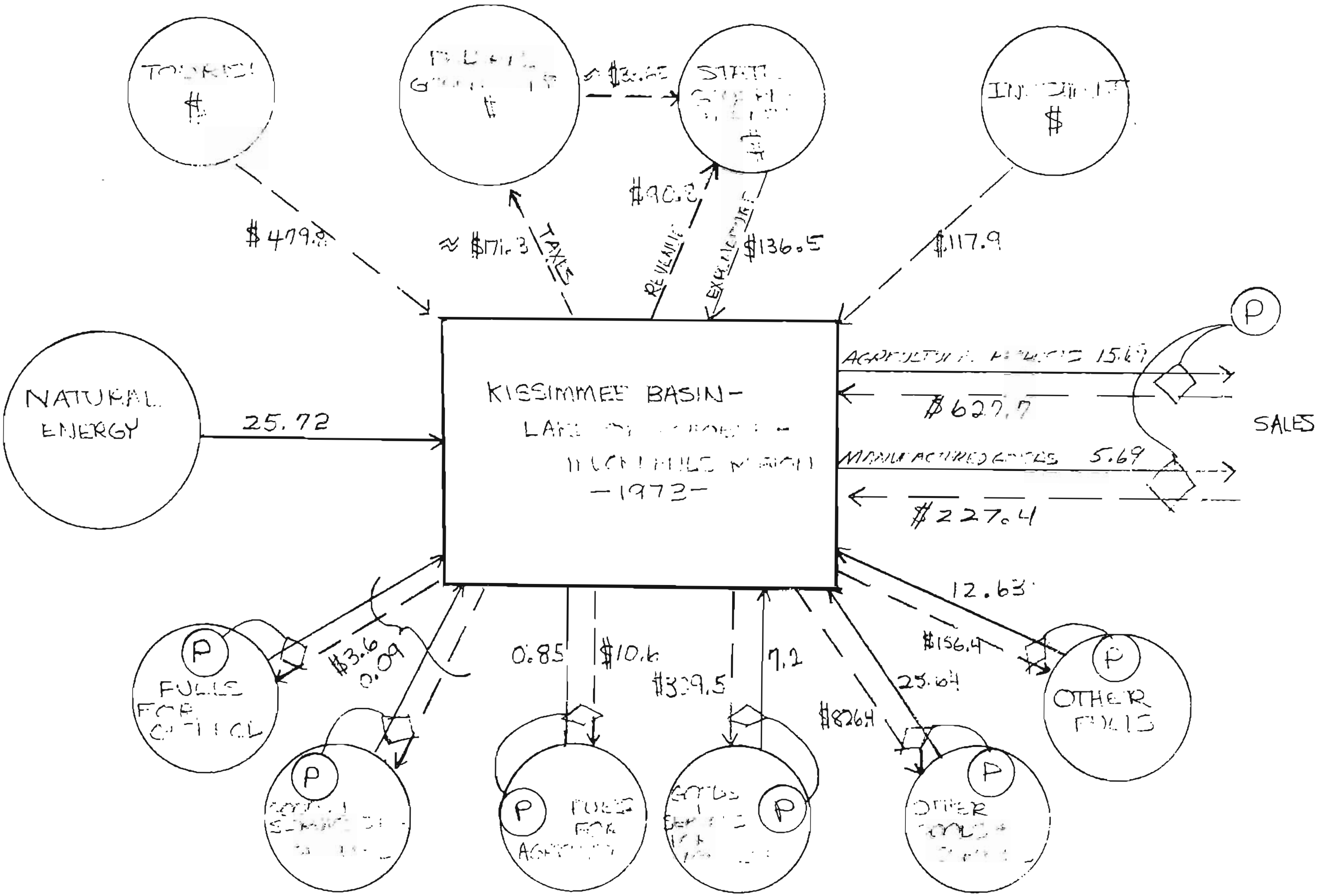


Fig. 6. Diagram for Region Showing Input and Output of Energy and Money. Energy flows (solid lines) in terms of fossil fuel equivalents (x 10^{12} FFE Kcal/yr). Money flows (dashed lines) in terms of 10^6 dollars per year.

Methods

Land Use Maps

Areas of land use were measured using land use maps (Figs. 1-3) obtained from the South Florida Environmental Project Phase II. Three temporal periods provide historic data on changes in land use from the primitive condition (Fig. 1), to 1953 (Fig. 2), and to 1973 (Fig. 3). The land use measurements provide the basis for alternative management calculations and energy value tables (see Appendices A-E).

Simplified Model of Energy, Money and Water

To organize, understand, and show relationships of the main contributions to the value of the area, a simplified diagram was prepared that includes the main work processes which contribute value each year (Fig. 4). The main bought and resident energy flows and the flows of water and nutrients are included. Diagramming the work of man and nature summarizes the main processes that contribute to regional vitality whether the work flows are paid for with money or not. Each pathway of the diagram was evaluated for relative magnitude and sensitivity to change.

Balance of Payments Diagram

A simple diagram summarizing the exchange of energy and money was evaluated for 1973 (Fig. 5). This evaluation points out the major characteristics of the region's economy and the sensitivity of these characteristics to external change.

Value Change Table

For comparative purposes, a table of work flows was calculated for management alternatives in the Kissimmee-Okeechobee basin. Energy flow categories that are expected to change (as deduced from the energy diagram) were recalculated for the projected condition. The sum of increases and decreases in useful work indicates which alternative or combination of alternatives may contribute the most useful work and thus approximate the most stable long-range pattern which can be sustained.

Calculation of Carrying Capacity

The total activity of man and nature that can be sustained depends on the amount of outside high quality energy that can be attracted to control, add to, and amplify resident energy. Regions compete to attract outside investments and those with lower investment ratios (the ratio of fossil fuel energy to resident energy) match outside energy with more value from inside and compete better in the products they can offer for exchange.

Regions compete so long as their investment ratio is less than that characteristic of the larger region within which they operate. In 1973 the investment ratio for the United States was 2.5. The outside energy that could be attracted at the 1973 ratio was calculated for the 1974 condition and the three alternative management proposals, and then for conditions of 10%, 20%, and 50% decrease in available outside fuels.

Results and Discussion

Land Use and Land Use Maps

Figs. 1-3 show land use maps for the region depicting the main landscape features in the primitive condition (Fig. 1), the patterns that developed including man by 1953 (Fig. 2), and the present condition (Fig. 3). Major features and changes in land use are easily discerned. Land use shifts are directly related to the activities of man as supported by energy purchased from outside the region.

The pristine Kissimmee basin consisted of large areas of lakes, pineland, and grassy scrub, interspersed with lowland marshes and seasonal marshes or wet prairies that divided the landscape into many smaller subbasins. Wet season rains and groundwater seepage was collected by many small creeks flowing through the marshes and slowly passed to the broad and flat basin of the Kissimmee River. Because the energy quality of water is high, greater potential for work is derived from using water over a wider area where it generates greater value. Consequently, a pattern of broad marshes and slow meandering streams and rivers developed to take advantage of the water flow as a vital energy source. Man's manipulation changed this pattern by straightening meanders, deepening streams and increasing runoff. The natural energy that was once used to its fullest is now relatively unused in many locations and the amplifying value of water in these locations is lost.

Agricultural development constitutes major land use shift and approximately 40 percent of the land has been developed for agriculture. Drainage of marsh and wet prairies for flood control and agriculture reduced these systems by more than 50 percent (Appendix A). The pineland and grassy scrub systems show the greatest change from the primitive to present with 53 percent of their area converted primarily to agriculture. Of the agriculture uses, improved pasture is predominant (58%). Sugarcane (24%), tree crops (13.4%), and vegetable crops (5.2%) are the remaining uses.

Regional Model of Energy, Money, and Water

The evaluated model in Fig. 4 shows the interactions of outside energy, man-dominated systems, those of nature, water flows through the basin, exports of goods, and returning cash flow. The heavy flow through the center of the diagram is the Kissimmee River with its flow volume for the primitive condition (in parentheses) and the present. The nutrient flow that accompanies the Kissimmee River reflects the total yearly volume of nutrients that is added to those already present in the river as it flows south. The diagram indicates that the largest single source of added nutrients is from agricultural runoff (42 percent), most of which is generated in the southern portion of the river valley. This, combined with the channelized condition of the river, decreases the amplifier value on photosynthetic processes that might occur if water laden with high nutrient loads was allowed to flow slowly through marshes. Nutrient uptake by marshes is variable but usually high. Work by Taylor (1975) and Burns (1975) suggests that approximately 35,000 acres of marsh along the Kissimmee River may be effective in reducing total phosphorus loads to the lake by 40-50 percent and transforming much of the remaining dissolved phosphorus into detrital forms that are less available for algal production (Appendix B). Present marsh along the river is estimated to be 8,000 acres (Druitt and Gatewood, 1975).

The decline in water quality in Lake Okeechobee appears to be accelerating due to: (1) the decreased lag time in rainfall-runoff relationships and the altered hydroperiod of water north of the lake, and (2) increased nutrient loads unfiltered by natural wetlands. The lake presently acts as a nutrient sink by entrapping nutrients in the sediments. This is demonstrated by subtracting nutrient inputs to the lake from nutrient outputs. Logic and empirical evidence indicate that the portion of the nutrient budget remaining in the lake is deposited as sediment (Gayle, 1975). Data from the Department of Pollution Control (1975) suggest that about 45 percent of the phosphorus and nitrogen loaded from the Kissimmee River to Lake

Okeechobee is contributed from agricultural areas bordering the river. Effective nutrient uptake and recycle pathways could be incorporated by a system of marsh areas with appropriate retention tines (Taylor, 1975) dispersed throughout agricultural areas where the cow would play the major role in recycle from marshes to higher lands. The amount of fertilizer runoff recovered in this manner would decrease loading to the Kissimmee River and would benefit ranchers (Gatewood and Cornwell, 1975).

Figure 4 and Table 1 show the relative power requirements for purchased energy in urban areas and in agricultural areas. The urban areas incompass only 2 percent as much area as agriculture systems (Appendix A), yet require about five times the purchased energy per year (Table 1).

Energy Budget and Balance of Payments Diagram

Figure 5 shows a simplified diagram of energy flow and money. Figure 4 shows that the region receives natural energy and that this naturel energy develops basic resources of land, water, and ecosystems which provide the basis for regional economic vitality and biologic survival. These resources attract tourist dollars, money from agriculture and industry, federal payrolls, and capital investments. Incomes are paid to buy additional energy inflows in the form of fuels, goods and services. Other regions compete with the Kissimmee-Okeechobee region to attract tourists and sell goods. The money obtained and energy consequently bought depend on the region's ability to maintain a balance of payments. This depends ultimately on worldwide prices of fuel and the availability of money from external sources. If prices increase and incomes decrease because of a national energy shortage, the purchased energy available to the basin will be less. The model shows the extent to which the basin's total vitality is based on external energy availability and effective maximization of free resident energy. Management techniques that maximize free resident energy are evolving.

Figure 6 shows a breakdown of the flows in Fig. 5. The total regional energy budget is as follows: (1) natural energy, 35.7 percent, (2) fossil fuel, 18.81 percent, and (3) goods and services, 45.49 percent. These percentages are tabulated in Tables 1, 2, and 3. No money is paid for nature's energy, but 10.76 and 83.28 percent of all money leaving the region is for the purchase of fossil fuel and goods and services, respectively. Of all money flow into the region, contributions are: (1) tourism, government, and investments, 45.47 percent, and (2) sales of agricultural products and manufactured goods, 54.58 percent. This analysis of energy and money flow suggests that if prices for fossil fuel and other goods and services rise, the cost of manufacturing as well as agriculture and general living cost will increase. If tourism, investment, and government money inflows decrease as a result of increased fuel prices, then the money used for the purchase of fuels and goods and services by the region will decline. If this money declines, agricultural and industrial output will also decline unless nature's free energy is maximized and used more efficiently.

TABLE 1.
Contributions of Various Factors to the Energy Budget of the Kissimmee-Lake Okeechobee Agriculture Area

	Present Contribution ($\times 10^{12}$ FFE Kcal/yr)	Percentage of Total Inflowing Energy
Natural Energy	25.72	35.70
Fuel and Goods & Services Purchased by the Central and Southern Florida Flood Control District	0.09	0.12
Fuel for Agriculture	0.85	1.18
Goods and Services for Agriculture	7.2	10.00
Other Fuel	12.63	17.51
Other Goods and Services	25.64	35.55
TOTAL	72.13	

TABLE 2.

Contributions of Various Factors to Total Money Flow into the Kissimmee-Lake Okeechobee Agricultural Area

	Present Contribution ($\times 10^6$ \$/yr)	Percentage of All Money Inflowing
Tourist Money	479.8	30.59
Government Money	136.5	8.70
Investments	97.0	6.18
Sales of Agricultural Products	627.7	40.02
Sales of Manufactured Goods	227.4	14.50
TOTAL	1,568.6	

TABLE 3.

Contributions of Various Factors to Total Money Outflow from the Kissimmee-Lake Okeechobee Agricultural Area

	Present Contribution ($\times 10^6$ \$/yr)	Percentage of All Money Outflowing
Fuels and Goods and Services Purchased by the Central & Southern Florida Flood Control District	3.6	0.23
Fuel for Agriculture	10.6	0.68
Goods and Services for Agriculture	309.5	19.73
Other Fuel	156.4	9.97
Other Goods and Services	826.4	52.68
Federal Taxes	171.3	10.92
State Revenues	90.8	5.79
TOTAL	1,568.6	

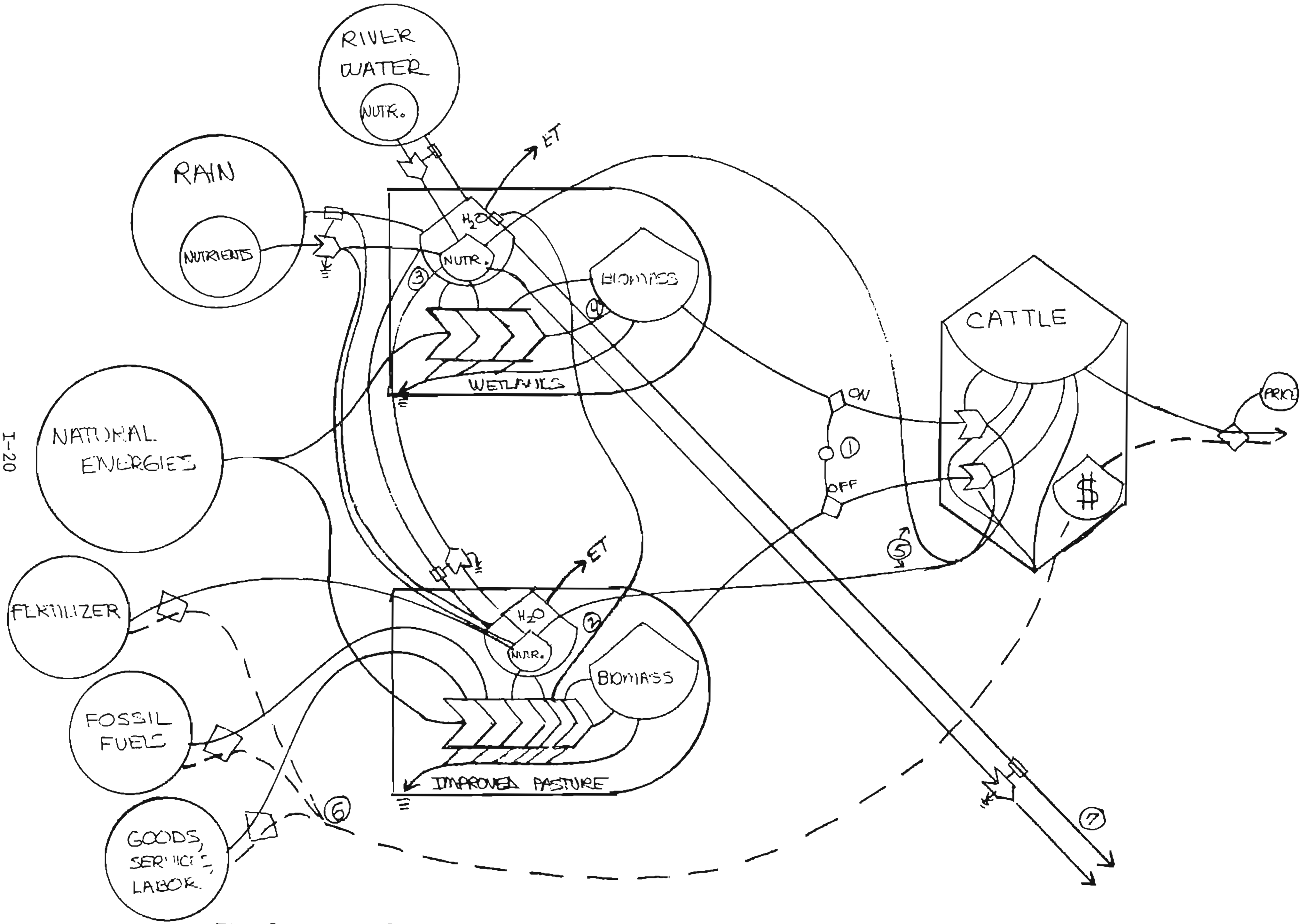


Fig. 7. Switch feeding action between improved pasture and marshlands by a cow-calf operation, showing positive feedbacks of reestablishing wetlands.

Discussion of Alternatives

Reestablishment of the Kissimmee River Flood Plain*

The model shows this alternative to increase regional energy flow by 76.29×10^{10} FFE kcal/yr (Table 4). The change is attributable to increased natural energy flow ($+27.0 \times 10^{10}$ FFE kcal/yr) because of reestablishment of marshes, increased water storage and associated value ($+45.0 \times 10^{10}$ FFE kcal/yr) and other purchased energy which has the potential of being attracted because of more efficient use of natural subsidies ($+7.28 \times 10^{10}$ kcal/yr). An increase in annual flood control cost has been calculated to be $\$1.3 \times 10^6$/yr.

Figure 7 conceptualizes the effects and benefits of this alternative. The model shows cattle grazing on improved pasture during the wet season and marshland during the dry season. Results of this switching are: (1) improved pastures become less dry during the dry season because of general raising of the water table, (2) the marsh areas assimilate much of the nutrients from pasture runoff before they are lost downstream by entering the Kissimmee River, (3) production in the marsh is stimulated, (4) this increases cow yields, (5) cows recycle nutrients back onto the marsh or pastureland, (6) less money is spent for maintenance of improved pasture, and 7, water which has passed through marshes comes out with improved water quality.

With prices of goods used to maintain pastureland currently increasing, the benefits of on-site nutrient recycle and water retention, in addition to

* See Appendix B for details of this alternative.

the other benefits, appear favorable. A 75 percent reduction in fertilizer application by some ranchers has already occurred because of increased costs (Gatewood and Cornwell, 1975). The establishment of marshy recycle areas for nutrients could also be employed in areas such as Taylor Creek and Nubbins Slough where significant nutrient loading to Lake Okeechobee occurs.

The number and costs of sewage treatment plants needed to prevent excess loading from the Kissimmee River to Lake Okeechobee were calculated. An average rainy season flow of approximately 3000 mgd was used in the calculations and yielded a necessity for about 30,100 mgd plants which would cost approximately \$5.25 x 10^9/yr (capital costs prorated over 25 years plus annual operation and maintenance costs; see Appendix B).

Water Table Elevation in the Agricultural Area*

This alternative appears to increase regional energy flow by 212 x 10^{10} FFE kcal/yr (Table 4), which is attributable to an increased life of muck soil and resultant greater, long term, yearly production figures (Appendix C). It was calculated that by extending the life of the muck an additional \$18.13 x 10^6/yr profit could be realized, most of which could then be used to attract other energy. If the cost of fuel and other goods and services rises, the calculated additional profit would probably decrease somewhat. The value of additional water stored in the Agricultural Area by this plan was determined to be about 14.6 x 10^6 FEE kcal/acre ft. stored/yr (Appendix C).

Alternative futures for the muckland area may include a peat re-deposition plan in which certain acreages of present muckland are farmed

---

*See Appendix C for details of this alternative.

while others are allowed to revert back to hyacinth marshes which deposit peat. The "crops" could then be switched.

Feasibility calculations for this alternative are based on (1) a hyacinth deposition rate of 1.5 cm of muck per year, (2) 50 percent of the agricultural area switching to hyacinth ponds every five years which is the number of years a tract can be farmed before it needs to be reconditioned, (3) raising the water table in the Agricultural Area by 18 inches. Under this alternative, the life of the muck soils is approximately doubled (see Appendix C) compared with present water management practices. This implies a 50 percent reduction in the present muck oxidation rate of 3 cm per year. Thus, one could acheive a steady state type agriculture with hyacinth ponds depositing peat at 1.5 cm per year and crop areas losing peat at a rate of 1.5 cm/yr. Calculations show that natural energy flows under this plan would increase by approximately 140.0×10^{10} FFE kcal/yr (Appendix F).

On Site Storage and Treatment of Agricultural Area Runoff

Assessment of the feasibility of this alternative depends heavily on obtaining more information, and calculations presented here are preliminary. For instance, since the land for retention areas to treat nutrient rich water could also be used to produce sugarcane or sawgrass, and since each has a different value in terms of productivity, these different values would shift the resultant cost to benefit ratio accordingly. Of course, hump removal represents an additional flood control expense. However, the yearly revenue lost from using sugarcane lands north of the hump (46×10^3 acres) would be significantly greater than the yearly cost of hump removal (\$$39.7 \times 10^6$/yr. as opposed to \$$1.64 \times 10^5$/yr.). Positive effects in terms of water quality in Lake Okeechobee would also occur if all waters were sent south (which necessitates hump removal). Table D-1 offers valuable information for decision-making concerning this alternative. It indicates that the best situation would probably be use of land not presently in agricultural production in combination with hump removal. This alternative could be easily combined with the future Agricultural Area management scheme mentioned earlier, that is, deposition of peat using hyacinth ponds. This is because the volume of water needed for the hyacinth ponds is almost exactly that which is backpumped to the lake (about 330,000 acre-ft./yr.). This backpumped water would work particularly well because of its high nutrient content.

Elevation of Stage Level in Lake Okeechobee

The net effect of this alternative is to increase regional energy flow by 14.0×10^{10} FFE kcal/yr. This change is attributable to an increase in energy flow of 41.0×10^{10} FEE kcal/yr. as a result of additional water storage for use during drought. A decrease in natural energy flow of 27.0×10^{10} FFE kcal/yr. occurs as a result and negates some of the positive effects since raising of the lake stage appears to diminish the total area of emergent marsh. The effect of diminishing the total area of marsh area may be deleterious to wading bird populations and may affect the trophic status of the lake deleteriously (Gayle, 1975). The calculated increase in submergent vegetation may, however, provide more breeding ground for game fish.

Carrying Capacity Evaluated for Present and Alternative Management Programs

The sustainable carrying capacity for man and nature depends on the amount of controlling high quality energy attracted from outside the region to amplify resident energy. The energy investment ratio is defined as the ratio of high quality energy from outside compaired to free resident energy. The energy investment ratio calculated by dividing total fossil fuel energy by resident energy for the United States in 1973 was 2.5 to 1.

The investment ratio provides one standard for evaluation of the competitiveness of a region. Regions with low investment ratios match outside energy with more value from inside the region and thus compete better in what they offer for exchange. Regions compete so long as their investment ratio is less than that which is characteristic of the larger system within which they operate. The investment ratio for the Kissimmee-Okeechobee Agriculture Area region was 1.8 to 1 in 1974, reflecting abundant resident energy and good competitive position. The region could conceivably attract more energy from outside as long as its ratio does not exceed the ratio of South Florida.

Table 6 shows the amount of outside energy that may be attracted using a ratio of 2.5 to 1 (line 1) for each alternative management scheme. Since the investment ratio is changing, three other ratios (10 percent, 20 percent, and 50 percent reductions in fuel availability) are shown. The table shows that with the ratio of 2.5 to 1, the region could attract 64.3×10^{12} kcal/yr FEE in outside energy and still remain competitive (column 1). Should all of the proposed management alternatives be implemented, the amount of energy the region can theoretically attract would be increased by 23 percent to 79.4×10^{12} kcal/yr FFE (column 7). If fuel availability were reduced by 50 percent, which would reduce the overall investment ratio from 2.5/1 to 1.75/1, and all management alternatives were implemented, the region could still attract its present amount of outside energy.

TABLE 5.

Carrying Capacities under Various Levels of Fossil Fuel Availability

Investment Ratio	Energy (x 10^{12} FFE kcal/yr) Which Can be Attracted by Present and Alternative Management Plans					
	Present Conditions*	Reestablishment of Kissimmee River Floodplain	Water Table Elevation in Mucklands	Crop Rotation Peat Deposition	On Site Storage and Treatment of Excess Agricultural Area Water	Elevation of Stage Level in Lake Okeechobee
2.50/1	64.3	66.1	68.5	67.8	69.8	51.5
2.25/1	57.9	59.5	61.7	61.0	62.8	55.3
2.00/1	51.4	52.9	54.8	54.2	55.8	49.2
1.75/1	45.0	46.27	48.0	47.5	48.8	43.0

*Present purchased energy attracted is 46.41 x 10^{12} FFE kcal/yr.

Present natural energy is 25.72 x 10^{12} FFE kcal/yr.

Investment Ratio	All Alternatives
2.5/1	79.4
2.25/1	71.4
2.00/1	63.4
1.75/1	55.6

Table A-1. Regional Energy Flow

Pathway No. on Fig. 4	Name of Energy Flow	Area of System[a] (x 10^3 Acres)	Annual Work of That System[b] (x10^6 Kcal/acre/yr.)	Energy Quality Factor[c]	Regions Annual Work[d] (x 10^{12} Kcal/yr. FFWE)	$ Equivalents for Human Worl (x 10^6 $/yr.)
Flows of Metabolic Work by Natural Systems						
(A)	Lake Okeechobee					
(1)	Phytoplankton or Epiphytes	436.0*	19.4[f]	.05	0.42	16.9
(2)	Submerged Vegetation	55.0	59.1[g]	.05	0.16	6.5
(3)	Freshwater Marsh	48.5	358.9[h]	.05	0.87	34.8
	Subtotal				1.45	58.2
(B)	Kissimmee River Basin					
(4)	Hardwoods	229.1	155.1[i]	.05	1.78	71.2
(5)	Wet Prairie	500.3	106.4[j]	.05	2.66	106.4
(6)	Cypress	45.6	79.8[k]	.05	0.18	7.2
(7)	Pineland	346.9	110.8[l]	.05	1.92	76.8
(8)	Freshwater Marsh/Slough	145.3	358.9[h]	.05	2.61	104.4
(9)	Dry Prairie	282.3	73.9[m]	.05	1.04	41.6
(10)	Rivers, Streams, Lakes	260.8	31.5[n]	.05	0.41	16.4
	Subtotal				10.60	424.0
Natures Metabolic Work on Managed Areas						
(A)	Kissimmee River Basin					
(11)	Vegetable Crops	20.1	47.3[o]	.05	0.60	24.0

*Total area of lake is approximately 443.8 x 10^3 acres, of which 103.5 x 10^3 acres are marsh or submergent vegetation.

Pathway No. on Fig.	Name of Energy Flow	Area of System (x 10^3 acres)	Annual Work of That System (x10^6 Kcal/ acre/yr.)	Energy Quality Factor	Regions Annual Work (x 10^{12} Kcal/yr. FFWE)	$ Equivalents for Human Wor (x 10^6 $/yr.)
(12)	Citrus Crops	215.1	51.7[p]	.05	2.18	87.2
(13)	Sugarcane	5.3	298.4[q]	.05	0.10	4.0
(14)	Improved Pasture	807.3	88.6[r]	.05	4.43	177.2
	Subtotal				7.31	292.4
(B)	Agricultural Areas					
(15)	Sugarcane	379.2*	298.4[q]	.05	5.66	226.3
	Vegetables	62.9	47.3[o]	.05	0.15	5.9
	Improved pasture	125.0	88.6[r]	.05	0.55	22.2
	NATURAL WORK SUBTOTAL				25.72	1028.8
Inventory of Physical Energy Flows to Region						
(16)	Rain-Elevation Potential	3,717.7	variable[s]	1.7	2.07	8.3
(17)	Rain-Chemical Potential	3,717.7	variable[s]	0.1	12.58	503.2
(18)	Wind	3,717.7	variable[s]	0.13	4.86	194.4
(19)	Heat Gradient from Sun's Heating	3,717.7	40.0[t]	1.0×10^{-4}	0.01	0.4
	Subtotal				19.52	706.3
Economic and Industrial Energy Flows						
(20)	Purchase of Fuels, Goods, and Services by Urban Sector				38.27[u]	1530.8
(21)	Purchases of Fuels, Goods and Services by Agricultural Sector				8.05[v]	322.0

*273.0 x 10^3 acres in actual production.

Table A-1 (Con'd.)

Pathway No. on Fig.	Name of Energy Flow	Area of System (x 10^3 acres)	Annual Work of That System (x10^6 Kcal/	Energy Quality Factor	Regions Annual Work (x 10^{12} Kcal/yr. FFWE)	$ Equivalents for Human Wor (x 10^6 $/yr.)
(22)	Purchases of Fuels, Goods and Services by Central and Southern Florida Flood Control District				0.09 [w]	3.6
	PURCHASED WORK SUBTOTAL				46.41	1856.4
	TOTAL REGIONAL WORK				72.13	2885.2

INVESTMENT RATIO: $\frac{\text{(Purchased Energy)}}{\text{(Natural Energy)}} = \frac{46.41}{25.72} = \frac{1.8}{1}$

Footnotes to Table A-1

a Unless noted otherwise, areas for the present are those planimetered from map of present conditions (Figure 3).

b Calculations of annual work of a system per unit area were determined from data obtained in situ or from the literature.

c The Energy Quality Factor is the inverse ratio of natural energy inputs (in heat equivalent units) into an energy conversion process to the energy output of the process. The energy output is expressed in fossil fuel equivalents (work equivalent to coal). This factor enables natural energy contributions to be converted to the same units as man's energy flows and the two types can be compared. Different energy conversion processes (photosynthesis, tides, winds, electricity, etc.) have differing abilities to perform useful work and various energy quality factors are represented in Column C. Some factors are less certain and are indicated with a question mark.

d A region's annual work expressed in Fossil Fuel Equivalents (FFE) was obtained by multiplying column A by column B and then multiplying by the Energy Quality Factor (column C).

e To gain perspective of various works done by the various components of a system which includes both man and nature, annual energy contributions (column D) were divided by the approximate ratio of work to money spent in our economy, ie. 25,000 kilocalories per dollar.

f Measured in situ by the author and others (see Gayle, 1975).

g Measured in situ by the author and others (see Gayle, 1975).

h Bayley and Burns (1974).

i Gross primary production calculated from tropical rain forest metabolism (Young, 1974) and corrected for lower leaf area index of southern mixed hardwood forest.

j From Carter, et al. 1973.

k From Costanza 1974.

l *Ibid*.

m *Ibid*.

n *Ibid*.

o DeBellevue, 1974.

p *Ibid*.

q *Ibid*.

r *Ibid*.

s Varies according to location in region. See Costanza (1974) for details.

t Potential energy available for winds and microclimate from temperature gradient developed between ground and air is equal to:

(Energy input from solar insolation X Carnot Ratio)

$$\text{Carnot Efficiency} = \frac{T \text{ between ground and air}}{\text{air temperature}}$$

T assumed to be 2^{o} C.
Air temperature = 74^{o} F = 23.33^{o}C = 296.33^{o} K

Carnot Efficiency = $2^{o}K/296.33^{o}K$ = .00675

Energy input from solar insolation = 4000 Kcal/m^2/day

Kcal/m^2/yr = 4000 Kcal/m^2/day X .0067 X 365 days/yr

= 9.885×10^3 Kcal/m^2/yr

Kcal/acre/yr = 9.885×10^3 Kcal/m^2/yr X 4047 m^2/acre

= 40.0×10^6 Kcal/acre/yr

Kcal/study region/yr = 40.0×10^6 Kcal/acre/yr

X 3.7×10^6 acres

=148.0×10^{12} Kcal/region/yr

=1.48×10^{10} FFEKcal/yr

u Purchases of fuels, goods and services by the urban sector were determined by various ways. Data from Brown (1974) suggest that 33% of a region's urban metabolism is fuels and the remaining 67% is goods and services. Since the total urban metabolsim for the region was calculated to be 38.27×10^{12} FFEkcal/yr, this yields figures of 12.76 and 25.51 ($\times 10^{12}$ FFEKcal/yr) for regional consumption of fuel and goods and services respectively.

Another method used to determine energy consumption was by multiplying the population in the study area (294,719) by the state of Florida per capita oil consumption (41.143 bands/yr) and then multiplying this figure by the energy per barrel of oil (1.47×10^{6} Kcal/bbl). This calculation yields a figure of 17.8×10^{12} FFEKcal/yr and was considered a high estimate.

Dollar values of fuel flows were estimated on the basis of approximately 80000 kcal/fuel energy per dollar in 1973. Dollar values of goods and services were estimated to be about 25,000kcal/$.

v Purchases of fuels, goods and services by the agricultural sector were determined using data from DeBellevue (1974). These data and relevant calculations are given in Table A*. Note also that dollars outflowing for these energy inputs are given in Table B*. In Table C* are given the cash receipts for agricultural products. Both Tables B* and C* were used in deriving numbers found in figure 6.

w Purchases of fuels, goods and services by the Central and Southern Florida Flood Control District were estimated by multiplying their yearly operating budget ($\$18.0 \times 10^{6}$) by the percent of their total canal network found in the study region (20%). This yielded a figure of $\$3.6 \times 10^{6}$ which is equal to 9.0×10^{10} FFEKcal/yr when an energy-dollar ratio of 25000 kcal/$ is applied. The breakdown of this figure into fuels or goods and services is not known.

Table A*. Energy Consumption by Agriculture (1973).

Crop	Acresx10^3	Fuels Consumed ($x10^6$FFE kcal/ac/yr)	Total Fuels Consumed $x10^9$FFEkcal/yr	Goods Consumed ($x10^6$FFE kcal/acre/yr)	Total Goods Consumed ($x10^9$FFE kcal/yr)	Services and Labor Consumed ($x10^6$FFE kcal/ac/yr)	Total Services and Labor Consumed ($x10^9$FFE kcal/yr
Vegetables	83.0	4.94	409.6	14.32	1188.3	17.55	1456.7
Citrus	215.1	0.853	183.5	3.16	678.9	4.04	868.8
Sugarcane	273.0	0.573	156.5	1.94	529.4	5.15	1404.9
Improved Pasture	932.3	0.106	98.9	0.59	551.9	0.55	516.5
	Totals		848.5		2948.5		4246.9

Total Energy Consumed = 8.04×10^{12} FFE kcal/yr

Table B*. Money Spent By Agriculture For Purchasing Energy (1973)

Crop	Acres x10^3	Costs of Fuel ($/acre/yr)	Total Fuel Costs ($\$ \times 10^6$)	Costs of Goods ($/acre/yr)	Total Goods Costs ($\$ \times 10^6$)	Costs of Services ($/acre/yr)	Total Service Costs ($x10^6$$/yr)
Vegetables	83.0	56.46	4.7	572.64	47.5	702.02	62.7
Citrus	215.1	10.16	2.2	126.23	21.5	161.56	57.6
Sugarcane	273.0	7.52	2.1	77.56	21.2	205.86	56.2
Improved Pasture	932.3	1.79	1.6	23.67	22.1	22.14	19.7
	Totals		10.6		112.3		197.2

Total Cost = $\$320.1 \times 10^6$/yr

Table C*

Cash Receipts for Sales of Agricultural Products (1973)

Crop	Acres X 10^3	Dollars received per acre per year	Total Cash receipts ($\$X\ 10^6/yr$)
Vegetables	83.0	1331.12	110.48
Citrus	215.1	446.92	192.26*
Sugarcane	379.2**	702.00	266.2
Improved pasture	932.3	63.00	58.73
		TOTAL	627.67

* Doubled to account for value added by citrus processers.

** Includes acreage not in production.

Calculation of Some Money Flows Found in Figure 6

Money flowing out of the region for energy purchases has already been inventoried in preceding sections. This section deals with money flows which fall into the category of government revenues and expenditures, tourism and investment.

Government Money Flows

(A) Expenditures by state government to region were calculated on a per capita expenditure of $463.00 per year (Fla. Stat. Abstract, 1974 p535). Thus, 294719 people X $463.00/capita/yr = $136.45 X 10^6/yr.

(B) Revenue to the state government from the region was calculated on the basis of $308.00 revenue to state government per capita per year (Fla. Stat. Abstract, 1974, p. 534). Thus, 294719 people X $308/capita/yr = $90.77 X 10^6/yr.

(C) Revenue to the federal government was figured two ways, results were averaged. The first method was based on a per capita revenue generation of $648.94/yr (Fla.Stat. Abstract, 1974). This yielded a high figure of $191.25 X 10^6. Another calculation yielded an estimate of $151.13 X 10^6. The average, $171.3 X 10^6, was used.

(D) Money flowing from the federal government to the state government was determined on the basis of $86.00/capita. (Fla. Stat. Abstract 1974, p. 534). This yielded a figure of $\$25.35 \times 10^6$/yr. Another calculation gave a figure of $\$41.9 \times 10^6$/yr. This gave an average of $\$33.65 \times 10^6$/yr.

Tourism

Tourist dollars were determined by multiplying total tourist dollars to South Florida ($\$4.6 \times 10^9$) by .1268 which represents the difference between the incomes of the study region and the South Florida region.

Investments were determined using the same factor. Money received for exported manufactured goods was determined as the difference between money inflows and outflows.

TABLE A-2
Regional Land Use Subsystem Areas and Total Annual Work:
Primitive Conditions (c. 1900)

Subsystems	FFWE Power Density ($x10^6$ FFWE Kcal/ac/yr)	Subsystem Area (acres)	Total Annual Work ($x10^{12}$ FFWE Kcal/yr)
Beach and Dune	0.30	0	0.00
Salt Flats	0.30	0	0.00
Lakes and Rivers	1.57	684,735	0.97
Estuarine Bays	2.73	0	0.00
Dry Prairies	3.69	649,803	2.44
Cypress Domes and Strands	4.00	49,756	0.20
Salt Water Marshes	5.17	0	0.00
Wet Prairies	5.32	531,234	2.83
Pinelands	5.57	675,586	3.76
Scrub Cypress	5.85	0	0.00
Hardwoods	7.75	237,479	1.84
Mangroves	9.97	0	0.00
Fresh Water Marshes/Sloughs	17.95	464,809	7.52
Saw Grass Marsh	27.45	576420	15.82
TOTALS		3,869,822	35.38

TABLE A-3.
Regional Land Use Subsystem Areas and Total Annual Work:
Present Conditions (c. 1953)

Subsystems	FFWE Power Density ($x10^6$ FFWE Kcal/ac/yr)	Subsystem Area (acres)	Total Annual Work ($x10^{12}$ FFWE Kcal/yr)
Cleared Land	0.70	7,274	0.01
Man Made Lakes/Reservoirs	0.73	0	
Recreational/Open Space	6.65	1,103	0.01
Residential (light)	200.00	3,372	0.03
Residential (medium)	400.00	8,868	3.55
Transportation Terminals	1,500.00	6,984	10.48
Commercial and Industrial	3,000.00	15	0.05
Urban subtotals		27,616	14.13
Improved Pasture	5.49	300,851.1	1.65
Tree Crops	10.13	135,789	1.38
Sugarcane	19.37	60,386	1.17
Vegetable Crops	30.00	173461	5.20
Agricultural subtotals		670,487.1	9.4
Beach and Dune	0.30	0	
Salt Flats	0.30	0	
Lakes and Rivers	1.57	685,169	0.55
Estuarine Bays	2.73	0	
Dry Prairies	3.69	426,284	1.57
Cypress Domes and Strands	4.00	48,719	0.19
Salt Water Marshes	5.17	0	
Wet Prairies	5.32	682,181	3.63
Pinelands	5.54	443,917	2.46
Scrub Cypress	5.85	0	
Hardwoods	7.75	250,288	1.94
Mangroves	9.97	0	
Fresh Water Marshes/Sloughs	17.95	304,873	6.50
Saw Grass Marshes	27.45	431,827	11.85
Natural subtotals		3,273,258	28.69
TOTALS		3,971,323	52.22

TABLE A-4
Regional Land Use Subsystem Areas and Total Annual Work:
Present Conditions (c. 1973)

Subsystems	FFWE Power Density ($x10^6$ FFWE Kcal/ac/yr)	Subsystem Area (acres)	Total Annual Work ($x10^{12}$ FFWE Kcal/yr)
Cleared Land	0.70	22,158	0.02
Man Made Lakes/Reservoirs	0.73	0	
Recreational/Open Space	6.65	3,529	0.02
Residential (light)	200.00	7,637	1.53
Residential (medium)	400.00	38,355	15.34
Transportation Terminals	1,500.00	6,130	9.20
Commercial and Industrial	3,000.00	3,967	11.90
Urban subtotals		81,776	38.27
Improved Pasture	5.49	932,346	5.02
Tree Crops	10.13	215,068	2.18
Sugarcane	19.37	379.167*	4.07
Vegetable Crops	30.00	82,939	2.40
Agricultural subtotals		1,609,515	13.67
Beach and Dune	0.30	0	
Salt Flats	0.30	0	
Lakes and Rivers	1.57	696,771	0.83
Estuarine Bays	2.73	0	
Dry Prairies	3.69	282,324	1.04
Cypress Domes and Strands	4.00	45,564	0.18
Salt Water Marshes	5.17	0	
Wet Prairies	5.32	500,273	2.66
Pinelands	5.54	346,861	1.92
Scrub Cypress	5.85	0	
Hardwoods	7.75	229,131	1.78
Mangroves	9.97	0	0.00
Fresh Water Marshes/Sloughs	17.95	248,837	3.64
Saw Grass Marshes	27.45	0	
Natural subtotals		2,349,761	12.05
TOTALS		4,041,052	72.13

* 273,0 x 10^6 in actual production

Table A-5

Calculated Changes In Energy Flows Associated With Alternative Plans

Changes in energy expressed as 10^{10} Kcal FFE/yr*;

Dollar equivalents expressed as 10^{6} Dollars/yr

Energy Flow Affected By Alternative	Reestablishment Of Kissimmee River Flood Plain (Appendix B)	Water Table Elevation in the Agri-cultural Area (Appendix C)	On Site Storage and Treatment of Excess Agricultural Area Water (Appendix D)	Crop Rotation Peat Deposition	Elevation Of Stage Level In Lake Okeechobee (Appendix E)
Change in Productivity	+27.0 (+$10.0)[a]	+167.0 (+1866.8[a])	+214.0 (+$85.6[a])	+140.0 (+$56.0[a])	-27.0 (-$10.9[a])
Productivity Value of Additional Water Stored Outside Region	+45.0 (+ $14.0)	NC	NC	NC	+41.0 (+$16.4)
Purchased Energies For Flood Control	≈ -3.0 ($1.3)[c]	NC	-0.65 (-$0.26)[c]	NC	NC
Purchased Energies Used By Urban And Agricultural Systems	+7.28 (+$2.91)[b]	+45.0 (+$18.13)[b]	NC	NC	NC

*All changes are calculated relative to present flows as given in Fig. 4 and Table A-1.

a Reflects one estimate of worth to man (dollar value) of new work done by natural systems (25,000 Kcal/$)

b Reflects money not spent for fertilizer and irrigation that can now be used for other expenditure or investment. Therefore, it has a positive value.

c Reflects additional money that will have to be spent for flood control.

APPENDIX B

CALCULATIONS CONCERNING REESTABLISHMENT OF THE KISSIMMEE RIVER FLOODPLAIN

Change in Natural Energy Flows

Changes resulting from dechannelization were determined by overlaying a land use map of present (1973) conditions with a 1953 land use map and a 1953 (prechannelization) flood extent map. The 1973 and 1953 land use maps are from Costanza (1975) and the 1953 flood extent map was found in the General Design Memorandum of the Jacksonville Corps of Engineers. Table B-1 shows the changes in land use patterns and energy flow resulting from reestablishment of the Kissimmee River floodplain. Also included in the evaluation of productivity changes is a possible change in Lake Okeechobee productivity. Odum (1953) measured total phosphorus in the Kissimmee River and found it to contain an average concentration of .012 mg/l. Since the average discharge of the river was then 1,450 cfs, this indicates a loading rate of 0.047 tons per day (17.5 tons/yr). Joyner (1971) found in 1969 an average concentration of total P in the Kissimmee River of .078 mg/l. This would reflect a loading of 0.72 tons per day based on a 1969 average cfs of 2,188 cfs (Joyner, 1971). Since this loading rate is equal to 262.8 tons per year and is about 15 times that calculated for 1953, it probably can be said with some assurance that productivity in Lake Okeechobee would be lowered if the Kissimmee River were returned to its 1953 condition. The degree of change is questionable, but for the purposes of this report a 25% reduction in plankton productivity will be assumed. This represents a change of $(0.25)(0.42 \times 10^{12}$ FFE kcal/yr) which equals 0.1×10^{12} FFE kcal/yr.

Change in Purchased Energy for Flood Control

According to Nichols and Cicchetti (1975), total annual costs of the channelization project are $1,324,000 (prorated over a project life of 50 years). Of this figure, $222,400/yr is estimated to be operation and

TABLE B-1.
Changes in Land Use Patterns and Energy Flow Resulting from Reestablishment of the Kissimmee River Floodplain

Land Use in Lower Kissimmee River Basin*	Change (acres x 10^3)	FFE Productivity Change (x 10^{11} kcal/yr)
Improved pasture	-75.62	-3.4
Dry prairie	+16.51	+ .6
Freshwater marsh	+25.95	+4.7
Pinelands	- 0.50	-0.0
Hardwoods	- 1.74	- .1
Wet Prairie	+35.40	+1.9
Subtotal Productivity Change		+3.7
Lake Okeechobee Productivity		-1.0
TOTAL PRODUCTIVITY CHANGE		+2.6 x 10^{11} kcal/yr FFE

*Area between lower end of Lake Kissimmee and upper portion of Lake Okeechobee.

maintenance costs. According to Storch (personal communication, 1974), costs of dechannelization could be as high as 90 million dollars and as low as 40 million dollars, depending upon whether the state has to purchase land which will be reflooded. These estimates would yield, when prorated over a project life of fifty years:

$\$40 \times 10^6/50 = \$0.8 \times 10^6/yr$

$\$90 \times 10^6/50 = \$1.8 \times 10^6/yr$

$\$65 \times 10^6 \text{ (average)}/50 = \$1.3 \times 10^6/yr$

It is not known what interest rates, if any, were included in these estimates.

These costs reflect a dechannelization process which would entail pushing spoil back into the channel. There may be less expensive alternatives, however, with the same degree of success in reestablishing a more natural floodplain. One idea which would deliver the same amount of flood protection yet spread water out on the floodplain is proposed in Fig. B-1. This method allows water to be routed on both sides of the existing canal, yet still be routed down the canal during peak flow. It is assumed that operation and maintenance costs will be incurred, whatever method is used. Therefore, flood control costs would become:

Present annual costs	=	\$ 1,324,000
Operating and maintenance costs of new system	=	222,400?
Future additional costs to modify existing structure	=	1,300,000
	TOTAL	\$ 2,646,400 per year

Since this represents an increase of $\$1.3 \times 10^6/yr$, this is counted as a negative quality since more money would have to be spent per year on flood control.

Changes in Purchased Energies Used by Agricultural and Urban Systems

If the Kissimmee River floodplain is reestablished and land use changes as indicated in Table B-1, there will be a loss of some improved pasture. However, there will be gains in other categories which may offset these losses. They are inventoried below:

(A) Cattle Carrying Capacity -- Present cattle carrying capacity was determined on the basis of 1 cow/2 acres of improved pasture. Thus, the 75.62×10^3 acres of improved pasture which may be affected by this alternative could carry 37,810 cows.

Under calculated future conditions, this acreage of improved pasture would be converted to freshwater marsh, wet prairie and dry prairie, having cattle carrying capacities of one cow per three, five, and twenty acres, respectively (Cornwell, 1975). The new cattle carrying capacity would thus be 16,555.5 cows (Table B-2).

(B) Economic Flow -- Present revenue generated from the 75.62×10^3 acres affected was determined on an assumed revenue of \$50.86/acre (DeBellevue, 1975), which gives a value of $\$3.846 \times 10^6$/yr. If this revenue is generated by land that carries 37,810 cows, then it can probably be assumed that land which carries 16,555.5 cows will generate a proportional amount. This amount is $\$1.684 \times 10^6$. Total costs under present and future conditions were calculated as shown in Table B-3. Total costs for present and future conditions were calculated to be $\$3.47 \times 10^6$ and $\$1.27 \times 10^6$, respectively. Subtracting total costs from total revenue in both cases gave the same net profit.

As discussed in the text, the value of retaining nutrients which originate in agricultural areas is calculated as follows:

According to the Department of Pollution Control (DPC), approximately

2.3×10^6 pounds of nitrogen and 0.24×10^6 pounds of phosphorus are loaded to the Kissimmee River from the agricultural areas in the basin. According to Cornwell (1975), most farmers use a 10-10-10 fertilizer. Thus, one hundred pounds of 10-10-10 would contain 10 lbs of total N and 10 lbs of P_2O_5, which equals 4.4 lbs total P. Using DPC data, the amount of runoff nutrients is equal to from 5.45×10^4 to 23×10^4 one hundred pound bags of 10-10-10 fertilizer. If an average of 14.2×10^4 100 lb bags is used and an average price of \$5.00/bag is assigned, the worth of the nutrients which could be retained is $\$7.1 \times 10^5$.

The total monetary savings to the farmer of this alternative would be $\$0.71 \times 10^6$ plus $\$2.2 \times 10^6 = \$2.91 \times 10^6$

Value of Additional Water Stored

The value of water that would be stored in the Kissimmee River Basin as a result of this alternative has already been calculated in terms of photosynthetic production and effect on agriculture. According to Gayle (1975), 200,000 acre ft. of water are presently shunted to the ocean under channelized conditions. Of this amount, it is assumed that half would be kept in the basin and half could be delivered further south. This additional 100,000 acre ft/yr has an estimated value for primary production of 121.5×10^{-5} kcal/gram H_2O (Odum and Brown, 1975). When multiplied out this yields a potential energy value of 0.3×10^{12} kcal/yr which equals 0.6×10^{12} FFE kcal/yr when multiplied by its energy quality factor.

Cost of Removing Nutrients from the Kissimmee River by Conventional Methods

Data from Smith (1968) were used to determine the cost of nutrient removal (Table B-4). Total yearly cost was arrived at by averaging the cost of three types of sewage treatment plants. To account for inflation,

TABLE B-2.

Type System Created	Acres Created	Cows/Acre	Cow Carrying Capacity
Freshwater marsh	25.95×10^3	1/3	8,650.0
Wet prairie	35.40×10^3	1/5	7,080.0
Dry prairie	16.51×10^3	1/20	825.5
TOTAL			16,555.5

TABLE B-3.
Changes in Economics of 75.62×10^3 Acres of Pastureland as Affected by Reestablishment of the Kissimmee River Floodplain

Category	Present	Future	Change
I. Cattle Carrying Capacity	37,810	16,555.5	-21,254.5
II. Revenue Generated	$\$3.85 \times 10^6$	$\$1.68 \times 10^6$	$-\$2.17 \times 10^6$
III. Total Costs (less taxes)	$\$3.47 \times 10^6$	$\$1.27 \times 10^6$	$-\$2.2 \times 10^6$
Taxes	$\$0.13 \times 10^6$ [a]	$\$0.0945 \times 10^6$ [b]	$-\$0.0355 \times 10^6$
Fertilizer	accounted for in total	\$0.0	$-\$0.81 \times 10^6$ [c]
Renovation	accounted for in total	\$0.0	$-\$0.77 \times 10^6$ [d]
Irrigation	accounted for in total	\$0.0	$-\$0.08 \times 10^6$ [e]
Services	accounted for in total	deduct 30% from present service costs	$-\$0.50 \times 10^6$ [f]
IV. Profit	$\$0.38 \times 10^6$	$\$0.41 \times 10^6$	≃ 0.0
V. Revenue generated per dollar invested	\$1.07	\$1.24	+\$ 0.17
VI. Profit generated per dollar invested	\$0.11	\$0.32	+\$0.21

[a] \$1.75/acre/yr for improved.

[b] \$1.25/acre/yr for unimproved.

[c] \$10.70/acre/yr (Cornwell, 1975).

[d] \$10.14/acre/yr (Cornwell, 1975).

[e] \$10.90/acre/yr (Cornwell, 1975).

[f] Present costs = \$22.13/acre/yr (DeBellevue, 1975); deduct 30% or \$6.64/acre/yr because of decreased cattle carrying capacity.

TABLE B-4.
Costs of Nutrient Removal by a Conventional 100 mgd Sewage Treatment Plant

Type Plant	Capital Costs Prorated over 25 Years	Annual Operating and Maintenance Costs	Total Annual Costs
Primary treatment	$\$ 9.0 \times 10^6$	@ $.12/1,000 gal = $\$5.48 \times 10^6$	$\$4.74 \times 10^6$
Activated sludge	$\$12.0 \times 10^6$	@ $.18/1,000 gal = $\$6.57 \times 10^6$	$\$7.05 \times 10^6$
Trickling filter	$\$12.0 \times 10^6$	@ $.15/1,000 gal = $\$5.48 \times 10^6$	$\$5.96 \times 10^6$
AVERAGE			$\$5.92 \times 10^6$

Thirty 100 mgd plants x $\$5.92 \times 10^6$/plant/yr = $\$1.78 \times 10^8$/yr.
Cost increased by five percent per year to account for inflation yields $\$2.63 \times 10^8$/yr.

cost was then increased by 5 percent per year for eight years since Smith's data were taken in 1967. Total yearly costs for a 100 mgd plant was determined to be $\$5.92 \times 10^{6}$/yr. Thirty such plants would cost $\$1.78 \times 10^{8}$/yr, which was then increased to $\$2.63 \times 10^{8}$/yr to account for inflation. Calculations had to be based on treatment of Kissimmee River water itself since non-point source nutrient flows are not treatable with conventional point source processes.

APPENDIX C

CALCULATIONS CONCERNING WATER TABLE ELEVATION IN THE AGRICULTURAL AREA

Changes in Natural Energy Flow

Changes in sugarcane production were evaluated for raising the existing water table level in the mucklands by twelve or eighteen inches. Presented here is only a summary table (Table C-1) -- all data used to generate this table are found in Morris (1975).

Changes in Purchased Energy Used by Agricultural and Urban Systems

Changes in total revenue to the sugarcane industry were calculated for the alternative water tables discussed above. Again, a summary table (C-2) is presented here -- see Morris (1975) for more detail.

Calculation of Value of Water to the Agricultural Area

From Tables C-1 and C-2:

Additional H_2O Stored (acre-ft)	Value (FFE kcal/yr) per unit water stored*		Value (dollars/yr) per unit water stored**	
	acre ft	gram	acre ft	gram
62,888	11.45×10^{6}	0.93×10^{-2}	112.58	0.9×10^{-7}
94,332	17.70×10^{6}	1.44×10^{-2}	192.19	1.6×10^{-7}

*Additional yearly production ÷ unit H_2O stored/year.

**Additional yearly revenue ÷ unit H_2O stored/year.

TABLE C-1.
Long Term Productivity of Sugarcane as Affected by Water Table Location

Location of Water Table	Additional Acre Feet of H_2O Stored/Yr	Years of Muck Left	Crop Losses Incurred	Gross Primary Production[a] of Sugarcane in Remaining Years (x 10^{13} FFE kcal/yr)	Gross Primary Production Prorated over 34.19 Years (x 10^{12} FFE kcal/yr)	Additional Yearly Production (x 10^{12} FFE kcal/yr)
Existing location	none	15.85	none	6.05	1.77	----
12" closer to surface	62,888	24.67	2.4	8.50	2.49	0.72
18" closer to surface	94,332	34.19	3.4	11.75	3.44	1.67

[a]Evaluated at 0.97×10^6 FFE kcal/acre/yr for 334.1×10^3 acres.

TABLE C-2
Long Term Revenue from Sugarcane Sales as Affected by Water Table Location[a]

Location of Water Table	Additional Acre Feet of H_2O Stored/Yr	Years of Muck Left	Crop Losses Incurred	Gross Revenue for Remaining Years of Muck (x 10^6 \$)	Gross Revenue Prorated over 34.19 Years (x 10^6 \$)	Additional Yearly Gross Revenue (x 10^6 \$)
Existing Location	none	15.85	none	665	19.45	-----
12" closer to surface	62,888	24.67	2.4	907	26.53	7.08
18" closer to surface	94,332	34.19	3.4	1,285	37.58	18.13

[a]Assuming constant returns/unit of sugar product sold and constant costs per unit of goods, services and labor bought.

APPENDIX C

CALCULATIONS CONCERNING ON SITE STORAGE
AND TREATMENT OF EXCESS MUCKLAND WATER

The area of marsh needed to store and treat runoff water from the Agriculture Area was estimated for two conditions: (1) "hump" removal and delivery of all water south from Lake Okeechobee (no input to lake), and (2) treatment of waters on each side of the "hump" separately (no "hump" removal).

Condition Number 1 -- Hump Removal

If the "hump" is removed, total loading from the agricultural area to the treatment site would be 4,869 tons of nitrogen and 266 tons of phosphorus per year (based on 1,233,255 acre-ft of runoff from the agricultural area, Morris, personal communication, 1975). This water could be delivered to either the conservation areas or to some area within the Agriculture Area. The total area of marsh needed to assimilate this nutrient loading was calculated as follows:

Assume a standing water marsh uptake and loss to sediments (net) of 3.26 lbs P/acre/yr (Morris, personal communication, 1975). In order to take up the 266 tons of phosphorus, $\frac{266 \text{ tons x } 2,000 \text{ lbs/ton}}{3.26 \text{ lbs P/acre/yr}} = 163,190.2$ acres would be needed. This reflects the maximum area needed. Based on a maximum net uptake and loss to sediments of 32.1 lbs P/acre/yr (Burns, personal communication, 1975) the number of acres needed is $\frac{266 \text{ tons x } 2,000 \text{ lbs/ton}}{32.1 \text{ lbs P/acre/yr}} = 16,573.2$ acres. The net uptake value used in this case is for a flowing vs. standing water marsh. For the purpose of this calculation an average (about 90,000 acres) of the two calculated marsh areas was used.

Included in this evaluation should be the cost of "hump" removal.

Proposed costs of construction and yearly operation and maintenance are $\$4.0 \times 10^6$ and \$4000/yr (construction costs, group communication, W. Storch, Central and Southern Florida Flood Control District; O M costs assumed to be 5 percent per year of yearly construction costs) which amount to $\$8.4 \times 10^4$ annually when prorated over a period of fifty years. The decision to prorate over fifty years is probably questionable since the life of the mucklands may not be but twenty-five years. Prorated over twenty-five years the annual costs would about double to $\$1.64 \times 10^5$/yr.

If storage necessitates building a new levee around the proposed holding basin, an estimate based on construction of 17.5 miles of levee (which will interface with existing levees) and a construction cost of \$45.00/ft yields a figure of 92,400 ft x \$25.00/ft = $\$2.31 \times 10^6$. This figure, when prorated over 25 years, yields $\$9.24 \times 10^4$/yr. Storage of this "waste" water may be useful to muckland farmers during times of drought since it would help to keep water table levels higher. In addition, the purchased nutrients in fertilizer may become available again for recycle instead of loss to the ocean. If these suppositions are true, a saving in fertilizer costs and irrigation during dry years may be incurred. The amount is not known at this time. The effect of this alternative on the dynamics of water in the immediate region of where the "hump" is to be removed needs further study. Preliminary calculations concerning the effects of this alternative are shown in Table D-1. If waters were stored in the conservation areas instead of in holding basins, some costs listed in Table D-1 might be avoided, such as construction of enclosing levees.

Condition Number 2 -- No Hump Removal

If the hump were not removed and water was treated on either side of it in holding basins, the cost of hump removal could be subtracted from Table D-1. The area needed for effective nutrient uptake north of the hump would be 83,435 acres (high estimate) based on a loading of 136 tons P/yr with 0.33×10^6 acre ft H_2O; marsh uptake as 3.26 lbs P/acre/yr (Morris, personal communication). A low estimate based on uptake of 3,201 lbs P/acre/yr would necessitate 8,473.5 acres. The average of the two values is about 46×10^3 acres. This acreage, if taken from land presently producing sugarcane, would cause a loss in 46×10^3 acres x \$382.92/acre = \$$17.6 \times 10^6$ revenue which could be used to attract energy. The change in gross primary productivity would be 1.20×10^{12} FFE kcal/yr - 0.69×10^{12} FEE kcal/yr = $+0.57 \times 10^{12}$ FEE kcal/yr assuming a saw grass marsh will be the replacement species. Level construction costs for the proposed acreage are estimated to be \$$2.25 \times 10^6$ and prorated over 25 years this equals \$$9.0 \times 10^4$/yr. This figure could be doubled to \$$18.0 \times 10^4$/yr if a similar holding basin were constructed south of the hump for the same purpose.

TABLE D-1.

	Present	Future	Change
Gross productivity in 90,000 acre area ($\times 10^{12}$ FFE kcal/yr)	1.74[a] { 0.48[b] 0.33[c]	2.47[d]	+0.73 (\$29.2 $\times 10^6$) to +2.14 (\$85.6 $\times 10^6$)
Flood control costs ($\times 10^6$ \$/yr)	3.6	3.6 plus at least 0.094	>0.094
Purchases by urban and agricultural sectors ($\times 10^6$ \$/yr)	?	?	0 to -34.5[e]

[a]If allotted acreage is in sugarcane.

[b]If wet prairie.

[c]If grassy scrub.

[d]If allotted acreage becomes a saw grass marsh with average productivity of \$27.45 $\times 10^6$ FFE kcal/acre/yr.

[e]If allotted acreage is sugarcane (90,000 x \$382.92/acre/yr).

APPENDIX E

CALCULATIONS CONCERNING ELEVATION OF STAGE LEVEL IN LAKE OKEECHOBEE

Change in Natural Energy Flows

Changes in natural energy flow as a result of increasing regulation levels in Lake Okeechobee are calculated as shown in Tables E-1 and E-2.

Value of Additional Water Stored

At present regulation levels (average = 14 ft MSL) the lake capacity is 3,527,000 acre ft. At proposed regulation levels (average = 16 ft MSL) the lake capacity would be 4,425,000 acre ft. The additional water stored (898,000 acre ft/yr) will create new potential energy as a result of change in head and is determined as follows:

PRESENT: For average annual discharge of 1,830,000 acre ft/yr (Joyner, 1971) the potential energy lost due to an elevation decrease of 14 ft is:

PE, $kcal/cm^3 = pg\Delta h$ where

p = density of water, 1.0 gm/cm^3

g = gravitation constant, 980 cm/sec^2

Δh = change in elevation, 14 ft = 426.72 cm

$$kcal/cm^3 = erg/cm^3 \cdot kcal/erg$$

$$= 1.0\ g/cm^3 \times 980\ cm/sec^2 \times 426.72\ cm \times 2.39 \times 10^{11}\ kcal/erg$$

$$= 1.0 \times 10^{-5}\ kcal/cm^3$$

Therefore, $kcal/yr = 1.0 \times 10^{-5}\ kcal/cm^3 \times 2.26 \times 10^{15}\ cm^3/yr$

$$= .0226 \times 10^{12}\ kcal/yr \times (\text{Energy Quality Factor} = 2)$$

$$= .0452 \times 10^{12}\ kcal/yr$$

PROPOSED: Same equations used but change in elevation = 16 ft = 487.68 cm. Therefore, PE = $1.142 \times 10^{-5}\ kcal/cm^3$. Using same annual discharge of 1.83×10^6 acre ft/yr ($2.26 \times 10^{15}\ cm^3/yr$) gives:

$$PE = .0258 \times 10^{12}\ kcal/yr \times (EQF = 2) = .05163 \times 10^{12}\ kcal/yr$$

Difference between present and proposed:

TABLE E-1.
Present Conditions (14 ft MSL)(from Gayle, 1975)

Contour (MSL)	Area (acres)	Vegetation Type	Gross Productivity $\times 10^6$ kcal/acre/yr	Gross Productivity $\times 10^{12}$ kcal/yr
12 - 14 ft	65,000[a]	Emergent }	>358.9[b]	17.4
11 - 12 ft	32,000[a]	Bullrush }		
8 - 11 ft	55,000	Submerged	59.1[c]	3.25
	436,000	Phytoplankton	19.4[c]	8.46
		TOTAL GROSS PRODUCTIVITY		29.11×10^{12} kcal/yr

TABLE E-2
Proposed Conditions (16 ft MSL)(from Gayle, 1975)

Contour (MSL)	Area (acres)	Vegetation Type	Gross Productivity $\times 10^6$ kcal/acre/yr	Gross Productivity $\times 10^{12}$ kcal/yr
14 - 16 ft	16,200[a]	Emergent }	>358.9[b]	10.23
13 - 14 ft	41,000[a]	Bullrush }		
10 - 12 ft	79,000	Submergent	59.1[c]	4.67
	452,200	Phytoplankton	19.4[c]	8.77
		TOTAL GROSS PRODUCTIVITY		23.67×10^{12} kcal/yr

CHANGE IN PRODUCTIVITY:

$$\begin{array}{r} 29.11 \times 10^{12} \text{ kcal/yr} \\ -23.67 \times 10^{12} \text{ kcal/yr} \\ \hline -\ 5.44 \times 10^{12} \text{ kcal/yr} \end{array}$$

$$= -\ 0.27 \times 10^{12} \text{ FFE kcal/yr}$$

[a] One-half is ponds and open water. Therefore, productivity was calculated on the basis of one-half these areas.

[b] Bayley (1973).

[c] Measured *in situ* by Gayle (1975) plus others.

$$\begin{array}{r} .0516 \times 10^{12} \text{ FFE kcal/yr} \\ - \underline{.0452 \times 10^{12} \text{ FFE kcal/yr}} \\ .0064 \times 10^{12} \text{ FFE kcal/yr} \\ \simeq .01 \times 10^{12} \text{ FFE kcal/yr} \end{array}$$

The additional 898 x 10^3 acre ft/yr (1.108 x 10^{15} cm^3) of water stored will also have value as a photosynthetic amplifier, especially if released during drought periods. Its value was determined to be:

$$1.21 \times 10^{-3} \text{ kcal/cm}^3 \text{ } H_2O \times 1.108 \times 10^{15} \text{ cm}^3\text{/yr}$$

$$= 1.35 \times 10^{12} \text{ kcal/yr} \times (\text{EQF} = 2)$$

$$= 2.7 \times 10^{12} \text{ kcal/yr}$$

This amount of water shows this value only if coupled with other factors such as dry conditions. If the water does not couple with dry conditions but once every seven years or so, its value is prorated to be:

$$\frac{2.7 \times 10^{12} \text{ kcal}}{7} = 0.386 \times 10^{12} \text{ kcal/yr}$$

$$\simeq 0.4 \times 10^{12} \text{ kcal/yr}$$

APPENDIX F

CALCULATIONS CONCERNING FUTURE ALTERNATIVES FOR AGRICULTURAL AREA (EAA) AGRICULTURE

As noted in the text, steady state agriculture yields require that fifty percent of the EAA area be put into agricultural production while the other half is in hyacinth ponds. In addition, water table levels must be raised as indicated previously.

I. Approximate area of available mucklands = 622000 acres

A) Let 311000 become hyacinth ponds.

B) Let 311000 become sugarcane, pasture and vegetable crops in the proportion, 10:3.7:1.9. (Approximately present conditions).

II. Steady state productivity

A) 311.0×10^3 acres (hyacinths) $\times 252.5 \times 10^6$ kcal/acre/yr

$= 3.93 \times 10^{12}$ FFEkcal/yr

B) 199.0×10^3 acres (sugarcane) $\times 298.4 \times 10^6$ kcal/acre/yr

$= 2.97 \times 10^{12}$ FFEkcal/yr

7 . $\times 10^3$ acres (pasture) $\times 88.6 \times 10^6$ kcal/acre/yr

$= 0.33 \times 10^{12}$ FFEkcal/yr

37.3×10^3 acres (vegetables) $\times 47.3 \times 10^6$ kcal/acre/yr

$= \underline{0.09 \times 10^{12}}$ FFEkcal/yr

7.32×10^{12} FFEkcal/yr

III. Present productivity

334.1×10^3 acres (sugarcane) $\times 298.4 \times 10^6$ kcal/acre/yr

$= 4.98 \times 10^{12}$ FFEkcal/yr

125.0×10^3 acres (pasture) $\times 88.6 \times 10^6$ kcal/acre/yr

$= 0.55 \times 10^{12}$ FFEkcal/yr

102.9×10^3 acres (vegetables) $\times 47.3 \times 10^6$ kcal/acre/yr

$= \underline{0.39 \times 10^{12}}$ FFEkcal/yr

5.92×10^{12} FFEkcal/yr

IV. Steady state productivity minus present productivity

$= 1.4 \times 10^{12}$ FFEkcal/yr

Literature Cited

Bayley, S. and L. Burns. 1974. Condensation of marsh data gathered in the Upper St. Johns River Basin. In: Carrying Capacity for Man and Nature in South Florida. H.T. Odum and M.T. Brown (eds). Center for Wetlands, Univ. of Fla.

Brown, M.T. 1974. Land, energy and water use and carrying capacity for Lee County, Florida. In: Carrying Capacity for Man and Nature in South Florida. H.T. Odum and M.T. Brown (eds). Center for Wetlands, Univ. of Fla.

Carter, M.R., L.A. Burns, T.A. Cavinder, K.R. Dugger, P.L. Fore, D.B. Hicks, H.L. Revells, and T.W. Schmidt. 1973. Ecosystem analysis of the big cypress swamp and estuaries. EPA Region IV, Atlanta, Ga.

Costanza R. 1974. Distribution of Energy-Based Value Production. In: Carrying Capacity for Man and Nature in South Florida. H.T. Odum and M.T. Brown (eds). Center for Wetlands, Univ. of Fla.

Cornwell, G. and S. Gatewood. 1975. An analysis of cattle ranching in the Kissimmee River Valley.

Debellevue. 1974. System of Energy, Water and Money in Hendry County, Florida. In: Carrying Capacity for Man and Nature in South Florida. H.T. Odum and M.T. Brown (eds). Center for Wetlands, Univ. of Fla.

Department of Pollution Control. 1975. Preliminary draft of Kissimmee-Okeechobee study.

Gayle, T.L. 1975. Systems models for understanding eutrophication in Lake Okeechobee. M.S. thesis. Univ. of Fla.

Young, D. 1974. Model of upland forest of Florida. In: Carrying Capacity for Man and Nature in South Florida. H.T. Odum and M.T. Brown (eds). Center for Wetlands, Univ. of Fla.

II. LAKE OKEECHOBEE AND ITS BIOLOGICAL COMMUNITIES*

Timothy L. Gayle

Lake Okeechobee is part of the Pamlico Terrace which is a plain that lies within the Coastal lowlands of Florida that was formed by recession of the sea during the late Pleistocene. It is the largest fresh-water lake within a single state in the United States. The lake is roughly trapezoidal and has an area of 720 square miles at lake level of 15.0 feet, and at that stage the volume is 4,020,000 acre-feet. The lake is bowl-shaped with the deepest part of the lake bed lying one foot below sea level. It is north to south, 35 miles long, and 30 miles wide. The average depth of the lake is less than nine feet and complete vertical mixing is effected because of average wave-heights of about 1.4 feet. The lake is violently agitated by storms and hurricanes and bottom substrates are thoroughly scoured; detrital material is cast out and loose sand is scarce on the bottom.

In normal years, Lake Okeechobee receives water in about equal proportions from rain on the lake and river inflow, and loses water to the regulation canals and evapotranspiration in equal proportions. The total volume of Lake Okeechobee is replaced about once a year. Water levels in the lake under natural conditions were high in the summer and low in the winter, but this regime has been modified by the flood control project and associated upland drainage by private interests in the lake's drainage basins. Because of the near-flat topography of the lake bed a change

*A review of available data prepared to facilitate project work. Some data were supplied in advance of publications. Citations should be made to original author as indicated on each Table or Figure.

in lake level has enormous effects on how much marsh area is in existence at any one period of time. The area of land covered by water of the lake and as a consequence surrounding marsh areas change perceptibly after a heavy rain or a sudden shift in wind direction.

The lake is noticeably turbid during periods of relative calm and is very turbid during storm periods. Joyner (1974) reports turbidity ranges of 7 to 56 Jackson Turbidity Units in the pelagic area of carbonate environment, which causes it to always be alkaline. The lake pH ranges from 7.8 to 9.0, with a median of 8.4. The pH is highest when lake photosynthetic activity is greatest. During normal lake levels, water color usually ranges from 30 to 50 units on the Pt-Co scale, which is much lower than the color of the ground-water inflows. Lake water is generally more highly mineralized than any of the tributary streams. Total nitrogen averages 1.4 mg/l and total phosphorus averages 0.05 mg/l in the lake. Since phosphorus values are so low relative to nitrogen, there may be phosphorus limitation in primary production. See Figures 1 through 3 for monthly averages of lake parameters, and Table 1 for yearly averages.

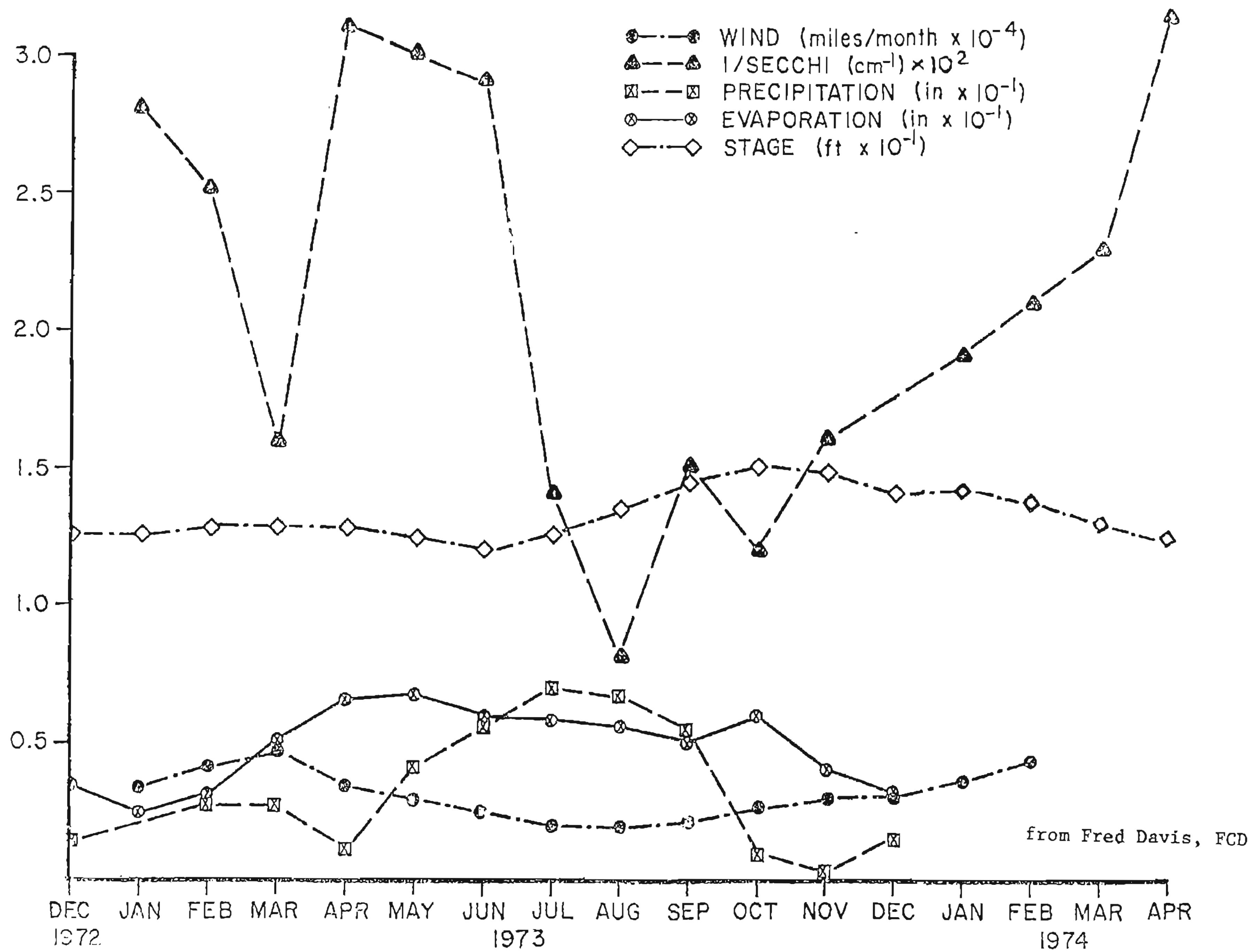


Fig. 1. Physical characteristics of Lake Okeechobee. Data from FCD.

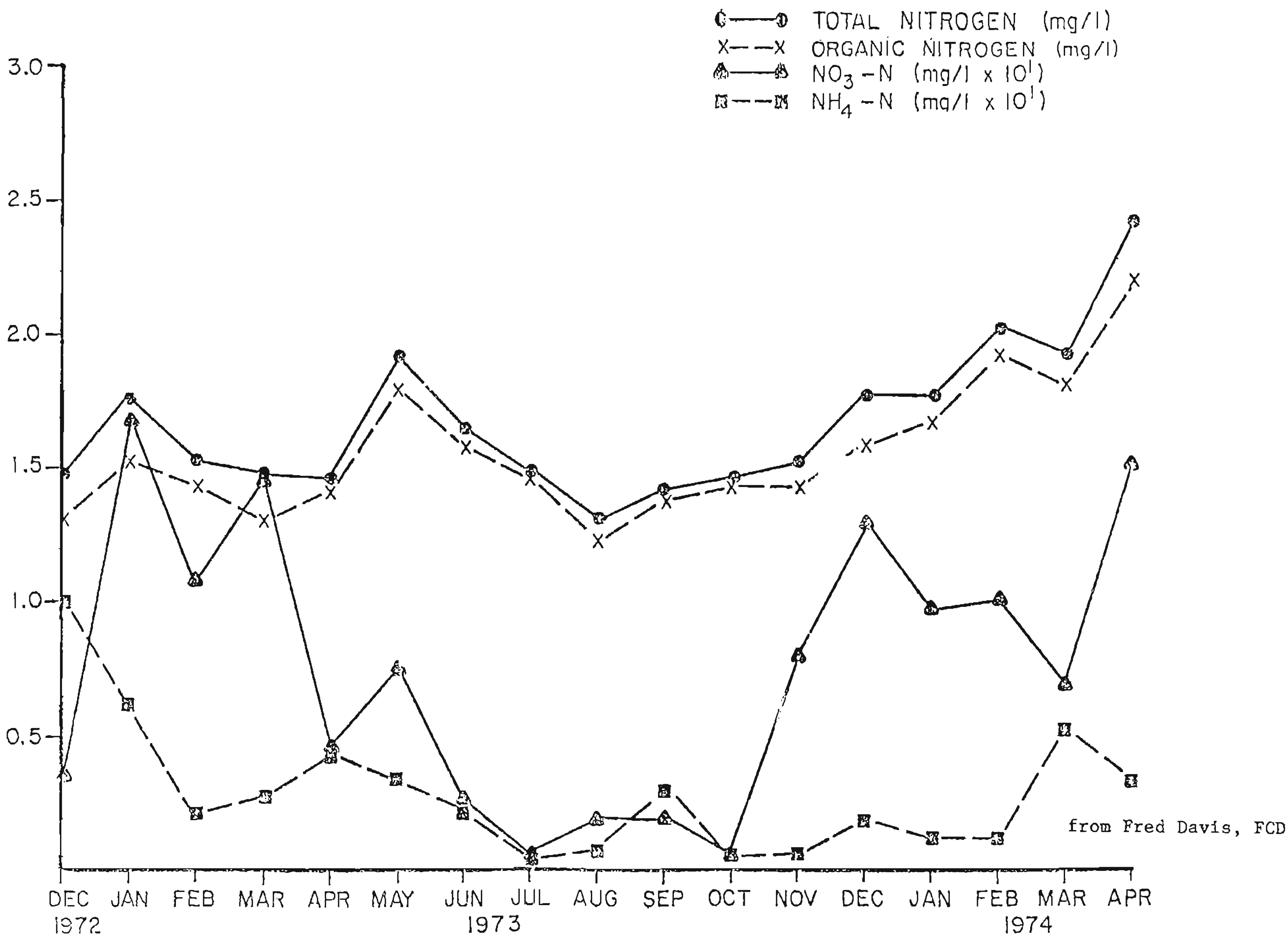


Fig. 2. Nitrogen in Lake Okeechobee. Data from FCD.

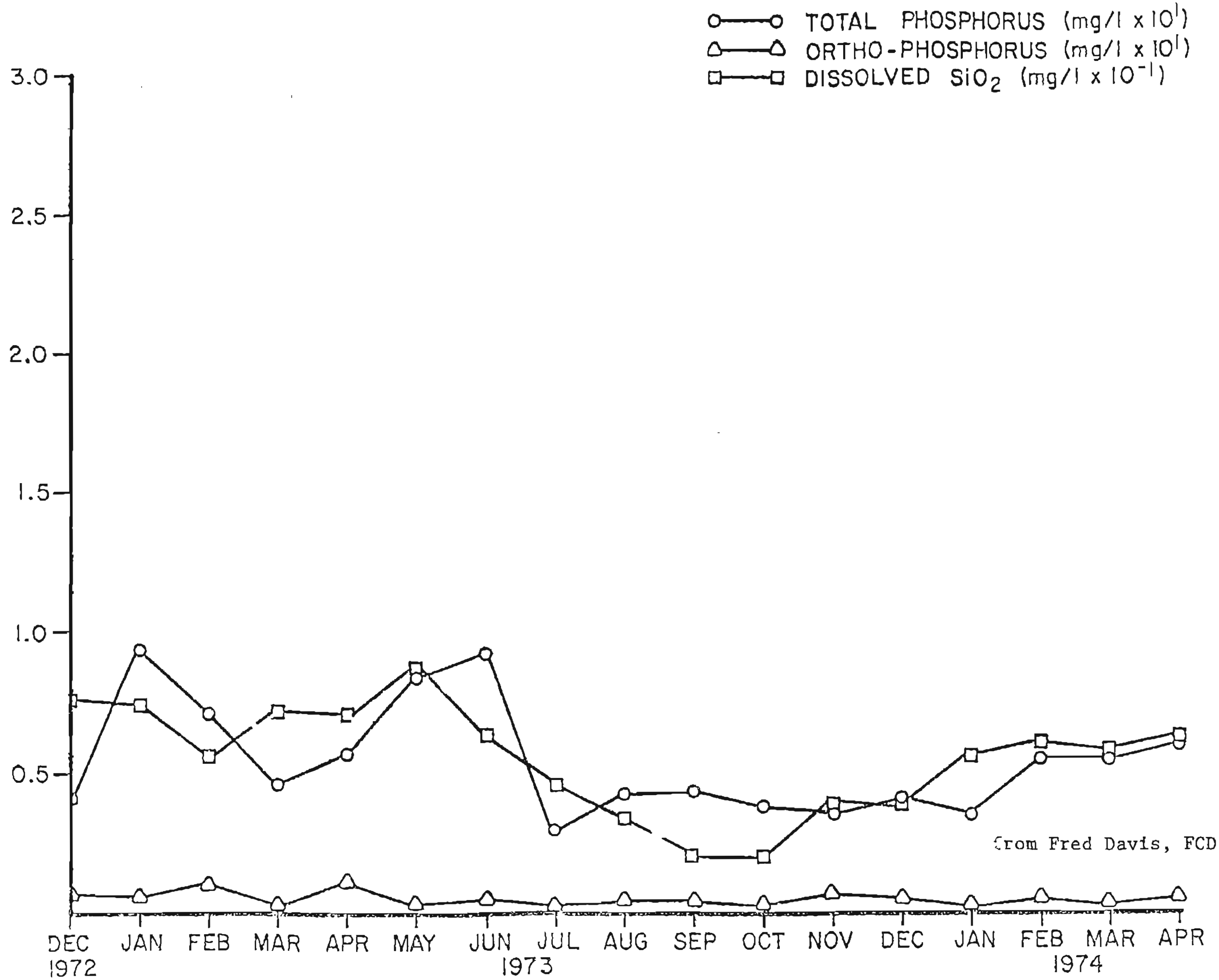


Fig. 3. Phosphorus and silica in Lake Ckeechobee. Data from FCD.

Table 1. Average Water Quality Parameters in Lake Okeechobee

Parameter	1940[a]	1950[b]	1952[c]	1965[d]	1969[e]	1970[e]	1971[e]	1972[e]	1973[f]
Stage					14.91	14.55	20.40	13.33	13.34
total phosphorus mg/ℓ P			0.013		0.024	0.070	0.051	0.038	0.071
total nitrogen mg/ℓ N					1.38	1.48	1.64	2.21	1.48
TDS mg/ℓ	185	234		376	337	279	342	378	
chloride mg/ℓ	35	30		69	63	48	61	74	87
Ca mg/ℓ	36	35		44	44	41	99	55	48
Total Organic Carbon mg/ℓ							21	20	
color Pt - scale							≤50		
Secchi disk cm							≈30cm	≈50	
pH							8.4		
P - loading $g/m^2/yr$					0.39				0.33
N - loading $g/m^2/yr$									

a Parker and others (1955)
b Schroeder and others (1954)
c Odum (1953)
d Brooks (1974)
e Joyner (1974)
f Davis and Marshall (1975)

The Pelagic Community

Phytoplankton Populations

Frequent algal blooms have been observed in the pelagic zone of Lake Okeechobee and this infers that the lake is enriched and eutrophic. Phytoplankton populations have been analyzed by Joyner (1974), Davis and Marshall (1975), and the author (samples collected in 1973 and 1974) for distribution, numbers, and community composition and dynamics.

Concentrations of primary producers in the pelagic zone of Lake Okeechobee vary considerably throughout the year. Joyner (1974) reported concentrations of phytoplankton as high as 473,700 cells/ml for an individual station with an average over the lake as high as 149,630 during a bloom period. Davis and Marshall (1975) reported much lower peak values of 23,598 cells/ml for a station and a lake arithmetic average of 11,928 cells/ml at any sampling date. Joyner reported a yearly average of about 26,000 cells/ml and Davis and Marshall reported an annual average of 7,750 cells/ml. The differences in these values may be accounted for by different counting techniques. Both researchers report individual measurements of zero cells/ml. Joyner reports a monthly minimum average over the lake of less than 50 cells/ml and FCD reports a low monthly average of 3,985 cells/ml. See Tables 2 and 3 for limnetic phytoplankton counts.

Table 2. Lake Okeechobee phytoplankton counts in 1972 and 1973. Data from M. Marshall, FCD.

Site	1972 D	1973 J	F	M	A	M	J	J	A	S	O	N	D	Σ	$\bar{X}$
1	19044		2632	7038	9108	10350	6210	14697	9310	6270	7790	5130	9310	113927	9494
2	6210	5175	6580	6417	8901	12006	4140	8901	6840	12160	6080	7980	7790	99180	7629
3	3105	7520	3572	23598	11799	14076	3105	4968	6460	19285	6460	5890	3800	113683	8741
4	4347	4550	8084	18216	11799	14904	4968	6417	12540	9690	9500	8170	4940	118125	9087
5	13455	11592	8272	4554	7659	3519	6003	3933	6650	12160	17480	13110	6270	114657	8820
6	2277	3933	3384	7659	12420	13869	3726	414	3990	7600	4560	3800	3040	70636	5434
7	2898	2070	1128	3312	13455	7038		621	0	2850	4560	4370	3420	45722	3810
8	19251	3948	7332	13041	18216	13455	1656	5175	7030	4180	10830	6840	6270	117224	9017
9		190	0	4761	4968	5796	207	414	380	0	0	3420			
Monthly Averages w/o #9	8823	5542	5123	10764	11928	11437	3985	5796	6626	9274	8431	6911	5605	$\bar{\bar{x}}$ 7750	

units/mil

* Palmer Counting Chamber used - 20 fields at 400x on two slides. A colony and a filament were each counted as a single unit.

Table 3.

Numbers of phytoplankter in cells per milliliter in Lake Okeechobee,
January 1969 to April 1971

Maximum and minimum not determined when cells per milliliter were less than 50

Date	Average number	Maximum	Minimum	Number of points
January 1969	Less than 50	Less than 50	Less than 50	15
May 1969	1,220	4,600	100	15
August 1969	Less than 50	Less than 50	Less than 50	15
January 1970	Less than 50	Less than 50	Less than 50	15
April 1970	1,560	7,500	Less than 50	7
July 1970	32,300	106,800	60	6
October 1970	25,400*	108,500*	2,100	6
January 1971	149,630*	473,700*	960*	6
April 1971	7,956*	37,400*	80*	8

* Estimated.

Concentration of Aphanazonenan polsuficum far exceeded the numbers of other algae except for a single sample collected in a phyto-oloom on June 29,1970 Ten phytoplankton in this bloom were represented almost exclusively by Anabacius flos aquae, which numbered 595,600 cells/ml.

The dominant forms of algae in the pelagic zone are blue-grass algaes mainly: Aphanizomenon holsaticum, Microcystic aeruginosa, and Anabaena flos-aquae. At other times green and yellow-brown algae contributed greatly to phytoplankton populations: Pediastrum duplex, P. simplex, and Melosira sp. and Stephanodiscus sp. FCD reported an average phytoplankton population composition of about 76% Cyanophyta, 18% Chlorophyta, 5% Chrysophyta, and 1% Euglenophyta (see Figure 4 and Table 4). The author investigated populations of diatoms for taxonomic purposes and for population composition. The population includes 29 genera of diatoms, some of which are typically marine or estuarine (Terpsinöe and Campyloma). The presence of marine and estuarine taxa may be due to high concentrations of chlorides and dissolved solids in the lake. The more often encountered genera in the lake were: Navicula, Tabellaria, Coscinodiscus, Cocconeis, Melosira, Cyclotella, Pinnularia, Gomphonema, and Surirella. It should be noted that the dominant, Stephanodiscus, cited by Joyner was not observed in FCD samples. See Figure 5 for analysis of the diatom populations.

Temporal patterns of phytoplankton population exhibit a bimodal annual cycle typical of temperate lakes throughout the U.S. Figure 6 shows peak concentrations occur in the spring and fall. Joyner's data seem to indicate this trend, but not with as great clarity and regularity (Table 3). In temperate lakes the bimodal character of the phytoplankton is ascribed to vernal and autumnal turn-over, and recycle of nutrients; however, this cannot be the case in Lake Okeechobee which is continuously mixed both vertically and horizontally. Bimodal character of phytoplankton concentrations may be caused by a combination of factors, including temperature, grazing, and timing and rate of nutrient loads.

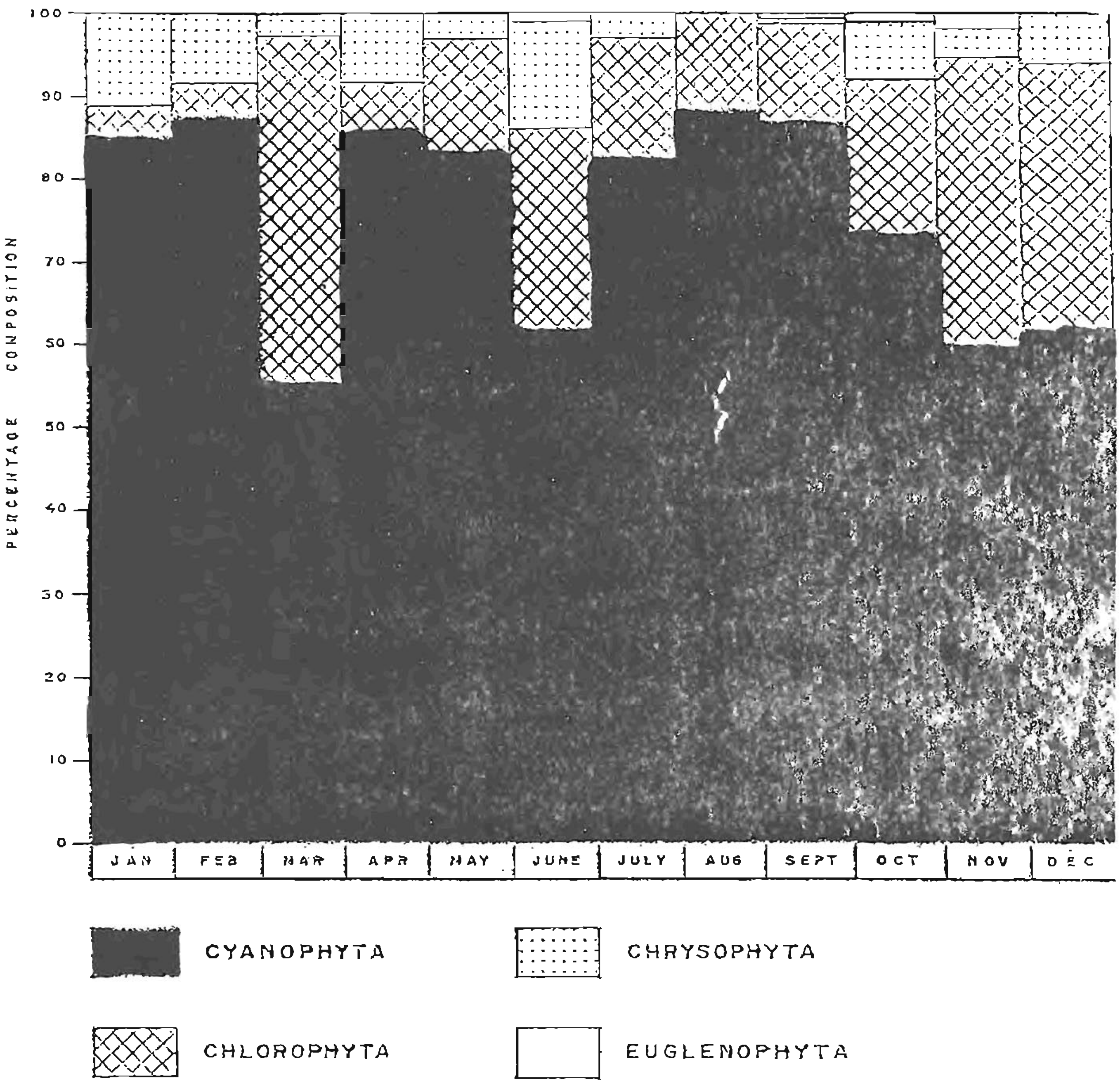


Fig. 4. Lake Okeechobee 1973 average phytoplankton composition by month. Data from FCD.

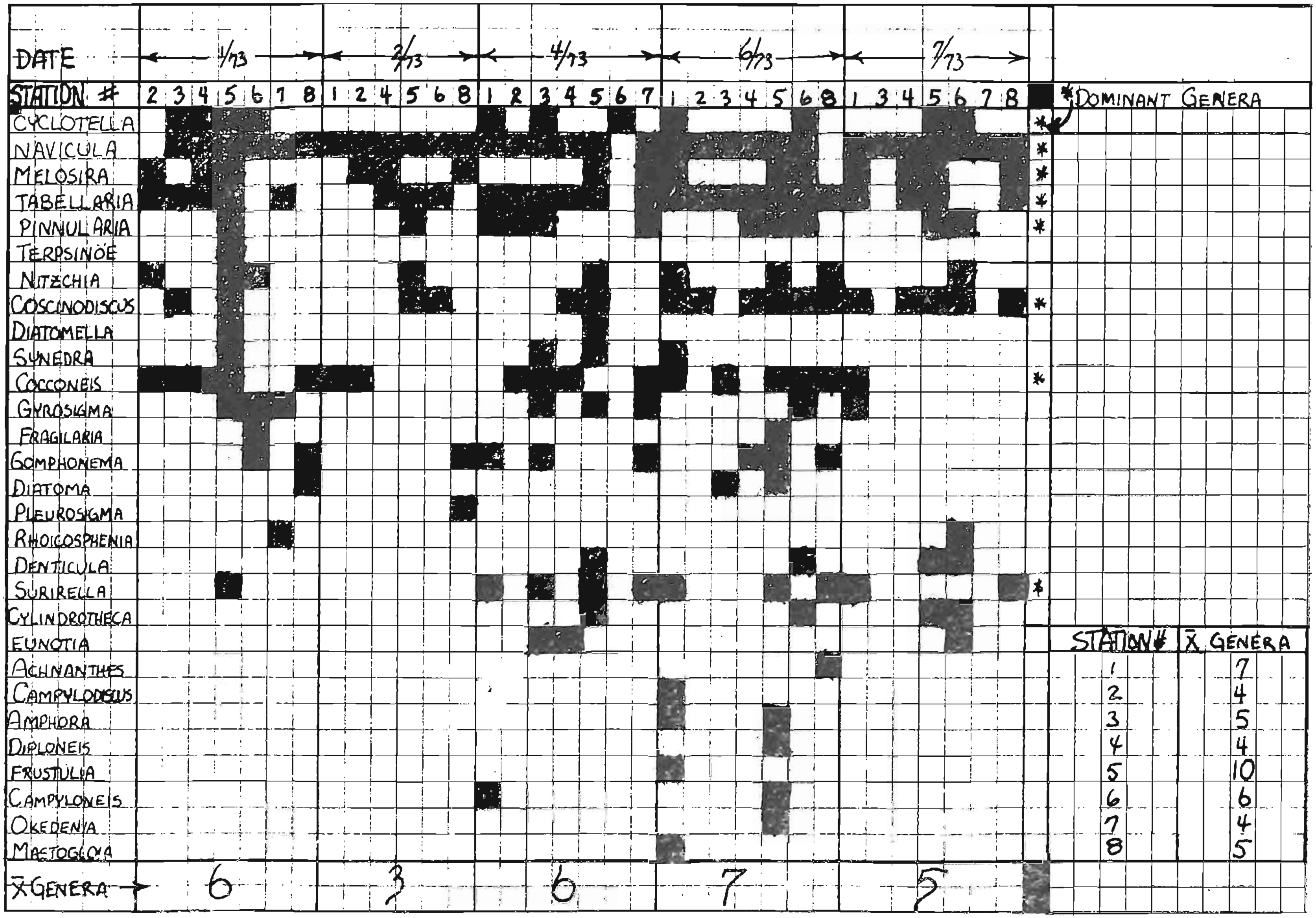


Fig. 5. Diatoms in Lake Okeechobee. Data from author.

Table 4 *

-Phytoplankton observed in Lake Okeechobee

(A abundant, P present, - not present)

	Jan 1969	May 1969	Aug 1969	Jan 1970	Apr 1970	July 1970	Oct 1970	Jan 1971	Apr 1971
Average water temperatures (°C)	15	26	29	12	30	30	27	22	27
CHLOROPHYTA (Green algae)									
Closterium parvulum	P	P	-	-	-	-	-	-	-
Closterium pronum	P	-	-	-	-	-	-	A	P
Mougeotia sp.	A	-	-	A	-	-	-	-	-
Pediastrum Boryanum	-	P	-	-	-	-	-	-	-
Pediastrum duplex	P	P	-	P	A	P	P	P	P
Pediastrum integrum	P	-	-	-	-	-	-	-	-
Pediastrum simplex	A	A	A	A	-	P	P	P	A
Pediastrum tetras	P	-	-	-	-	P	P	-	P
Scenedesmus bijuga	-	-	-	-	-	-	-	-	-
Staurastrum sp.	P	P	-	-	-	P	P	P	P
CHRYSOPHYTA (Yellow-brown algae including diatoms)									
Cyclotella sp.	P	-	-	-	P	A	-	-	-
Melosira sp.	A	P	-	A	-	-	P	P	P
Stephanodiscus sp.	-	P	-	-	-	A	P	P	A
Synedra sp.	P	P	-	P	-	-	P	P	P
Tabellaria sp.	-	P	-	-	-	-	P	-	-
PYRROPHYTA (Dinoflagellates)									
Ceratium hirundinella	P	-	-	-	-	-	-	-	-
CYANOPHYTA (Blue-green algae)									
Anabaena circinalis	-	-	-	-	-	A	-	-	-
Anabaena flos-aquae	-	P	-	P	-	A	P	P	A
Aphanizomenon holsaticum	-	-	A	-	A	A	A	A	A
Lyngbya contorta	P	-	-	-	-	-	P	-	-
Merismopedia elegans	-	A	-	-	-	A	A	P	P
Microcystis aeruginosa	P	-	A	P	-	P	P	P	-
Oscillatoria cortina (?)	A	-	A	-	-	-	-	-	-
Spirulina sp.	-	-	-	-	-	-	A	P	A

*from Joyner (1972)

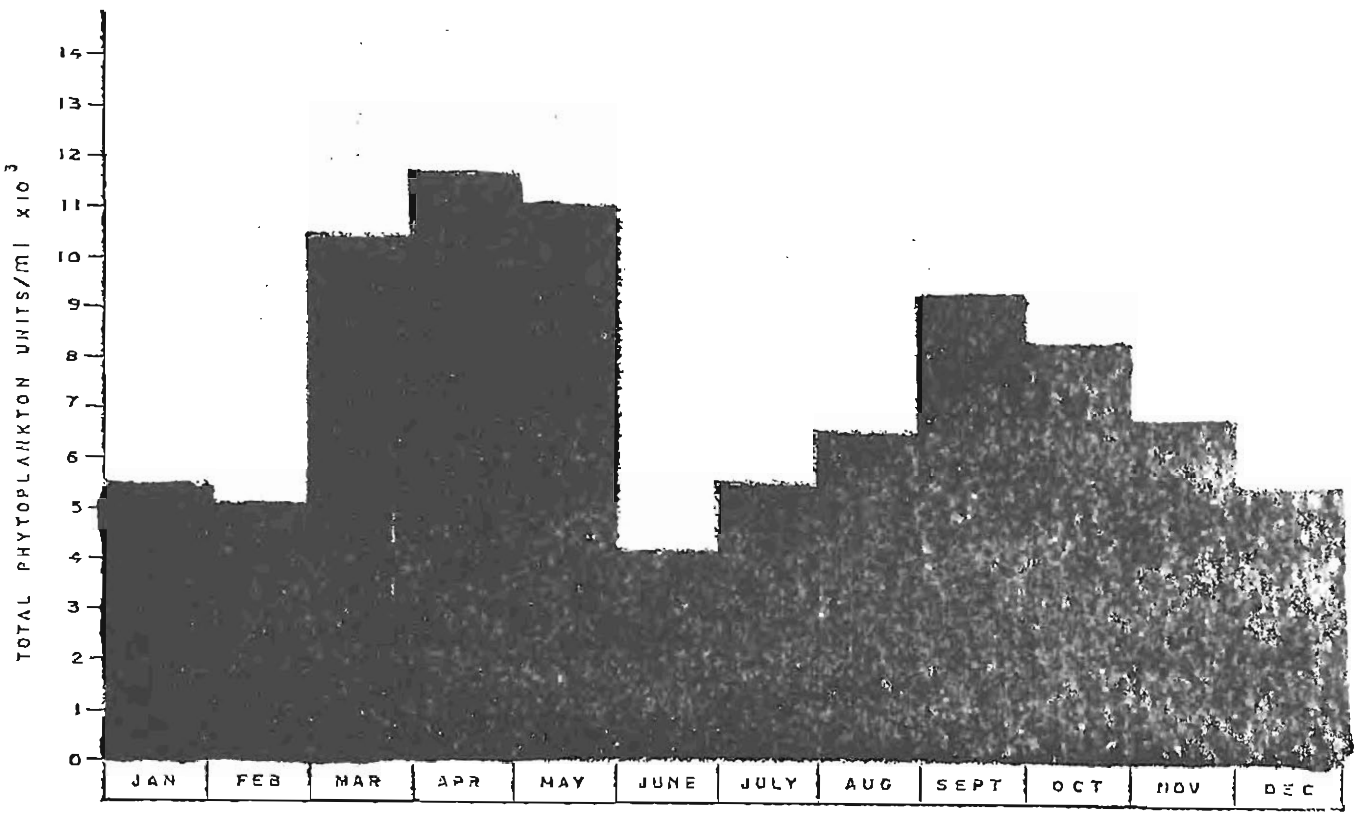


Fig. 6. Lake Okeechobee 1973 average phytoplankton totals by month.

Mike Marshall
FCD

Spatial patterns of phytoplankton populations indicate great lateral mixing and population compositions (Figure 7) and concentrations (Figure 8) are similar at all stations. However, it is noteworthy that the plankton counts (Table 1) at the south end of the lake around Rocky Reef and South Bay are generally lower (annual average of 4622 cells/ml) than counts in the rest of the lake (annual average of 8798 cells/ml). This situation could be due, in part, to lower than average phosphorus values in the southern end of the lake, and could be evidenced for phosphorus limited primary production in the lake.

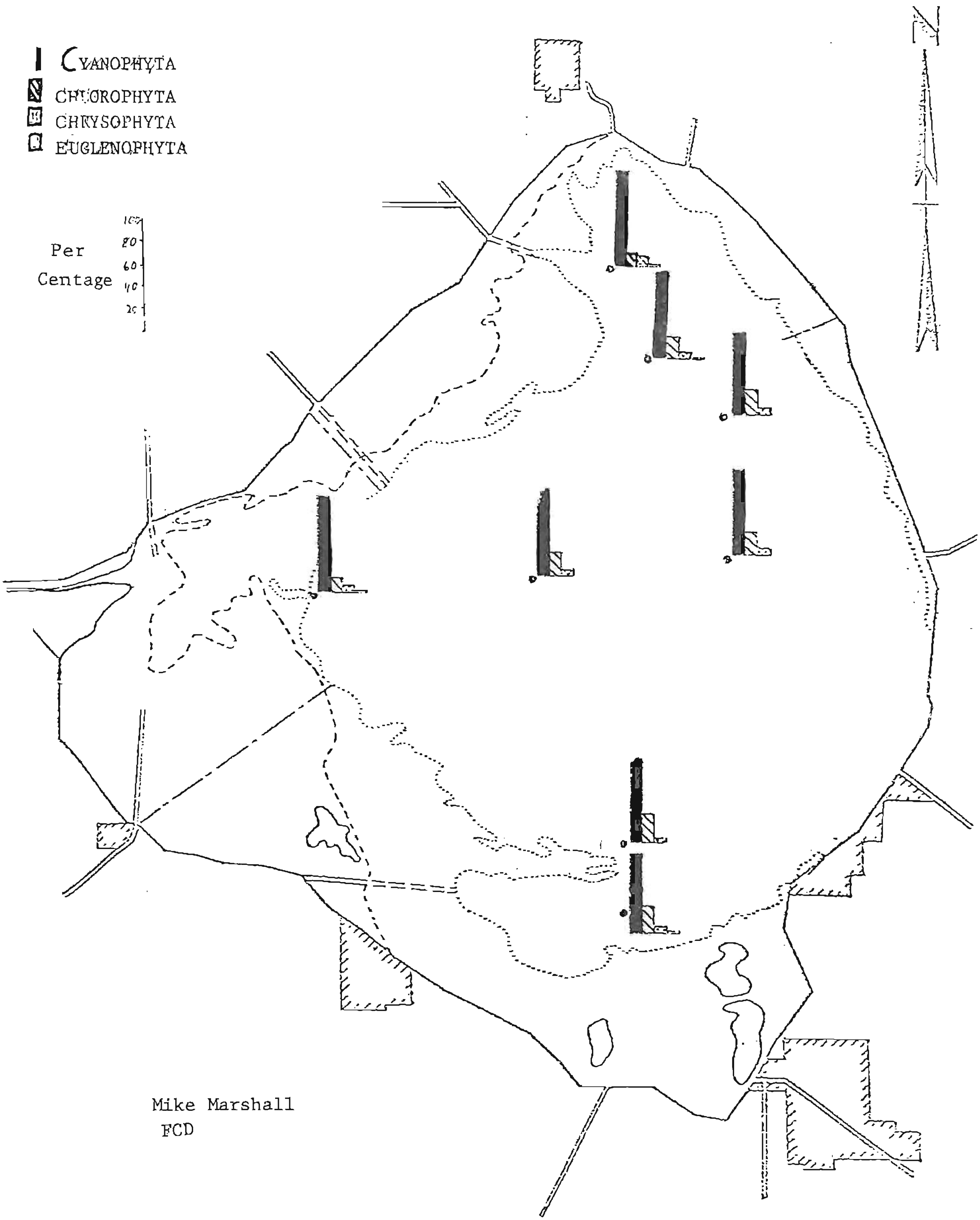


Fig. 7. Lake Okeechobee 1973 phytoplankton distribution.

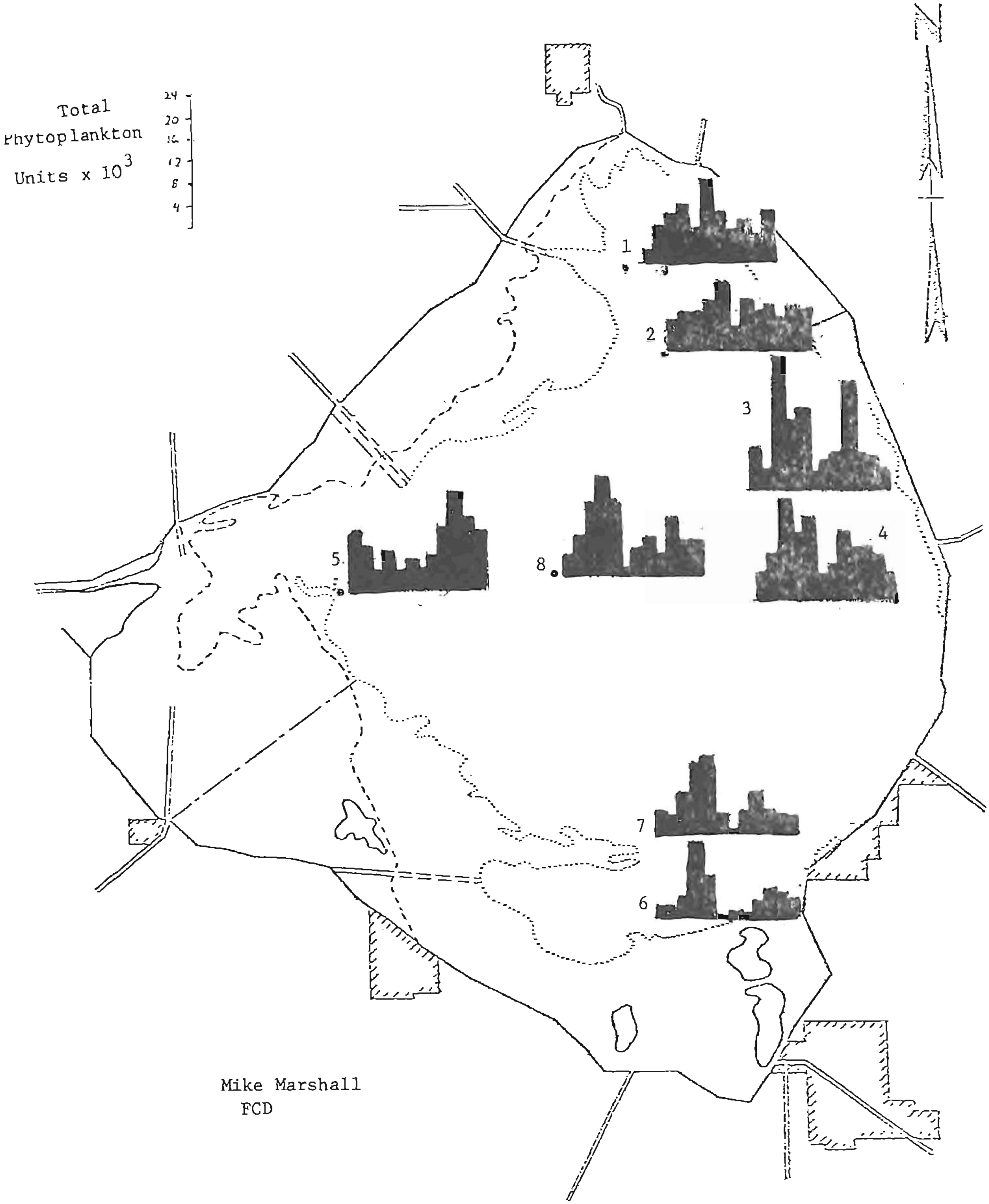


Fig. 8. Lake Okeechobee 1973 phytoplankton distribution.

Zooplankton Populations

Very little work has been done on the limnetic zooplankton populations on Lake Okeechobee. The author has analyzed a series of plankton tows collected by the FCD. Individuals were counted for an idea of relative zooplankton abundance. The results are shown in Table 5.

The zooplankton community is composed on the average of about 48% copepods, 29% protozoans, 22% rotifers, and 1% cladocerans and other organisms. The dominant copepods are Diaptomus sp. and the various nauplii; the dominant protozoans are several species of Difflugia and Ceratium; the dominant rotifers are Keratella sp. and Brachionus sp.; the dominant cladoceran is Daphnia. Copepods were most numerous during all sampling dates except during November when protozoans became the most numerous organism. Because the volume of lake water sampled is yet unknown, it is impossible to give an absolute value of zooplankton concentrations. Values relative to phytoplankton will be discussed in the section on marsh zooplankton. It should be noted that some of the genera observed are soft-water rotifers (Filinia and Polyarthra) in a hard water lake.

Table 5.

Zooplankton of Lake Okeechobee

		PROTOZOA		ROTIFERA						COPEPODS						CLADOCERANS				
		Difflugia		Keratella		Brach-ioa…		Filinia		Daptomus		Cyclops		Napulii		Daphnia		Misc		Total
Date	Site	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#
3/5/73	1	-	-	3	1.3	6	2.7	1	0.4	8	3.5	7	3.1	199	88.1	2	0.9	-	-	226
3/5/73	4	-	-	-	-	-	-	-	-	4	3.3	13	10.7	104	86.0	-	-	-	-	121
3/5/73	5	137	63.1	1	0.5	14	6.5	1	0.5	7	3.2	9	4.1	25	11.5	2	0.9	21	9.7	217
3/6/75	6	9	7.8	1	0.3	-	-	-	-	2	0.6	2	0.6	300	93.8	5	1.6	-	-	320
7/12/73	1	2	2.1	14	14.6	38	39.6	-	-	2	21	15	15.6	25	260	-	-	-	-	96
7/13/73	4	33	28.8	1	0.7	3	2.1	-	-	-	-	5	3.4	101	69.7	-	-	2	1.4	145
7/10/73	5	50	22.1	59	26.1	10	4.4	-	-	10	4.4	11	4.9	83	4.9	3	1.3	1	0.4	226
11/15/73	1	452	54.9	178	21.6	22	2.8	2	0.2	96	11.7	9	1.1	57	6.9	7	0.9	-	-	823
11/15/73	4	1091	88.7	75	6.1	-	-	-	-	3	0.2	18	1.5	43	3.5	-	-	-	-	1230
11/20/73	5	98	71.8	25	19.1	1	0.8	-	-	1	0.8	-	-	6	4.6	-	-	-	-	131
11/20/73	6	4	0.9	128	30.2	-	-	1	0.2	128	30.2	9	2.1	159	37.5	11	2.6	-	-	424
3/20/74	1	41	40.2	33	32.4	-	-	-	-	4	3.9	1	1.0	9	8.8	1	1.0	13	12.7	102
3/20/74	4	48	22.6	74	34.9	-	-	2	0.9	1	0.5	1	0.5	83	39.2	-	-	3	1.4	212
3/20/74	5	44	44.0	20	20.0	1	1.0	4	4.0	1	1.0	1	1.0	29	28.7	1	1.0	-	-	101
3/20/74	6	30	26.3	9	7.9	-	-	1	0.9	29	25.4	9	7.9	37	32.5	-	-	-	-	114
6/6/74	1	6	2.8	70	32.1	5	2.3	-	-	4	1.8	-	-	133	61.0	-	-	-	-	218
6/6/74	4	20	9.2	78	35.8	2	0.9	.3	1.3	-	-	-	-	115	52.7	-	-	-	-	218
6/7/74	5	77	33.9	74	32.6	7	3.1	1	0.4	-	-	-	-	68	29.9	-	-	-	-	227
6/7/74	6	-	-	30	30.6	-	-	-	-	41	41.8	-	-	27	27.6	-	-	-	-	98

Benthic Invertebrate Fauna

The pelagic benthic organisms reported by Joyner averaged about 1,800 organisms per square meter, ranging between 40 and 10,400 organisms per square meter at any station, and ranging between 664 and 3755 organisms per square meter at any sample date in his study. A later study by FCD shows about one-half (900 orgs/m^2) Joyner's value as a lake average. FCD values ranged between 50 and 2800 organisms per square meter at any station, and varied between 734 and 1102 organisms per square meter at any sampling date. Highly enriched lakes in central Florida support numbers ranging from thousands to tens of thousands per square meter. Numbers in excess of 10,000 per square meter are often indicative of organic pollution (Beck, 1970). Both studies indicate levels of benthic fauna well below the "polluted" level in the open-water zone.

Analysis of Joyner's data indicates a benthic community composition of 36 percent Gastropods, 34 percent Tubificids, and 25 percent Dipterans (mostly chironomids) with a few isopods and amphipods. Comparing this with FCD data, 3 percent Gastropods, 31 percent Tubificids, 21 percent Dipterans, 23 percent Pelecypods, and 18 percent amphipods and isopods. One may assume a rather large shift in populations and community structure between the two sampling dates. At least, there appears to be a noteworthy difference between the data collected in 1969 and that collected in 1973. Generally, the relative proportions of dipterans and tubificids have remained the same in both samples; the genera of dipterans common to both studies being: *Procladius*, *Chironomus*, *Tanytarsus*, and *Chaoborus*. The greatest change in population composition occurred in the pelecypod, gastropod, amphipod and isopod sectors of the community. Joyner's report large numbers of lymnaeid snails which were all but absent in the study a few years later, and the snails were replaced by large numbers of the asiatic clam, Corbicula. Corbicula were first found along the Okeechobee Waterway, at the Pahokee Marina, and at Port Mayaca in early 1970. It is apparent from the FCD study that Corbicula have invaded most of the lake in large numbers. Significant changes in amphipod and isopod populations have occurred with the greater proportion of invaders in estuarine or marine forms, specifically the appearance of Ampelisca, Corphium, and Sphaeroma in the latter study sample. Presence of Mysis throughout the lake is of significance because the only aquatic Mysis of North America inhabits deep, cold, oligotrophic lakes of the north (Pennak, p. 422). This habitat is certainly not a general condition in Lake Okeechobee.

In looking for hypothesis to explain these shifts in benthic fauna composition, the following facts are relevant. Steadily rising chlorinity and dissolved solids concentrations have been experienced in the lake for the past few decades (Brooks, 1974). This has been attributed to high evaporation rates, influx of high chlorinity water from ground water upseepage in channels and borrow pits in and around the lake, and increased backpumping of the highly mineralized water from the Agricultural Area south of the lake. The higher chlorinity and dissolved solids concentrations create a more suitable environment for marine forms. The presence of marine forms in the diatom, benthic and fish populations suggest a more haline environment. One must also take into account the abnormally wet period during the U.S.G.S. study, and the dryer conditions during the FCD study as well as different sampling locations.

Seasonal variations of benthic fauna populations in the pelagic zone are shown in Figure 9, which shows numbers of pelagic benthos rising in the late spring, peaking in the summer and early fall, then declining to a low in the early spring.

There is a section entitled "analysis of location" on the top right-hand corner of Tables 6 and 7 from which the map (Figure 10) of bottom type was compiled as well as from notes on navigational charts and from people sampling bottom fauna. During Joyner's study, benthic populations were more dense in muck areas than in areas of hard sand, however, data from FCD do not follow this trend.

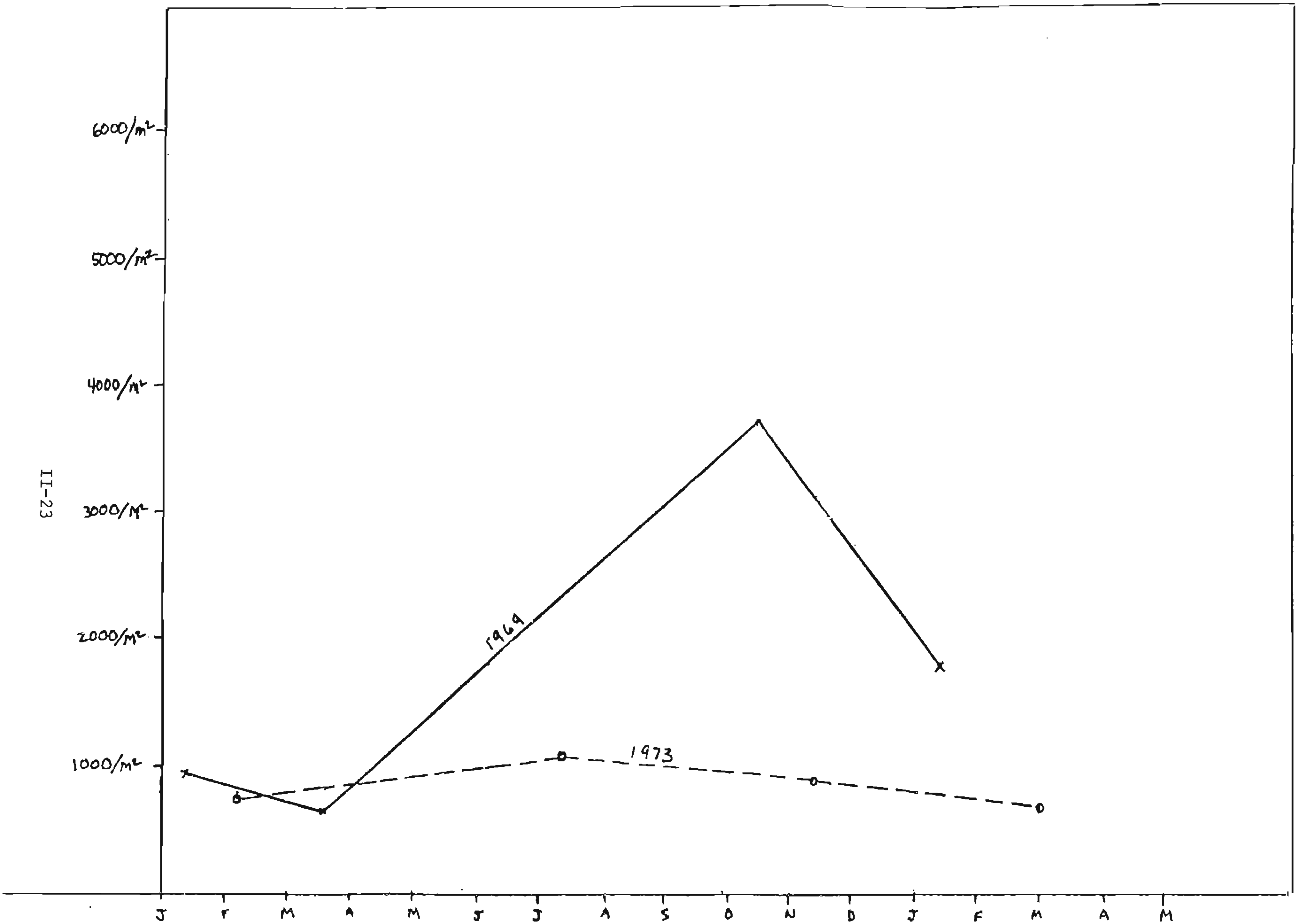


Fig. 9. Numbers of benthic fauna in Lake Okeechobee in 1969 and 1973 from Joyner (1974) and Davis and Marshall (1975), respectively.

Table 6 . Benthic Fauna Populations (1969-70)*

Organism	January, 1969							May, 1969						
Site:	1	5	6	8	9	11	15	1	5	6	8	9	11	15
Oligochaeta (Tubificidae)	387	129	43	43	43	129	924	21	65	108	86	21	43	926
Gammarus sp.	-	21	-	-	-	-	21	21	21	151	129	65	-	-
Cyathura polita	-	193	-	129	-	-	-	-	108	-	65	65	-	-
Cyclotanypus sp.	258	21	172	301	387	774	823	-	65	-	21	86	474	-
Procladius sp.	-	21	-	-	-	-	-	-	-	-	-	-	-	237
Chironomus crassicaudatus	-	-	-	-	666	-	-	-	-	-	-	-	-	-
Glytotendipes lobiferous	-	21	-	-	-	-	-	-	-	-	-	-	-	-
Glytotendipes paripes	-	-	-	-	43	-	-	-	-	-	-	-	-	-
Taneytarsus sp.	-	21	-	64	-	64	-	-	-	-	-	-	-	-
Chaoborus	-	-	21	-	-	-	21	-	-	-	-	-	-	-
Campeloma sp.	-	-	-	-	172	-	-	-	-	-	-	43	-	-
Bulimnidae (Lymaeidae)	-	-	-	-	-	817	-	-	-	-	-	-	1701	-
Taphromysis sp.	-	-	-	-	-	-	-	-	43	21	-	-	21	-
Unid. snail	-	-	-	-	-	-	-	-	-	-	-	-	-	43
Hyalella azteca	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cladotanytarsus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Polypedulum	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL	645	427	236	537	1311	1784	1789	43	302	280	301	280	2239	1206
Average	961 org/m^2							644 org/m^2						

*from Joyner, 1974

Table 6. (Continued) Benthic Fauna Populations

Organism	September, 1969							January, 1970						
Site:	1	5	6	8	9	11	15	1	5	6	8	9	11	15
Oligochaeta (Tubificidae)	3182	1354	43	236	1999	236	1569	150	430	709	838	344	193	172
Gammarus sp.	107	-	-	-	-	-	-	21	-	43	43	-	21	21
Cyathura polita	-	258	86	-	43	-	-	-	236	215	279	21	-	64
Cycltanypus sp.	43	129	236	215	344	301	365	193	21	258	473	258	1010	172
Procladius sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chironomus crassicaudatus	838	21	-	1859	1633	301	-	-	-	-	-	-	580	-
Glytotendipes lobiferous	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Glytotendipes paripes	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Taneytarsus sp.	-	387	64	-	-	-	-	-	-	-	-	-	-	-
Chaoborus	-	-	-	21	-	-	-	-	-	-	-	-	-	-
Campeloma sp.	21	-	-	-	21	-	-	64	-	-	-	21	21	43
Bulmnidae (Lymaeidae)	-	-	-	-	-	9524	1247	-	-	-	-	-	5525	64
Taphromysis sp.	-	-	-	-	-	-	-	-	21	-	-	-	-	-
Unid. snail	-	-	-	-	-	-	342	-	-	-	-	-	-	43
Hyalella azteca	21	-	-	-	-	-	-	-	-	-	-	-	-	-
Cladotanytarsus sp.	-	193	-	-	-	-	-	-	-	-	-	-	-	-
Polypedulum	-	43	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL	4212	2385	429	1231	4040	10362	3523	428	708	1225	1633	644	7350	579
Average	3755 org/m^2							1795 org/m^2						

Table 6. (Continued) Benthic Fauna Populations

Organism	Σ	$\overline{X}$(#/m²)	% of Total	Analysis of Location Site	Σ	$\overline{X}$ #/station-m²
Oligochaeta (Tubificidae)	18,680	667	34			
Gammarus sp.	685	24	1	1	5328	1332
Cyathura polita	1,762	63	3	5	3822	956
Cyclotanypus sp.	7,400	264	13	6	2170	543
Procladius sp.	258	9	**	8	3802	951
Chironomus crassicaudatus	5,898	211	11	9	6275	1569
Glytotendipes lobiferous	21	1	**	11	21735	5434***
Glytotendipes paripes	43	2	**	15	7097	1774
Taneytarsus sp.	600	21	1			
Chaoborus	63	2	**	Grand Mean (#/m²)		
Campeloma sp.	406	15	1	1794 org/m²		
Bulimidae (Lymaeidae)	18,878	674	34	17 taxa		
Taphromysis sp.	106	4	**			
Unid. snail	428	15	1			
Hyalella azteca	21	1	**			
Cladotanytarsus sp.	193	7	**			
Polypedulum	43	2	**			
TOTAL		$\Sigma\overline{X}$ =1981				

Table 7.
Pelagic Benthic Fauna (1973-1974)*

Date Sampled	2/73									7/73								
Site Sampled	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
Tubificidae	8	-	9	11	7	1	-	27	14	65	6	32	22	101	50	3	49	24
Gammarus faciatus	-	1	10	6	-	-	2	-	1	1	-	4	2	-		131	1	12
Ampelisca tenuicornus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Corophium lacustre	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cyathura polita	20	1	1	-	27	1	-	5	2	3	-	-	-	10	-	15	-	8
Sphaeroma terebrans	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Pentaneurini sp.	24	3	18	36	63	10	2	20	22	7	2	25	18	5	4	1	7	16
Chironomus (Chronomus) sp.	-	-	79	2	-	-	-	-	-	2	-	-	9	-	-	-	-	-
Tanytarsus sp.	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-
Chaoborus punctipennis	-	-	-	1	-	-	-	1	1	-	-	-	-	3	-	-	-	1
Procladius sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-
Corbicula leanus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Corbicula fluminea	-	-	1	-	-	1	37	-	134	-	-	10	-	-	1	106	-	140
Elliptio sp.	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-
Pleuroncera sp.	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-
Viviparus sp.	-	-	-	-	-	-	-	2	-	-	-	5	-	-	-	-	-	-
Mysis sp.	-	-	-	-	-	1	-	-	-	2	-	5	2	-	1	-	1	-
	52	5	118	56	97	14	46	57	174	80	8	81	53	122	56	256	58	201
$\bar{X}$	59 org/ft^2									102 org/ft^2								
$\bar{X}$	745 orgs/m^2									1102 org/m^2								

Table 7. (cont'd)
Pelagic Benthic Fauna (1973-1974)*

Date Sampled	11/73									3/74								
Site Sampled	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
Tubificidae	45	8	44	46	45	-	4	104	12	32	-	22	23	32	1	1	53	-
Gammarus faciatus	1	1	5	2	1	2	7	-	1	-	1	-	2	2	4	7	4	-
Ampelisca tenuicornus	-	-	-	-	-	28	-	-	-	-	-	-	-	-	-	-	-	-
Corophium lacustre	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	-	-	-
Cyathura polita	1	-	-	-	12	2	33	-	-	5	1	3	-	9	2	16	-	-
Sphaeroma terebrans	-	-	-	-	-	21	-	-	-	-	-	-	-	-	31	-	-	-
Pentaneurini sp.	15	5	42	31	5	1	-	18	-	13	5	27	35	36	-	-	23	-
Chironomus (*Chronomus*) sp.	1	-	-	-	1	-	1	1	1	-	-	-	-	-	-	-	-	-
Tanytarsus sp.	-	-	-	-	-	-	-	-	-	3	1	-	-	1	-	-	-	-
Chaoborus punctipennis	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Procladius sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Corbicula leanus	-	-	-	-	-	2	45	-	75	-	-	-	-	-	-	80	-	-
Corbicula fluminea	-	1	6	-	-	-	-	-	-	-	1	10	-	-	15	-	-	-
Elliptio sp.	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-
Pleuroncera sp.	-	-	-	-	-	51	-	-	-	-	-	-	-	-	-	-	21	-
Viviparus sp.	3	-	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Mysis sp.	9	2	3	1	-	-	-	5	-	2	1	2	2	1	-	-	3	-
	75	17	101	80	64	108	91	128	89	55	10	65	62	83	62	104	104	
$\bar{X}$	84 org/ft^2									68 org/ft^2								
$\bar{X}$	907 orgs/m^2									734 orgs/m^2								

Table 7. (cont'd)
Pelagic Benthic Fauna (1973-1974)*

Analysis of TAXA

		$\bar{X}$ taxon/ft^2	(#/m^2)	% of total***
Tubificidae	901	26 mg/ft^2	279	31%
Gammarus faciatus	211	6	65	7%
Ampelisca tenuicornus	28	1	9	1%
Corophium lacustre	9	*	3	**
Cyathura polita	225	6	70	8%
Sphaeroma terebrans	53	2	16	2%
Pentaneurini sp.	523	15	162	18%
Chironomus (Chronomus) sp.	96	3	30	3%
Tanytarsus sp.	8	*	2	**
Chaoborus punctipennis	8	*	2	**
Procladius sp.	4	*	1	**
Corbicula leanus Corbicula fluminea	665	19	206	23%
Elliptio sp.	4	*	1	**
Pleuroncera sp.	74	2	23	3%
Viviparus sp.	12	*	4	**
Mysis sp.	43	1	13	1%

Analysis of LOCATION

Site	X, #/ft^2	(#/m^2)
1	66	713
2	10	108
3	91	983
4	63	680
5	92	994
6	60	648
7	124	1339
8	87	940
9	155	1674

$\bar{\bar{X}}$ (Grand Mean) = 81 org/ft^2 = (872 orgs/m^2)

* less than 1 org/ft^2

** taxa not given total 1% of #'s

*** 886 is total by this calculation and is used for calculating % composition

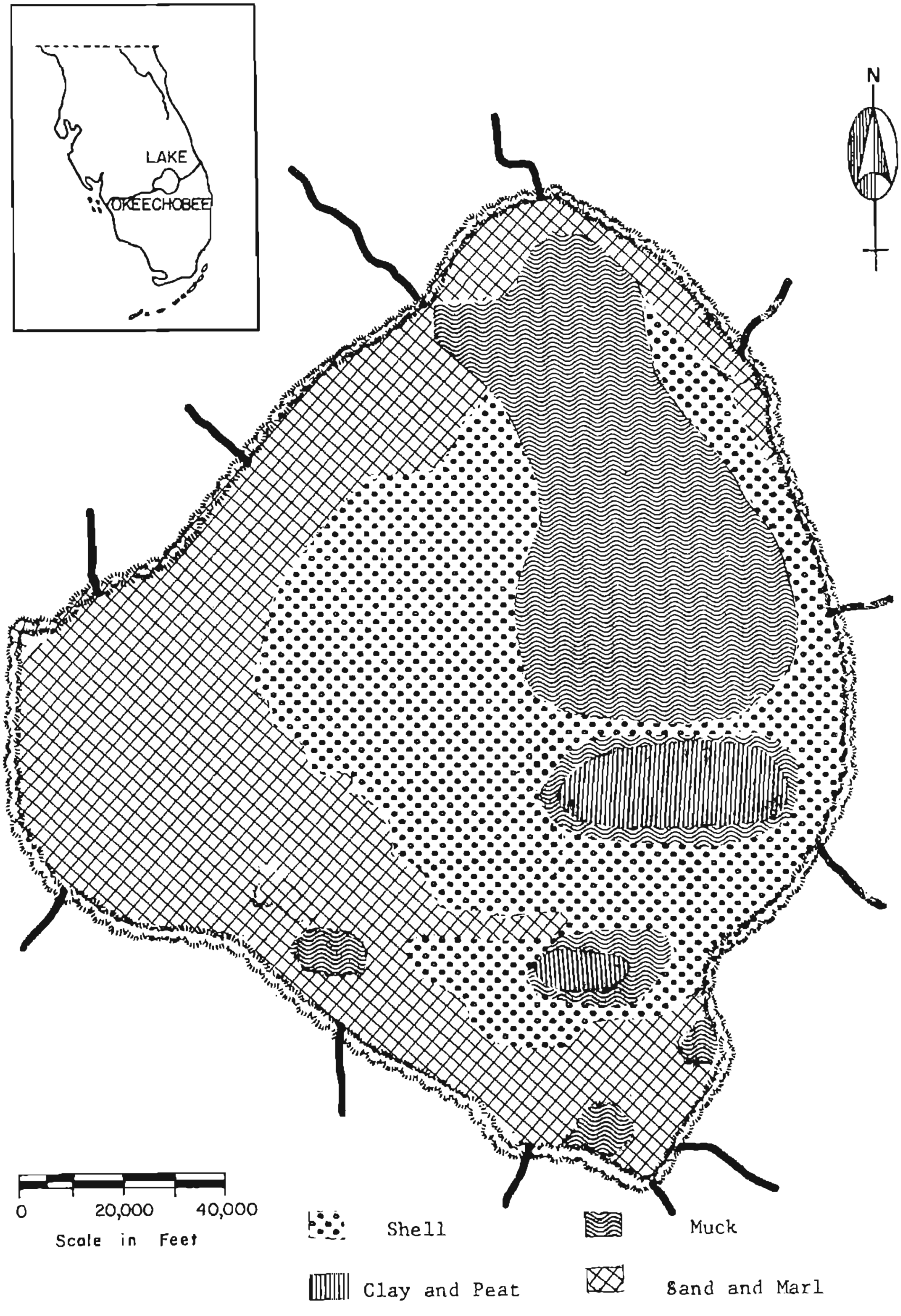


Figure 10. Bottom Types in Lake Okeechobee.

Vertebrate Populations

Since there have been very few samples of population of pelagic vertebrates in Lake Okeechobee; an accurate analysis of fish population composition and dynamics is not possible. As far as known only one direct investigation has been made of the population of pelagic vertebrates in Lake Okeechobee. Lothian Ager (1973) obtained, by block netting and rotenon in a four acre sampling station, samples of fish typical of the open water populations.

Ager reports that approximately 92 percent of the biomass of the dominant pelagic fish in Lake Okeechobee is composed by the following species: gizzard shad, threadfin shad, catfish, bullheads, garfish and black crappie. Shad comprises 41 percent of the fish biomass and gars comprise 22 percent. Other fish in order of their biomass contribution are: black crappie, 15 percent; catfish and bullheads, 14 percent shellcracker, 3 percent; sunfish, 3 percent; needle fish, 2 percent; bass, 1 percent; bowfin pickerel, less than 1 percent. The estimated yield in the four acre sampling station was 400 pounds of fish. This value is conservative as Ager estimated only 10 percent of the biomass of rotenoned fish were recovered and weighed.

Table 8.

Fresh Water Fishes Collected from Lake Okeechobee, Florida.

Amia calva	1. Bowfin	Canals & vegetated areas
Lepisosteus platyrhincus	2. Florida gar	Lakewide
Lepisosteus osseus	3. Longnose gar	Pelagic
Dorosoma cepedianum	4. Gizzard shad	Pelagic
Dorosoma petenense	5. Threadfin shad	Pelagic
Esox niger	6. Chain pickerel	Submergent veg.
Esox americanus	7. Redfin pickerel	Emergent veg. (shallow waters)
Erimyzon succetta	8. Lake chubsucker	Lakewide
Notemigonus crysoleucas	9. Golden shiner	Canals & vegetated areas
Notropis maculatus	10. Taillight shiner	Submergent veg.
Ictalurus catus	11. White catfish	Pelagic
Ictalurus punctatus	12. Channel catfish	Pelagic
Ictalurus natalis	13. Yellow bullhead	Canals
Ictalurus nebulosus	14. Brown bullhead	Canals & vegetated areas
Noturus gyrinus	15. Tadpole madtom	Pelagic
Anguilla rostrata	16. American eel	Pelagic
Jordanella floridae	17. Flagfish	Emergent veg. (shallow
Cyprinodon variegatus	18. Sheephead minnow	Emergent veg. water)
Lucania goodei	19. Bluefin killifish	Emergent & submergent veg.
Fundulus seminolis	20. Seminole killifish	Submergent veg.
Fundulus chrysotus	21. Golden topminnow	Emergent veg. (shallow waters)
Mollienisia latipinna	22. Sailfin molly	Canals & vegetated areas
Gambusia affinis	23. Mosquito fish	Canals & vegetated areas
Heterandria formosa	24. Least killifish	Canals & vegetated areas
Menidia beryllina	25. Tidewater silversides	Submergent veg.
Labidesthes sicculus	26. Brook silversides	Submergent veg.

from (Ager, 1968, 1969)

Table 8. (Cont.)

Fresh Water Fishes Collected from Lake Okeechobee, Florida

Micropterus salmoides	27.	Largemouth bass	Canals & vegetated areas
Pomoxis nigromaculatus	28.	Black crappie	Pelagic
Enneacanthus gloriosus	29.	Bluespotted sunfish	Submergent veg.
Chaenobryttus coronarius	30.	Warmouth	Submergent veg.
Lepomis marginatus	31.	Dollar sunfish	Emergent veg.
Lepomis punctatus	32.	Spotted sunfish	Canals & veg. areas
Lepomis macrochirus	33.	Bluegill	Lakewide
Lepomis microlophus	34.	Redear sunfish	Lakewide
Etheostoma barratti	35.	Scalyhead darter	Canals & emergent veg.

From Ager 1968 and 1969.

Table 9.

Marine or Brackish Water Fishes Collected From Lake Okeechobee, Florida

Strongylura marina	36. Atlantic Needlefish	Emergent veg.
Mugil cephalus	37. Striped mullet	Lakewide
Microgobius gulosus	38. Clown goby	Submergent veg. (shallow water)
Trinectes maculatus	39. Hogchocker	Pelagic
Centropomus undecimalis	40. Snook	Canals & channels
Elops saurus	41. Ladyfish	Pelagic
Megalops atlantica	42. Tarpon	Pelagic

Additional Fishes Reported by Other Investigations to be Present in Lake Okeechobee

Anchoa sp.	Anchovy
Notropis chalybaeus	Ironcolor shiner
Notropis petersoni	Coastal shiner
Aphredoderus sayanus	Pirate perch

The Marsh Community

Littoral Zone

There are several plant communities in Lake Okeechobee's extensive marsh and littoral zone; marsh-woody plants, pasture, Spikerush, white water lily pond, cattail, bulrush and submergent vegetation. The total vegetation acreage is estimated to be 75,867 acres (Ager, 1973). In addition, the Fish and Game Commission conducted extensive plant surveys in 1956, the results of which are combined with a more recent study by them. The FCD under direction of Walter Dineen is presently conducting a study of Okeechobee's rooted plant communities. This survey includes extensive mapping of the vegetation and soils done to the present. This survey should result in an accurate assessment of plant communities around the lake.

The following is the result of vegetation surveys made by the Florida Game and Fish Commission around the lake. Figure 12 shows the location and expanse of each major plant community (Ager & Kerce, 1974). For convenience the community is named by the dominant species.

Bulrush zone: Bulrush, Scirpus californicus, is the dominant emergent species with some scattered peppergrass, Potamogeton illinoensis, and Southern naiad, Najas guadalupensis, Chara sp., Nitella sp. and coontail, Ceratophyllum sp. as submerged aquatics. Another bulrush Scirpus americanus, or three square, is growing in dry or shallow shore areas of sandy bottom habitat.

Cattail zone: Two species of cattail and possibly a hybrid make up a large part of this marsh. Typha angustifolia is the most abundant species followed by Typha latifolia. A large part of the cattail band reproduces vegetatively, has not been observed to flower and could be a hybrid between the two identified cattails. Growing submerged with the cattail are a number of aquatics: Southern naiad, Najas guadalupensis, bladderwort, Utricularia sp., and emergents: white water lily, Nymphaea odorata, yellow water lily, Nymphaea mexicana, cow lily, Nuphar macrophyllum, lotus, Nelumbo lutea, horse grass, Hydrochloa caroliniensis, torpedo grass, Panicum repens, salvinia, Salvinia rotundifolia, duckweed, Lemna sp., blue flag, Pontederia cordata, arrowhead, Sagittaria falcata and S. Latifolia.

Grass and herb zone: This shallow portion of lake marsh supports a varied mixture of plants due to the effects of water level fluctuation and cattle grazing. Grasses, torpedo grass, Panicum repens and horse grass, Hydrochloa caroliniensis are the dominant species. The area is dotted with clumps of switch grass, Spartina bakeri and small stands of buttonbush, Cephalanthus occidentalis. Lower elevations of the marsh or ponds are comprised of arrowhead, Sagittaria falcata, needlegrass, Eleocharis equisetoides, E. cellulosa, blue flag, Pontedaria cordata, white water lily, Nymphaea odorata and cow lily, Nuphar macrophyllum. Lotus, Nelumbo lutea, is also scattered in pond locations.

Needlegrass zone: Needlegrass, Fuirena squarrosa, F. pumila, Eleocharus cellulosa and bladderwort, Utricularia vulgaris are plants that dominate this area lying between the cattail and grass and herb zone.

Potamogeton zone: Peppergrass, Potamogeton illinoensis, grows heavily in this zone with large patches of Southern naiad, Najas guadalupensis, coontail, Ceratophyllum sp., eelgrass, Vallisneria americana, Nitella sp., Chara sp., maidencane, Panicum hemitomon, torpedo grass, P. repens, maidencane, P. geminatum, cattail, Typha sp., and bulrush, Scirpus californicus.

Salix zone: Willow, Salix caroliniana grows on higher elevations in the lake marsh and around island edges. There are no large stands of willow, possibly due to water level fluctuation; however, the Flood Control District (personal communication, 1975) states that there are some willow stands that can be measured in square miles. A vine, climbing hempweed, Mikania scandens, climbs freely on the willow branches.

Agricultural zone: All the larger islands in the lake have been farmed in the past or are now under cultivation. This accounts for a larger plant variety than under natural conditions. Observation Island is a large sandy ridge covered with strangler fig, Ficus aurea, Ficus sp., guava, Psidium guajava and edged with wax myrtle, Myrica cerifera and willow, Salix caroliniana. A few cypress, Taxodium sp. are growing along the edges of the island.

Kreamer Island has lain fallow since 1969 (FCD, 1975). Torry Island is presently being cultivated, in part, and both islands have had many cultivated or exotic plants released on them. Many species of native grasses are abundant along with coconut, Cocos nucifera, royal palm, Roystonea regia, cabbage palm, Sabal palmetto, castor bean, Ricinus communis, sour orange, Citrus aurantium, custard apple, Annona glabra and guava, Psidium guajava. Large portions of the rim canal adjacent to the levee are planted with Australian pine, Casuarina equisetifolia, melaleuca, Melaleuca leucandendra and bamboo which have proliferated into areas of the lake that are dry most of the year. In these same areas, wax myrtle, Myrica cerifera and sea myrtle, Baccharis glomeruliflora are very abundant. Elephant ear or Colocasia sp. is very common on the canal spoil area near Belle Glade.

The total estimate of vegetation acreage was 75,867 acres. Communities of woody plants and pasture comprised an estimated 7,587 acres and occupied a portion of the contours above 13.8 feet mean sea level.

Spikerush, the most extensive community, comprised an estimated 28,115 acres between the 11.8 and 13.8 contours. Several other species occurred within these same contours. Chara, sawgrass, umbrella grass, horse grass, panic grass, pickerelweed, and arrowhead were the more common ones.

White water lily ponds comprised an estimated 4,016 acres and occurred throughout the marsh occupying depressions in the spikerush and cattail communities. The bottom substrate was composed of about six or more inches of organic sediment. Bladderwort was sometimes abundant along with the water lily.

The cattail community occupied a good percentage of the littoral area and comprised an estimated 12,049 acres between the 10.8 and 13.3 contours. Cattail was usually the dominant vegetation between the 11.3 and 11.8 contours. The bottom substrate consisted of about six inches of organic sediment. Isolated cattail communities occurred throughout the spikerush habitat in slight depressions. Evidently depth determines the difference between the cattail and white water lily communities with cattail occupying the shallower depressions.

The bulrush community occupied a relatively narrow band between submergent vegetation or open water and the cattail community and comprised an estimated 8,033 acres. Bulrush occurred between the 10.8 and the 12.3 contours and was usually the dominant vegetation between the 10.8 and 11.3 contours. In much of this community submergent vegetation also occurred.

The submergent community comprised an estimated 16,066 acres. Peppergrass and eelgrass were the dominant species. Some southern naiad and Hydrilla were present, but did not dominate any area. Both peppergrass and eelgrass grew, mostly in combination, between the 6.8 and 11.8 contours and were more dense in the middle range of these contours. Chara occurred in large expanses in areas of rocky substrate throughout these same contours.

Table 10, following the map, lists species of pteridophytes and vascular plants found in Lake Okeechobee. Over 150 species of higher plants have been identified within the dikes of the lake.

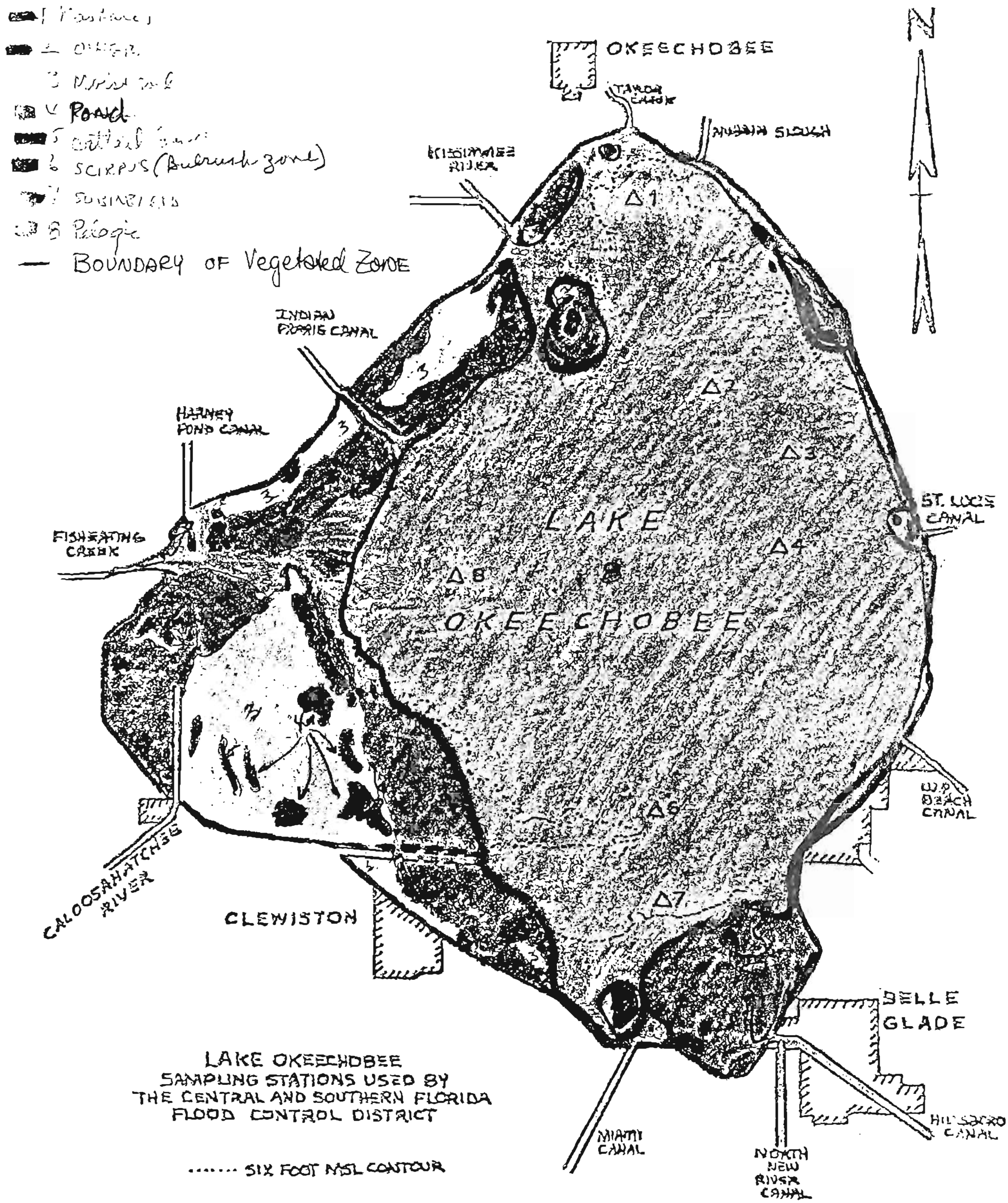


Fig. 12. Major communities in Lake Okeechobee. Redrawn from Ager, 1974.

Table 10

Lake Okeechobee Plants *

Osmunda cinnamomea L.	Cinnamon fern
Osmunda regalis L.	Royal fern
Pteridium aquilinum (L.) Kuhn	Bracken fern
Polypodium polypodioides (L.) Watt	Resurrection fern
Azolla caroliniana Willd.	Mosquito fern
Salvinia rotundifolia Willd.	Water fern
Taxodium distichum (L.) Richard	Bald cypress
Taxodium ascendens Brongn.	Pond cypress
Typha latifolia L.	Common cattail
Typha angustifolia L.	Narrow leaved cattail
Potamogeton illinoensis Morong	Peppergrass
Najas guadalupensis (Sprengel) Magnus	Southern haiad
Sagittaria subulata (L.) Buch.	
Sagittaria lancifolia L.	Arrowhead
Sagittaria falcata Pursh	Arrowhead
Sagittaria latifolia Willd.	Duck Potato

* from Ager, 1974

Table 10(Cont.)

Hydrilla verticillata (L.F.) Royle	Elodea
Valisneria americana Michaux	Eelgrass
Limnobium spongia (Bosc) Steudel	Frog's bit
Phragmites communis Trinius	Giant reed
Eragrostis elliotii S. Wats.	Love grass
Eriochloa michauxii (Poir.) Hitchcock	
Sporobolus poiretti (R. & S.) Hitchcock	Smutgrass
Dactyloctenium aegyptium (L.) Beauvois	Crowfoot grass
Eleusine indica (L.) Gaertner	Goose grass
Cynodon dactylon (L.) Persoon	Bermuda grass
Spartina bakeri Merr.	Switchgrass
Chloris petraea Swartz	Fingergrass
Hydrochloa caroliniensis Beauvois	Horsegrass
Manisuris rugosa (Nutt.) Kuntze	Jointgrass
Setaria magna Grisebach	Giant foxtail
Setaria geniculata (Lam.)	Knotroot foxtail
Pennisetum setosum (Swartz) L. Rich	
Cenchrus incertus M. A. Curtis	Coast sandspur
Cenchrus pauciflorus Bentham	Field sandspur
Echinochloa colonum (L.) Link	Jungle rice
Echinocloa walteri (Pursh) Heller	Wild millet
Rhynchelytrum repens (Willd.) Hubb	Natal grass
Paspalum fluitans (Ell.) Kunth	Water paspalum
Paspalum dissectum (L.) L.	
Paspalum vaginatum Swartz	
Paspalum distichum L.	Knotgrass

Paspalum notatum Flugge	Bahia grass
Paspalum urvillei Steud.	Vasey grass
Digitaria filiformis (L.) Koel.	Slender crabgrass
Axonopus furcatus (Flugge) Hitchc.	Carpet grass
Reimarochloa oligostachya (Munro) Hitchc.	
Panicum purpurascens Raddi	Para grass
Panicum bartowense Scribn. & Merr.	
Panicum repens L.	Torpedo grass
Panicum hemitomon Schult	Maidencane
Panicum geminatum Forsk.	Maidencane
Sacciolepsis striata (L.) Nash	
Andropogon virginicus L.	Broomsedge
Sorghum halepense (L.) Persoon	Johnson grass
Cyperus polystachyos Rottb.	Sedge
Cyperus articulatus L.	Bulrush sedge
Cyperus rotundus L.	Sedge
Cyperus compressus L.	Sedge
Cyperus iria L.	Sedge
Cyperus lecontei Torrey	Sedge
Cyperus distinctus Steudel	Sedge
Cyperus pseudovegetus Steudel	Sedge
Cyperus strigosus L.	Sedge
Cyperus globulosus Aublet	Sedge
Cyperus ligularis L.	Sedge
Cyperus pollardii Britt.	Sedge
Eleocharis equisetoides (Ell.) Torrey	Jointed spikerush
Eleocharis cellulosa Torrey	Needlegrass

Eleocharis robinsii Oakes	Triangle spikerush
Eleocharis flavescens (Poir.) Urban	Needlegrass
Eleocharis acicularis (L.) R. & S.	Maidenhair
Eleocharis intermedia (Muhl.) Schultes	Dwarf spikerush
Dichromena colorata (L.) Hitch.	Whitetop sedge
Psilocarya nitens (Vahl) Wood	Bald rush
Fimbristylis spadicea (L.) Vahl	
Fimbristylis autumnalis (L.) R. & S.	
Scirpus americanus Persoon	Three square
Scirpus validus Vahl	Bulrush
Scirpus californicus (Meyer) Steud	Bulrush
Scirpus cubensis Poepp. & Kunth	Cyperus bulrush
Fuirena squarrosa Michaux	Umbrella grass
Fuirena pumila Torrey	Umbrella grass
Rhynchospora tracyi Britton	Beak rush
Rhynchospora caduca Ell.	Beak rush
Rhynchospora schoenoides (Ell.) Wood	Beak rush
Cladium jamaicense Crantz	Sawgrass
Scleria reticularis Michaux	Nut-rush
Cocos nucifera L.	Coconut
Serenoa repens (Bartram) Small	Saw palmetto
Sabal palmetto Lodd ex Schultes	Cabbage palm
Peltandra virgenica (L.) Kunth	Green arum
Pistia stratiotes L.	Water lettuce
Lemna minor L.	Duckweed
Wolffia columbiana Karsten	Watermeal

Table 10 (cont.)

Xyris ambiqua Beyr. ex Kunth	Yellow-eyed grass
Tillandsia usneoides (L.) L.	Spanish moss
Eichornia crassipes (Mart.) Solms in DC	Water hyacinth
Pontederia cordata L.	Pickerelweed
Juncus effusus L.	Soft rush
Juncus biflorus Ell.	Juncus
Juncus canadensis J. Gay ex Laharpe	Juncus
Juncus scirpoides Lam.	Juncus
Canna flaccida Salisb.	Canna lily
Thalia geniculata L.	Arrowroot
Saururus cernuus L.	Lizard's tail
Casuarina equisetifolia Forst.	Australian pine
Salix caroliniana Michaux	Swamp willow
Myrica cerifera L.	Wax myrtle
Quercus durandii Buckley	Durand's white oak

Table 10 (cont)

Celtis laevigata Willd.	Hackberry
Rumex verticillatus L.	Swamp dock
Polygonum densiflorum Meissner	Smartweed
Polygonum hydropiperoides Michaux	Smartweed
Alternanthera philoxeroides Mart.	Alligator-weed
Amaranthus spinosus L.	Pigweed
Amaranthus cannabinus (L.) J. D. Sauer	Water hemp
Rivina humilis L.	Baby peppers
Phytolacca americana L.	Poke weed
Portulaca pilosa L.	
Portulaca oleracea L.	
Ceratophyllum demersum L.	Coontail
Nuphar macrophyllum (Small) E. O. Beal	Cow lily
Nymphaea odorata Aiton	White water lily
Nymphaea mexicana Zucc.	Yellow water lily
Nelumbo lutea (Willd.) Persoon	Pond nuts, lotus
Annona glabra L.	Custard apple
Lepidium virginicum L.	Poor man's pepper

Rubus trivialis Michaux	Dewberry
Cassia obtusifolia L.	Sicklepod
Cassia occidentalis L.	Coffee senna
Crotalaria spectabilis Roth	Rattlebox
Crotalaria micronata Desvaux	Rattlebox
Melilotus alba Desr.	White sweet clover
Desmodium tortuosum (Swartz) DC	Beggarticks
Alysicarpus rugosus (Willd.) DC	False moneywort
Sesbania macrocarpa Muhl.	Sesbania
Sesbania vesicaria (Jacquin) Ell.	Bladderpod
Vigna luteola (Jacquin) Bentham	Wild pea
Oxalis violaceae L.	Violet wood sorrel
Oxalis corniculata L.	Creeping sorrel
Melia azedarach L.	Chinaberry
Ricinus communis L.	Castor bean
Euphorbia heterophylla L.	Painted-leaf
Rhus radicans L.	Poison ivy
Acer floridanum (Chapman) Desmarais	Southern sugar maple
Parthenocissum quinquefolia (L.) Planchon	Virginia Creeper

Table 10 (cont.)

Melaleuca leucadendra L.	Melaleuca
Abutilon theophrastii Medicus	Velvet leaf
Urena lobata L.	Hibiscus
Sida rubromarginata Nash	
Hibiscus militaris Cav.	Marsh mallow
Hibiscus grandiflorus Michaux	Rose-mallow
Carica papaya L.	Papaya
Ludwigia bonariensis (Micheli) Hara	Primrose willow
Ludwigia peruviana L.	Water primrose
Ludwigia palustris (L.) Ell.	
Hydrocotyl umbellata L.	Marsh pennywort
Hydrocotyl bonariensis Lam.	Pennywort
Centella asiatica (L.) Urban	Centella
Ammi majus L.	Bishop's weed
Vinca rosea L.	Periwinkle
Ipomoea bona-nox L.	Moonvine
Verbena hastata L.	Verbena
Lippia nodiflora (L.) Michaux	Matchstick
Lantana camara L.	Lantana

Teucrium canadense L.	Germander
Hyptis alata (Raf.) Shinners	
Physalis angulata L.	Ground cherry
Solanum americanum Miller	Nightshade
Bacopa monnieri (L.) Pennell	Bacopa
Bacopa caroliniana (Walter) Robinson	Bacopa
Lindernia grandiflora (Nutt.) Benth.	False pimpernel
Utricularia cornuta Michaux	Bladderwort
Utricularia purpurea Walter	Bladderwort
Utricularia inflata var. minor (L.) Chapman	Bladderwort
Utricularia vulgaris L.	Bladderwort
Cephalanthus occidentalis L.	Buttonbush
Diodia virginiana L.	Buttonweed
Sambucus simpsonii Rehder	Elderberry
Melothria crassifolia Small	Creeping cucumber
Momordica charantia L.	Wild balsam apple
Cucumis anguria L.	Gooseberry gourd
Ambrosia artemisiifolia L.	Ragweed
Senecio glabellus	Butterweed

Table 10 (Cont.)

Eupatorium capillifolium (Lam.) Small	Dog fennel
Eupatorium aromaticum L.	Wild hoar-hound
Eupatorium coelestinum L.	Mist flower
Mikania scandens (L.) Willd.	Climbing hempweed
Baccharis glomeruliflora Persoon	Groundsel tree
Erigeron strigosus Muhl. ex Willd.	Daisy fleabane
Solidago petiolaris Aiton	Goldenrod
Eclipta alba (L.) Hasskarl	
Helianthus angustifolia L.	Marsh sunflower
Coreopsis lanceolata L.	Tickweeds
Bidens bipinnata L.	Beggar ticks
Bidens nashii Small	Beggar ticks

From Ager, 1974.

Marsh Phytoplankton Populations

Ager (1974) determined annual phytoplankton concentrations for several marsh zones as shown in Figure 13. Highest phytoplankton concentrations in the pond zone were 1,686 cells per milliliter, and the annual average was 706 cells per milliliter. Eelgrass communities averaged 506 plankton per milliliter annually, bulrush averaged 470 plankton per milliliter, and spikerush and peppergrass averaged 422 and 317 plankton per milliliter annually, respectively. The densest population of phytoplankton was 1,740 plankton per milliliter in the spring sample of the pond. However, considering the lake averages, 8,000 to 26,000 cells per milliliter, the amount of phytoplankton in the marsh water is small indeed. The average of all phytoplankton in the marsh, 484 cells per milliliter, is between 17 to 50 times more dilute than the lake average. The pond zone and eelgrass communities usually have very clear water and little shading action inducing more phytoplankton growth.

The community composition of the marsh phytoplankton is predominated by diatoms (63%), followed by blue-green algae (21%) and green algae (16%). This is considerably different from pelagic phytoplankton population which are predominantly (76%) blue-green. The composition of plankton in the bulrush zone is more typical of pelagic plankton composition, probably due to its proximity to the pelagic area.

Note: The values above each column are numbers of zooplankton per milliliter.

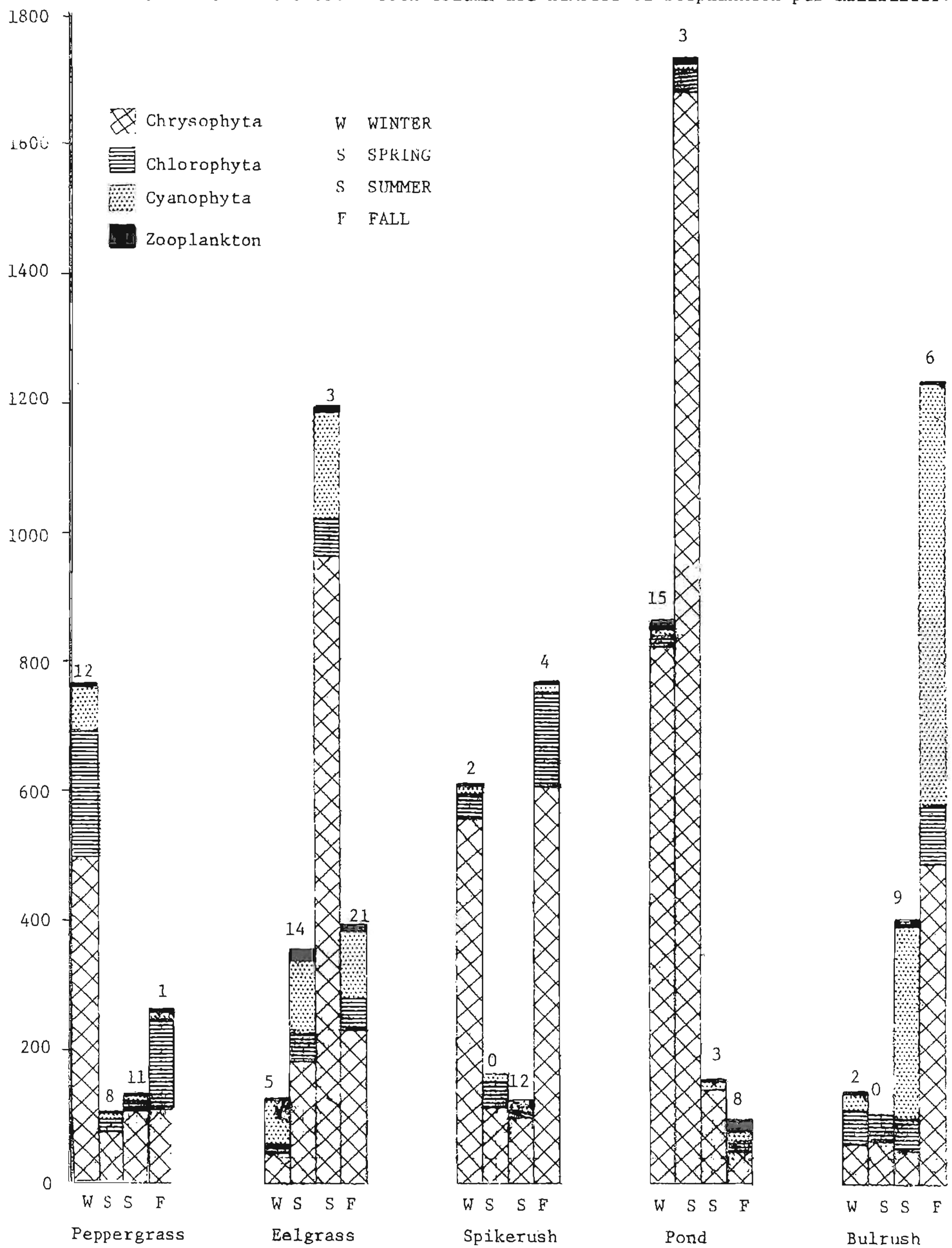


Fig. 13. Littoral plankton populations. From Ager, 1974.

Marsh Zooplankton

Ager (1974) shows marsh zooplankton counts that are very low and never exceed 21 counts per milliliter. No data are available on pelagic zooplankton densities and it is impossible to say exactly how low the marsh counts are. However, an average estimate (Nordlie, F. G., personal communication, 1975) of zooplankton biomass of 1.3 gC/m^2 is reasonable for Lake Okeechobee pelagic areas. This value certainly infers much higher counts than 21 counts per milliliter.

No clear pattern of distribution within the marsh is noticed, however it is apparent that the higher numbers of phytoplankters are associated with higher numbers of zooplankton.

Marsh Benthic Fauna

Ager, of the Game and Fresh Water Fish Commission, conducted a study of the benthic fauna in the various plant communities around Lake Okeechobee from early 1969 to late 1971, and results are shown in Table 11.

Samples of benthic fauna were analyzed from five plant communities: bulrush, eelgrass, peppergrass, spikerush and white water lily. Peppergrass averaged the highest density of invertebrates, with 4,215 per square meter, followed by spikerush with 3,577, bulrush with 2,828, eelgrass with 2,428, and white water lily with 1,992 organisms per square meter. Peppergrass had the highest diversity and white water lily the lowest in the survey. The most numerous forms in all plant communities were amphipods, insects (especially the tendipids), (tubificids), leeches and gastropods. Ephemeropterans were almost exclusive to the spikerush community.

Ager also made a few collections in limnetic areas and reported benthic populations (1962 organisms/M^2) very similar to the pelagic populations from Joyner (1975) (1,800 organisms/M^2). The community composition of both limnetic and pelagic populations are also very similar; however, the diversity of the limnetic samples is considerably lower. It is important to note the much higher levels of benthic fauna in littoral areas, as these form an important part of the food chain of many fish. The littoral benthic fauna are able to reach greater densities and diversities, because of higher food availability.

Another important feature shown by Ager is the near exclusive nature of isopod and pelecypod populations within the bulrush community. The author suspects the presence of the isopods *Cyathura* and *Sphaeroma* and the pelecypod, *Corbicula*. This is supported by samples that were taken during a time of intrusion of these organisms. Ager also reports the presence of *Mysis* sp. in the bulrush community in an earlier publication (Annual Report - Lake Okeechobee Project 1971-1972). It is also reasonable that these forms are associated with the peppergrass and bulrush communities because of their proximity to open water zone.

Table 11. The average number of invertebrates per square meter from selected aquatic plant communities and from the limnetic substrate. Data from Ager, 1974.

Organisms	Bulrush	Eelgrass	Peppergrass	Spikerush	White Waterlily	Limnetic Zone
Paleomonetes	4	51	4	2	7	-
Macrobrachium	-	-	-	-	-	11
Amphipoda	697	172	583	276	104	139
Ostracoda	25	51	145	33	15	-
Cladocera	-	11	990	4	7	-
Isopoda	156	-	38	-	-	-
Copepoda	2	3	4	6	-	-
Tendipedidae	922	808	1,018	2,111	1,304	1,491
Chaoborus	14	3	7	13	97	-
Ceratopogonidae	13	11	27	39	22	-
Trichoptera	27	59	124	31	36	-
Ephemeroptera	20	3	9	711	23	-
Zygoptera	7	3	9	6	61	-
Anisoptera	-	8	4	20	30	-
Hemiptera	2	-	-	4	-	-
Coleoptera	2	8	6	20	47	-
Stratomyiidae	-	-	-	4	-	-
Lepidoptera	-	3	11	2	4	-
Oligochaeta	294	813	768	152	54	107
Hirudinae	66	19	73	50	11	-
Turbellaria	16	-	14	-	-	-
Gastropoda	212	320	285	61	58	193
Pelecypoda	330	11	34	-	-	21
Hydracarina	13	57	20	23	101	-
Nematoda	2	6	40	-	-	-
Unknown	4	8	2	9	11	-
Average No./M^2	2,828	2,428	4,215	3,577	1,992	1,962
Diversity	20	20	22	20	17	6
No. of Samples	24	16	24	24	12	4

Littoral Fish Communities

Semi-annual rotenone sampling within selected aquatic plant communities provided estimates of standing crop and species composition over a three-year period. Fourteen species of fish were found to be dominant within the aquatic plant communities of Lake Okeechobee. Rotenone samples found only three fish throughout all major aquatic plant communities: largemouth bass, bluegill, and redear during both fall and spring periods. Bowfin occurred throughout all major plant communities sampled except for fall samples in peppergrass communities.

Bulrush

Standing crop estimates within the bulrush community (Table 13) varied from 283.3 pounds per acre to 964.8 pounds per acre from the spring samples and from 42.4 pounds per acre to 267.6 pounds per acre for the fall samples. Generally the standing crop estimates were highest during the spring period. Eight species of fish were characteristic of the bulrush community for both the spring and fall periods--largemouth bass, bluegill, redear, black crappie, channel catfish, gizzard shad, bowfin, and golden shiner.

Eelgrass

Standing crop estimates (Table 14) varied from 43.4 to 612.8 pounds per acre in the spring period and from 31.7 to 652.7 pounds per acre during the fall period within the eelgrass community. Generally, standing crop estimates were higher during the fall for individual sample sites, but the average standing crop of all samples for fall and

Table 12.

Standing crop estimates of fishes according to habitat type. Data from Ager, 1974.

Number of Samples	Habitat Type	Estimated Area	Estimated Standing Crop	Expanded Estimate*	Percent Harvestable
13	Submergent	16,066	170 lbs/a	2,731,220 lbs	86.8
8	Spikerush	28,115	90	2,530,350	76.6
4	Pond	4,016	169	678,704	72.3
8	Bulrush	8,033	318	2,554,494	90.8
			Total	8,494,768	

* The expanded estimate is the standing crop multiplied by the area of the habitat.

spring were only slightly different. Seven species of fish were characteristic of the eelgrass community during fall and spring periods: largemouth bass, bluegill, redear, brown bullhead, golden shiner, bowfin, and warmouth. Channel catfish and threadfin shad occurred only during the fall sample periods. The lake chubsucker and black crappie occurred most frequently during spring sample periods.

Standing crop estimates within the peppergrass community (Table 15) varied from 57.1 to 130.5 pounds per acre during the spring and from 40.6 to 286.2 pounds per acre during the fall. Standing crop estimates did not vary significantly from spring to fall. Six species of fish were commonly associated with the peppergrass community: largemouth bass, bluegill, redear, chain pickerel, gizzard shad, and golden shiner. Threadfin shad and channel catfish occurred primarily during the fall while black crappie, brown bullhead, bowfin and warmouth were more frequent in the spring samples.

Spikerush

Standing crop estimates within spikerush communities (Table 16) varied from 28.9 to 206.5 pounds per acre for the spring samples and from 36.8 to 139.0 pounds per acre for the fall. Standing crop estimates were generally higher for the fall samples. Eight species of fish were characteristic of the spikerush community: largemouth bass, bluegill, redear, bowfin, lake chubsucker, brown bullhead, warmouth, and spotted sunfish. Black crappie, chain pickerel, and golden shiner occurred primarily during the fall periods while Florida gar and dollar sunfish occurred during the spring periods.

White Water Lily

Standing crop estimates for white water lily communities (Table 17) varied extremely from 0 to 63.0 pounds per acre for the fall and 52.6 to 560.8 pounds per acre for the spring. Seven species of fish were characteristic of the white water lily community: largemouth bass, bluegill, redear, Florida gar, bowfin, lake chubsucker and warmouth. Golden shiner occurred only in fall samples while spotted sunfish occurred primarily during the spring samples.

Percent composition by weight and number of dominant species of fish within the bulrush community
Data from Ager, 1974.

	Percent by Weight						Percent by Number					
	Fall			Spring			Fall			Spring		
Year	1969	1971	1972	1969	1972	1973	1969	1971	1972	1969	1972	1973
Number of Samples	2	2	2	2	2	2						
Largemouth bass	13.5	-	15.0	0.1	9.8	12.9	11.3	-	7.3	0.1	2.8	6.0
	9.3	27.4	18.3	1.7	11.7	4.3	1.4	2.2	7.6	0.3	5.6	1.8
Bluegill	40.3	12.8	43.2	11.8	20.8	15.6	62.1	86.1	57.3	11.7	45.0	36.4
	52.0	39.6	34.9	45.8	52.7	36.1	44.5	85.6	46.7	40.1	66.6	57.9
Redear	12.5	1.3	16.9	4.0	32.1	12.7	10.1	2.9	22.9	4.6	29.2	18.2
	3.9	2.2	30.6	1.1	20.2	23.4	5.7	3.7	40.0	3.4	20.2	20.3
Black crappie	3.5	17.4	2.6	24.8	1.2	50.1	2.2	2.5	2.1	14.8	1.6	35.0
	6.4	11.2	1.3	4.6	2.3	7.6	1.2	2.9	1.0	4.0	2.0	5.0
Chain pickerel	3.9	-	-	-	-	0.6	0.5	-	-	-	-	0.1
	2.0	-	-	-	0.8	-	0.1	-	-	-	0.2	-
Channel catfish	2.0	8.4	-	17.4	10.8	-	0.2	0.4	-	2.8	2.0	-
	7.2	12.0	1.3	10.6	7.6	1.5	1.1	1.5	0.2	4.2	2.8	0.4
Brown bullhead	0.1	-	-	-	-	0.1	0.2	-	-	-	-	0.1
	-	-	-	-	-	-	-	-	-	0.1	-	-
Gizzard shad	12.4	5.4	12.7	36.2	21.8	1.2	5.9	0.7	7.3	23.0	16.9	0.7
	15.3	2.0	7.7	27.7	2.0	17.5	5.3	0.2	2.8	23.6	1.5	6.8
Threadfin shad	-	0.1	-	5.5	-	-	0.5	0.4	-	42.5	-	-
	3.6	-	-	0.3	-	0.1	31.7	-	-	7.6	-	0.3
Florida gar	-	-	-	-	-	0.2	-	-	-	-	-	0.1
	-	0.3	-	0.1	-	0.3	-	0.2	-	0.2	-	0.3
Bowfin	7.7	53.9	9.6	-	1.8	5.3	2.2	1.8	3.1	-	0.4	0.6
	-	3.0	4.1	1.2	1.5	-	-	0.2	0.8	0.1	0.3	-
Golden shiner	1.5	0.3	-	0.2	1.6	0.3	1.8	0.4	-	0.2	1.6	0.8
	0.5	0.2	1.6	6.9	0.4	6.4	0.5	0.2	1.0	11.3	0.7	5.5
Lake chubsucker	2.4	-	-	-	-	-	1.3	-	-	-	-	-
	-	2.1	-	-	0.2	-	-	0.2	-	-	0.1	-
Others	0.2	0.4	-	-	0.1	1.0	1.7	4.8	-	0.3	0.5	2.0
	-	-	0.2	-	0.6	2.8	8.5	3.1	-	5.2	-	1.7
Pounds/Acre	205.9	84.6	267.6	283.3	964.8	370.5						
	100.5	42.4	75.9	563.4	303.5	685.5						

Table 14

Percent composition by weight and number of dominant species of fish within eelgrass communities. Data from Ager, 1974.

	Percent by Weight						Percent by Number					
	Fall			Spring			Fall			Spring		
Year	1969**	1971	1972	1969**	1972	1973	1969**	1971	1972	1969**	1972	1973
Number of Samples	1	2	2	1	2	2						
Largemouth bass	12.0	13.0	2.2	13.8	9.0	0.8	4.7	6.8	2.3	0.7	9.2	1.1
	-	15.9	11.8	-	5.4	0.5	-	8.0	8.7	-	17.3	5.5
Bluegill	3.5	34.5	15.8	5.4	7.6	4.7	41.1	44.9	40.7	23.2	10.7	9.7
	-	32.8	9.4	-	12.1	3.4	-	24.8	47.3	-	13.7	33.0
Redear	1.4	28.2	29.5	20.4	5.2	11.9	1.1	35.0	52.5	49.3	21.9	13.3
	-	28.3	41.0	-	15.0	9.7	-	26.7	33.8	-	35.6	29.8
Black crappie	0.5	1.5	-	8.5	6.3	-	0.3	1.7	-	1.1	1.1	-
	-	0.8	-	-	20.2	-	-	0.4	-	-	5.0	-
Chain pickerel	6.7	2.5	8.4	3.0	5.8	-	1.4	1.0	0.2	0.2	0.2	-
	-	5.7	-	-	1.6	-	-	0.7	-	-	0.2	-
Channel catfish	2.0	-	-	-	-	-	0.3	-	-	-	-	-
	-	4.0	-	-	-	-	-	0.3	-	-	-	-
Brown bullhead	0.1	Tr.	0.9	23.7	2.4	6.7	0.4	0.3	1.1	3.5	22.6	0.5
	-	0.2	5.9	-	3.2	2.5	-	3.0	4.3	-	14.5	4.7
Gizzard shad	70.2	2.2	-	-	15.0	-	35.9	1.7	-	-	1.3	-
	-	2.6	-	-	3.2	43.2	-	0.7	-	-	0.5	4.3
Threadfin shad	0.5	Tr.	-	-	-	-	4.3	0.2	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-
Florida gar	-	0.2	-	3.1	-	-	-	0.5	-	1.1	-	-
	-	0.4	-	-	0.4	-	-	0.1	-	-	0.2	-
Bowfin	-	2.8	23.7	10.1	24.8	21.5	-	0.6	0.2	0.2	0.3	0.2
	-	-	14.5	-	27.2	37.0	-	-	0.1	-	1.1	1.0
Golden shiner	2.2	0.9	0.2	0.6	0.9	0.5	9.5	1.8	0.5	0.2	4.2	0.2
	-	4.3	3.8	-	0.7	-	-	2.0	1.8	-	0.7	-
Lake chubsucker	-	8.3	-	1.1	15.6	25.0	-	4.4	-	0.1	4.6	0.5
	-	4.3	-	-	7.2	-	-	0.7	-	-	1.1	-
Warmouth	-	0.1	2.2	8.8	1.5	4.9	-	0.4	1.2	9.9	1.4	1.3
	-	-	5.9	-	2.1	2.3	-	-	3.6	-	3.8	4.6
Others	0.9	5.8	17.1	1.5	5.9	24.0*	1.0	0.7	1.3	10.5	22.5*	73.2*
	-	0.7	7.7	-	1.7	1.4	-	32.6	0.4	-	6.3	17.1
Pounds/Acre	152.6	652.7	31.7	185.3	214.0	43.4						
	-	337.4	43.3	-	612.8	105.6						

* Mostly dollar sunfish

** No duplicate sample taken

Table 15

Percent composition by weight and number of dominant species of fish within the peppergrass community.

Data from Ager, 1974.

	Percent by Weight						Percent by Number					
	Fall			Spring			Fall			Spring		
Year	1969**	1971	1972	1969**	1972	1973	1969**	1971	1972	1969**	1972	1973
Number of Samples	1	2	2	2	2	2						
Largemouth bass	16.8	16.5	6.3	3.0	4.9	2.1	1.3	2.5	1.9	0.4	12.9	3.6
		64.3	10.0	1.4	2.6	5.0		7.4	7.9	0.3	5.0	38.1
Bluegill	53.3	7.5	13.1	42.2	5.5	7.6	88.8	57.4	35.7	79.6	2.4	64.0
		5.7	10.7	24.7	0.7	6.9		46.8	9.6	22.6	5.0	12.8
Redear	4.3	18.7	24.9	4.3	24.8	7.5	2.4	24.6	51.8	7.3	27.4	18.6
		18.2	27.2	19.6	74.3	5.8		12.6	56.0	11.5	59.4	20.1
Black crappie	-	18.0	17.1	24.1	-	12.2	-	6.0	4.6	2.4	-	3.1
		-	8.3	9.7	0.7	11.4		-	1.3	3.2	0.2	1.7
Chain pickerel	10.7	7.6	2.9	1.9	9.5	2.2	0.2	0.4	0.1	0.1	0.3	0.1
		-	-	-	-	-		-	-	-	-	-
Channel catfish	2.9	14.5	9.4	4.0	-	2.4	Tr.	1.0	1.7	0.1	-	0.1
		4.6	-	2.5	-	-		0.5	-	0.2	-	-
Brown bullhead	Tr.	-	-	0.3	0.5	-	0.1	-	-	0.1	1.7	-
		-	1.3	1.3	-	1.1	0.1	-	1.3	0.3	-	3.7
Gizzard shad	1.9	8.3	12.9	11.4	21.0	23.3	-	0.1	2.4	1.3	2.0	4.2
		-	-	31.8	1.1	-		-	-	8.6	0.2	-
Threadfin shad	1.6	0.1	0.1	3.5	-	-	1.2	0.4	0.1	2.8	-	-
		-	0.7	0.6	-	-		-	0.4	10.8	-	-
Florida gar	1.6	-	-	-	-	-	0.1	-	-	-	-	-
		-	-	-	-	-		-	-	-	-	-
Bowfin	-	-	3.2	-	24.3	11.1	-	-	0.1	-	0.2	0.6
		-	-	-	20.7	24.5		-	-	-	0.2	0.7
Golden shiner	7.0	0.1	3.0	4.5	0.3	1.0	5.3	0.4	1.1	5.0	0.4	0.8
		2.1	1.2	5.3	-	1.9		1.1	1.2	10.9	-	7.5
Lake chubsucker	-	8.4	6.1	-	-	29.8	-	0.7	0.5	-	-	2.2
		4.1	14.0	2.4	-	29.5		0.5	1.8	0.3	-	3.1
Warmouth	-	-	0.2	Tr.	3.4	0.3	-	-	0.2	0.2	3.2	0.1
		-	16.8	-	Tr.	6.6		-	17.5	-	0.2	7.3
Spotted sunfish	-	-	0.1	-	0.1	-	-	-	0.1	-	0.1	-
		-	2.8	-	0.1	0.9		-	3.1	-	0.4	5.1
Others	-	0.3	0.7	0.8	5.7	0.5	0.5	5.6	-	0.7	49.4+	2.6
		1.0	7.0	0.7	-	6.4	-	31.1*	-	31.3++	29.4+	-
Pounds/Acre	51.3	40.6	286.2	130.5	57.1	153.1						
		50.5	98.7	113.8	100.2	87.5						

** No duplicate sample taken
* All seminole killifish
+ Miscellaneous minnows and dollar sunfish.
++ Taillight shiners

Table 16

Percent composition by weight and number of dominant species of fish within the spikerush community. Data from Ager, 1974.

	Percent by Weight						Percent by Number					
	Fall			Spring			Fall			Spring		
Year	1969	1971	1972	1969	1972	1973	1969	1971	1972	1969	1972	1973
Number of Samples	2	2	2	2	2	2						
Largemouth bass	19.0	12.4	19.6	12.4	6.7	15.2	9.8	3.4	10.4	2.9	6.8	13.9
	26.7	9.4	15.3	13.8	8.4	6.5	8.1	6.5	13.3	3.3	2.0	6.9
Bluegill	4.7	9.0	13.1	7.6	2.3	0.3	9.1	6.9	15.4	11.5	0.6	4.2
	11.7	13.7	8.6	11.7	1.3	12.9	17.5	6.5	8.7	12.2	0.9	8.4
Redear	20.6	46.4	29.5	32.8	58.6	8.8	24.2	80.7	49.2	45.1	30.0	24.8
	19.7	44.4	24.2	27.0	20.0	23.9	25.8	75.7	59.8	14.3	49.4	20.2
Black crappie	-	-	1.6	-	-	-	-	-	0.2	-	-	-
	2.9	-	0.9	-	-	-	1.2	-	0.1	-	-	-
Chain pickerel	-	5.1	1.6	-	-	-	-	1.3	0.1	-	-	-
	6.6	6.2	-	-	-	-	1.4	0.9	-	-	-	-
Redfin pickerel	1.6	-	-	1.4	-	-	0.8	-	-	0.3	-	-
	1.3	-	-	12.1	-	0.3	1.4	-	-	2.4	-	0.5
Brown bullhead	0.1	-	Tr.	2.6	0.2	-	1.3	-	0.1	0.3	1.5	-
	1.1	Tr.	0.6	1.3	-	-	0.9	0.9	0.6	0.2	-	-
Florida gar	-	-	-	1.0	2.5	3.1	-	-	-	Tr.	0.4	0.6
	-	-	0.6	1.8	-	-	-	-	0.1	0.2	-	-
Bowfin	31.5	13.1	10.5	30.6	15.8	54.5	2.5	1.7	0.2	0.2	0.2	3.0
	6.4	-	30.2	9.1	52.4	25.9	1.8	-	0.6	Tr.	0.4	2.0
Golden shiner	0.7	0.8	1.0	1.2	-	-	2.5	1.3	1.9	1.6	-	-
	1.9	0.4	0.5	-	-	0.2	1.6	0.9	1.0	Tr.	-	2.0
Lake chubsucker	15.9	11.5	8.8	2.8	-	4.4	4.8	3.9	1.2	0.3	-	1.2
	11.2	24.9	4.8	4.2	-	6.2	4.6	5.6	0.6	2.8	-	2.0
Warmouth	5.7	1.1	9.2	3.0	7.7	7.1	29.0	0.9	14.4	2.1	1.1	6.1
	7.5	1.0	9.4	6.0	7.6	20.2	15.2	2.8	10.1	3.0	1.4	13.8
Spotted sunfish	Tr.	-	3.5	0.8	2.4	4.7	0.8	-	6.7	0.8	0.6	7.9
	2.9	-	2.8	4.1	1.8	2.4	10.1	-	5.2	4.0	1.1	2.0
Dollar sunfish	0.1	-	-	2.0	2.4	1.3	6.0	-	-	18.8	29.3	36.4
	-	-	-	6.1	7.7	1.0	-	-	-	38.6	44.9	36.5
Others	0.1	0.6	1.6	1.8	1.4	0.6	9.2*	-	0.2	16.1*	29.5*	1.9
	0.1	-	2.1	2.8	0.8	0.5	10.4*	0.2	-	19.0*	-	5.8**
Pounds/Acre	94.5	119.4	139.0	206.5	32.2	41.4						
	98.2	36.8	104.5	101.9	28.9	50.8						

* Miscellaneous minnows

** Blue spotted sunfish

Table 17

Percent composition by weight and number of dominant species of fish within white water lily community

Data from Ager, 1974.

	Percent by Weight						Percent by Number					
	Fall			Spring			Fall			Spring		
Year	1969**	1971**	1972*	1969**	1972**	1973	1969**	1971**	1972*	1969**	1972**	1973+
Number of Samples	1	1	2	1	1	0						
Largemouth bass	-	16.5	-	12.0	14.7	-	-	2.5	-	8.9	3.9	-
	18.1	-	32.6	-	-	-	7.4	-	53.6	-	-	-
Bluegill	-	29.7	-	13.8	13.8	-	-	7.5	-	16.1	2.5	-
	29.5	-	2.1	-	-	-	49.1	-	17.4	-	-	-
Redear	-	31.4	-	-	11.3	-	-	80.0	-	-	29.8	-
	10.4	-	2.7	7.6	-	-	13.5	-	15.9	13.1	-	-
Black crappie	6.0	-	-	6.2	-	-	3.1	-	-	4.5	-	-
Chain pickerel	-	-	-	0.7	-	-	-	-	-	0.3	-	-
Channel catfish	12.7	-	-	-	-	-	4.3	-	-	-	-	-
Brown bullhead	-	-	-	4.6	-	-	-	-	-	1.9	-	-
Gizzard shad	-	-	-	-	-	-	-	-	-	-	-	-
Florida gar	-	-	-	-	5.6	-	-	-	-	-	0.4	-
	1.9	-	-	0.4	-	-	2.5	-	-	1.4	-	-
Bowfin	-	-	-	24.7	45.1	-	1.8	-	-	2.6	0.4	-
	16.8	-	62.6	-	-	-	-	-	13.0	-	-	-
Golden shiner	-	2.9	-	-	-	-	-	6.3	-	-	-	-
	1.7	-	-	-	-	-	6.7	-	-	-	-	-
Lake chubsucker	-	19.3	-	21.0	-	-	-	2.5	-	9.0	-	-
	2.5	-	-	-	-	-	1.2	-	-	-	-	-
Warmouth	-	0.2	-	4.8	4.0	-	-	1.3	-	7.6	1.7	-
	0.4	-	-	-	-	-	1.2	-	-	-	-	-
Spotted sunfish	-	-	-	3.2	1.9	-	-	-	-	5.5	2.3	-
	Tr.	-	-	-	-	-	0.6	-	-	-	-	-
Others	-	-	-	1.0	3.6	-	8.6	-	-	29.1+	59.0+	
Pounds/Acre	51.9	20.0	63.0	560.8	52.6							

** No duplicate sample taken.
* One sample contained no fish.
\+ Due to low water level no samples were taken.
++ Miscellaneous minnows and dollar sunfish.

Table 18

Estimated standing crop and percent by weight of dominant species according to habitat type. Data from Ager, 1974.

Species	Submergent lbs	Submergent %	Spikerush lbs	Spikerush %	Ponds lbs	Ponds %	Bulrush lbs	Bulrush %	Total Composition of Littoral Zone lbs	Total Composition of Littoral Zone %
Largemouth bass	353,452	34.3	376,741	36.6	86,746	8.4	213,678	20.7	1,030,617	12.8
Bluegill	686,018	33.5	213,674	10.4	106,424	5.2	1,039,470	50.8	2,045,586	25.4
Redear	663,526	35.4	812,524	43.3	60,240	3.2	339,796	18.1	1,876,086	23.3
Black crappie	117,282	38.1	-	-	38,152	12.4	152,627	49.5	308,061	3.8
Chain pickerel	131,741	63.6	53,419	25.8	4,418	2.1	17,673	8.5	207,251	2.6
Channel catfish	41,772	14.4	-	-	6,827	2.4	241,793	83.3	290,392	3.6
Brown bullhead	88,363	61.6	28,115	19.6	26,104	18.2	803	0.6	143,385	1.8
Gizzard shad	290,745	45.3	-	-	-	-	351,042	54.7	641,837	8.0
Florida gar	14,459	69.2	5,623	26.9	-	-	803	3.8	20,885	0.3
Bowfin	104,429	12.3	506,070	59.4	172,688	20.3	68,280	8.0	851,467	10.6
Golden shiner	67,477	47.0	22,492	15.7	803	0.6	52,886	36.8	143,658	1.8
Lake chubsucker	159,053	31.8	208,051	41.6	123,693	24.7	9,640	1.9	500,437	6.2
Composition of Littoral Area	2,718,367	33.7	2,226,709	27.6	626,095	7.8	2,488,491	30.9	8,059,662	

References

Ager, L.A. and K.E. Kerce. 1974. Aquatic plant communities - associated fauna investigation; completion report. Florida Game and Fresh Water Fish Commission.

Andersson, G., G. Cronberg and C. Gelin. 1973. Planktonic changes following restoration of Lake Trummen, Sweden. Ambio 2:44-73.

Barrett, P.H. 1952. Relationship between alkalinity and adsorption of phosphorus and regeneration of added phosphorus in fertilized trout lakes. Trans. Am. Fish Soc. 82:78-90.

Baylor, E.R., W.H. Sutcliffe, and D.S. Herschfield. 1962. Adsorption of phosphate onto bubbles. Deep Sea Res. Vol. 9 (2):120-124.

Brezonik, P.L. and A. Federico. 1975. Effects of backpumping from agricultural canals on water quality in Lake Okeechobee. Completion Report to Fla. Dept. of Poll. Control.

Brooks, H.K. 1974. "Lake Okeechobee" in Environment of South Florida: Past and Present, Memoir 2, Miami Geological Society, Patrick J. Gleason, Editor, p. 256-286.

Browder, J. 1975. Alligator holes in Carrying capacity for man and nature in south Florida, H.T. Odum and M. Brown, eds. Completion report to Dept. of Interior.

Burton, T.M., R.C. Harriss, C.F. Dreyer, and D.H. Taylor. 1975. Studies of the geochemical exchanges across the sediment-water interface in the Kissimmee River - Lake Okeechobee watershed. Completion Report to Fla. Dept. of Poll. Control.

Casselman, T.W. 1970. The climate of the Belle Glade area. Agri. Exp. Sta., Univ. of Florida, cir. S-205, 17 p.

Davis, F.E. and M.L. Marshall. 1975. Chemical and biological investigations of Lake Okeechobee, January 1973-June 1974, Interim Report. Central and Southern Florida Flood Control District Technical Publication 75-1.

Duchrow, R.M. 1970. Annual progress report for investigation project as required by Federal Aid in Fish Restoration, Dingell-Johnson Project F-21-4, 1969-70: Florida Game and Freshwater Fish Commission.

EPA. 1971. Storm Water Receiving Model

Gatewood, S. 1975. An analysis of cattle ranching in the Kissimmee River Basin. Preliminary draft submitted by EcoImpact, Inc. to Florida Division of State Planning. 171 pp.

Gerking, S.D. 1962. Production and food utilization in a population of blue-gill sunfish. Ecol. Mono. 32:31-78.

Green, J. and J.A. Holmes. 1947. Calculation of the pH saturation of tricalcium phosphate. Journal of the American Water Works Association 39:1090-1096.

Hall, K. 1964. The dynamics of a natural population of Daphnia. Verh. Int. Verein. Limnol. 15:660-664.

Harder, R.D. 1968. Adsorption of phosphorus by lake sediment. Soil Sci. Soc. Amer. Proc. 32:514-518.

Hartwell, J.H. 1970. Some aspects of the availability of water from the Everglades to the Everglades National Park, Florida. USGS Open-file report-SL-70007.

Heaney, J.P. and W.C. Huber. 1974. Environmental resources management studies in the Kissimmee River Basin, Phase I. Progress Rept. to the Central and Southern Fla. Flood Control Dist. 132 pp.

Holcomb, D.E. 1968. Annual progress report for research project as required by Federal Aid and Fish Restoration, Dingell-Johnson Project F-21-R-2: Florida Game and Fresh Water Fish Commission, 1967-68.

Holcomb, D.E. and W. Wegener. 1972. Lake Tohopekaliga drawdown. Florida Game and Fresh Water Fish Commission. Progress Report Job No. 5, Project No. F-29-1.

Hortenstine, C.C. and R.B. Forbes. 1972. Concentrations of nitrogen, phosphorus, potassium, and total soluble salts in soil solution samples from fertilized and unfertilized histosols. Journal of Environmental Quality. 1(4):446-449.

Huff, D.D., J.F. Koonce, W.R. Ivarson, P.R. Weiler, E.H. Dettman, and R.F. Harris. 1973. Simulation of urban runoff, nutrient loading, and biotic response of a shallow eutrophic lake. Pages 33-55 in E.J. Middlebrooks, D.H. Falkenborg, T.E. Maloney, eds., Modeling the eutrophication process. Utah State Univ.

Hutchinson, G.E. 1957. A treatise in limnology. Geography, Physics, and Chemistry, Vol. I. John Wiley & Sons, New York. 1015 pp.

Joyner, B.F. 1974. Chemical and biological conditions in Lake Okeechobee, Florida, 1969-72. Rept. Inv. 71. United States Geological Survey.

Kamp-Nielsen, L. 1974. Mud-water exchange of phosphate and other ions in undisturbed sediment cores and factors affecting the exchange rates. Arch. Hyd. 73(2):218-237.

Kirchner, W.B. and P.J. Dillon. 1975. An empirical method of estimating the retention of phosphorus in lakes. Water Resources Research. 11(1):182-183.

MacCormick, A.J.A., O.L. Loucks, J.F. Koonce, J.F. Kitchell, P.R. Weiler. 1972. An ecosystem model for the pelagic zone of Lake Wingra. U.S. I.B.P. E.D.F.B. memo report 72-177 103 pp.

Mathiesen, J. 1971. Summer maxima of algae and eutrophication. Mitt. Verh. Internat. Verein. Limnol. 19:161-181.

Middlebrooks, E.J., D.H. Falkenborg, and T.E. Maloney, eds. 1973. modeling the eutrophication process. Ann Arbor Science, Ann Arbor, Michigan. 228 pp.

Odum, H.T. 1953. Dissolved phosphorus in Florida waters. Report of investigations #9. Fla. Geol. Survey. 40 pp.

Odum, H.T. 1957. Primary production in flowing waters. Limnology and Oceanography. 1:102-117.

Odum, H.T. 1971. Environment, power, and society. John Wiley Interscience, New York. 317 pp.

Odum, H.T. 1972. An energy circuit language for ecological and social systems: its physical basis. Pages 139-211 in B.C. Patten, ed., Systems analysis and simulation in ecology. Vol. II.

Park, R.A., J.W. Wilkinson, J.A. Bloomfield, R.C. Kohberger, and C. Sterling. 1972. Aquatic modeling, data analysis, and data management at Lake George. U.S. I.B.P. E.D.F.B. memo report 72-70. 32 pp.

Park, R.A. 1974. A generalized model for simulating lake ecosystems. Simulation 4(2):33-50.

Parker, G.G., G.E. Ferguson and S.K. Love. 1955. Water resources of Southeastern Florida. U.S. Geol. Survey Water Supply Paper 1255. 965 pp.

Parker, R.A. 1968. Simulation of an aquatic ecosystem. Biometrics 24:803-822.

Price, W.A. 1947. Equilibrium of form and forces in tidal basins of coasts of Texas and Louisiana. Bull. Amer. Ass. Petrol. Geol. 31:1619-1663.

Prosser, C.L. and F.A. Brown. 1961. Comparative animal physiology. W.B. Saunders Co., Philadelphia. 688 pp.

Riebsame, W.E., W.L. Woodley and F.E. Davis. 1974. Radar inference of Lake Okeechobee rainfall for use in environmental studies. Weatherwise 27(5):206-211.

Sheffield, C.W. and W.H. Kuhrt. 1970. Lake Apopka - its decline and proposed restoration. Proc. Florida's Environmental Engineering Conference, Water Pollution Control Bulletin 135. Univ. of Florida Eng. Ind. Exper. Sta., Gainesville.

Sincock, J.L., J.A. Powell, R.K. Hyde, and H.E. Wallace. 1957. The relationship of wintering water fowl populations of the Kissimmee River Valley to the hydrology, topography, distribution of the vegetation and the proposed hydrological regulations. Bureau of Sport Fish and Wildlife.

Soumela, A.J. 1958. A detailed report on the fish and wildlife resources in relation to the Corps of Engineer's plan of development of the northwest shore of Lake Okeechobee, Florida. U.S. Fish and Wildlife Service.

U.S.G.S. Surface water records. 1931-74.

Vollenweider, R. A. 1968. Scientific fundamentals of eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus factors in eutrophication. OECD Technical Report. DAS/CSI/68.27, Paris, 159 pp.

Waters, T. F. 1969. The turnover ratio in production ecology of fresh-water invertebrates. Am. Nat. 103:173-185.

IV. LAKE OKEECHOBEE FISHERIES MODEL

M. Sell

Introduction

Lake Okeechobee supports a large population of phytoplankton, zooplankton, invertebrate detritivores and fish spun into an intricate food web. How will these organisms be affected by changes in the nutrient loading into the lake? Will raising or lowering the lake have any negative impact? A model of the lake ecosystem with emphasis on the fish was conceived and simulated in an attempt to answer these questions. The model is described below.

Description of Model

A simplified model of the Lake Okeechobee food web is shown in Figure 7. Values for the flows and storages are included. In this model the driving forces include total organic carbon inflow to the lake from rainfall and surface waters, net production of phytoplankton and zooplankton, and net production of marsh plants. The inputs to the organic carbon compartment of the lake include carbon inflows from the rivers,creeks and canal that feed the lake. The primary flow is from the Kissimmee River. Rainfall also supplies a portion of the carbon inflow. The net production of phytoplankton and zooplankton also is a major source of organic carbon. A small amount of organic carbon is also exported by the marsh. The production by marsh plants flows into the marsh biomass compartment. The outflow from the organic carbon compartment includes settling of carbon to the bottom of the lake to become bottom detritus and outflow through the canals draining the lake. A relatively small amount of organic carbon in the lake is ingested by forage fishes, and also by the omnivores. A fraction of the detritus is resuspended by turbulence and detritus feeding organisms disturbing the sediments. Forage fishes include gizzard shad (Dorosoma

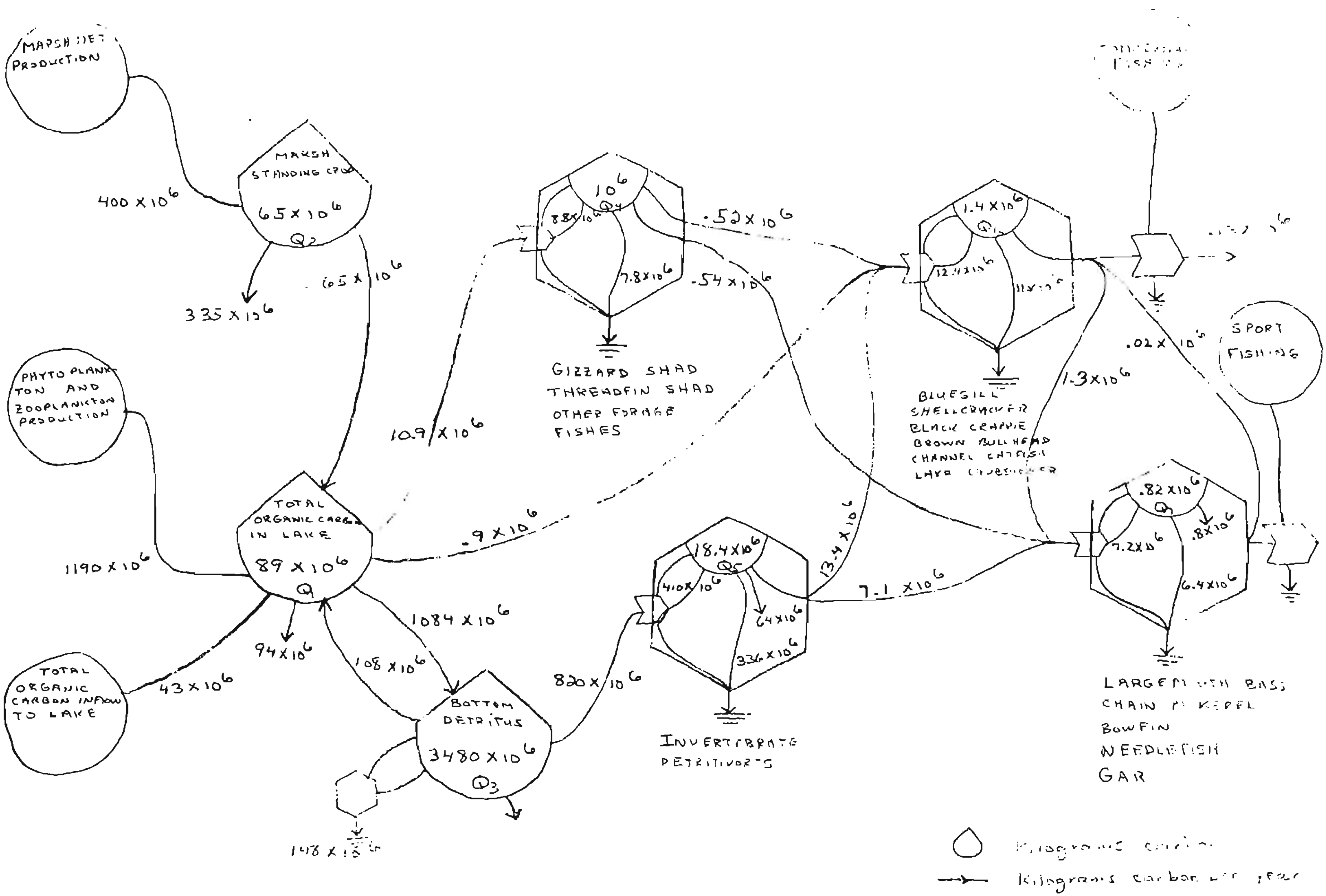


Fig. 1. Lake Okeechobee fisheries model with values for flows and storages.

cepedianum), threadfin shad (Dorosoma petenense) and smaller fish such as Fundulus and Gambusia spp. Invertebrate detritivores ingest large amounts of detritus. Omnivores, including the bluegill (Lepomis macrochirus), the redear sunfish (Lepomis microlophus), the brown bullhead (Ictalurus punctatus), the lake chubsucker (Erimyzon sucetta) and the black crappie (Pomoxis nigromaculatus) feed on invertebrate detritivores, organic carbon, and forage species. The carnivores feed on invertebrate detritivores, forage species and omnivores and chain pickerel (Esox niger), bowfin (Amia calva), needlefish (Strongylura marina) and Florida gar (Lepisosteus platyrhincus).

Sport fishing harvests a small number of largemouth bass and black crappie from the lake and commercial fishing harvests channel catfish and brown bullheads.

Evaluation of Data

Data compiled in various Game and Freshwater Fish Commission reports were used in this model. The calculations of the numbers for the various flows and storages are discussed below and summarized in Tables 1, 2, and 3. The discussion will look at the level of each compartment and the flows in and out of that compartment.

Organic Carbon in Lake

The level of total organic carbon in Lake Okeechobee was measured and averaged using data from Joyner (1975) and Brezonik and Federico (1975) and found to be 20 grams per cubic meter. If the volume of the lake is taken as 4.45×10^9 cubic meters, then the total organic carbon occurring in the lake is 89×10^6 kilograms. Organic carbon inflow from surface

TABLE 1.

Identification of and Values for Driving Forces in the Lake Okeechobee Fisheries Model

Driving Force	Calculation		Reference
Inflow of Organic Material, N_1	Average concentrations of total organic carbon		
	Taylor Creek	18 gm/m^3	Joyner (1974)
	Kissimmee River	13 gm/m^3	Joyner (1974)
	North New River	39 gm/m^3	Earle (1973)
	Other inflows	18 gm/m^3	estimated
	Precipitation	3 gm/m^3	Earle (1973)
	Average annual inflow of water		} Joyner (1974)
	Taylor Creek	$1.6 \times 10^8\ m^3/yr$	
	Kissimmee River	$17 \times 10^8\ m^3/yr$	
	North New River	$.2 \times 10^8\ m^3/yr$	
	Other inflows	$6.4 \times 10^8\ m^3/yr$	
	Precipitation	$20 \times 10^8\ m^3/yr$	
	Average annual inflow of carbon		
	Taylor Creek	2.9×10^6 kg/yr	
	Kissimmee River	22×10^6 kg/yr	
	North New River	$.8 \times 10^6$ kg/yr	
	Other inflows	11.5×10^6 kg/yr	
	Precipitation	6.0×10^6 kg/yr	
	TOTAL	43.2×10^6 kg/yr	
Nutrient Based Phytoplankton and Zooplankton Net Production, N_2	Net Production of phytoplankton		
	Pelagic zone	$2\ gm\ C/m^2 \cdot day$, or	
		$\frac{2 gmC}{m^2 \cdot day} \times 365 \frac{days}{year} \times \frac{1.46 \times 10^9 m^2}{}$ $= 1060 \times 10^6 \frac{kgs\ Carbon}{year}$	

TABLE 1. - continued

Driving Force	Calculation		Reference
Phytoplankton and Zooplankton Net Production, N_2	Phytoplankton Littoral zone	1 gm C/m^2 day, or $\frac{1gmC}{m^2 \cdot day} \times 365 \times .276 \times 10^9 m^2$ $= 100 \frac{\text{kgs Carbon}}{\text{year}}$	
	Zooplankton production Entire lake value was estimated as	$31 \times 10^6 \frac{\text{kgs Carbon}}{\text{year}}$	
	TOTAL	$(1060 + 100 + 31) \times 10^6$ $= 1190 \times 10^6 \frac{\text{kgs Carbon}}{\text{year}}$	
March net production, N_3	Estimated gross production for south Florida marshes	$27 \text{ gm } C/m^2 \cdot day$	Bayley and Odum
	Net assumed as 30% of gross, or	$8.1 \frac{gmC}{m^2 \cdot day}$ $8.1 \frac{gmC}{m^2 \cdot day} \times 365 \times /276 \times 10^9 m^2 \times \frac{1kg}{1000gm}$ $= 815 \times 10^6 \frac{\text{kgs Carbon}}{\text{year}}$	
	The Lake Okeechobee marsh was not believed to be this high in net production and so a value of ~1/2 the above or was used.	$400 \times 10^6 \frac{\text{kgs C}}{\text{year}}$	

TABLE 2.
Identification of and Values for Compartments in the Lake Okeechobee Fisheries Model

Compartment	Calculation	Reference
Total Organic Carbon in Water, Q_1	Average value for total organic carbon of 20 gm/m^3 was used for Lake Okeechobee. Volume of lake equals $1.74 \times 10^9\ m^2 \times 2.56$ m depth or $4.45 \times 10^9\ m^3$ Total amount of carbon in lake equals $.02\ \frac{kg}{m^3} \times 4.45 \times 10^9\ m^3$, or 89.0×10^6 kgs C Maximum value taken as 500×10^6 kgs C.	
Marsh Storage, Q_2	Total marsh storage calculated using acreage and standing crop for various marsh communities. Cattail $48.8 \times 10^6 m^2 \times \frac{.376\ kgC}{m^2} = 18.4 \times 10^6$ kgs C Spikerush $113.8 \times 10^6 m^2 \times \frac{.152\ kgC}{m^2} = 17.3 \times 10^6$ kgs C Bulrush $32.5 \times 10^6 m^2 \times \frac{.683\ kgC}{m^2} = 22.2 \times 10^6$ kgs C Submergents (peppergrass, eelgrass) $65 \times 10^6 \times \frac{.090\ kgC}{m^2} = 5.9 \times 10^6$ kgs C Water lily $16.3 \times 10^6 \times \frac{.090\ kgC}{m^2} = 1.5 \times 10^6$ kgs C Total standing crop $= 65.3 \times 10^6$ kgs C Maximum value taken as 300×10^6 kgs C.	

TABLE 2. - continued

Compartment	Calculation	Reference
Bottom Detritus, Q_3	Average depth of bottom detritus equals .27 meters and active part assumed as 0.05 meters. Bulk density assumed to be $1 \frac{\text{gm sed.}}{\text{cm}^3\text{sed.}}$ or $10^6 \frac{\text{gm}}{\text{m}^3}$ Sediments contain 4% carbon. Amount of detritus actually involved in flows equals $.05\text{m} \times 1.74 \times 10^9\text{m}^2 \times \frac{10^3\text{kg sed.}}{\text{m}^3} \times \frac{.04 \text{ kg C}}{1 \text{ kg sed.}}$ $= 3480 \times 10^6$ kgs C, or 2000 gm C/m^2 Maximum value taken as 10,000 x 10^6 kgs C.	
Gizzard Shad, Threadfin Shad and Other Forage Species, Q_4	Standing crop of gizzard shad equals 13,282,492 lbs wet weight or 3.7 x 10^6 kgs dry weight (assuming dry weight = 27.8% of wet weight). At 50% carbon to dry weight this becomes .85 x 10^6 kgs C. Standing crop of threadfin shad equals 1,562,306 lbs wet weight or .1 x 10^6 kgs C. Standing crop of forage species equals 640,000 lbs wet weight or .04 x 10^6 kgs C. Total equals 0.00 x 10^6 kgs C. Maximum value taken as 2.5 x 10^6 kgs C.	

TABLE 2. - continued

Compartment	Calculation	Reference
Invertebrate Detritivores, Q_5	Marsh Standing Crop	
	Total Biomass 18.4×10^6 kgs C	
	Maximum value of 50×10^6 kgs C	
Bass, Pickerel, Gar, Bowfin, Needlefish, Q_6	Standing Crop	
	Bass $.16 \times 10^6$ kgs C	
	Pickerel $.04 \times 10^6$ kgs C	
	Gar $.43 \times 10^6$ kgs C	
	Bowfin $.15 \times 10^6$ kgs C	
	Needlefish $.04 \times 10^6$ kgs C	
	TOTAL $.82 \times 10^6$ kgs C	
	Maximum value taken as 2.5×10^6 kgs C	

TABLE 2. - continued

Compartment	Calculation	Reference
Sunfish, Black Crappie, Brown Bullhead, Channel Catfish, Lake Chubsucker, Q_7	Standing Crops Sunfish (Bluegill and Shellcracker) 8,715,032 lbs wet weight or $.55 \times 10^6$ kgs C Black Crappie 6,017,948 lbs wet weight or $.38 \times 10^6$ kgs C Brown Bullhead and Channel Catfish 5,671,048 lbs wet weight or $.36 \times 10^6$ kgs C Lake Chubsucker 1,075,840 lbs wet weight or $.07 \times 10^6$ kgs C TOTAL STANDING CROP 1.4×10^6 kgs C Maximum value of 4×10^6 kgs C	

TABLE 3.
Identification of and Values for Pathways in the Lake Okeechobee Fisheries Model

Pathway Number	Identification	Calculation	Reference
1	Outflow of organic matter, k_1Q_1	Total organic carbon concentration equals 20 gm/m^3 for outflow, and total surface water outflow is 47 x 10^{8}m^3/year Outflow of organic carbon from lake equals 94 x 10^6 kgs C/year	
2	Settling rates of particulates to bottom detritus, k_2Q_1	Value assumed to be 1084 kgs C/year	
3	Resuspension rate of bottom detritus, k_5Q_3	Value taken as 10% of settling rate or 108.4 x 10^6 kgs C/year	
4	Inflow of marsh plant debris to particulates in water, k_7Q_2	Assumed to be equal to standing crop or 65 x 10^6 kgs/year	
5	Ingestion of particulate food by by gizzard shad, threadfin shad and other forage species, $k_3Q_1Q_4$	Total gross ingestion equals 10.9 kgs C/year	
6	Miscellaneous marsh losses (grazing, etc.), k_6Q_2	Assumed to be 335 x 10^6 kgs C/year	
7	Decomposition of bottom detritus, $k_8Q_3^2$	Assumed to be 148 x 10^6 kgs C/year	
8	Total ingestion of bottom detritus by invertebrate detritivores, $k_9Q_3Q_5$	820 x 10^6 kg C/year	
9	Ingestion of particulates by sunfish, black crappie, brown bullhead, channel catfish, lake chubsucker, $k_4Q_1Q_4$	Assumed to be .9 x 10^6 kgs C/year	

TABLE 3. - continued

Pathway Number	Identification	Calculation	Reference
10	Assimilation rate for gizzard shad, threadfin shad, etc., $k_{10}Q_1Q_4$	8.8×10^6 kgs C	
11	Respiration rate of gizzard shad, etc., $k_{11}Q_4$	7.8×10^6 kgs C	
12	Ingestion of gizzard shad, etc., by sunfish, etc., $k_{12}Q_4Q_7$	Assumed to be $.52 \times 10^6$ kgs C/year	
13	Ingestion of gizzard shad, etc., by bass, etc., $k_{13}Q_4Q_6$	Assumed to be $.54 \times 10^6$ kgs C/year	
14	Potential harvest of gizzard shad, $k_{25}Q_4N_5$	0 at start	
15	Assimilation by invertebrate detritivores, $k_{24}Q_5Q_3$	410×10^6 kgs C/year	
16	Respiration of invertebrate detritivores, $k_{23}Q_5$	336×10^6 kgs C/year	
17	Ingestion of invertebrate detritivores by sunfish, etc., $k_{22}Q_5Q_7$	Assumed to be $.54 \times 10^6$ kgs C/year	
18	Assimilation by bass, etc., $k_{14}Q_4Q_6+k_{15}Q_6Q_7$	Total of 7.2×10^6 kgs C	
19	Respiration rate of bass, etc. $k_{17}Q_6$	6.4×10^6 kgs C	
20	Harvest by sport fishermen, $k_{16}Q_6N_4$	Negligible	

TABLE 3. - continued

Pathway Number	Identification	Calculation	Reference
21	Assimilation of food by sunfish, etc., $k_{28}Q_1Q_7+k_{26}Q_4Q_7+k_{27}Q_5Q_7$	Total 12 x 10^6 kgs C/year	
22	Respiration rate of sunfish, etc., $k_{20}Q_7$	10.6 x 10^6 kgs C/year	
23	Harvest by sport fishermen, $k_{18}Q_7N_4$	.02 x 10^6 kgs C/year	
24	Harvest by commercial fishermen, $k_{21}Q_7N_5$	.13 x 10^6 kgs C/year	
25	Ingestion of sunfish, etc. by bass, etc., $k_{19}Q_6Q_7$	1.4 x 10^6 kgs C/year	
26	Miscellaneous losses of invertebrate detritivores		
27	Ingestion of invertebrate detritivores by bass, etc.	Assumed to be 7.1 x 10^6 kgs C	

water flow and precipitation amounts to 43.2 x 10^6 kilograms C per year with the Kissimmee River contributing approximately 50 percent (22 x 10^6 kgs C/yr.) to the total. Another source of organic carbon is phytoplankton production within the lake. For the open-water or pelagic zone the level of net production was taken as 70 percent of gross production. Gross production was found to average about 2.9 grams carbon per square meter per day. This gives a net production of 2 grams per m^2 per day or 1060 x 10^6 kgs carbon per year for the open-water zone of the lake. In the littoral zone where the marsh vegetation is found, a conservative estimate of annual average marsh phytoplankton production of 1 gram carbon per m^2 per day was used, based on data from Ager (1972), Davis and Marshall (1975) and Gayle (1975). This yields a total net production for phytoplankton in the marsh area of 100 x 10^6 kilograms carbon per year. Zooplankton net production for the lake was estimated as 31 x 10^6 kilograms of carbon per year. The marsh area also exports carbon to the lake. No values exist for the amount of detritus that marsh plants export to the pelagic zone. Day et al. (1973) found that 50 percent of net production of salt marsh is exported each year. Applied to Lake Okeechobee this gives a value of 200 x 10^6 kgs carbon per year. This value seems high and so the standing crop of 65.3 x 10^6 kilograms of carbon per year was used.

The carbon outflows include a surface water outflow calculated as 94 x 10^6 kilograms of carbon per year based on an average concentration of 20 grams organic carbon per m^3 and an average outflow of 150 cubic meters per sec. Settling of organic carbon was assumed to be the greatest outflow from this compartment and was estimated, based on work by Day et al. (1973) and Gayle (1975), to be 1084 x 10^6 kilograms carbon per year. Resuspension of sediments back into the organic carbon compartment was estimated as 10 percent of the settling rate.

Marsh Standing Crop

The only data available on productivity of freshwater marshes is that measured by Bayley (1973). Bayley found that gross primary production was about 27 grams carbon per m^2 per day for a *Typha* marsh. If net production is assumed to be 30 percent of gross production, this gives a value of 8.1 grams carbon per m^2 per day as net production. The average value for the Okeechobee marshes was estimated as 50 percent of this or about 4 grams carbon per m^2 per day. A marsh area of 276×10^6 m^2 would then give an annual marsh net production of 400×10^6 kilograms carbon for the lake. The Okeechobee marshes consist of five types each named by the most dominant plant species. The total standing crop for these marshes was estimated to be 65.3×10^6 kilograms carbon divided as follows: Cattail marsh - 18.4×10^6 kilograms, Spikerush marsh - 17.3×10^6 kilograms, Bulrush marsh - 22.2×10^6 kilograms, Submergent plants - 5.9×10^6 kilograms, Water lily marsh - 1.5×10^6 kilograms.

Bottom Detritus

The mean thickness of bottom detritus was assumed to be 27 centimeters and the active part was estimated as 5 centimeters. Day, et al.(1973), states that wet organic sediments of a salt marsh have a bulk density of about 1.1 and carbon content is about 0.04 of this bulk density of the bottom sediments of Okeechobee; therefore, it was estimated to be 1 gram per cm^3 and the carbon content of the sediments to be 4 percent. Therefore, the amount of detritus actively involved in the structure and function of the lake ecosystem was 2000 grams carbon per m^2 or 3480 x 10^6 kilograms carbon for the lake. Flow into detritus was already discussed. Ingestion of bottom detritus by invertebrate detritivores was calculated to be 820 x 10^6 kgs C per year. Decomposition of detritus was assumed to be 148 x 10^6 kgs C per year. This corresponds to a rate of decomposition of 85 gm carbon m^{-2} $year^{-1}$. This compares to a rate of 144 gm carbon m^{-2} $year^{-1}$ for mangrove detritus (Lugo and Snedaker, 1973). Fresh water decomposition is slower than that in brackish water as measured by Heald (1971).

The amount being decomposed was found by difference after assuming that net accumulation of sediments was 0.1 mm per year. If Lake Okeechobee was formed about 4000 years ago and the mean depth of sediments is now 27 centimeters, then the rate of accumulation would be about 0.07 mm per year. This value was rounded to 0.1 mm per year.

Invertebrate Detritivores
(Molluscs, Insects, Gastropoda, Crustacea, Annelida)

The standing crop of invertebrate detritivores was estimated as 18.4 x 10^6 kilograms carbon. This value was calculated using numbers of organisms data from Game and Freshwater Fish Commission reports and average weights for these organisms. Respiration was estimated to be 5 percent of body weight per day or 336 x 10^6 kilograms per year, based on Waters (1969) measured invertebrate respiration of 5 percent of body weight per day. Net production was estimated as 4 times standing crop and thus equals 74 x 10^6 kilograms per year. Assimilation equals respiration plus net production or 410 x 10^6 kilograms per year. Gross ingestion was taken as twice the assimilation rate or 820 x 10^6 kilograms per year. Grazing rates on the detritivores include 13.4 x 10^6 kgs per year by the trophic level containing sunfish, black crappie, brown bullhead, channel catfish and lake chubsucker and 7.1 x 10^6 kilograms per year by the trophic level containing largemouth bass, chain pickerel, bowfin, Florida gar and needlefish. The remaining 53.5 x 10^6 kilograms was assumed to be a function of detritivore standing crop.

Forage Fish

Forage fish include gizzard shad and threadfin shad and many smaller species. The standing crop of gizzard shad was estimated by Ager to be 13,300,000 lbs. wet weight or 0.85 x 10^6 kilograms carbon. (The weight in carbon was calculated assuming that dry weight equals 27.8 percent of wet weight and 1 gram dry weight equals 0.5 grams carbon. Gerking (1962) measured the ratio of dry weight of sunfish to wet weight to be 0.278. It is generally wide knowledge in ecological circles that 1 gram of organic matter is approximately equivalent to 0.5 grams of carbon.) Threadfin shad standing crop was estimated as 1,560,000 lbs. wet weight or 0.1 x 10^6 kilograms carbon and other forage species were estimated as 0.04 x 10^6 kilograms carbon. The total standing crop of forage fishes was therefore 0.85 x 10^6 + 0.1 x 10^6 + 0.04 x 10^6 or 0.99 x 10^6 kilograms carbon. Annual net production was assumed to be equal to standing crop based on work by Gerking (1962) who used a factor of 140 percent of standing crop for net fish production. Respiration was taken as 7.85 times standing crop or 7.8 x 10^6 kilograms carbon per year. Annual egestion loss was 2.1 times standing crop or 2.1 x 10^6 kilograms carbon per year. Annual gross ingestion rate was equal to net production plus respiration plus egestion loss or 10.9 x 10^6 kilograms carbon per year. These fish were assumed to graze only on material from the organic carbon compartment as *Dorosoma cepedianum* and *D. petenense* comprise most of the biomass of the herbivore compartment and they feed predominantly on phytoplankton and zooplankton. Grazing on the forage fish amounted to 0.52 x 10^6 kgs carbon by sunfish, black crappie, etc., and 0.54 x 10^6 kgs carbon by bass pickerel, etc. A pathway is also shown for potential future harvest of this trophic level. This will be discussed further in the simulation section.

Sunfish, Black Crappie, Channel Catfish Brown Bullhead, Lake Chubsucker

The dominant sunfish in Lake Okeechobee are the bluegill and shell-crackers with a combined standing crop of 8,700,000 lbs wet weight or 0.55 x 10^6 kilograms carbon. Black crappie standing crop equals 6,000,000 lbs wet weight or 0.38 x 10^6 kilograms carbon. Other fish in this trophic level are brown bullhead and channel catfish with a combined standing crop of 5,700,000 lbs wet weight or 0.36 x 10^6 kilograms carbon and also the lake chubsucker with a standing crop of 1,100,000 lbs wet weight or 0.07 x 10^6 kilogram carbon. The total standing crop is 1.4 x 10^6 kilograms carbon; respiration is 10.6 x 10^6 kilograms carbon per year; net production is 1.4 x 10^6 kilograms carbon per year; assimilation is 12.0 x 10^6 kilograms carbon per year; and gross ingestion rate is 14.8 x 10^6 kilograms carbon per year. Sport fishing removes 315,000 lbs of black crappie (wet weight) or 0.02 x 10^6 kilograms carbon per year and commercial fishing removes 2,100,000 lbs of brown bullheads and channel catfish (wet weight) or 0.13

x 10^6 kilogram carbon per year. If the omnivore biomass level is at steady state, then the feeding rate of bass, pickerel, gar, bowfin, needlefish equals 1.3 x 10^6 kgs carbon $year^{-1}$, and therefore this value was used.

<u>Bass, Chain Pickerel, Gar, Bowfin, Needlefish</u>

The standing crop of largemouth bass was estimated by Ager as 2,600,000 lbs wet weight or 0.16 x 10^6 kilograms carbon. Other fish at this level are the chain pickerel with a standing crop of 600,000 lbs wet weight or 0.04 kilograms carbon, the gars with a standing crop of 6,800,000 lbs wet weight or 0.43 x 10^6 kilograms carbon, the bowfin with a standing crop of 2,300,000 lbs wet weight or 0.15 x 10^6 kilograms carbon and the needlefish with a standing crop of 670,000 lbs wet weight or 0.04 x 10^6 kilograms carbon. The total standing crop of fish at this level is equal to 6.4 x 10^6 kilograms carbon per year; net production equals 0.82 x 10^6 kilograms carbon per year; assimilation rate equals 7.2 x 10^6 kilograms carbon per year; and gross ingestion rate equals 9.0 x 10^6 kilograms carbon per year. Sport fishing was considered to have a negligible impact on the fish in this trophic level. Miscellaneous losses were assumed to equal net production, as if the biomass of carnivores is at steady state, then miscellaneous losses equal net production.

Equations and Coefficients for Simulation Model

Figure 2 depicts the simulated model with all the pathways described by their correct equation. The differential equations for each compartment are listed in Table 4. Table 5 lists the pathway coefficients and their calculated values while Table 6 gives the scaled differential equations that were used for the analog simulation.

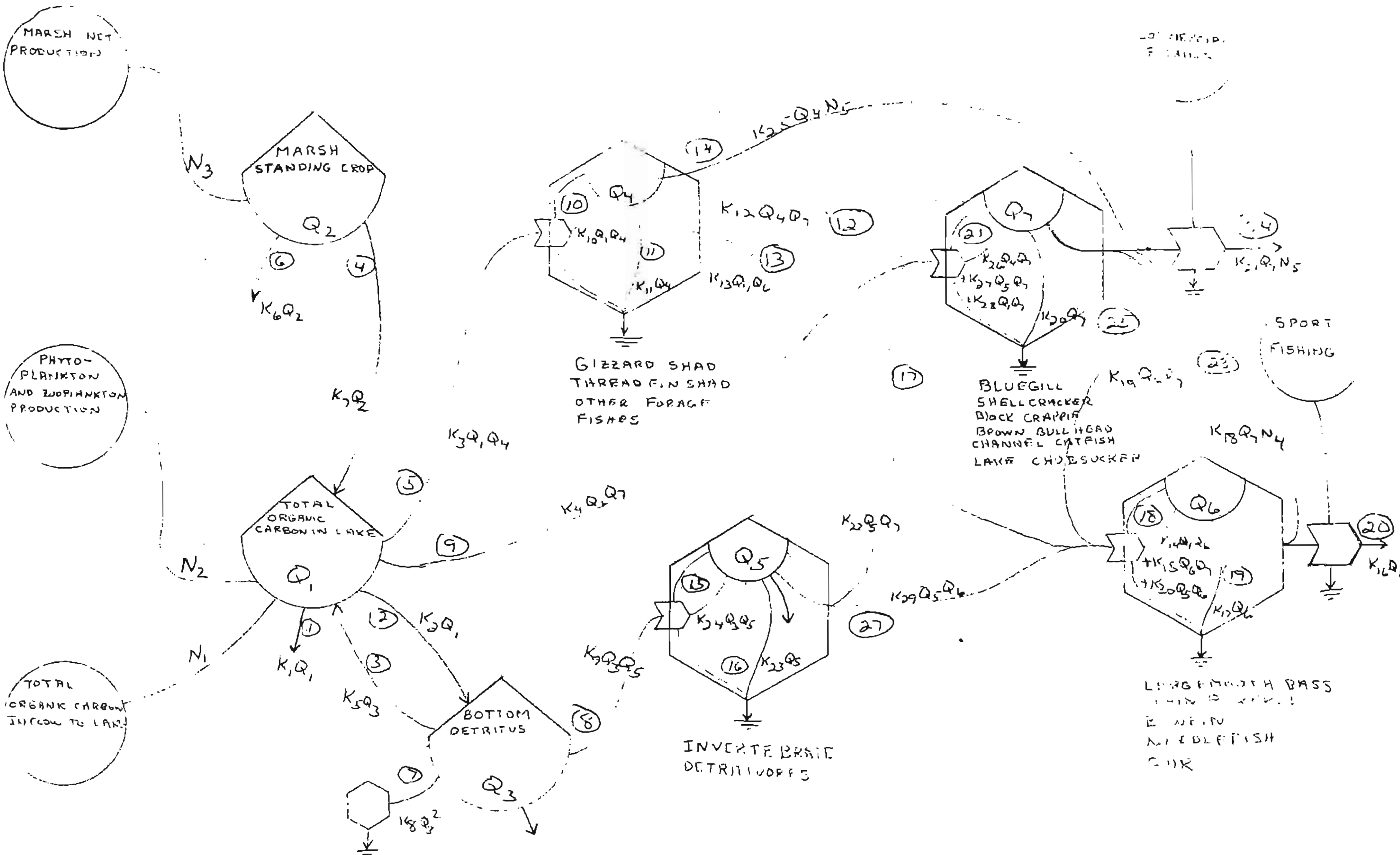


Fig. 2. Lake Okeechobee fisheries model with equations for flows.

Table 4
Differential Equations Used In The Simulation
Of The Lake Okeechobee Fish Model

Total Organic Carbon

$$\dot{Q}_1 = N_1 + N_2 + k_5 Q_3 + k_7 Q_2 - k_3 Q_1 Q_4 - K_1 Q_1 - k_2 Q_1 - k_4 Q_1 Q_7$$

Biomass of Marsh Plants

$$\dot{Q}_2 = N_3 - k_6 Q_2 - k_7 Q_2$$

Bottom Detritus

$$\dot{Q}_3 = k_2 Q_1 - k_5 Q_3 - k_8 Q_3^2 - k_9 Q_3 Q_5$$

Forage Fish

$$\dot{Q}_4 = k_{10} Q_1 Q_4 - k_{11} Q_4^2 - k_{12} Q_4 Q_7 - k_{13} Q_4 Q_6 - k_{25} Q_4$$

Invertebrate Detritivores

$$\dot{Q}_5 = k_{24} Q_3 Q_5 - k_{23} Q_5^2 - k_{22} Q_5 Q_7 - k_{29} Q_5 Q_6$$

Carnivorous Fish

$$\dot{Q}_6 = k_{14} Q_4 Q_6 + k_{15} Q_6 Q_7 - k_{17} Q_6^2 - k_{16} Q_6 + k_{30} Q_5 Q_6$$

Omnivorous Fish

$$\dot{Q}_7 = k_{28} Q_1 Q_7 + k_{26} Q_4 Q_7 + k_{27} Q_5 Q_7 - k_{20} Q_7^2 - k_{21} Q_7$$

Table 5
Calculated Values For rate Coefficients
In Lake Okeechobee Fish Model

Coefficient	Value
k_1	1.06 $year^{-1}$
k_2	12.18 $year^{-1}$
k_3	$1.22x10^{-7}$ Kgs^{-1} $year^{-1}$
k_4	$7.22x10^{-9}$ Kgs^{-1} $year^{-1}$
k_5	.031 $year^{-1}$
k_6	5.13 $year^{-1}$
k_7	1.0 $year^{-1}$
k_8	$1.22x10^{-11}$ Kgs^{-1} $year^{-1}$
k_9	$1.28x10^{-8}$ Kgs^{-1} $year^{-1}$
k_{10}	$.99x10^{-7}$ Kgs^{-1} $year^{-1}$
k_{11}	$7.8x10^{-6}$ $year^{-1}$
k_{12}	$3.71x10^{-7}$ Kgs^{-1} $year^{-1}$
k_{13}	$6.59x10^{-7}$ Kgs^{-1} $year^{-1}$
k_{14}	$4.32x10^{-7}$ Kgs^{-1} $year^{-1}$
k_{15}	$1.88x10^{-6}$ Kgs^{-1} $Year^{-1}$
k_{16}	.009 $year^{-1}$
k_{17}	$9.5x10^{-6}$ $year^{-1}$
k_{18}	.014 $year^{-1}$
k_{19}	$1.22x10^{-6}$ Kgs^{-1} $year^{-1}$
k_{20}	$5.43x10^{-6}$ $year^{-1}$
k_{21}	.093 $year^{-1}$
k_{22}	$5.2x10^{-7}$ Kgs^{-1} $year^{-1}$
k_{23}	$.99x10^{-6}$ $year^{-1}$
k_{24}	$6.4x10^{-9}$ Kgs^{-1} $Year^{-1}$
k_{25}	Variable (0 at start)

Table 5 (Cont.)

k_{26}	$3x10^{-7}$ Kgs^{-1} $year^{-1}$
k_{27}	$4.2x10^{-7}$ Kgs^{-1} $year^{-1}$
k_{28}	$5.86x10^{-9}$ kgs^{-1} $year^{-1}$
k_{29}	$3.8x10^{-7}$ Kgs^{-1} $year^{-1}$
k_{30}	$4.7x10^{-7}$ Kgs^{-1} $year^{-1}$

Table 6
Scaled Differential Equations Used In The Analog Simulation
Of The Lake Okeechobee Fish Model

Total Organic Carbon

$$\frac{\dot{Q}_1}{5\times10^8(10)} = .009 + .238 + .062\left[\frac{Q_3}{10^{10}}\right] + .06\left[\frac{Q_2}{2\times10^8}\right] + .0305\left[\frac{Q_1}{5\times10^8}\right]\left[\frac{Q_4}{2.5\times10^6}\right] - .106\left[\frac{Q_1}{5\times10^8}\right] - 1.218\left[\frac{Q_1}{5\times10^8}\right] - .003\left[\frac{Q_1}{5\times10^8}\right]\left[\frac{Q_7}{4\times10^6}\right]$$

Biomass Of Marsh Plants

$$\frac{\dot{Q}_2}{3\times10^8(10)} = .133 - .513\left[\frac{Q_2}{3\times10^8}\right] - .100\left[\frac{Q_2}{3\times10^8}\right]$$

Bottom Detritus

$$\frac{\dot{Q}_3}{10^{10}(10)} = .061\left[\frac{Q_1}{5\times10^8}\right] - .003\left[\frac{Q_3}{10^{10}}\right] - .012\left[\frac{Q_3}{10^{10}}\right]^2 - .064\left[\frac{Q_3}{10^{10}}\right]\left[\frac{Q_5}{5\times10^7}\right]$$

Forage Fish

$$\frac{\dot{Q}_4}{2.5\times10^6(10)} = 4.95\left[\frac{Q_1}{5\times10^8}\right]\left[\frac{Q_4}{2.5\times10^6}\right] - 1.95\left[\frac{Q_4}{2.5\times10^6}\right]$$

Table 6 (Cont.)

$$- .148 \left[\frac{Q_4}{2.5\times10^6}\right]\left[\frac{Q_7}{4\times10^6}\right] - .165 \left[\frac{Q_4}{2.5\times10^6}\right]\left[\frac{Q_6}{2.5\times10^6}\right]$$

Invertebrate Detritivores

$$\frac{\dot{Q}_5}{5\times10^7} = 6.4 \left[\frac{Q_3}{10^{10}}\right]\left[\frac{Q_5}{5\times10^7}\right] - 4.95 \left[\frac{Q_5}{5\times10^7}\right]^2 - .208 \left[\frac{Q_5}{5\times10^7}\right]\left[\frac{Q_7}{4\times10^6}\right]$$

$$- .095 \left[\frac{Q_5}{5\times10^7}\right]\left[\frac{Q_6}{2.5\times10^6}\right]$$

Carnivorous Fish

$$\frac{\dot{Q}_6}{2.5\times10^6(10)} = .132 \left[\frac{Q_4}{2.5\times10^6}\right]\left[\frac{Q_6}{2.5\times10^6}\right] + .752 \left[\frac{Q_6}{2.5\times10^6}\right]\left[\frac{Q_7}{4\times10^6}\right]$$

$$+ 2.35 \left[\frac{Q_6}{2.5\times10^6}\right]\left[\frac{Q_5}{5\times10^7}\right] - 2.38 \left[\frac{Q_6}{2.5\times10^6}\right]^2$$

Omnivorous Fish

$$\frac{\dot{Q}_7}{4\times10^6\,(10)} = .293 \left[\frac{Q_1}{5\times10^8}\right]\left[\frac{Q_7}{4\times10^6}\right] + .075 \left[\frac{Q_4}{2.5\times10^6}\right]\left[\frac{Q_2}{4\times10^6}\right]$$

$$+ 2.1 \left[\frac{Q_5}{5\times10^7}\right]\left[\frac{Q_7}{4\times10^6}\right] - 2.17 \left[\frac{Q_7}{4\times10^6}\right]^2 - .009 \left[\frac{Q_7}{4\times10^6}\right]$$

$$- .305 \left[\frac{Q_6}{2.5\times10^6}\right]\left[\frac{Q_7}{4\times10^6}\right]$$

Results

The results of the simulation runs are shown in Figs. 3-8. Figures 3a-f show the effect of abruptly changing the rate of phytoplankton and zooplankton production on total organic carbon bottom detritus; invertebrate detritivores, forage fish, omnivorous fish and carnivorous fish. Figure 4 shows the effect of commercial fishing for omnivores, such as brown bullhead and channel catfish on levels of omnivores, carnivores, forage fish and detritivores. Figures 5a, b look at sport fishing for the carnivorous fishes. Figure 6 looks at the possibility of commercial fishing of the forage fishes, such as gizzard and threadfin shad. Figures 7b-g look at the impact on total organic carbon, detritus, invertebrate detritivores, forage fish, omnivorous fish and carnivorous fish where the rate of phyto- and zooplankton production is allowed to change during a ten-year period. Figures 8b-d show what happens to bottom detritus, omnivores and carnivores when predation on the invertebrate detritivores (Fig. 8a) is varied.

Abrupt Changes In Phytoplankton And Zooplankton Production

The four rates of annual production of phytoplankton and zooplankton simulated were 1190×10^6 Kgs carbon, 590×10^6 Kgs carbon, 2380 Kgs carbon and 4760 Kgs carbon. The base level used in the model was 1190×10^6 Kgs carbon. If this rate is reduced by 50 percent, the level of organic carbon in the lake is reduced 50% from 120×10^6 to 60×10^6 Kgs. Bottom sediments are reduced only 25 percent from 3200×10^6 to 2400×10^6 Kgs carbon. Invertebrate detritivores, forage

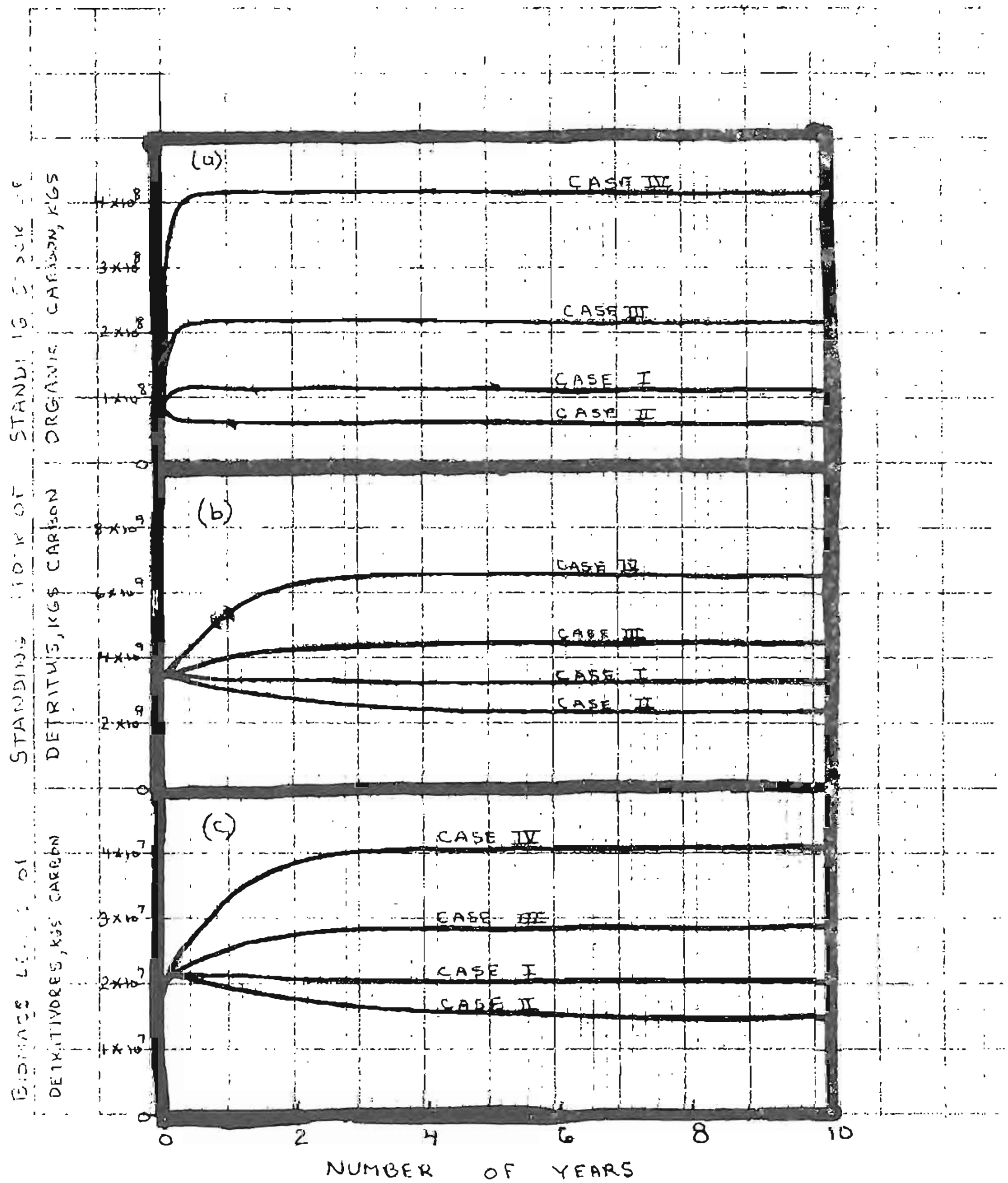


Figure 3 - Effect of changes in phytoplankton and zooplankton production on (a) organic carbon in lake, (b) detritus, (c) detritivores, (d) forage fish, (e) omnivores, (f) carnivores.

Case I - Production equals 1190 kgs carbon/year
Case II - Production equals 590 kgs carbon/year
Case III - Production equals 2380 kgs carbon/year
Case IV - Production equals 4760 kgs carbon/year

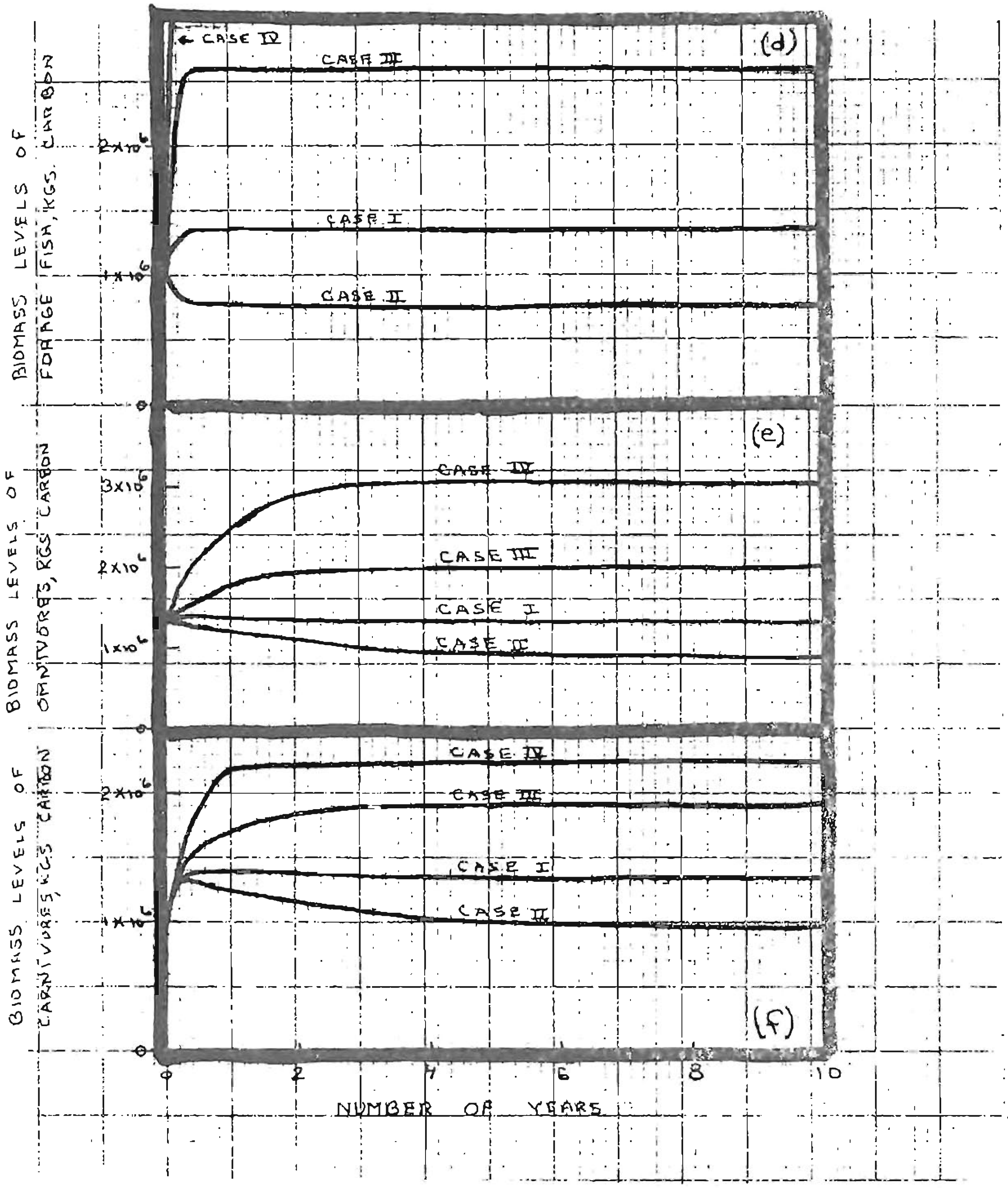


Figure 3 - Continued

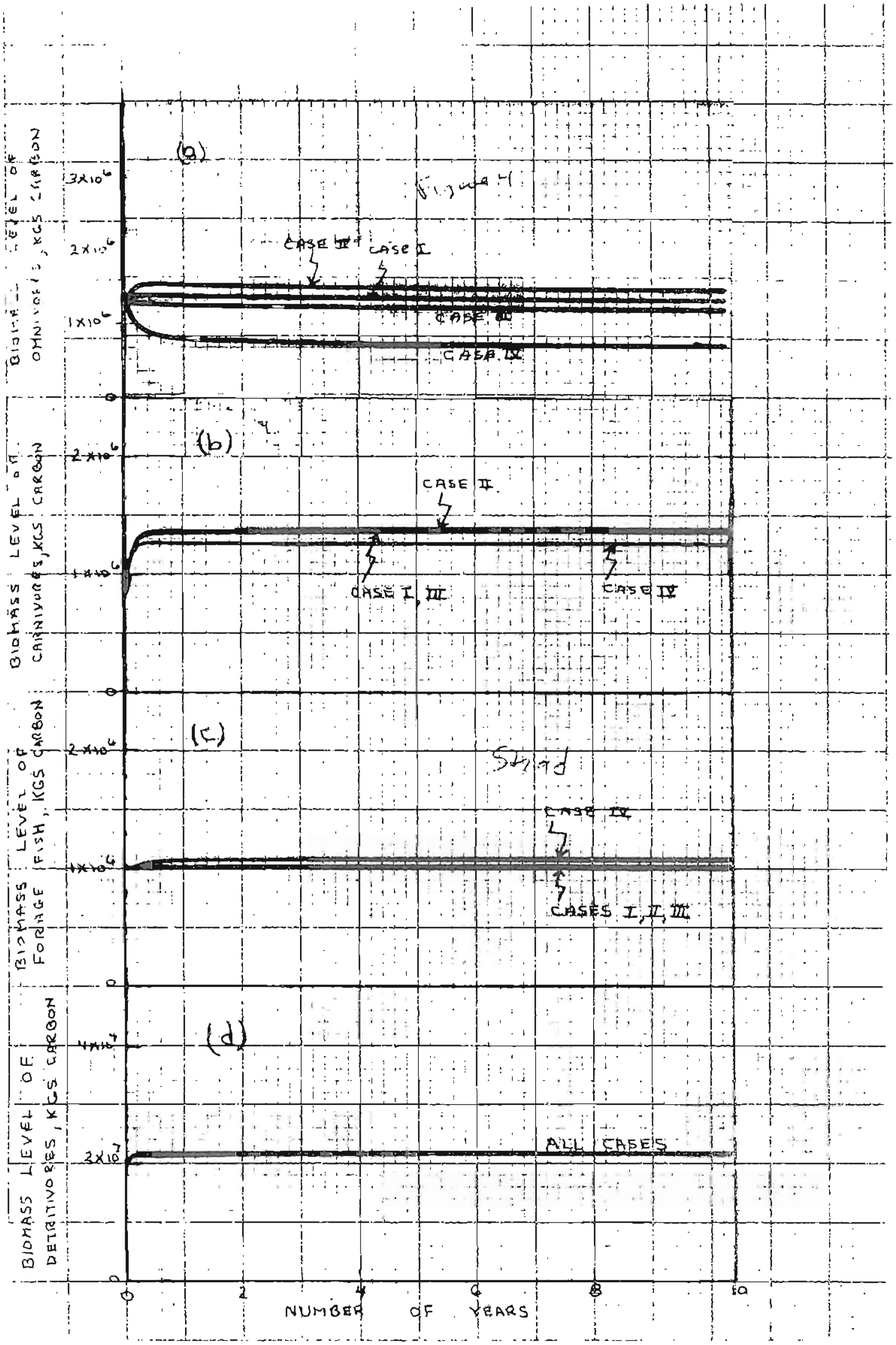


Figure 4 - Effect of commercial fishing on omnivores, carnivores, forage fish and detritivores.

Case I - Base Level
Case II - No Fishing
Case III - 2 x Base Level
Case IV - 5 x Base Level

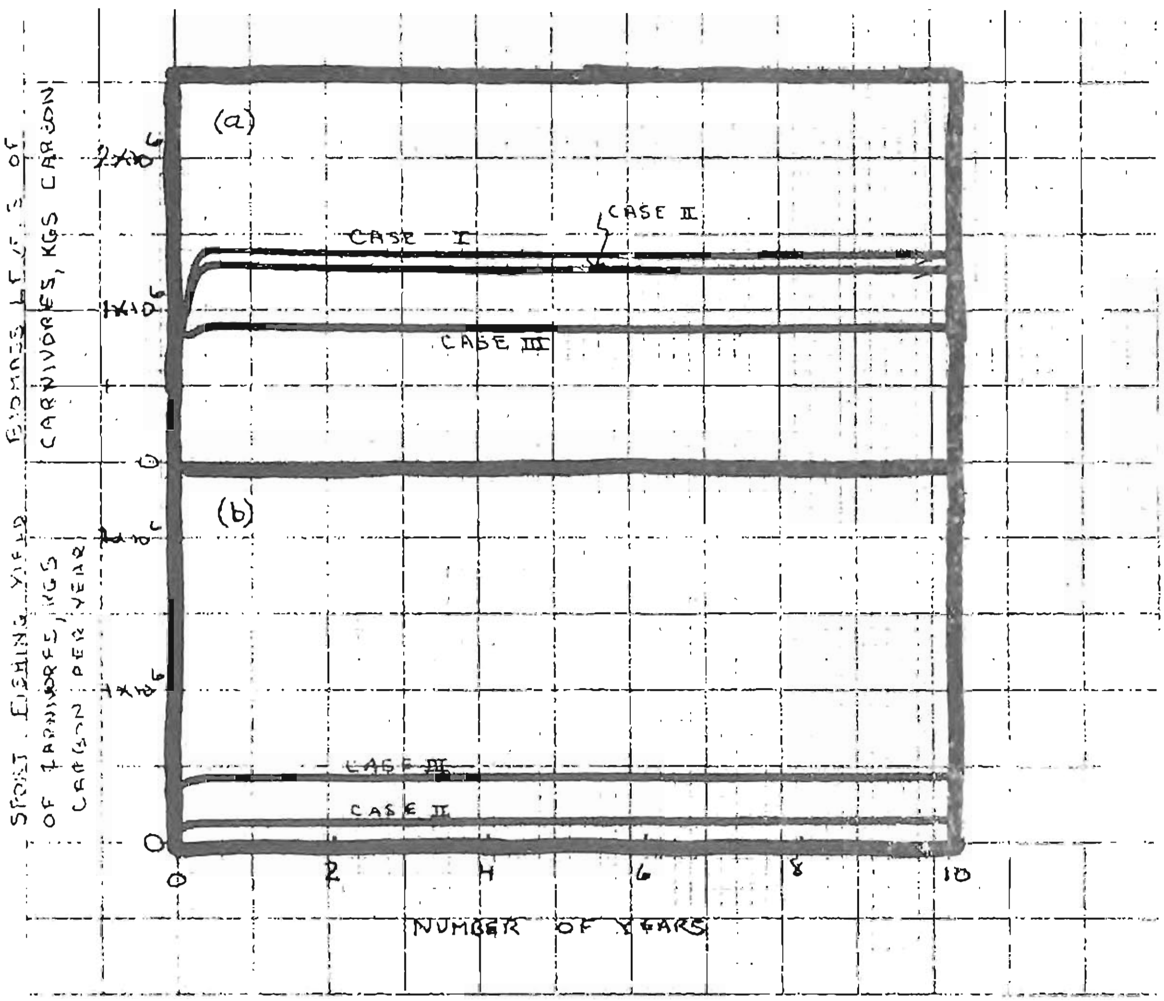


Figure 5 - Effect of sport fishing on (a) biomass of carnivores and (b) yield of carnivores.

Case I - Sport fishing takes no carnivores
Case II - Sport fishing takes 10 per cent of standing crop
Case III - Sport fishing takes 50 per cent of standing crop

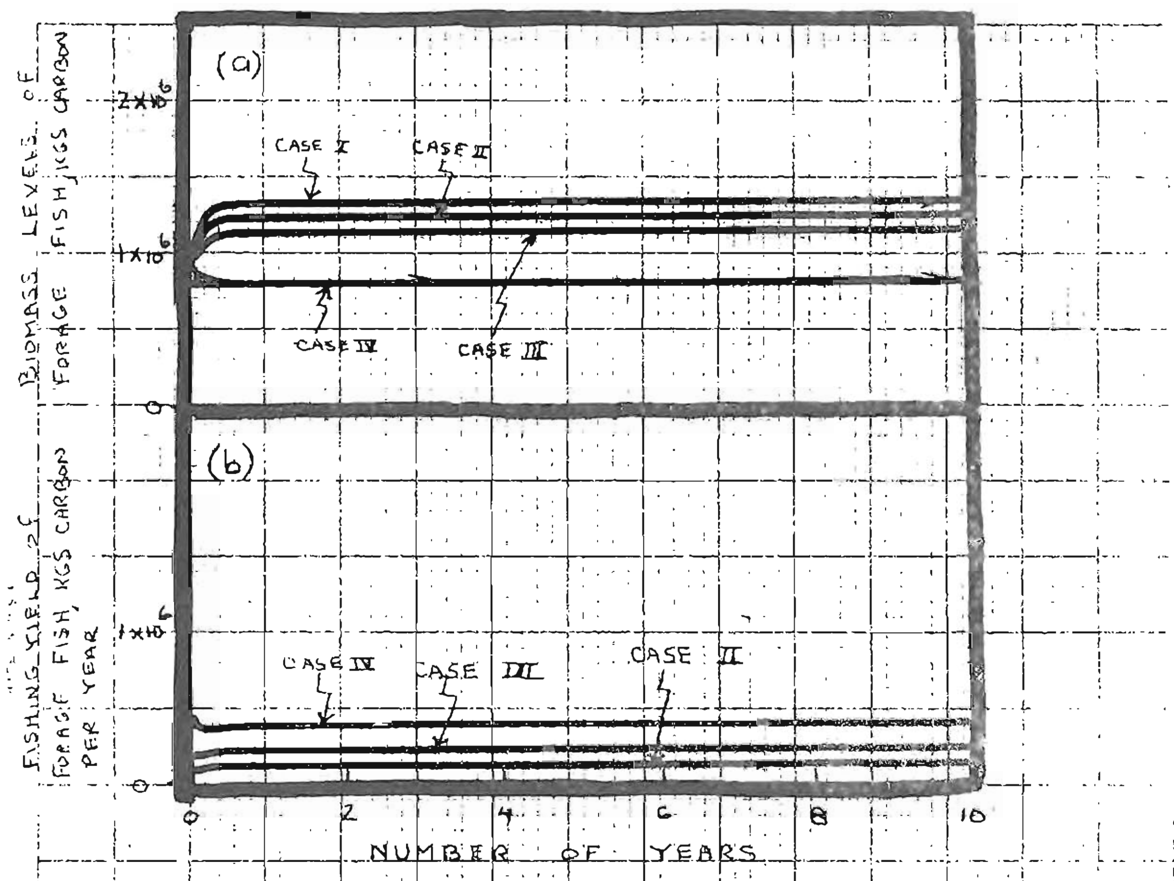


Figure 6 - Effect of commercial fishing for forage fish on (a) biomass level of forage fish and (b) yields of forage fish.

Case I No sustained yield
Case II Sustained yield of 10 percent of standing stock
Case III Sustained yield of 20 percent of standing stock
Case IV Sustained yield of 50 percent of standing stock

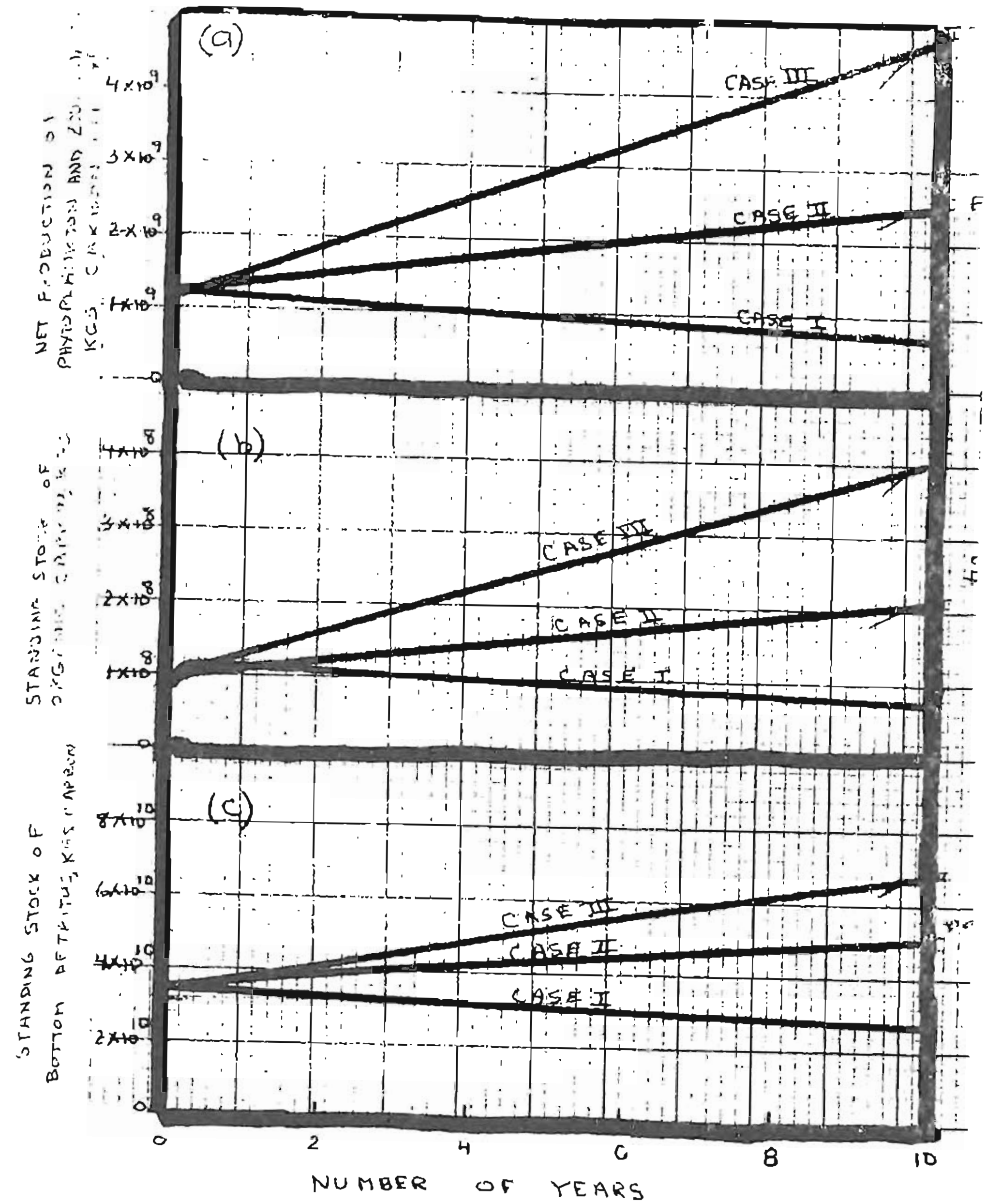
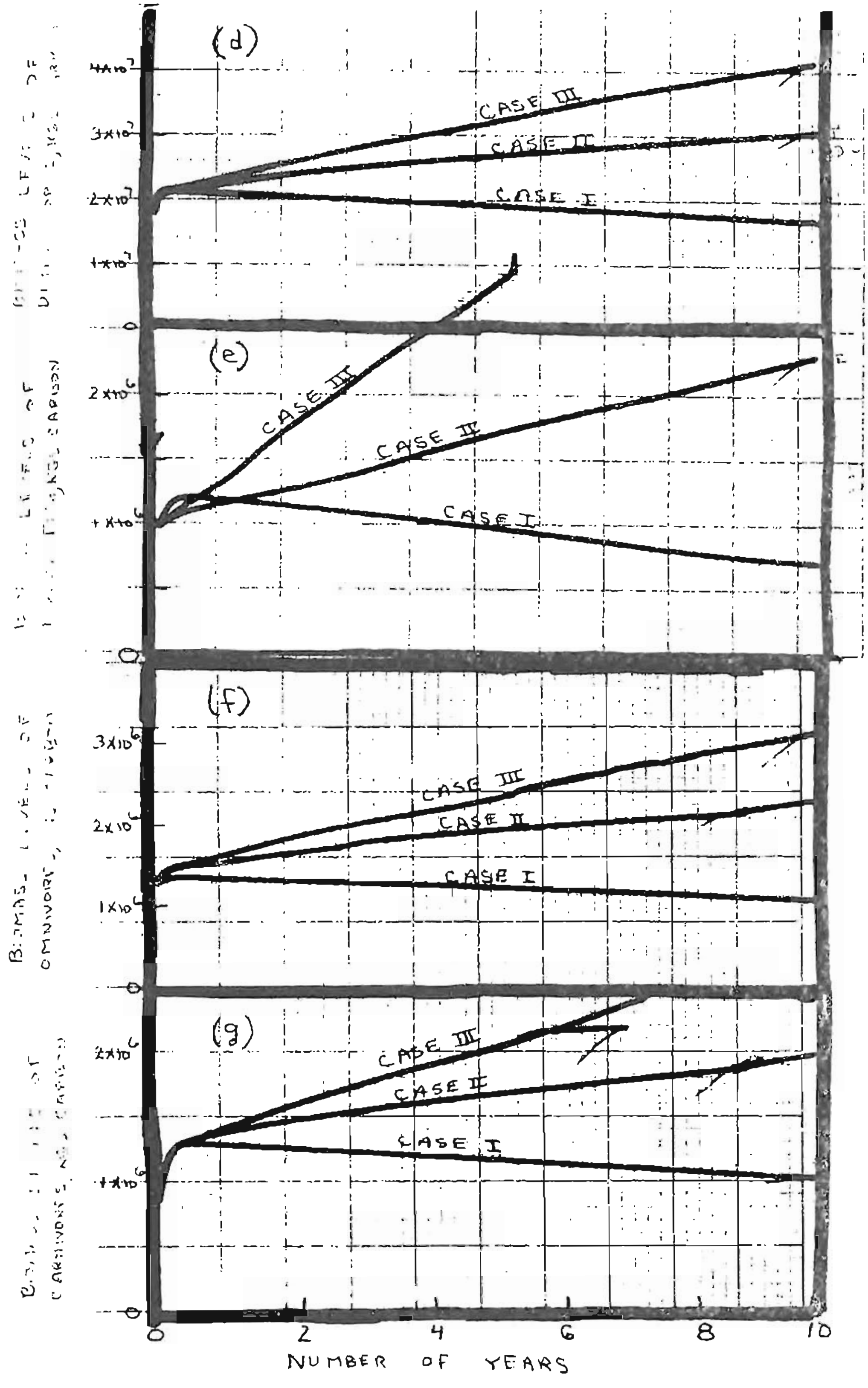


Figure 7 - Effect of changing levels of phytoplankton and zooplankton production (Fig. 8a) on (b) organic carbon, (c) bottom detritus, (d) detritivores (e) forage fish, (f) omnivorous fish (g) carnivorous fish. For Fig. 8a, the three cases are: I. Production decreases 50% over ten years span. II. Production doubles over ten years. III. Production quadruples over ten years.



(d)
4x10^7
3x10^7
2x10^7
1x10^7
0
CASE III
CASE II
CASE I
(e)
2x10^6
1x10^6
0
CASE III
CASE II
CASE I
(f)
3x10^6
2x10^6
1x10^6
0
CASE III
CASE II
CASE I
(g)
2x10^6
1x10^6
0
CASE III
CASE II
CASE I
0
2
4
6
8
10
NUMBER OF YEARS

Fig. 7. (con.)

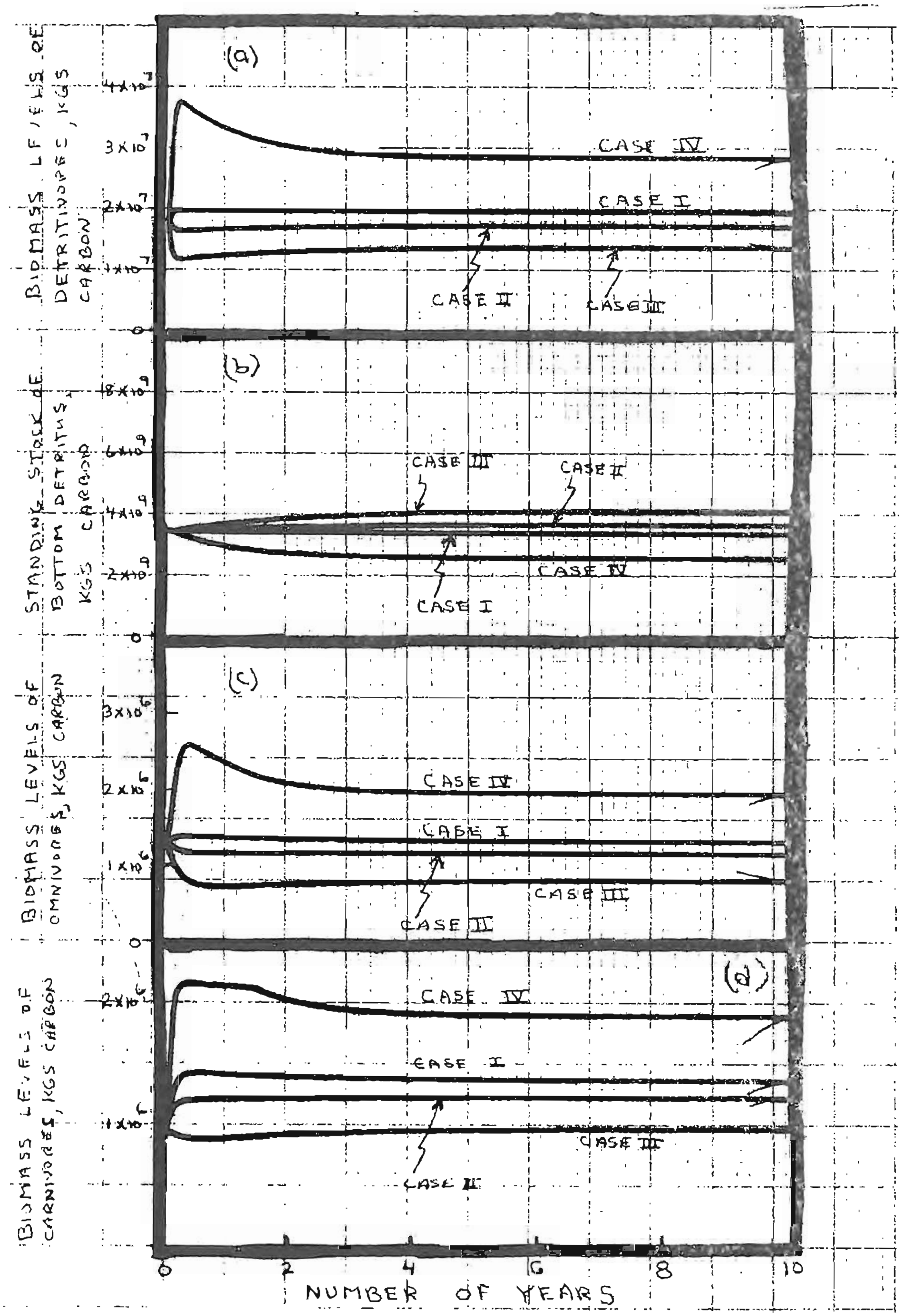


Figure 8 - Effect of changing levels of detritivore predation on (a) detritivores, (b) detritus, (c) omnivores, (d) carnivores.

Case I Base level

Case II 125 percent of base level

Case III 200 percent of base level

Case IV 50 percent of base level

fish, omnivorous fish and carnivorous fish also decreased about 25 percent. Increasing production from 1190×10^6 to 2380×10^6 Kgs carbon caused a doubling of organic carbon, from 120×10^6 to 240×10^6 Kgs, a 40 percent increase in bottom sediments from 3200×10^6 to 4400×10^6 Kgs, a 40 percent increase in invertebrate detritivores, a 90 percent increase in forage fish, a 40 percent increase in omnivores and a 40 percent increase in carnivores. If phytoplankton and zooplankton production are 4 times the base level or 4760 Kgs carbon per year, then organic carbon increases from 120×10^6 to 440×10^6. The level of detritus increased about 100 percent and there was a 100 percent increase in detritivores, an estimated 300 percent increase in forage fish, a 120 percent increase in omnivores and a 70 percent increase in carnivores.

Commercial And Sport Fishing Impact

Figures 4a-d show the response of commercial fishing for omnivores on the biomass levels of omnivores, carnivores, forage fish and invertebrate detritivores. The base level of fishing equals $.13 \times 10^6$ Kgs carbon and presently consists of brown bullheads and channel catfish. If this fishing were halted, the level of omnivores would increase only about 10 percent. A doubling of the fishing effort would lower the level about 10 percent and at 5 x the present fishing effort the level would decrease from 1.4×10^6 down to $.80 \times 10^6$ Kgs carbon. The effects on other trophic levels were negligible, as can be seen in Fig. 4b for carnivores, Fig. 4c for forage fish, and in Fig. 4d for invertebrate detritivores.

In Fig. 5, the effect of sport fishing for carnivores on the level of carnivores and the yield is indicated. At present the amount of fish taken from this trophic level by sport fishing is negligible. If the rate is 10 percent of the standing crop, then the level of carnivores drops 10 percent and the yield is $.15 \times 10^6$ Kgs carbon per year. If sport fishing takes 50 percent of the standing crop, then the level drops 40 percent to 1.4×10^6 Kgs carbon and the yield is $.4 \times 10^6$ Kgs carbon/year.

Figures 6a and b show the impact of commercial fishing for forage fish on the level of forage fish and the yields. If the yield is 10 percent of the standing crop, the decrease in forage fish levels is about 10 percent. If 50 percent of standing crop is harvested annually, the forage fish levels decrease from 1.35×10^6 to 0.8Kgs carbon.

Constant Change In Phytoplankton And Zooplankton Production Over Ten Years

Figures 7b-g show the effects on various lake compartments of a constant rate of change in phytoplankton and zooplankton production over a period of ten years. The rates of change chosen were 5% per year decrease, 10% per year increase, and 30% per year increase. These three rates are shown in Fig. 8a. Total organic carbon (Fig. 8b) increased (decreased) at the same rate as phytoplankton and zooplankton production. Bottom detritus changed at rates only one-half those of the production rates as did the detritivores, omnivores and carnivores. However, the forage fish showed a rate of change equal to the rate of change for production of phytoplankton and zooplankton.

Effect Of Detritivore Predation

Figures 8a-d show the effect of detritivore predation other than fish on the levels of detritivores, bottom detritus, omnivores and carnivores. A 50 percent reduction causes the level of detritivores to double initially, but at steady-state the increase is only 40 percent.

Detritus levels are reduced 30 percent, omnivores increase 50 percent and carnivores increase 40%, all at steady-state. A 100 percent increase in predation causes a 30 percent reduction in detritivores, a 20 percent increase in detritus, a 40 percent decrease in omnivores, and a 30 percent decrease in carnivores.

Discussion

The model in Figure 1 was constructed to look at the effects of eutrophication on the aquatic life found in Lake Okeechobee. Any changes in the rate of production of phytoplankton and zooplankton in the lake will usually indicate changes in the rate of nutrient loading into Lake Okeechobee. In Figure 7, phytoplankton and zooplankton production was allowed to change at three rates. The first rate was a decrease in production so that after ten years the rate of production was 50 per cent of the initial value. This resulted in a decrease in the levels of all compartments in the model. Thus, if the amount of available energy and the lower trophic levels were lowered, the fish biomass that could be supported by the lake system was also lowered. This also applied to increasing the amount of available energy which caused subsequent increases in the fish biomass of the lake. Forage fish such as gizzard and threadfin shad showed the greatest response to changes in phytoplankton and zooplankton production. The values for predation of forage fish by other fish were low and this may mean that increased nutrient loading could result in an overabundance of fish at this trophic level. If this happened, consideration might then be given to commercial harvesting of these fish to keep the stocks down. Figure 6 showed that this could be done at levels up to 50 per cent of the standing stock without serious depletion of the forage fish biomass. However, a reduction in the biomass of an individual fish might occur. Species changes might also occur which were not able to be shown with this model.

The omnivores and carnivores were shown in the model as getting most of their food from detritivores. The reliability of this assumption may be subject to debate. Based on this assumption, however, the rate of predation by other organisms was changed to observe the impact on omnivore biomass and carnivore biomass. Reducing the predation by other organisms causes an increase in omnivores and carnivores to counterbalance the increase in detritivores.

Changes in the area occupied by marsh plants had no significant effect on any compartment in this model. This may not be true for individual fish species but may be the case at the large scale used for this model.

The simulation output for this model followed the correct patterns for the model as it was conceived. However, without any validation data, it was difficult to determine whether or not the output curves are realistic. The scarcity of data for fish and other pathways is needed to produce reliable simulations.

REFERENCES

Ager, L. A. 1972 Annual Report - Lake Okeechobee-Kissimmee River Project, 1972-73.

Bayley, S. and H. T. Odum (1973), Energy Evaluation of Water Management Alternatives in the Upper St. Johns River Basin of Florida, Environmental Protection Agency Report.

Brezonik, P. L. and A. Federico (1975), "Effects of Backpumping from Agricultural Canals on Water Quality in Lake Okeechobee," Completion Report to Florida Department of Pollution Control.

Davis, F. E. and M. L. Marshall (1975), "Chemical and Biological Investigations of Lake Okeechobee, January 1973-June 1974." Interim Report, Central and Southern Florida Flood Control District Technical Publications 75-1.

Day, J. W., W. G. Smith, P. R. Wagner and W. C. Stowe (1973), Community Structure and Carbon Budget of a Salt Marsh and Shallow Bay Estuarine System in Louisiana, Publ. No. LSU-SG-72-04, Center for Wetland Resources, Louisiana State University.

Earle, J. E., B. G. Waller, B. F. McPherson, and H. C. Mattraw (1973), Water Quality Monitoring and Study of the Everglades Basin, Florida. U. S. Geological Survey.

Gerking, S. D. (1962), "Production and Food Utilization in a Population of Bluegill Sunfish," Ecological Monographs 32, 31-78.

Heald, E. J. (1971), The Production of Organic Detritus in a South Florida Estuary Sea Grant Tech. Bull. #6, University of Miami.

Joyner, B. F. (1974), "Chemical and Biological Conditions in Lake Okeechobee, Florida, 1969-1972," Report Inv. 71, United States Geological Survey.

Lugo, A. E. and S. C. Snedaker (1973), The Role of Mangrove Ecosystems in the Maintenance of Environmental Quality and a High Productivity of Desirable Fishes, Contract #14-16-008-606, Bureau of Sport Fisheries and Wildlife.

Waters, T. F. (1969), "The Turnover Ratio of Production Ecology of Freshwater Invertebrates," Am. Nat. 103, pp. 173-185.

V. COLIFORM MODEL FOR LAKE OKEECHOBEE

Tom Fontaine

Results of simulations of a model describing coliform bacterial populations in Lake Okeechobee are presented here. The coliform bacteria group includes two species, *Escherichia coli* and *Aerobacter aerogenes*, the former being a normal inhabitant of the intestinal tract of man and other animals. The latter species is found associated more often with grains and plants, but may also occur in the intestinal tract of man. The presence of large numbers of either species in natural waters can thus be used as an indicator of possible contamination with domestic sewage and any associated pathogens.

Results

Shown in Figure 1 is the evaluated coliform model for Lake Okeechobee. The model is basically an "average conditions" hydrologic model of Lake Okeechobee (simplified, from Gayle, 1975) with added coliform flows and storages. Further explanation of flows and storages, as well as scaled differential equations, analog diagram, transfer coefficients, etc., can be found in the appendix.

Results of simulations are presented in Figure 2. The top four sets of graphs refer to the hydrological components of the model. These appear to agree well with those of Gayle, 1975. The bottom set is a family of curves depicting possible populations of total coliforms in Lake Okeechobee under various mortality rates. These curves, as shown from top to bottom, reflect mortality rates of 1, 2, 4, 12 and 24 percent per day. Since the mortality rate of coliforms in Lake Okeechobee has not yet been determined, it is not possible to state which population curve would fit real data. However, if the mortality rate exceeds 12 percent

TOTAL COLIFORM MODEL FOR LAKE OKEECHOBEE

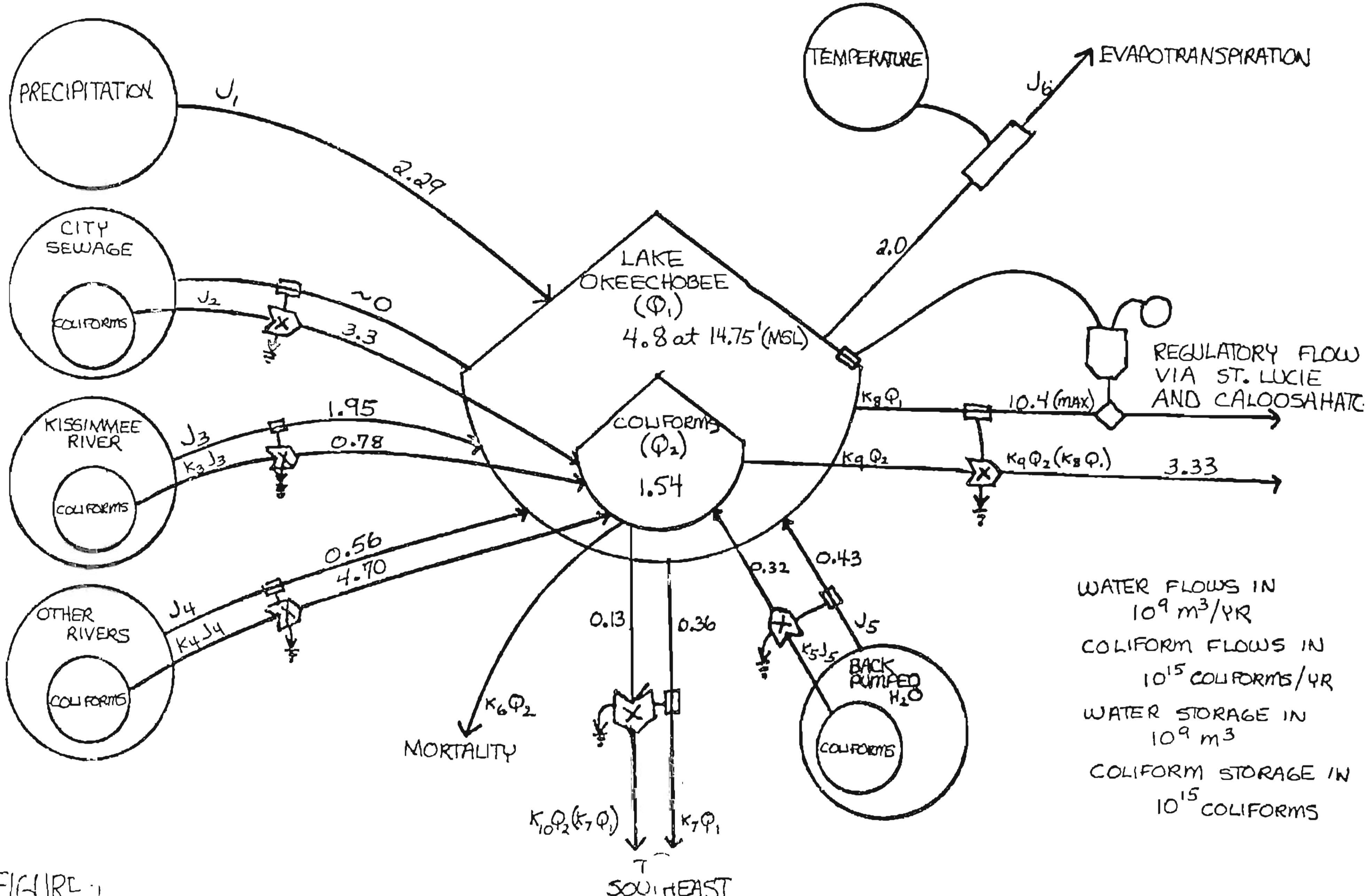


FIGURE 1

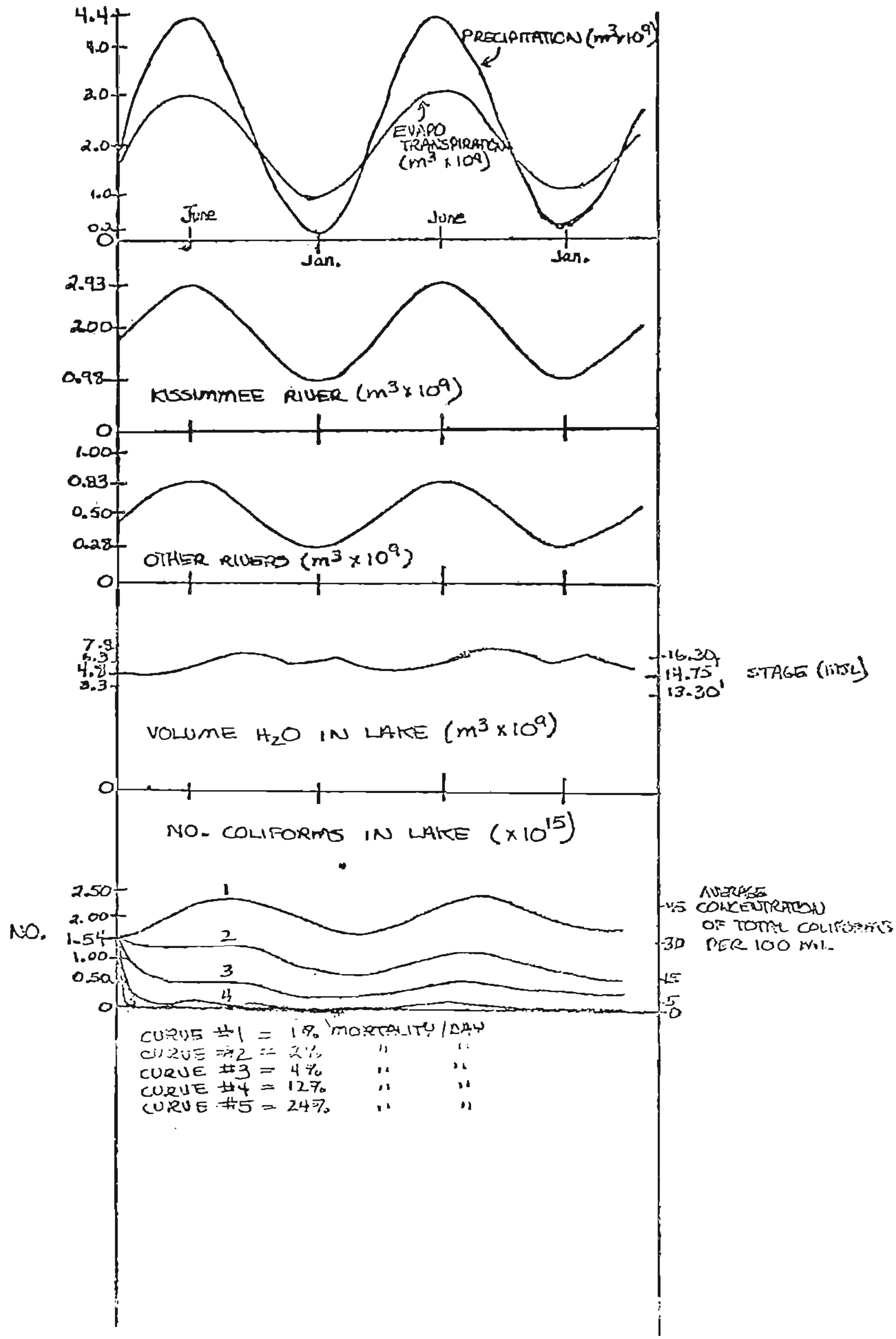


FIGURE 2. RESULTS OF SIMULATION

per day, the simulation shows that negligible concentrations of total coliforms would exist in the lake. The simulation also shows that highest concentrations of coliforms would occur during July as a result of highest river inflow in June. Since coliform concentrations were determined for an average 100 ml. of lake water, it is possible that areas nearest point source loadings may contain greater concentrations than the model indicates. Figure 3 indicates that coliform concentrations under present loading rates never exceed 50 organisms per 100 ml.; which is well within the coliform standards for Class 1 waters.

References

Gayle, T. L., Nordlie, F. G. and T. D. Fontaine, 1975. Lake Okeechobee: Its hydrologic, biologic and ecosystem characteristics. In H. T. Odum and M. Brown (eds), Carrying capacity for man and nature in South Florida. January, 1975. 946p.

Appendix

Table 1
Description of Model Components

Flow	Value	Description	Source
J_1	$2.29\times10^9 m^3/yr$	yearly rainfall on lake	Hartwell (70007)
___	$4.4\times10^6 m^3/yr$	sewage input to lake/yr	DPC - personal communication
J_2	3.3×10^{15} TC/yr	no. of total coliforms per year entering lake with city sewage (ave. no. TC/m^3 of sewage = $750\times10^6/m^3$)	DPC storet
J_3	$1.95\times10^9 m^3/yr$	Kissimmee River water input to lake per year	Joyner (1971)
k_3J_3	0.78×10^{15} TC/yr	no. of total coliforms per year entering lake via Kissimmee River water (ave. no. TC/m^3 of water = 0.4×10^6 TC/m^3)	DPC storet
J_4	$0.56\times10^9 m^3/yr$	other river water input to lake per year	Joyner (1971)
k_4J_4	4.7×10^{15} TC/yr	no. of total coliforms per year entering lake with other river H_2O (ave. no. TC/m^3 of river water = 8.4×10^6 TC/m^3)	DPC storet
J_5	$0.47\times10^9 m^3/yr$	water backpumped to lake per year	1971 water resources data for Florida
k_5J_5	0.32×10^{15} TC/yr	no. of total coliforms per year entering lake with backpumped H_2O (ave. no. TC/m^3 of backpumped water = $.32\times10^6$ TC/m^3; assumed to be same concentration as in lake.	DPC storet

Flow	Value	Description	Source
k_6Q_2	varied between 5.77×10^{15} TC/yr and 136.8×10^{15} TC/yr	mortality of coliforms per year (varied from 1% to 24% mortality per day)	
J_6	$2.0 \times 10^9 m^3$/yr	evapotranspiration from lake per year	Hartwell (70007)
k_7Q_1	$0.36 \times 10^9 m^3$/yr	outflow to southeast Florida	Hartwell (70007)
k_8Q_1	$10.4 \times 10^9 m^3$/yr	outflow from lake (regulatory) $10.4 \times 10^9 m^3$/yr = max discharge rate	Parker (1255)
$k_9Q_2(k_8Q_1)$	3.33×10^{15} TC/yr	outflow of TC per year through regulatory canals (ave. no. TC/m^3 = 0.32×10^6 TC/m^3; assumed to be same concentration as in lake.)	
$k_{10}Q_2(k_7Q_1)$	0.13×10^{15} TC/yr	outflow of TC/yr through S.E. canals (ave. concentration same as in lake)	

Storage	Value	Description	Source
Q_1	$4.8 \times 10^9 m^3$	water in lake	FCD stage-volume-area tables
Q_2	1.54×10^{15} TC	coliforms in lake (based on 0.32×10^6 TC/m^3)	DPC storet

Table 2
Further Descriptions of Forcing Functions

Flow	Description	Program	Yearly rates* Min.	Ave.	Max.
J_1	Precipitation	Sinusoid with maximum rate in July; minimum in December	0.20	2.29	4.40
J_2	Coliforms in city sewage	Constant rate of input	----	3.30	----
J_3	Kissimmee River	Sinusoid with Maximum rate in July; minimum in December	0.98	1.95	2.93
J_4	Other river inputs	Sinusoid with maximum rate in July; minimum in December	0.28	0.56	0.83
J_5	Backpumped water	Sinusoid with maximum rate in July; minimum in December	0.00	0.12	0.24
J_6	Evapotranspiration	Sinusoid with maximum rate in July; minimum in December	1.00	2.00	3.00
—	Regulation level	Sinusoid with maximum storage allowed in December; minimum in July.	4.40**	4.80**	5.20

*Water flows in $10^9 m^3$/yr
Coliform flows in 10^{15}TC/yr

**Storage in $10^9 m^3$

EQUATIONS

$$\mathring{Q}_1 = J_1 + J_3 + J_4 + J_5 - J_6 - k_7Q_1 - k_8Q_1$$

$$\mathring{Q}_2 = J_2 + k_3J_3 + k_4J_4 + k_5J_5 - k_6Q_2 - k_9Q_2(k_8Q_1) - k_{10}Q_2(k_7Q_1)$$

Calculations Of Transfer Coefficients

$$k_3J_3 = 0.78\text{x}10^{15} \therefore k_3 = \frac{0.78\text{x}10^{15}}{1.95\text{x}10^9} = 4.0\text{x}10^5 = k_3$$

$$k_4J_4 = 4.7\text{x}10^{15} \therefore k_4 = \frac{4.7\text{x}10^{15}}{0.56\text{x}10^9} = 8.4\text{x}10^6 = k_4$$

$$k_5J_5 = 0.32\text{x}10^{15} \therefore k_5 = \frac{0.32\text{x}10^{15}}{1.0\text{x}10^9} = 3.24\text{x}10^5 = k_5$$

$$k_6Q_2 = 5.77\text{x}10^{15} \therefore k_6 = \frac{5.77\text{x}10^{15}}{1.54\text{x}10^{15}} = 3.72 \text{ to } 88.8 = k_6$$

$$k_7Q_1 = .4\text{x}10^9 \therefore k_7 = \frac{.4\text{x}10^9}{4.8\text{x}10^9} = .0833 = k_7$$

$$k_8Q_1 = 10.4\text{x}10^9 \therefore k_8 = \frac{10.4\text{x}10^9}{4.8\text{x}10^9} = 2.16 = k_8$$

$$k_9Q_2(k_8Q_1) = 3.33\text{x}10^{15} \therefore k_9 = \frac{3.33\text{x}10^{15}}{(10.4\text{x}10^9)(1.54\text{x}10^{15})} = 2.08\text{x}10^{-10} = k_9$$

$$k_{10}Q_2(k_7Q_1) = 0.13\text{x}10^{15} \therefore k_{10} = \frac{0.13\text{x}10^{15}}{(1.54\text{x}10^{15})(.4\text{x}10^9)} = .211\text{x}10^{-9} = k_{10}$$

Scaled Variables

$$\left[\frac{J_1}{5\text{x}10^9}\right]\left[\frac{J_2}{5\text{x}10^{15}}\right]\left[\frac{J_3}{5\text{x}10^9}\right]\left[\frac{J_4}{2\text{x}10^9}\right]\left[\frac{J_5}{5\text{x}10^8}\right]\left[\frac{J_6}{5\text{x}10^9}\right]\left[\frac{Q_1}{10^{10}}\right]\left[\frac{Q_2}{5\text{x}10^{15}}\right]$$

Scaled Equations

$$-\mathring{Q}_1 = -J_1 - J_3 - J_4 - J_5 + J_6 + K_7Q_1 + K_8Q_1$$

$$\left[\frac{-\dot{Q}_1}{10^{10}}\right] = -\frac{5\text{x}10^9}{10^{10}}\left[\frac{J_1}{5\text{x}10^9}\right] \frac{-5\text{x}10^9}{10^{10}}\left[\frac{J_3}{5\text{x}10^9}\right]\frac{-2\text{x}10^9}{10^{10}}\left[\frac{J_4}{2\text{x}10^9}\right]\frac{-5\text{x}10^8}{10^{10}}\left[\frac{J_5}{5\text{x}10^8}\right]$$

$$+\frac{5\text{x}10^9}{10^{10}}\left[\frac{J_6}{5\text{x}10^9}\right] + \frac{(.083)\ 10^{10}}{10^{10}}\left[\frac{Q_1}{10^{10}}\right] + \frac{(2.16)\ 10^{10}}{10^{10}}\left[\frac{Q_1}{10^{10}}\right]$$

$$\left[\frac{-\mathring{Q}_1}{10^{10}}\right] = -0.5\left[\frac{J_1}{5\text{x}10^9}\right] - 0.5\left[\frac{J_3}{5\text{x}10^9}\right] - 0.2\left[\frac{J_4}{2\text{x}10^9}\right] - .05\left[\frac{J_5}{5\text{x}10^8}\right]$$

$$+ 0.5\left[\frac{J_6}{5\text{x}10^9}\right] + .083\left[\frac{Q_1}{10^{10}}\right] + 2.16\left[\frac{Q_1}{10^{10}}\right]$$

$$-\mathring{Q}_2 = -J_2 - k_3 J_3 - k_4 J_4 - k_5 J_5 + k_6 Q_2 + k_9 Q_2 \; (k_8 Q_1) + k_{10} Q_2 \; (k_7 Q_1)$$

$$\left[\frac{-\mathring{Q}_2}{5\text{x}10^{15}}\right] = \frac{-3.3\text{x}10^{15}}{5\text{x}10^{15}} \left[\frac{J_2}{5\text{x}10^{15}}\right] - \frac{(4.0\text{x}10^{5}).(5\text{x}10^{9})}{5\text{x}10^{15}} \left[\frac{J_3}{5\text{x}10^{9}}\right]$$

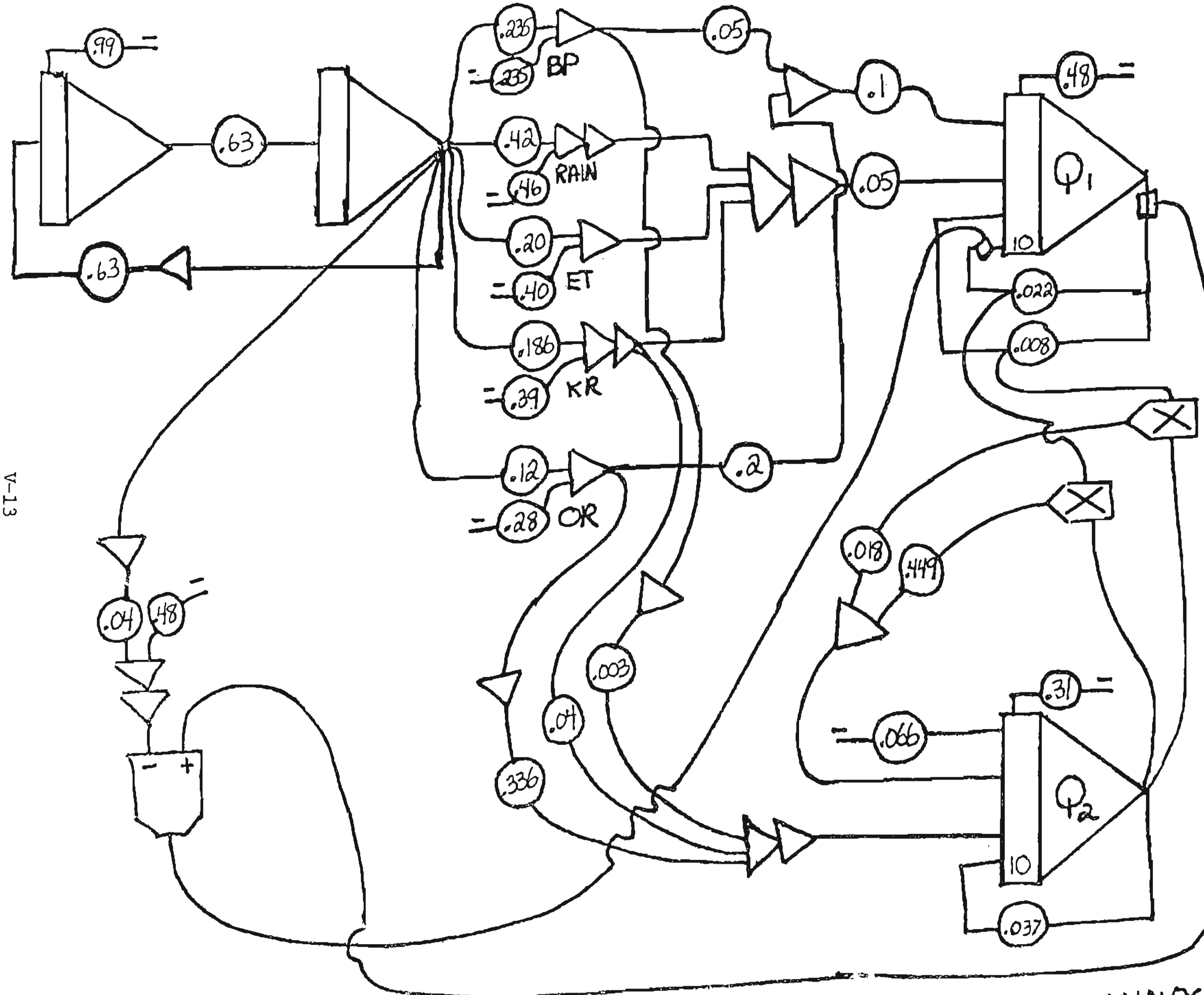
$$- \frac{(8.4\text{x}10^{6})(2\text{x}10^{9})}{5\text{x}10^{15}} \left[\frac{J_4}{2\text{x}10^{9}}\right] - \frac{(3.24\text{x}10^{5})(5\text{x}10^{8})}{5\text{x}10^{15}} \left[\frac{J_5}{5\text{x}10^{8}}\right]$$

$$+ \frac{(3.72)(5\text{x}10^{15})}{5\text{x}10^{15}} \left[\frac{Q_2}{5\text{x}10^{15}}\right] + \frac{(2.08\text{x}10^{-10})(5\text{x}10^{15})}{5\text{x}10^{15}} \left[\frac{Q_2}{5\text{x}10^{15}}\right] (2.16)(10^{10}) \left[\frac{Q_1}{10^{10}}\right]$$

$$+ \frac{(.211\text{x}10^{-9})(5\text{x}10^{15})}{5\text{x}10^{15}} \left[\frac{Q_2}{5\text{x}10^{15}}\right] (.083)(10^{10}) \left[\frac{Q_1}{10^{10}}\right]$$

$$\left[\frac{-\mathring{Q}_2}{5\text{x}10^{15}}\right] = 0.66 \left[\frac{J_2}{5\text{x}10^{15}}\right] - 0.4 \left[\frac{J_3}{5\text{x}10^{9}}\right] - 3.36 \left[\frac{J_4}{2\text{x}10^{9}}\right] - .032 \left[\frac{J_5}{5\text{x}10^{8}}\right]$$

$$+ 3.72 \left[\frac{Q_2}{5\text{x}10^{15}}\right] + 4.49 \left[\frac{Q_2}{5\text{x}10^{15}}\right] \left[\frac{Q_1}{10^{10}}\right] + .18 \left[\frac{Q_2}{5\text{x}10^{15}}\right] \left[\frac{Q_1}{10^{10}}\right]$$



ANALOG DIAGRAM

ALL INTEGRATOR INPUTS TIME SCALED BY $\frac{1}{10}$

VI. POSSIBLE EFFECT ON WADING BIRDS ON RAISING LAKE WATER REGULATION LEVELS

Joan Browder

Lake Okeechobee marshes are a major feeding area for wading birds of South Florida and were possibly the only areas of any significance supporting the colony of Wood Storks at Corkscrew Swamp Sanctuary during the latter part of their 1973-74 breeding season. An aerial surveillance of Wood Stork feeding activity during the period from December, 1973 through May, 1974 (Browder, 1974) showed that in April, Wood Storks discontinued the use of feeding areas nearer to the rookery and began feeding in the Lake Okeechobee marshes, which are from 40 to 65 miles from the rookery. Until at least the latter part of May, adults were still flying back and forth from the rookery to the lake to feed young on the nest. By late May, fledgings may have joined the adults in feeding flights to the lake.

Over southwest Florida the general decline in the number of wading birds other than Wood Storks in March was dramatic. This can be partially explained by the northward migration of birds that had been wintering in southwest Florida, but is also believed to have been related to the marked increase in wading birds, particularly White Ibis, in the marshes of Lake Okeechobee beginning at about that time. Wetlands of southwest Florida that had previously been heavily utilized by the birds were almost entirely dry.

The number of Wood Storks feeding in the Lake Okeechobee marshes increased steadily through April and May. White Ibis and other wading birds, but not Wood Storks, were observed feeding there as early as February, and their number increased as the dry season progressed. The feeding aggregations in the marshes, including Roseate Spoonbills, Great Egrets, and other heron species, as well as the Wood Storks and White Ibis, numbered as many as 10,000 birds a sighting throughout the month of May.

The most extensive marsh occurs around the western and northwestern shore. The major areas used by wading birds are: (1) near Observation Island, (2) Moonshine Bay, (3) near the outlet to Indian Prairie Creek Canal, and (4) on King's Bar, at the mouth of the Kissimmee River (Fig. 1). These marshes occupy approximately one quarter of the total surface area of the 720 square mile lake. They resemble most South Florida wetlands in that much of their area is only seasonally flooded.

Lake regulation, designed to protect towns on the lake perimeter from hurricane floods, results in lower than normal water levels during summer, however, the level of the lake is allowed to rise during late fall to store water for dry season use. From these higher stages, the lake level gradually declines to minimum levels in May.

All the wading birds depend heavily on seasonally drying marshes, rather than on marshes that are permanently flooded. The gradual lowering of the lake during the dry season creates isolated pockets of water in the lake marsh. Fish and other aquatic organisms are trapped and concentrated in the depressions which provide ideal feeding for wading birds. Wood Storks, particularly those that are feeding young, require a higher concentration of food organisms than is needed by other wading birds because they locate their food by touch rather than by sight. The arrival of Wood Storks in newly available feeding areas is preceded several days to several weeks by the presence of other wading birds such as White Ibis.

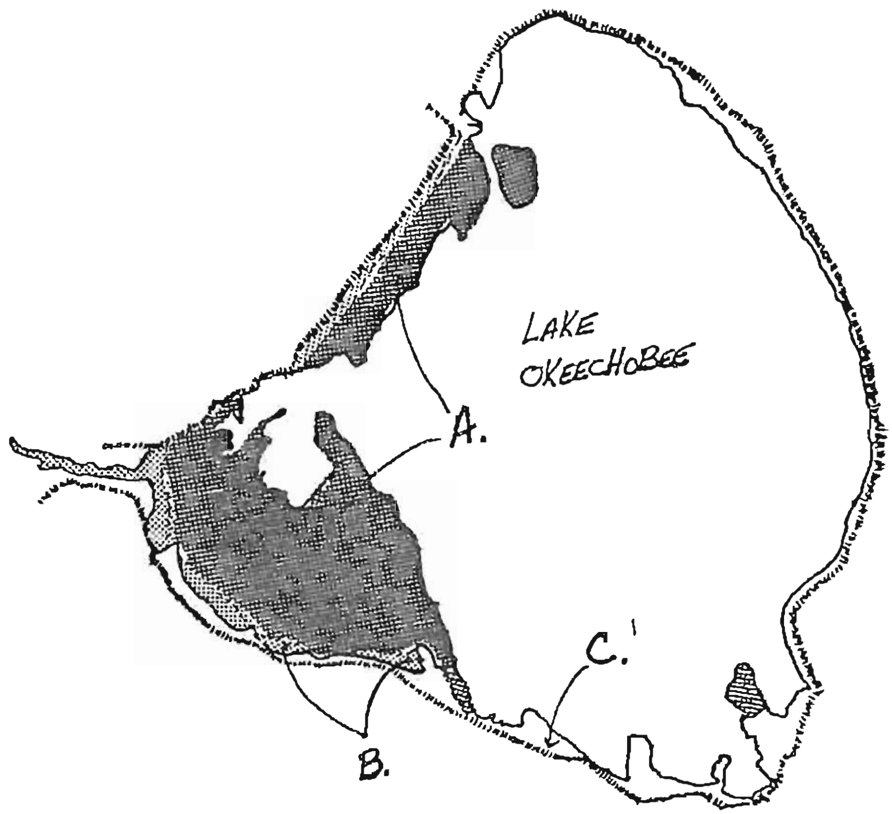


Fig. 1. Seasonal marshes of Lake Okeechobee.

Good feeding conditions in Okeechobee marshes occur later in the year than in other wetlands of southwest Florida. When few, if any, other areas are available, Lake Okeechobee marshes provide food for wading birds, especially nesting Wood Storks. It is possible that the lake marshes now are substituting for former feeding areas that have been destroyed by the drainage of approximately 900,000 acres of wetlands in Lee, Hendry, and Collier counties within the past 15 years. It is extremely unlikely that the Wood Stork breeding effort in 1973-74 would have been successful had not the marshes of Lake Okeechobee provided suitable feeding conditions in April and May to help complete the raising of young. This was the first successful breeding season for the Wood Storks in South Florida in three years and was followed by another successful season in 1975.

Within the past 40 years, Wood Stork populations in South Florida have been reduced from an estimated 50,000 breeding birds to about 9,000 breeding birds. Wood Storks are thought to be long lived birds that may not breed until they are three or four years old, and probably do not need to have a successful breeding season every year in order to maintain a viable population; however, any sustained reduction in the frequency of successful years is a definite threat to the population. A reduction in the number of young produced during successful breeding years causes the total population to gradually decline and makes the population more susceptible to reduced breeding frequency.

An aerial search of Collier, Hendry, Lee, Charlotte, and Glades counties during early May 1974 turned up no feeding areas of any significance (more than one or two birds feeding). However, a heavily traveled flight path between Corkscrew Swamp and Lake Okeechobee was discovered, and aggregations of feeding Wood Storks numbering up to 200 were found in the lake marshes on each of 4 flights in April and May (1974).

New information on Wood Stork feeding activities of Lake Okeechobee was provided by observations made in the spring of 1975. Wood Storks numbering up to 1000 were reported feeding in Lake Okeechobee throughout the month of May and the early part of June, 1975 (Chandler, Ogden, personal communication, 1975). A large aggregation of Wood Storks switched their feeding from Conservation Area 3 to the lake in early May when water levels in the Conservation Area increased due to rain (SWFWMD, personal communication). In comparison to other places in South Florida where Wood Storks and other wading bird species feed, the lake is apparently slower to rise in response to the advent of rain as well as slower to decline in response to lack of rain. For this reason, feeding areas in Lake Okeechobee marshes, under the present lake regulation schedule, act as a buffer for wading bird populations by providing adequate food at times when feeding areas are not available elsewhere. This makes the Lake Okeechobee marshes a vital feeding area for Wood Storks and other wading birds. The lake, in conjunction with other remaining undrained feeding areas in South Florida, provides a continuous food source throughout the period of time that wading birds are in South Florida, which coincides with the breeding season of Wood Storks, White Ibis, and some populations of egrets and herons. If the lake marshes were not available, the continuous supply of food to Wood Storks and their growing young would be interrupted and Wood Stork populations may be threatened. This may be equally true of White Ibis and other species.

The importance of Lake Okeechobee marsh as wading bird feeding areas raises new concern regarding the lake's new lake regulation schedule. The Corps now manages the lake in accordance with a stage regulation schedule of 15.5 to 13' MSL (during the past water year, October 1973 - September, 1974, the regulation schedule was changed to 16 - 14' MSL, but the year was so dry that little change in actual conditions was noted). Actual fluctuation has varied in wet years from 16.5 around October to 14.0' in May, and in dry years between 14.5 around October to 10.5' in May. The area that is alternately flooded and dried and thus provides feeding habitat for wading birds, reaches its maximum extent of slightly more than 120,000 acres in dry years.* Much less marsh is exposed to drying in wet years. Even under the present regulation schedule the presence of the Hoover Dike at an approximate elevation of 15.5 ft. MSL (14-15 ft. MSL from Harney Pond Canal south to Fisheating Creek, 15-16 ft. MSL north of Harney Pond Canal, and 14-16 ft. MSL along the west shore marshes; J. Carroll, personal communication, 1975) results in little or no feeding areas for wading birds in wetter years.

Structures to enable a new two feet higher regulation schedule (between 17.5 and 15.5 ft. MSL) are almost completed. This would result in a general two-foot increase in actual fluctuation ranges and suitable

---

*The 120,000 acre estimate is based on a 1962 depth area curve by the Corps of Army Engineers (Figure 3, Meyer). A later Corps survey changed the area above 13.83 MSL, but plotting the new values on the 1962 curve showed no difference between the 1962 estimate and the 1968 survey. Since that time, Pernel of the FCD has done more detailed work in this area. His work shows that there are 87,488 acres of total marsh presently existing from Clewiston to the mouth of the Kissimmee River, including Kings Bar, and 6,559 acres of emergent littoral zone adjacent to Kramer, Torey and Rita Islands.

Okeechobee feeding marshes may be almost entirely eliminated in moderate and wet years and greatly reduced in dry years. Figure 2 from Gayle (1975) shows the general contours of the lake and marsh. Figure 3 from Meyer (1971) shows the approximate acreage of seasonally drying marsh during dry years under the present regulation schedule (A) and projected extent of seasonally drying marsh during dry years under the new regulation schedule (B), under an assumption that the new schedule will shift the range of fluctuation up two feet.

According to Carroll (personal communication, 1975) Flood Control District hydrologists predict that, based on computer analysis, the 17.5 to 15.5 ft. MSL schedule can be maintained more easily than the old schedule. If this proves correct, the above assumption that a two-foot upward shift would occur will not apply and the area of seasonally drying marsh will be even smaller. A Corps representative, on the other hand, feels it unlikely that actual lake levels will adhere to the new schedule. If the new schedule is maintained, there will be no wading bird feeding habitat in the lake in either dry years or wet years.

It is clear that no one knows for sure what will happen should the new regulation schedule go into effect. It is also clear that the fate of South Florida's wading bird populations could hang in the balance. Reduction in feeding habitat is particularly crucial with respect to the Wood Stork, whose recent modest come-back from dangerously low levels may have been considerably aided by feeding opportunities afforded at the lake. The White Ibis using the lake for at least a four-month period during 1973-74 may represent a large proportion of the South Florida White Ibis population. Kushlan (1974) estimates the total White Ibis population

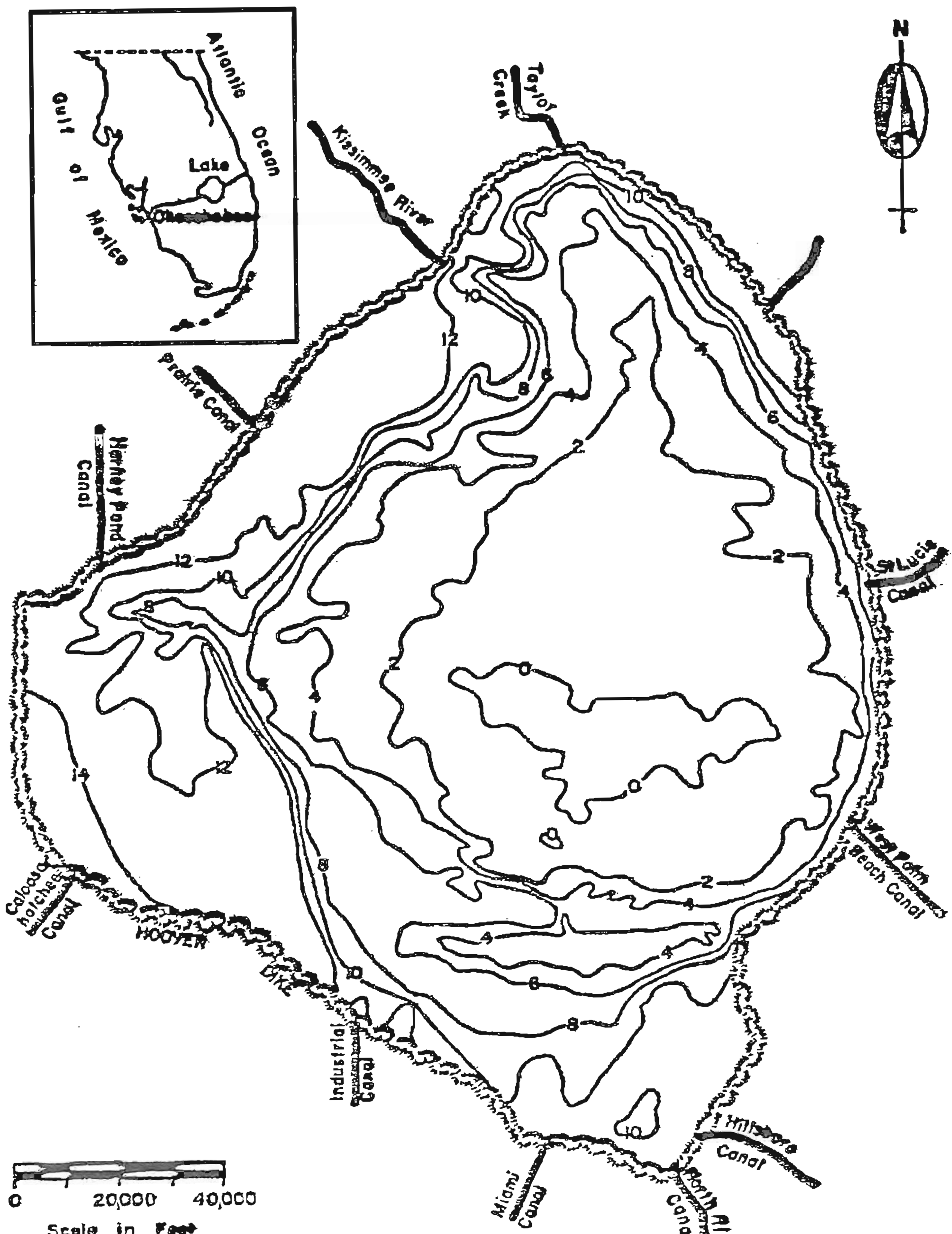


Fig. 2. Contour map of Lake Okeechobee (from Gayle ; redrawn from Brooks, 1974).

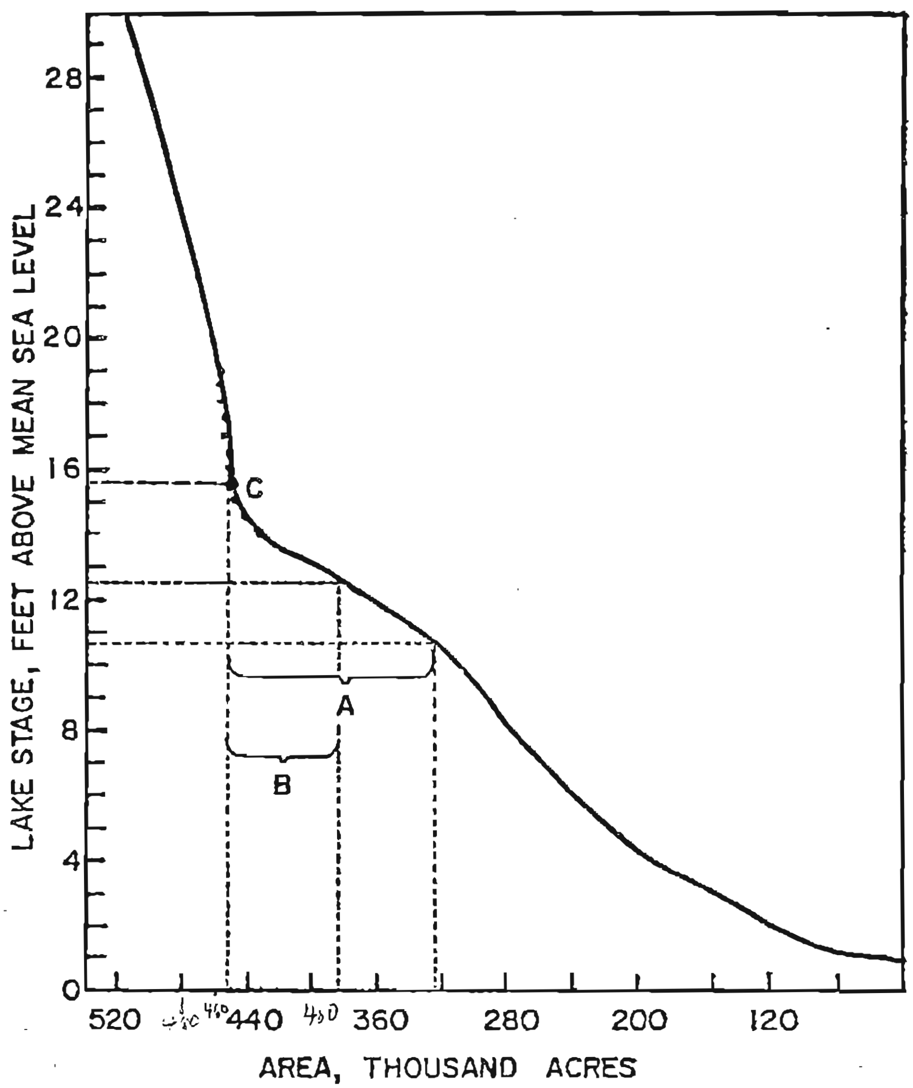


Fig. 3. Depth-area curve for Lake Okeechobee, showing approximate area of seasonally drying marsh in dry years under present stage regulation schedule (A) and projected area of this type of marsh under new regulation schedule (B), assuming a two-foot rise in present fluctuation levels. The approximate location of the Hoover Dike is designated with the "C".

(From a graph from Meyer, 1971. The curve was drawn by the U.S. Corps of Army Engineers in 1962.)

in South Florida at 60,000. At least 10,000 were seen feeding in the lake on several occasions. As birds spend time flying to and from the feeding areas and to roosts and rookeries, the 10,000 birds may have represented a much larger number of birds actually using the lake to feed. This is true for other species as well.

For at least the past five years, Wood Storks have successfully raised young only in dry years (1970-71, 1973-74 and 1974-75). Flights over the lake in the spring of 1974 found Wood Storks feeding in the marshes only when declining levels reached 12.27 ft. MSL (in higher zones) or 11.60 ft. MSL (in lower zones) (Table 1). No Wood Storks were seen when water levels were higher. A flight over the marshes on December 17, 1974, when lake level was 14.16 ft. MSL, discovered no birds, although Wood Storks were feeding at nearby Fisheating Creek and White Ibis were feeding at Rainey Slough. Wood Storks were consistently sighted in the Moonshine Bay area from April 30 through June 10, 1975 (Chandler, Ogden, personal communication, 1975) during which time lake levels ranged from 11.71 to 12.3 ft. MSL. The feeding aggregations grew to a maximum of more than 1,000 birds on May 30, when the lake level was at 11.98 ft. MSL, and gradually declined thereafter (Table 2).

Thousands of other wading birds, particularly White Ibis, were observed in the marshes when the lake level was 13.80 ft. MSL and lower. Presumably White Ibis feed in these marshes during all but the wettest years under the present regulation schedule; but, during dry years, use can be much more extensive and of longer duration.

The question has been posed: Is the reason that Wood Storks do <u>not</u>

TABLE 1.

Feeding Area and Recorded Water Level and Dates that Wood Storks and Other Wading Birds Were Sighted Feeding at Lake Okeechobee

Date (1974)	Species	General Area	Elevation MSL	Recorded Water Level* (Ft. MSL) on Date of Siting
Feb. 9	W.I. and other	West marsh, just west of Observation Island	<12 <14	13.80
April 17	W.S., W.I. and other	West marsh, just west of Observation Island	<12 <14	12.27
May 5	W.I. and other	West marsh, Moonshine Bay (west of Observation Shoal)		11.60
May 5	W.S., W.I. and other	Northwest marsh near mouth of Indian Prairie Creek Canal	<10 <12 or slightly above 12	11.60
May 5	W.S., W.I. and other	North Shoal (Kings Bar)	<10 <12	11.60
May 26	W.I. and other	Northwest marsh near mouth of Indian Prairie Creek Canal	<10 <12 or slightly above 12	11.08
May 26	W.S.	North Shoal (Kings Bar)	<10 <12	11.08

W.S. = Wood Stork
W.I. = White Ibis

*From 1974 Water Resources Data for Florida. Part I. Surface Water Records. Volume 3: Lakes.

TABLE 2.

Lake Stage at Lake Okeechobee on Days in Late Spring, 1975, When Wood Storks were Seen Feeding[a] in Moonshine Bay, Okeechobee Marshes.

Date (1975)	Average Lake Stage (Ft. Above MSL)	Number Feeding Storks
APR 30	12.12	10
MAY 2	12.04	21
MAY 5	11.90	46
MAY 7	11.88	75
MAY 9	11.82	200
MAY 10	11.79	500
MAY 11	11.73	600
MAY 13	11.73	800
MAY 14	11.71	125
MAY 21	11.91	234
MAY 22	11.90	550[b]
MAY 23	11.89	450
MAY 26	11.87	1000
MAY 30	11.98	1200
JUN 1	12.10	450
JUN 3	12.14	300
JUN 5	12.26	225
JUN 7	12.24	70
JUN 10	12.30	25
JUN 15	12.32	none

[a] Sightings by Rod Chandler, National Audubon Society

[b] Sighting by John Ogden, National Audubon Society

feed in the marshes when the lake level is above 12.3 ft. MSL because there are other preferential feeding areas available during these periods or because feeding conditions at the lake are not suitable for Wood Storks during these periods?

The information available can be summarized as follows:

1. In order to have a successful breeding season, Wood Storks require more concentrated food stocks than other wading bird species. Small rises in water levels, sometimes caused by winter rains of three or four inches over several days, can cause Wood Storks to abandon their young. There is a narrow range of local water levels coupled with food concentration that provides conditions for efficient feeding by nesting Wood Storks.

2. Wood Storks have not been seen feeding in the lake marshes when the level is above 12.3' MSL. A December 17, 1974 flight over the western marshes when the lake stage was 14.16' MSL revealed no Wood Storks or other wading birds; however, Wood Storks were feeding not far away at Fisheating Creek. White Ibis were feeding at Rainey Slough, also not far from Lake Okeechobee. The point is that Wood Storks, although already beginning to concentrate at the Corkscrew rookery in December, were still feeding long distances from the rookery. Fisheating Creek is about the same distance from the rookery as Lake Okeechobee. Circumstantial evidence strongly suggests that they were not feeding in the Okeechobee marshes because suitable feeding conditions did not exist there at that time. 1975 observations of feeding Wood Storks at Lake Okeechobee coincided with times when the lake was at or below 12.3 ft. MSL.

The question is not "Can the marshes of Lake Okeechobee <u>alone</u> support the nesting colonies of wading birds of South Florida?" The question is "Can the other existing feeding areas do this job without Lake Okeechobee, and will the lake marshes still function, as they do now, to feed South Florida's wading birds at crucial times when other feeding areas are not available, if the lake regulation schedule is raised?"

The information that has recently come to light was not available and these questions were not raised when the decision was made to raise the Lake Okeechobee stage regulation schedule. Other important questions in regard to marsh vegetation, fish breeding and feeding activities, lake eutrophication problems, and lake circulation also were not adequately studied or answered before the decision to raise lake stage regulation levels was made. In light of new information that is available, it seems that the question should be reopened, further studies should be made, and other alternatives for storing water for South Florida should be considered.

If the new stage regulation schedule does go into effect it might be advisable, in the interest of safeguarding South Florida's wading bird populations, to draw the lake down or allow the lake to dry down to about 12.0 ft. MSL by May 1 in dry years and to at least 14.0 ft. MSL by May 1 in moderate and wet years.

LITERATURE CITED

Ager, L. A. and K. E. Kerce. 1974. Aquatic plant communities--associated fauna investigation; completion report. Florida Game and Freshwater Fish Commission.

Allen, R. P. 1942. The Roseate Spoonbill. Research Report No. 2. National Audubon Society. New York.

Browder, J.A. 1974. Aerial monitoring of Feeding Areas Nesting at Corkscrew Swamp Sanctuary. In: Odum, H.T. and K.C. Ewel. Cypress Wetlands for Water Management, Recycling, and Conservation. Annual Report: National Science Foundation - RANN Division Grant GI-38721, and the Rockefeller Foundation, Grant RF-73029. Pages 657-732.

Joyner, B. F. 1974. Chemical and biological conditions in Lake Okeechobee, Florida, 1969-72. Report of Investigations No. 71. For Florida Dept. Natural Resources, Bureau of Geology, by U.S. Geological Survey. Tallahassee, Fla.

Kahl, M. P., Jr. 1964. Food ecology of the Wood Stork (Mycteria americana) in Florida. Ecological Monographs 34(2): 97-117.

Kushlan, J. A. 1974. The ecology of the White Ibis in southern Florida, a regional study. Dissertation. University of Miami. Coral Gables, Fla.

Meyer, F. W. 1971. Seepage beneath Hoover Dike, southern shore of Lake Okeechobee, Florida. Report of Investigations No. 58. For Florida Dept. Natural Resources, Bureau of Geology, by U.S. Geological Survey. Tallahassee, Fla.

U.S. Geological Survey. 1974 Water Resources Data for Florida Part 1. Surface Water Records. Volume 3: Lakes.

Wegener, W. and V. Williams. 1974. Completion report, Lake Tohopekaliga drawdown study. July 1, 1970-June 30, 1974. Water Level Manipulation Project. Dingell-Johnson F-29.

VIII. PHOSPHORUS DYNAMICS OF THE KISSIMMEE UPPER CHAIN OF LAKES

Lawrence Shapiro

Introduction

The Kissimmee upper chain of lakes consists of four large lakes and other smaller lakes in the upper Kissimmee River Valley. Major lakes are: Lake Tohopekaliga (Toho), Cypress, Hatchineha, and Kissimmee. The lake chain begins south of Orlando and discharges into the Kissimmee River some 60 miles to the south. Lake stages and fluctuations have been regulated since 1964 for flood control purposes.

Due to urbanization and resultant sewage inputs and changing land use patterns, the water quality of Lake Tohopekaliga has been deteriorating at an alarming rate. It has been hypothesized that given present conditions, this water quality deterioration will spread to the downstream lakes and ultimately affect Lake Okeechobee.

Lake Tohopekaliga receives heavy nutrient loads from at least five sewage treatment plants and is considered to be hypereutrophic (Brezonik, 1972) with a phosphorus loading rate of 1.4 $g/m^2/yr$. Even under these excessive conditions Lake Toho does not presently discharge "dangerous" loads of phosphorus downstream. Figures 1 and 2 show concentration of phosphorus decreasing sharply down the chain. Lake Tohopekaliga acts as a very efficient phosphorus sink. The important question is: how long will the lake continue to function in this manner? This is a very difficult question as many of the physical and chemical mechanisms involved in the exchange of substances between the sediments and water are poorly understood (Lee, 1970).

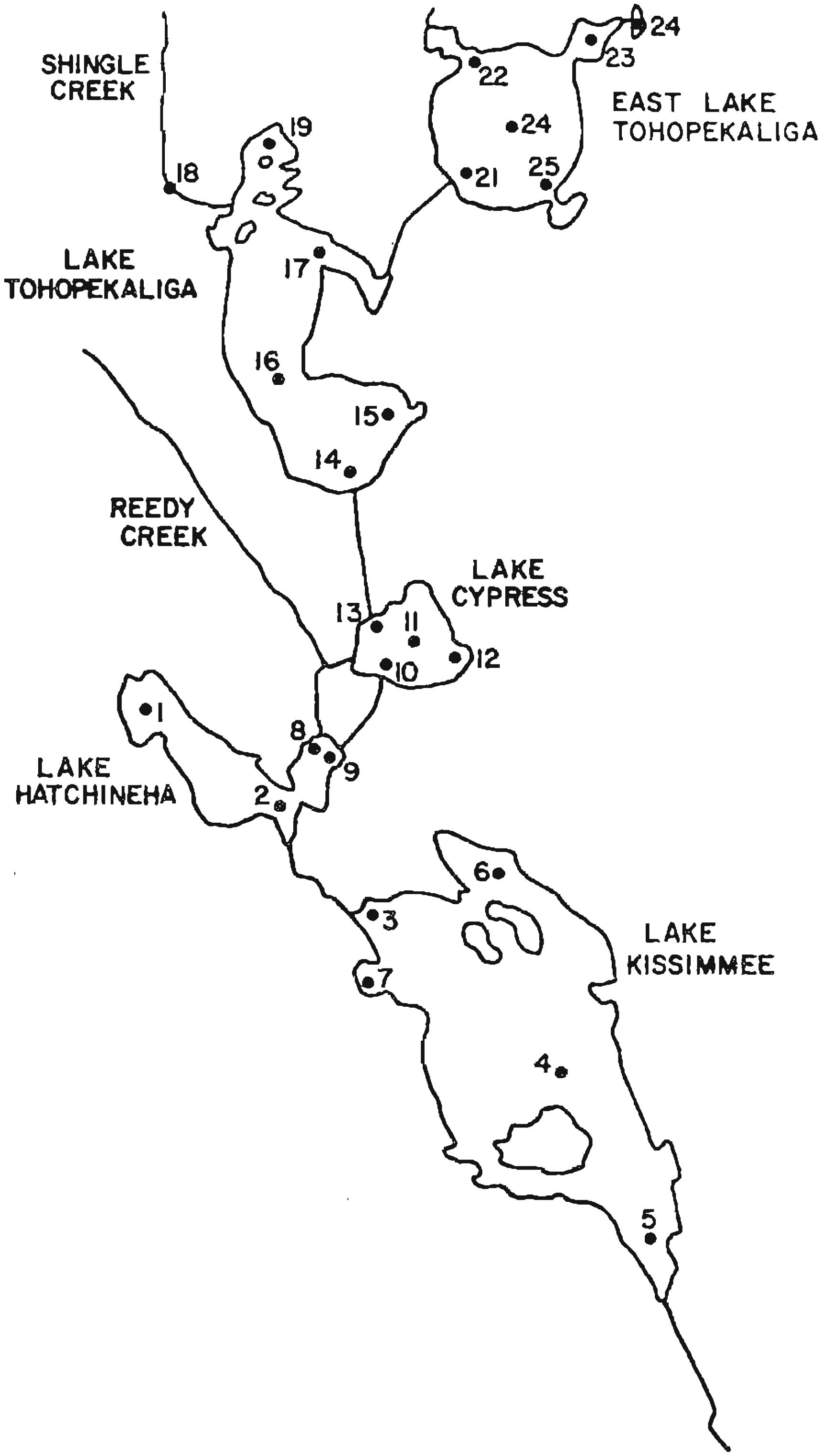


Fig. 1. Location of sampling sites in the Upper Chain of Lakes (Department of Pollution Control, 1974).

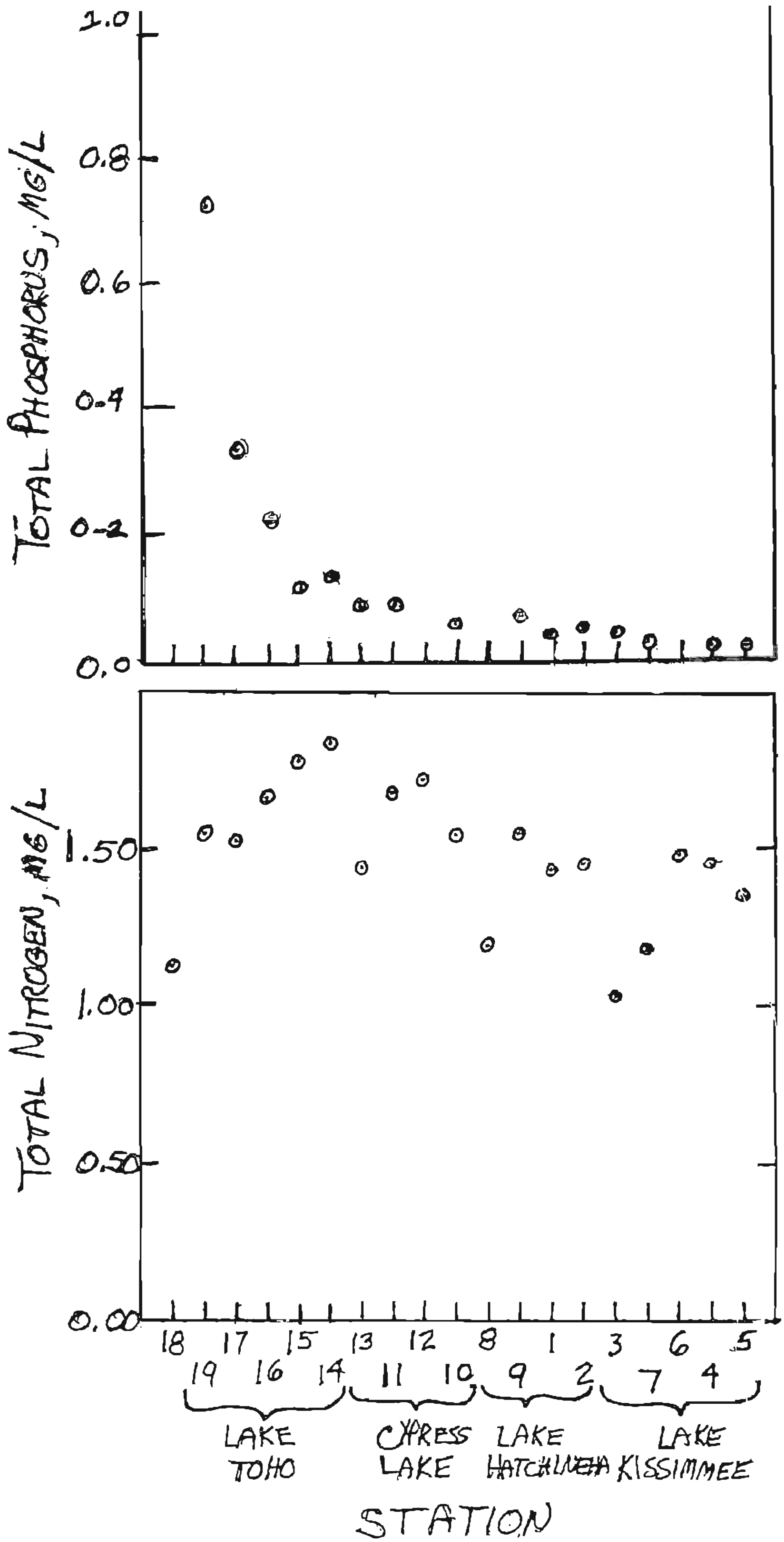


Fig. 2. Graph of total nitrogen and total phosphorus down the Upper Chain of Lakes. Station locations are given in Figure 3.

This study examines this question through the use of comprehensive water and nutrient budgets and a predictive model. Emphasis is placed on lake regulation and how it may affect phosphorus dynamics and trophic states.

Methods

Budget Calculations

Water budgets were calculated for Lakes Tohopekaliga, Cypress, Hatchineha and Kissimmee for the year 1973 as this was the only year for which both water flows and nutrient concentrations were available. Lakes Cypress and Hatchineha, treated as one lake in the hydrology literature, were treated accordingly in this study. Flows were obtained from U.S. Geological Survey records. Rainfall and evaporation were obtained from Climatological Data, Florida Summary. Runoff from different land use regimes was generated from a model developed by Philip Bedient, Department of Environmental Engineering Sciences, University of Florida.

Nutrient concentrations were obtained from measurements made during 1973 by Department of Pollution Control (unpub.). Concentrations for rainfall and for the runoff from different land uses shown in Table 1 were taken from Brezonik (1972).

Model Construction

Figure 3 shows the basic lake model. The model is simply a simulated water budget which matches the actual flows of the lakes for 1973. The model takes empirical rainfall and inflow data and simulated discharge based on the regulation schedule.

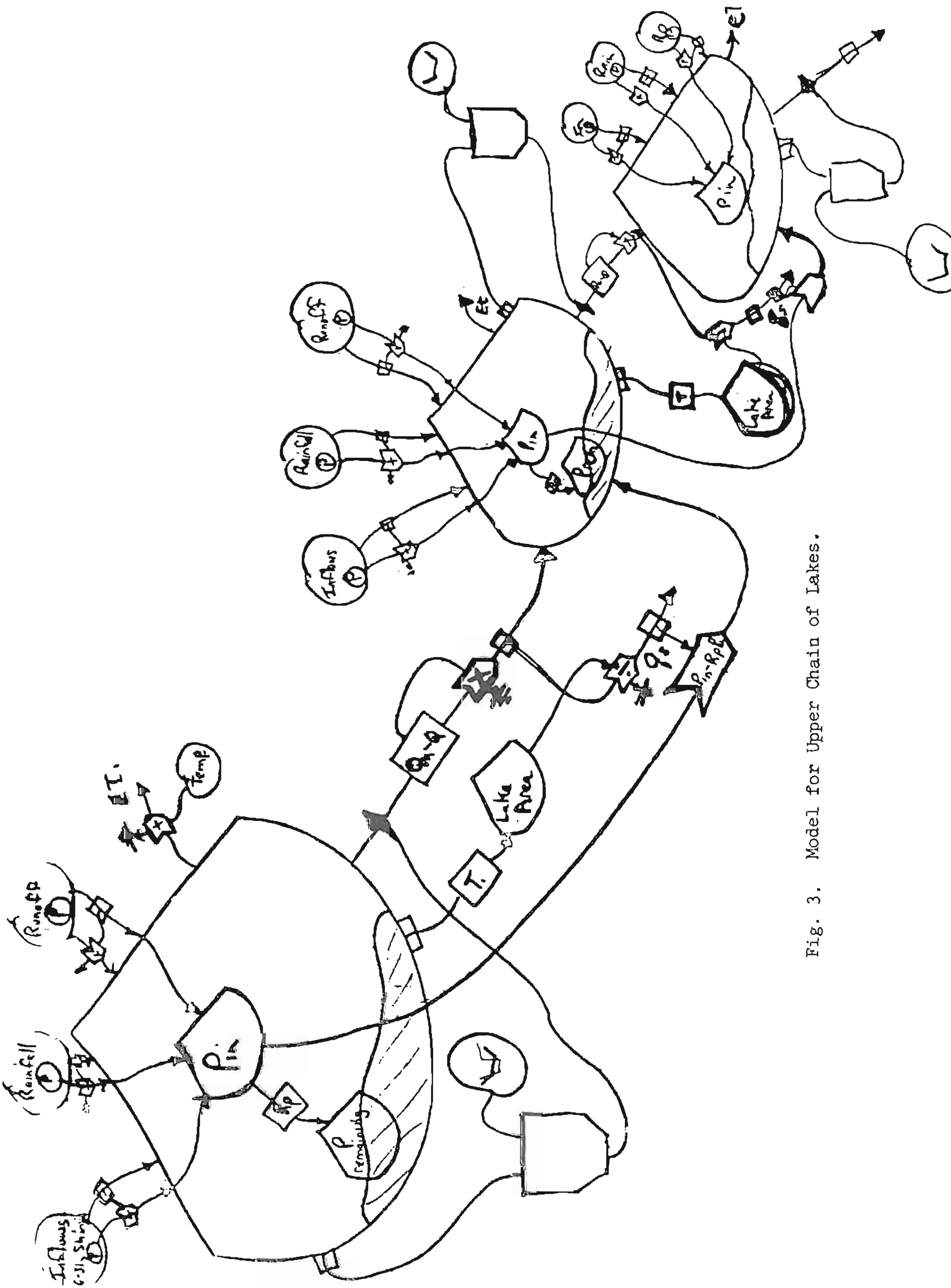


Fig. 3. Model for Upper Chain of Lakes.

Table 1. P Concentrations from Various Sources

Type of Flow	Phosphorus Concentration mg/l
Rainfall	0.03
Urban	0.5
Improved pasture	0.3
Unimproved pasture	0.05

A predictive regression equation developed by Dillon et al. (1975) is built into the model.

$$R_p = 0.426 \exp(-0.271\ q_s) + 0.574 \exp(-.00949\ q_s) \qquad \text{Eq. 1}$$

The equation predicts the amount of phosphorus which remains in a lake per year (R_p) as a function of $q_s = \frac{[\text{outflow } (m^3 yr^{-1})]}{[\text{area } m^2]}$ with a correlation coefficient of 0.94.

The model was written in Dynamo language and simulated on the IBM 370 digital computer (see Appendix). It is important to note that the equation was used on a monthly not yearly basis. The implications of this will be discussed later.

Results and Discussion

Model Validation and Initial Findings

The basic lake model (Fig. 3) was run to simulate monthly phosphorus output from Lake Toho. Phosphorus outflow from one lake, being the loading rate to the next lake in the chain, is an important index of trophic state. To predict future discharge rates of phosphorus is to predict future downstream trophic states. Model inputs were the monthly loading rate of phosphorus and the areal flushing rate. Simulation (Fig. 4) showed a high correlation between simulated and actual output levels.

The model was used to measure the effect of the proposed regulation schedule on phosphorus outflow. Figure 5 shows both the present and the proposed regulating schedules. These are the monthly stage levels at which the lake is kept if conditions allow. When monthly inputs are large and the lake levels rise above the prescribed levels, excess water is discharged

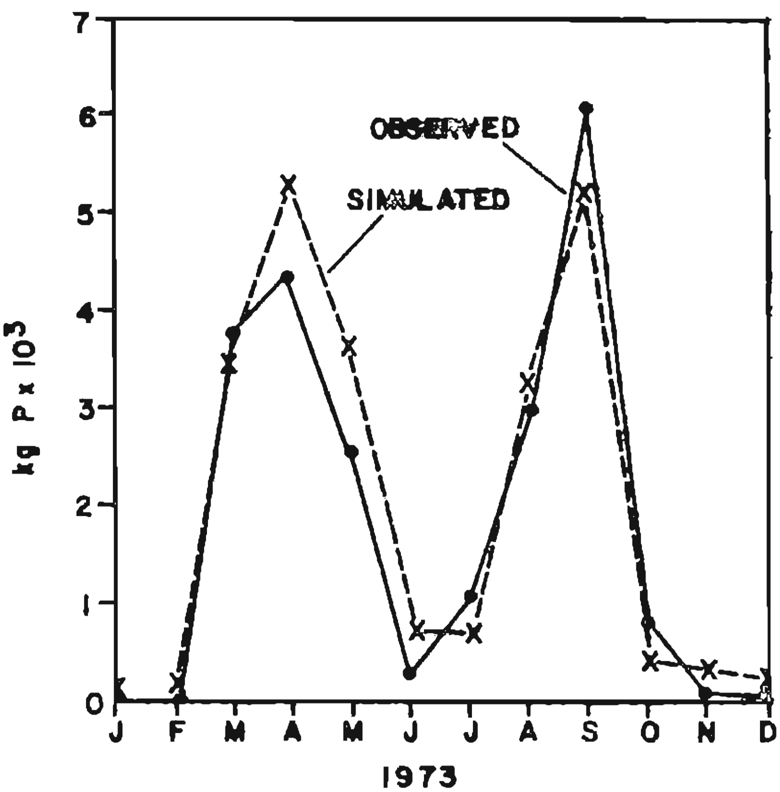


Fig. 4. Comparison of simulated and observed P discharge from Lake Toho.

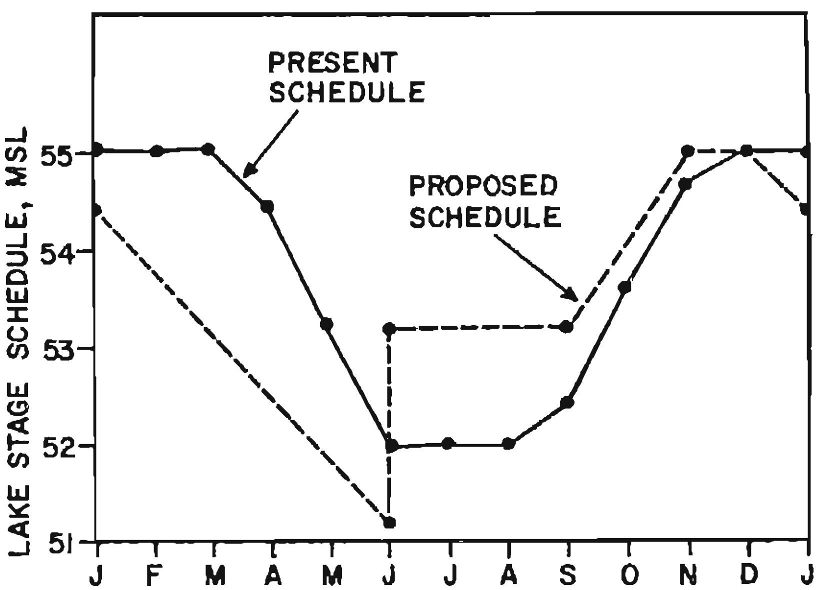


Fig. 5. Present and proposed regulating schedule.

downstream. If monthly levels do not exceed prescribed levels there is no outflow that month. Monthly water discharge is shown in Figure 6. Discharge rates are similar except for the months of April, July, and September. Phosphorus outflow, however, is not significantly different under the two regimes for these three months (Fig. 7).

Figure 8 shows the response of Lake Toho when allowed to respond naturally to 1973 inputs. This simulation was accomplished by programming Figure 9 into the model in place of the regulating schedule. Figure 9 was compiled from the lake's response previous to regulation. Under a natural regime there is some discharge every month, whereas, when the lake is regulated there are certain months, four in this case, in which there is zero discharge. This is significant and will be discussed later. When phosphorus outputs are compared under the two regimes (Fig. 10) there is an increased phosphorus discharge of 9.2×10^3 kg/yr.

Effect of Regulation

It appears that more phosphorus leaves the lake under natural conditions due simply to the increased water discharge. In order to test this, the areal flushing rate was calculated on a yearly rather than monthly basis and equation 1 was utilized. The results are in Table 2.

The output predicted that the difference in turnover time or flushing rate accounts for only about a 2 percent difference in phosphorus output. The actual difference was 10 percent, which raises the question: Does regulation affect phosphorus dynamics through a mechanism other than by changing the yearly flushing rate? If only yearly turnover times are used

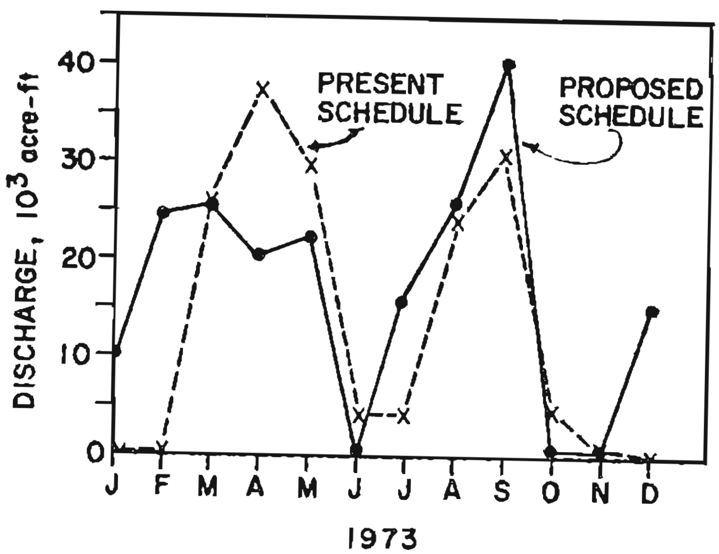


Fig. 6. Monthly water discharge for present schedule. Simulated water discharge for proposed schedule.

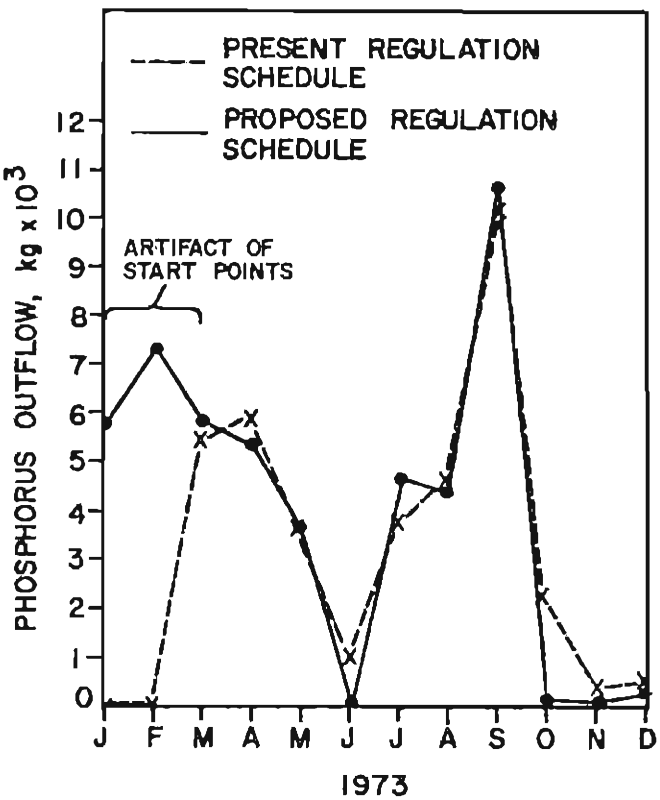


Fig. 7. Phosphorus outflow.

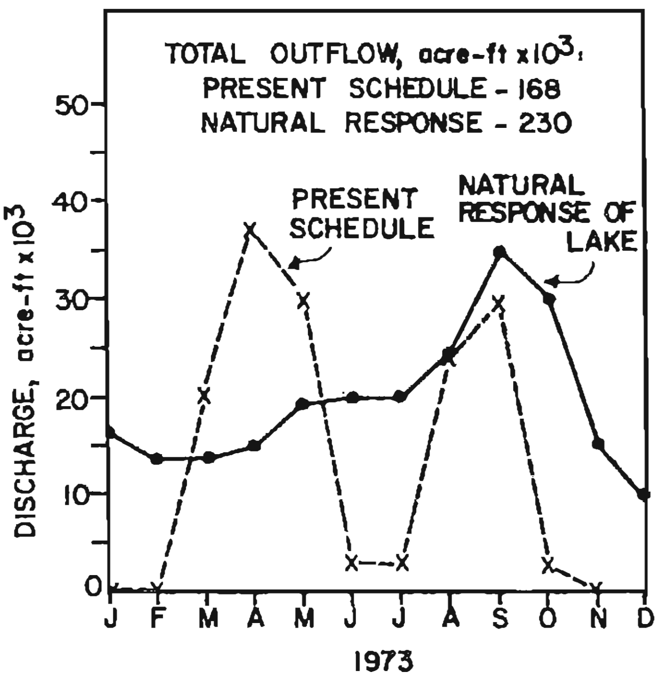


Fig. 8. Simulated natural response of Lake Toho to 1973 inputs.

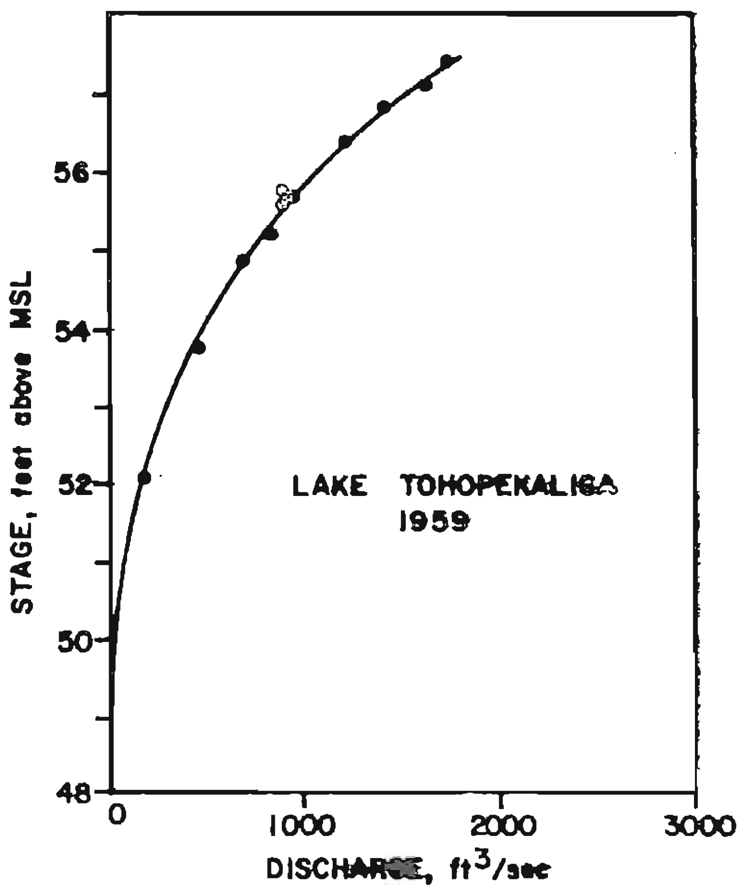


Fig. 9. Response of Lake Toho previous to lake regulation.

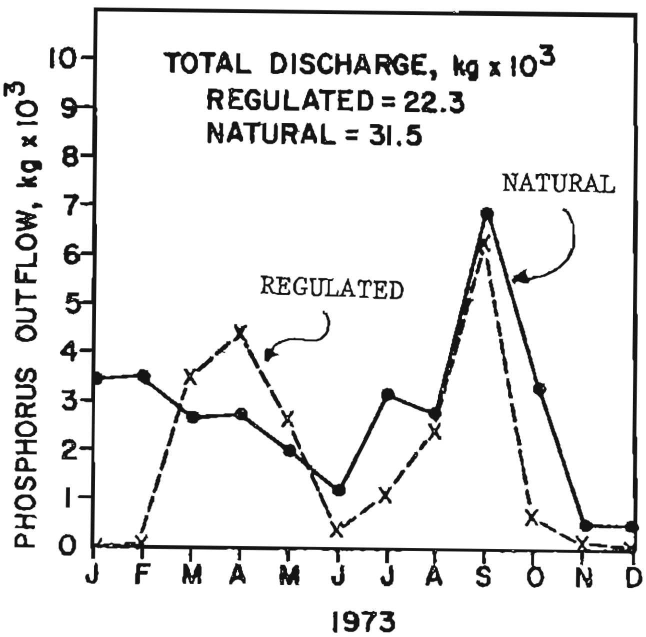


Fig. 10. Comparison of phosphorus outputs.

Table 2. Predicted and Actual Phosphorus Discharge

	Predicted Output (As of % of incoming P)	Actual Output
Regulated	26%	19%
Natural	28%	29%

to guage the effect of regulation, the conclusion would be that regulation has no effect, as Figure 11 indicates that ten year average turnover times for Lake Toho pre and post regulation are not significantly different. The effects of lake stage regulation on phosphorus retention are evidently missed by looking only at yearly turnover times. By using equation 1 on a monthly basis, the effects of regulation become evident.

Recall that the output of phosphorus was calculated by taking a percentage of the input for only that month, which results in the load that came in during the previous month being completely lost to the calculation. Since this method produced a high degree of accuracy (Fig. 4), it seems to indicate that phosphorus uptake occurs within thirty days or less after the phosphorus enters the lake.

This has implications for lakes regulated on a monthly basis. Figure 12 indicates that the rainy season, which is a time of large phosphorus inputs, is precisely when outflows are kept low and lake levels allowed to rise. All of the phosphorus which comes in during a high inflow month is lost to uptake even if water discharge the next month is abnormally high.

It is evident that the equation does not accurately predict Lake Toho's response, as it was developed from lakes that respond naturally. That is, large inputs are matched by large outputs the same month. Viewed in this light it is reasonable to expect an over prediction of the amount of discharged phosphorus. Further study with detailed nutrient sampling needs to be undertaken, but these preliminary results indicate that regulation may result in a lake retaining more phosphorus than it would under natural conditions.

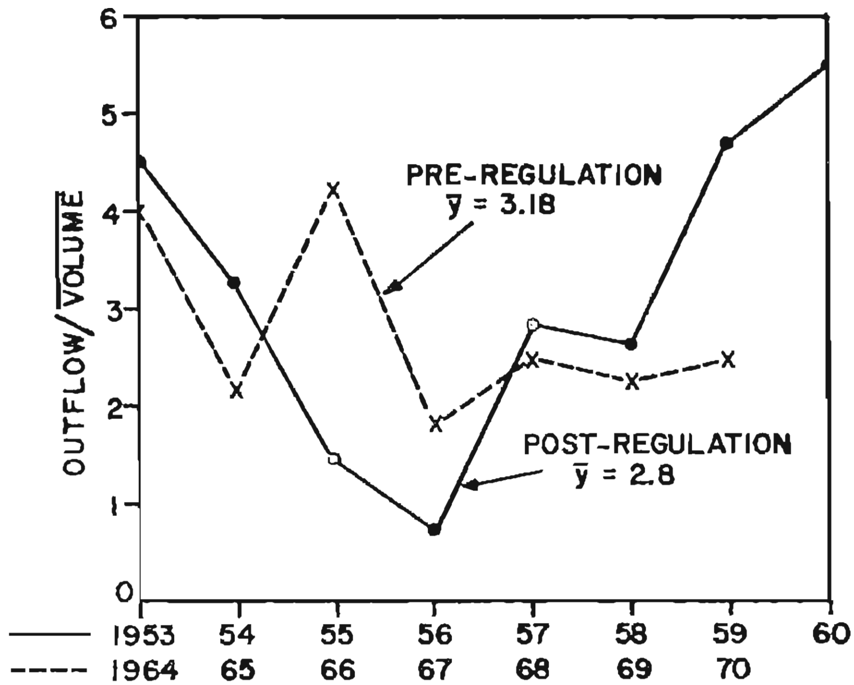


Fig. 11. Yearly turnover time for Lake Toho.

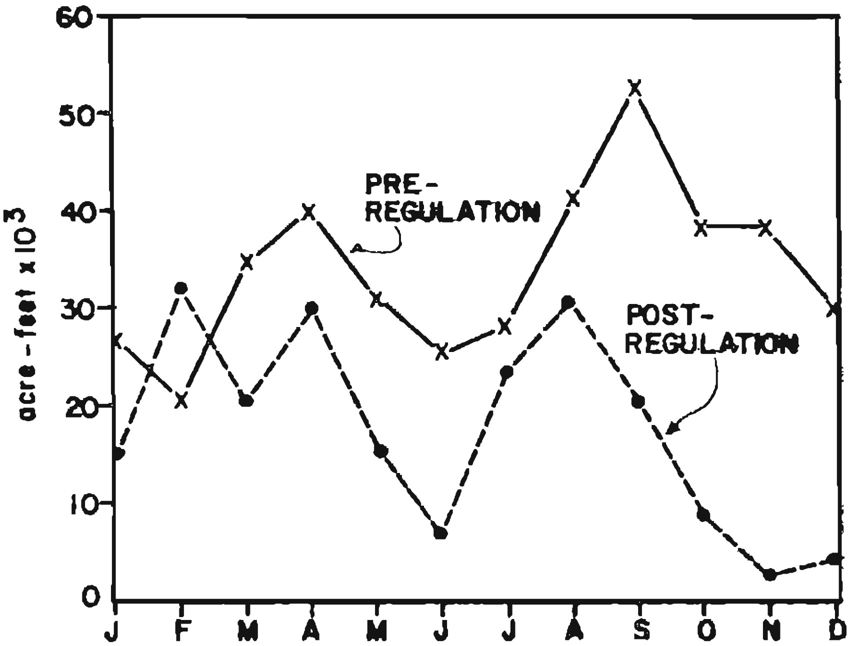


Fig. 12. Ten-year average outflow for Lake Toho.

Implications and Management Alternatives

Two methods were used to simulate future lake trophic states: (1) a steady state between the sediments and the water column was assumed and phosphorus loading was increased, (2) phosphorus input was held steady and the time required for the sediments in Lake Toho to begin to spill over into the next lake was calculated.

Figures 13 and 14 show results of simulated increases in phosphorus loads to Lake Toho under regulated and natural conditions. Eutrophic or hypereutrophic levels are taken from Shannon and Brezonik (1972). Even with 1958 land use and 1/5 the present phosphorus loading from Shingle Creek (the lake's largest nutrient inflow), the lake is hypereutrophic under both natural and regulated regimes.

Simulations with regulated conditions show that Lake Cypress/ Hatchineha is not yet eutrophic; however, when simulated under natural conditions becomes eutrophic. Using 1973 land use and present inputs, a comparison indicates a more even spreading of the nutrients under the natural regime. In neither case is Lake Kissimmee at a critical level. Figure 15 shows the effects of doubling the present loading to Toho under regulated conditions. The model indicates that Lake Kissimmee would receive acceptable loads even with a loading rate to Toho of 2.8 g $P/m^2/yr$.

The above analysis shows that the lakes move toward eutrophic conditions in two patterns. When they are regulated and therefore retain more phosphorus, one lake reaches extremely high levels, then the next, and so on. When left to respond naturally, the lakes move up the trophic scale in a more even fashion. The outflow of phosphorus to the Kissimmee

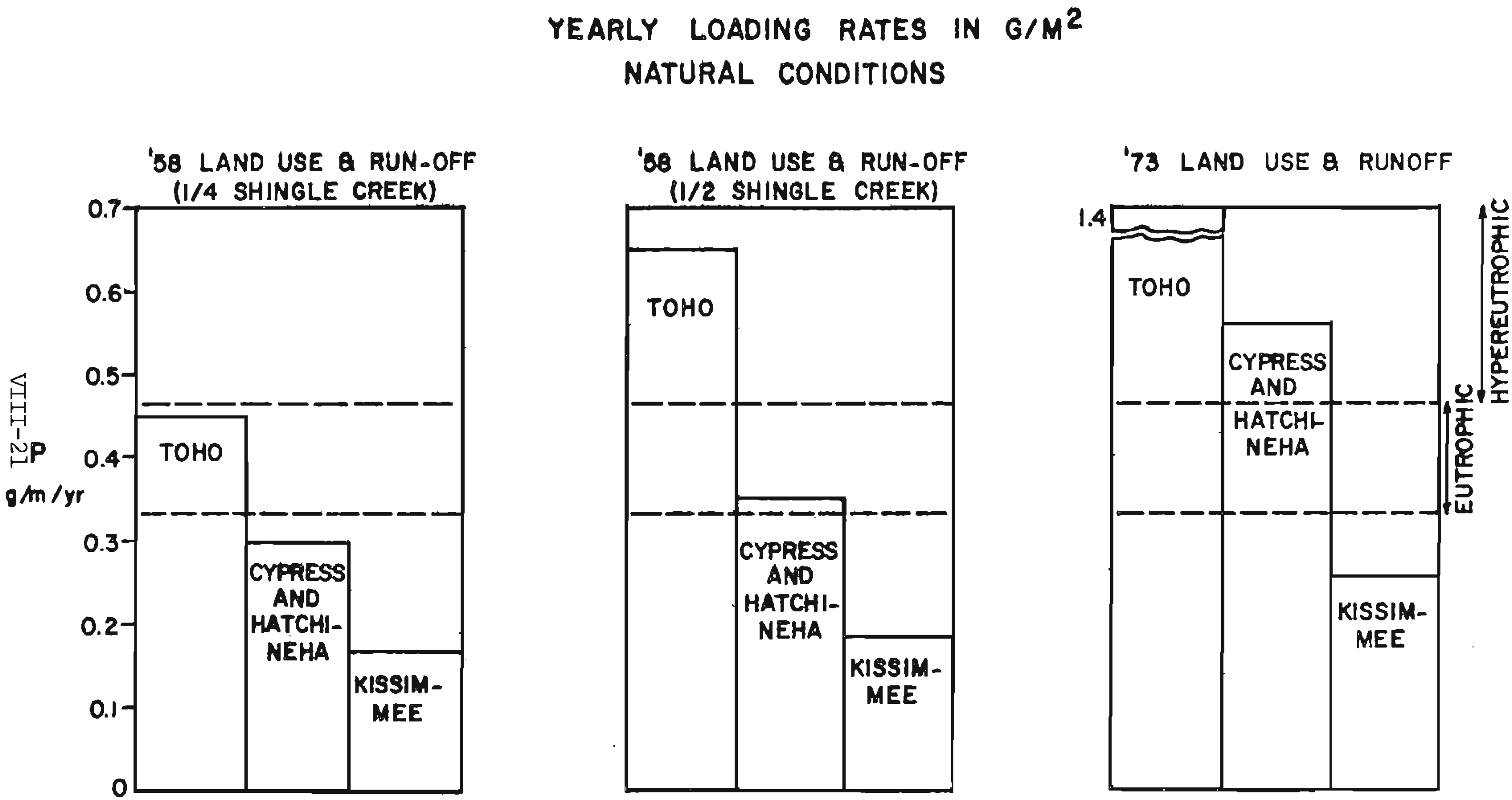


Fig. 13. Computer simulated loading rates for changing land use with natural lake discharge.

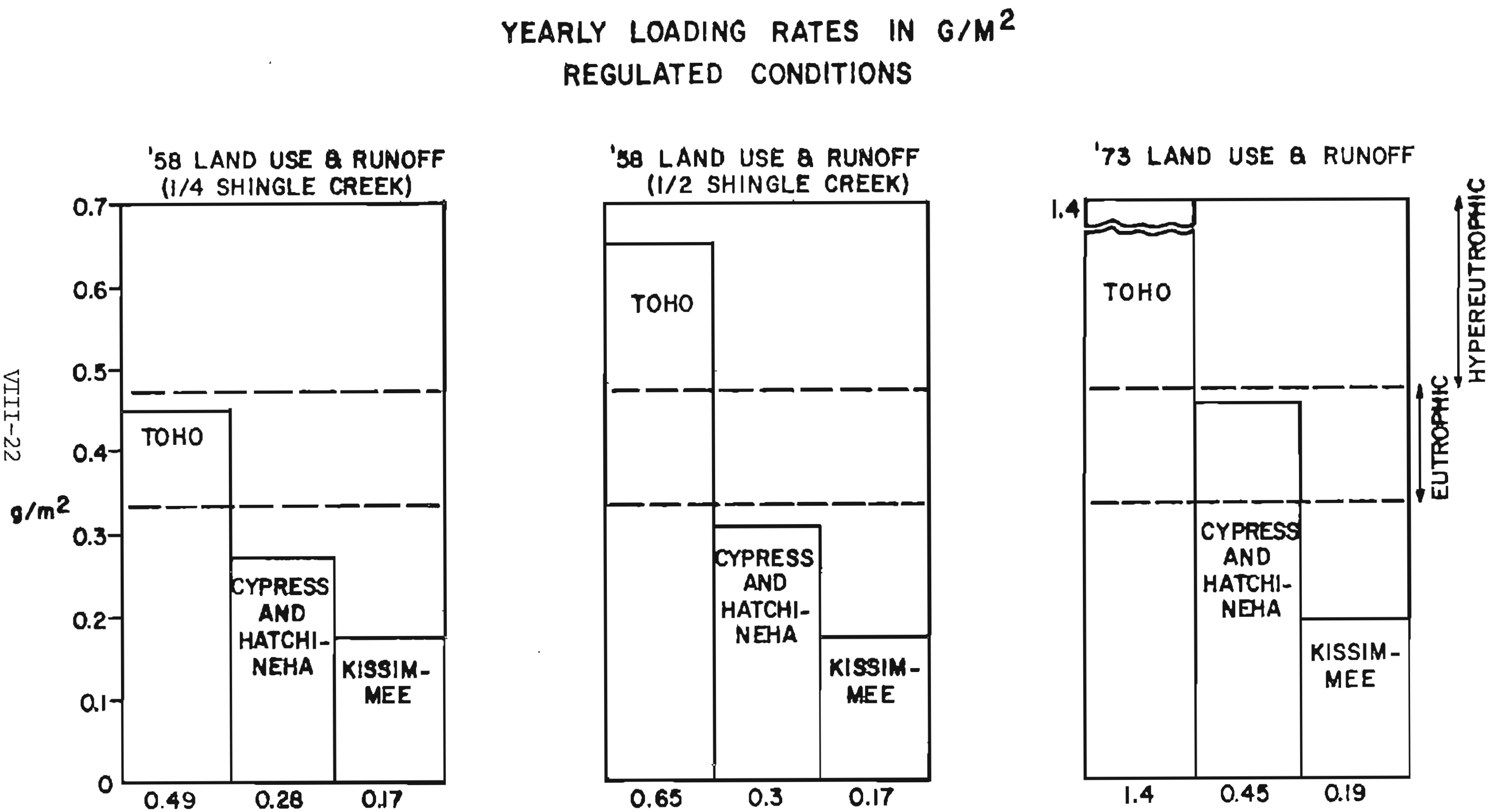


Fig. 14. Computer simulated loading rates for changing land use with present regulation schedule.

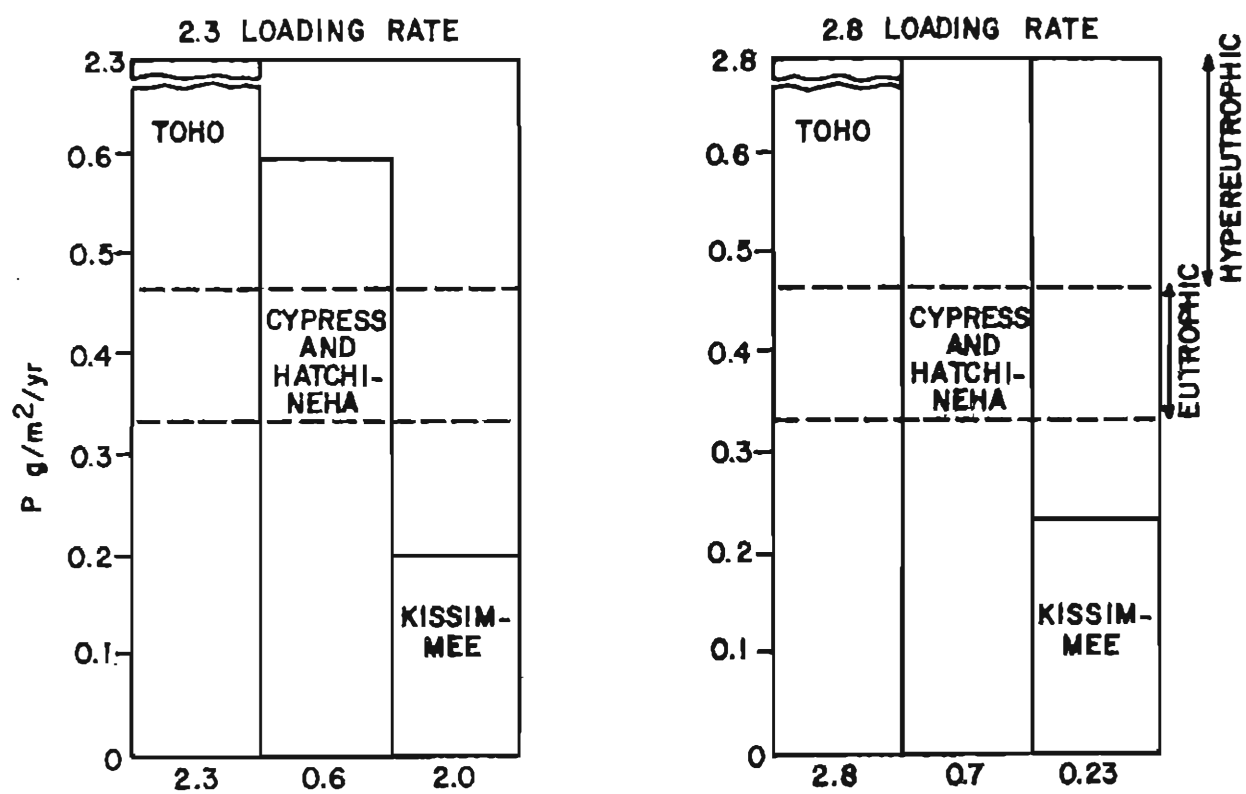


Fig. 15. Computer simulated loading rates in g/m^2 for present land use and present regulation schedule with increasing phosphorus concentrations to Lake Toho.

River would obviously be greater under natural conditions. Lake regulation, therefore, would seem to benefit Lake Okeechobee as less nutrients would be transported downstream to it via Canal 38.

If, however, lake regulation actually has a "sink" effect, Okeechobee itself may be retaining more phosphorus than it would on a more natural regulation schedule which allowed large monthly inputs to be matched by large monthly outputs. Phosphorus might then be delivered to estuarine areas where nitrogen is perhaps the limiting element.

While many details concerning sediment-water column interactions remain to be worked out, some degree of predictability may be obtained by utilizing Equation 2 (Price, 1947).

$$y = .4x + 3$$

This equation determines a lake's equilibrium level. When a lake becomes shallower than the equilibrium depth, the sediments begin to spill over into the next lake. Using a primary production value of 4g Carbon/m^2/day, it was calculated that one cm of sediment will be deposited every 7 years. Average width $\frac{m^3}{m}$ was calculated and substituted for x in equation 2. The equation predicted an equilibrium level of 5 feet. This is one foot shallower than the present depth of Lake Toho. Thus, at the present loading rate, in approximately 30 years Lake Toho would begin to export large quantities of phosphorus downstream.

Dillon (1975) discusses the importance of flushing rates in determining critical loadings. He reports that Vollenweider's relation of P loading vs. mean depth worked only because all of the lakes Vollenweider worked on had very low flushing rates. A lake with a large flushing rate can tolerate a greatly increased loading rate without experiencing a detrimental change in trophic state (Dillon, 1975). Conversely, a regulated lake could tolerate less of a loading rate than a naturally responding lake of the same morphometery and flushing rate.

Shannon and Brezonik (1972) note that Florida lakes tolerate slightly larger loading rates than indicated by Vollenweider's curves. One explanation, given by Dillon, is that Florida lakes have flushing rates which average about an order of magnitude greater than those of Vollenweider. The effects of regulation may counteract this, and keep the flushing rates similar to those of Vollenweider.

The main objective of lake stage regulation is to provide adequate flood control; however, it should be useful to know that regulating a lake also provides the ability to retain more or less phosphorus in the lake than under natural conditions.

APPENDIX

Digital Program for Chain of Lakes Model

```
NSTREAM EUTROPHICATION MODEL      5/28/75
 DOWNSTREAM EUTROPHICATION MODEL
  AUX1.K=RAIN.K+RUNOFF.K+SHING.K+IN31.K-EVAPO.K+AUXO.K
  LEV1.K=AUX1.K-OUTFLO.K
  OUTFLO.K=FIFGE(DIFFV.K,ZERO,AUX1.K,CSTGV.K)
     QUS.K=((DIFFV.K*123015)/(AREA.K*4047))*12
 ( AUX9.K=LEV2.K*(1-AUXRP.K))
   RATE9.K=FIFGE(AUX9.K,ZERO,AUX1.K,CSTGV.K)
  DIFFV.K=AUX1.K-CSTGV.K
  CTB=94/124/144/133/101/84/85/92/92/120/130/124
     LEV2.K=RAIN.K*C2+C4.K+SHING*CON6.K+IN31.K*C10
   CON6.K=TABLE(CON6TB,TIME.K,0,11,1)
     CON6TB=1/1/1/1/1/1/.2/.2/.2/.2/
   AUXRP.K=.426*EXP(-.271*QUS.K)+.574*EXP(-.00949*QUS.K)
   AREA.K=TABLE(ARTB,LEV1.K,50,150,10)
  ARTB=15.2/16/16.8/17.5/19.5/20.5/20.9/21.1/21.8/22.6/23.2
  RAIN.K=TABLE(RAINTB,TIME.K,0,11,1)
  RAINTB=8.72/4.5/4.4/3.8/6.65/9.8/13.4/13.1/20.5/1.75/1.4/3.1
  RUNOFF.K=TABLE(RUNTB,TIME.K,0,11,1)
  RUNTB=11/3.2/.095/0/1.9/2.4/5.6/3.5/17/4.2/.1/0
  SHING.K=TABLE(INFLTB,TIME.K,0,11,1)
  INFLTB=5.18/6.27/2.31/2.97/.734/1.21/3.67/9.17/13.27/7.35/1.67/1.52
  IN31.K=TABLE(INCTB,TIME.K,0,11,1)
  INCTB=0/.684/17.16/12.57/12.92/0/1.38/7.65/16.67/11.76/0/0
  EVAPO.K=TABLE(EVAPTB,TIME.K,0,11,1)
  EVAPTB=3.85/4.9/7.9/8.25/8.1/7.6/8.5/6.86/7.59/6.98/5.73/3.81
  AUXO.K=TABLE(OTB,TIME.K,0,11,1)
  CSTGV.K=TABHL(STAGTB,TIME.K,0,11,1)
  C2=.037
     STAGTB=143/143/133/105/85/85/95/93/119/133/143/143
     C4.K=(.01*RUNOFF.K)*.6+(.16*RUNOFF.K)*.37+(.8*RUNOFF.K)*.06
  C6=2.17
     C10=.2
  ZERO=0.0
     TSIT.K=TABHL(TSTT,AUXTT.K,0,.5,.1)
     TSTT=0/2/4/8/12/15
     AUXTT.K=(LEV2.K*1000)/(AREA.K*4047)*12

AUXTT=((LEV2*1000.)/(AREA*4047.))*12.
     HATCH1.K=RAINH.K+RUNOFH.K+OUTFLO.K+C34.K+S88+AUXOH.K-EVAPH.K
  LEVH.K=HATCH1.K-OUTFLH.K
     AUXOHT=63/78/70/62/55/48/48/55/62/78/80/62/
    AUX9H.K=LEVPH.K*(1-AUXRPH.K)
     RATEH.K=FIFGE(AUX9H.K,ZERO,HATCH1.K,CSTGH.K)
     OUTFLH.K=FIFGE(DIFF.K,ZERO,HATCH1.K,CSTGH.K)
  DIFF.K=HATCH1.K-CSTGH.K
     QUSH.K=((DIFF.K*123015)/(AREAH.K*4047))*12
     LEVPH.K=RAINH.K*C2+RUNOFH.K*C13+(RATE9.K*.5)+C34.K*C15
    AUXRPH.K=.426*EXP(-.271*QUSH.K)+.574*EXP(-.00949*QUSH.K)
    RAINH.K=TABLE(RAINTH,TIME.K,0,11,1)
    RUNOFH.K=TABLE(RUNOTB,TIME.K,0,11,1)
    RAINTH=15.2/5.48/1.3/6.1/7.3/8.6/18.0/16.7/25.7/1.58/1.5/5.9
    RUNOTB=5.7/2/.002/0/.72/.92/2.6/1.7/11/3.7/.080/0
    C34.K=TABLE(C34TB,TIME.K,0,11,1)
    S88=5
    C34TB=2.5/5.4/1.5/6.1/1.7/0/0/4.2/4.2/1.7/.2/0
    C37.K=TABLE(C37TB,TIME.K,0,11,1)
    C37TB=0/29/55/63/62/9/7/33/42/10/0/0
    AUXOH.K=TABLE(AUXOHT,TIME.K,0,11,1)
```

DOWNSTREAM EUTROPHICATION MODEL(CONT)5/28/75

```
A       CSTGH.K=TABLE(CSTBH,TIME.K,0,11,1)
T       CSTBH=0/72/64/55/48/52/60/65/72/90/90/85
A        AREAH.K=TABLE(ARHTB,LEVH.K,48,56,1)
T        ARHTB=9/10/10.2/13/17/22/30/40/46
A       EVAPH.K=TABLE(EVAP2,TIME.K,0,11,1)
T       EVAP2=3.8/4/6/6/6/6/6/6/7.5/7.7/11/4.7/
A        AUXTH.K=(LEVRH.K*1000)/(AREAH.K*4047)*12

NG  -  AUXTH=((LEVPH*1000.)/(AREAH*4047.))*12.
A        TSIH.K=TABHL(TSTT,AUXTH.K,0,.5,.1)
A        KISS1.K=RAINK.K+RUNOFK.K+TOTIN.K+C37.K+AUXOK.K-EVAPK.K
A       LEVK.K=KISS1.K-OUTFLK.K
A        CSTGK.K=TABLE(CSTBK,TIME.K,0,8,1)
T        CSTBK=308/300/261/255/260/270/290/280/330/335
A        LEVPK.K=RAINK.K*C2+RUNOFK.K*C17+TOTIN.K*C18+RATEH.K
A       AUXRPK.K=.425*EXP(-.271*QUSK.K)+.574*EXP(-.00949*QUSK.K)
A       RAINK.K=TABLE(RAINTK,TIME.K,0,8,1)
T       RAINTK=18.2/7.6/9/9.7/12.4/15.6/31.2/14.9/32.2
A        RUNOFK.K=TABLE(RUNOTK,TIME.K,0,8,1)
T        RUNOTK=8.1/3.8/.028/0/.6/.82/3.7/2.2/19
A        TOTIN.K=TABLE(TOTTB,TIME.K,0,8,1)
A       AUXOK.K=TABLE(AUXOKT,TIME.K,0,8,1)
T        TOTTB=20/55/8/73/13/0/0/30/60
T        AUXOKT=260/300/325/290/280/260/240/260/280/300
A       AUX9K.K=LEVPK.K*(1-AUXRPK.K)
A        RATEK.K=FIFGE(AUX9K.K,ZERO,KISS1.K,CSTGK.K)
A        QUSK.K=((DIFFK.K*1230.5)/(AREAK.K*4047))*12
A        DIFFK.K=KISS1.K-CSTGK.K
A         OUTFLK.K=FIFGE(DIFFK.K,ZERO,KISS1.K,CSTGK.K)
A        S65.K=TABLE(S65TB,TIME.K,0,8,1)
T        S65TB=.1/60.2/90/143/95/1.9/.076/49/99.5
A        EVAPK.K=TABLE(EVAP3,TIME.K,0,8,1)
T        EVAP3=6.5/7.6/12/13.6/14/12.2/10/9/8.6
A        AUXTK.K=(LEVPK.K*1000)/(AREAK.K*4047)*12

G  -  AUXTK=((LEVPK*1000.)/(AREAK*4047.))*12.
A        TSIK.K=TABHL(TSTT,AUXTK.K,0,.5,.1)
A        AREAK.K=TABLE(ARKTB,LEVK.K,48,55,1)
T        ARKTB=31/31.5/34/36/39/42.4/52/64
C        C14=.12
C        C15=.06
C        C16=.04
C        C17=.06
C        C18=.037
C        C19=.05
A        PLOTT.K=LEV2.K*AUXRP.K
A        PLOYK.K=LEVPK.K*AUXRPK.K
A        PLOTH.K=LEVPH.K*AUXRPH.K
PRINT         C4
PRINT         LEVPH,LEVPK
PRINT         AUXTH,AUXTK
PRINT         LEV1,LEV2,OUTFLD,RATE9,QUS
PRINT         OUTFLH,OUTFLK,TSIT,TSIH,TSIK
PRINT          ATEH,RATEK
PLOT         RATE9=9
SPEC         DT=.1/LENGTH=11/PRTPER=1/PLTPER=.5
RUN
```

Literature Cited

Bedient, P. 1974. An Evaluation of Drawdown and Nutrient Loading in Lake Tohopekaliga, Florida. Unpublished.

Dillon, P.J. 1975. The Phosphorus budget of Cameron Lake, Ontario: the Importance of Flushing Rate to the Degree of Eutrophy of Lakes. Limnol. Ocean. Vol. 20:28-40.

Kirchner, W.B. and Dillon, P.J. 1975. An Empirical Method of Estimating the Retention of Phosphorus in Lakes. Water Resources Research. Vol II:182-83.

Price, W. Armstrong. 1947. Equilibrium of Form and Forces in Tidal Basins of Coast of Texas and Louisiana. American Association of Petroleum Geologists Bulletin. Part 2.

Shannon, Earl E., and Brezonik, Patrick, L. 1972. Relationships between Lake Trophic State and Nitrogen and Phosphorus Loading Rates. Environmental Science and Technology. Vol 6:719-24.

Vollenweider, R.A. 1968. Scientific Fundamentals of the Eutrophication of Lakes and Flowing Waters with Particular Reference to Nitrogen and Phosphorus as Factors in Eutrophication. Tech. Rep. DAS/C81/68, 159 pp. Organ. Coop. Dev., Paris, 1968.

IX. BASIC LAKE MODEL FOR UPPER CHAIN OF LAKES

D. Grocki

Introduction

This study constructed a basic lake model which could be applied to the principal lakes of the upper Kissimmee drainage system including Lakes Kissimmee, West Tohopekaliga, Cypress, Hatchineha, and Istoppoga. The first four lakes are located in north central Florida and are interconnected by a series of canals. The effect of drawdown, increased nutrient load, and increased fishing pressure were evaluated for a ten-year time period. By viewing the major energy flows of the system, predictions can be made concerning expected changes in the lake.

These lakes are excellent fishing and waterfowl areas. Deterioration in the form of algal blooms and decreased fish production has occurred in recent years, and it is felt that regulated water levels and higher nutrient inputs are responsible. Lake Tohopekaliga presently receives the effluent from five sewage plants, 14 million gallons per day (Wegener and Williams, 1974).

Data were drawn from federal, state, and regional agencies such as the Department of Pollution Control, the Central and South Florida Flood Control District, the Army Corps of Engineers, the Florida Game and Fresh Water Fish Commission, the Environmental Protection Agency, the United States Weather Bureau, and the United States Geological Survey. Values from the literature were used to determine food habits, respiration, excretion, assimilation and production rates.

Basic Lake Model

Figure 1 shows the energy flow for a generalized Florida lake ecosystem. External forcing functions (external influences on the lake system) include solar radiation, temperature, water, nitrogen, phosphorus, oxygen and fishing pressure. Storages are comprised of water, nitrogen and phosphorus in the water and in the sediments, organics, oxygen, phytoplankton, macrophytes with their adhering periphyton, zooplankton, invertebrates and fish. Primary producers are phytoplankton, phytoperiphyton and macrophytes which include emergent, submergent and floating vegetation. The producers in a system capture sunlight and use it to convert carbon dioxide and water into organic material and oxygen.

Emergent vegetation consists of rooted plants with their principal photosynthetic surfaces projecting above the water. They obtain carbon dioxide from the air and nutrients from the water and the sediments. Examples of such plants encompass cattails (*Typha*), bullrushes (*Scirpus*), water lilies (*Nymphaea*), arrowheads (*Sagittaria*), alligatorweed (*Alternanthera*), panic grass (*Panicum*), pickeralweeds (*Pontederia*), spike rushes (*Eleocharis*), and spatterdock (*Nuphar*). These plants provide a connection between shore and lake and a resting place for aquatic and semi-aquatic invertebrates. Areas between two systems, called ecotones, are characterized by large numbers and high diversity of organisms, and for this reason, there are more invertebrates on and around emergent vegetation than submergent vegetation, supplying ample food for fish. Lakeward extension of emergent vegetation is determined by the low level of water fluctuations, which stimulates germination of seedlings (Wegener, 1973).

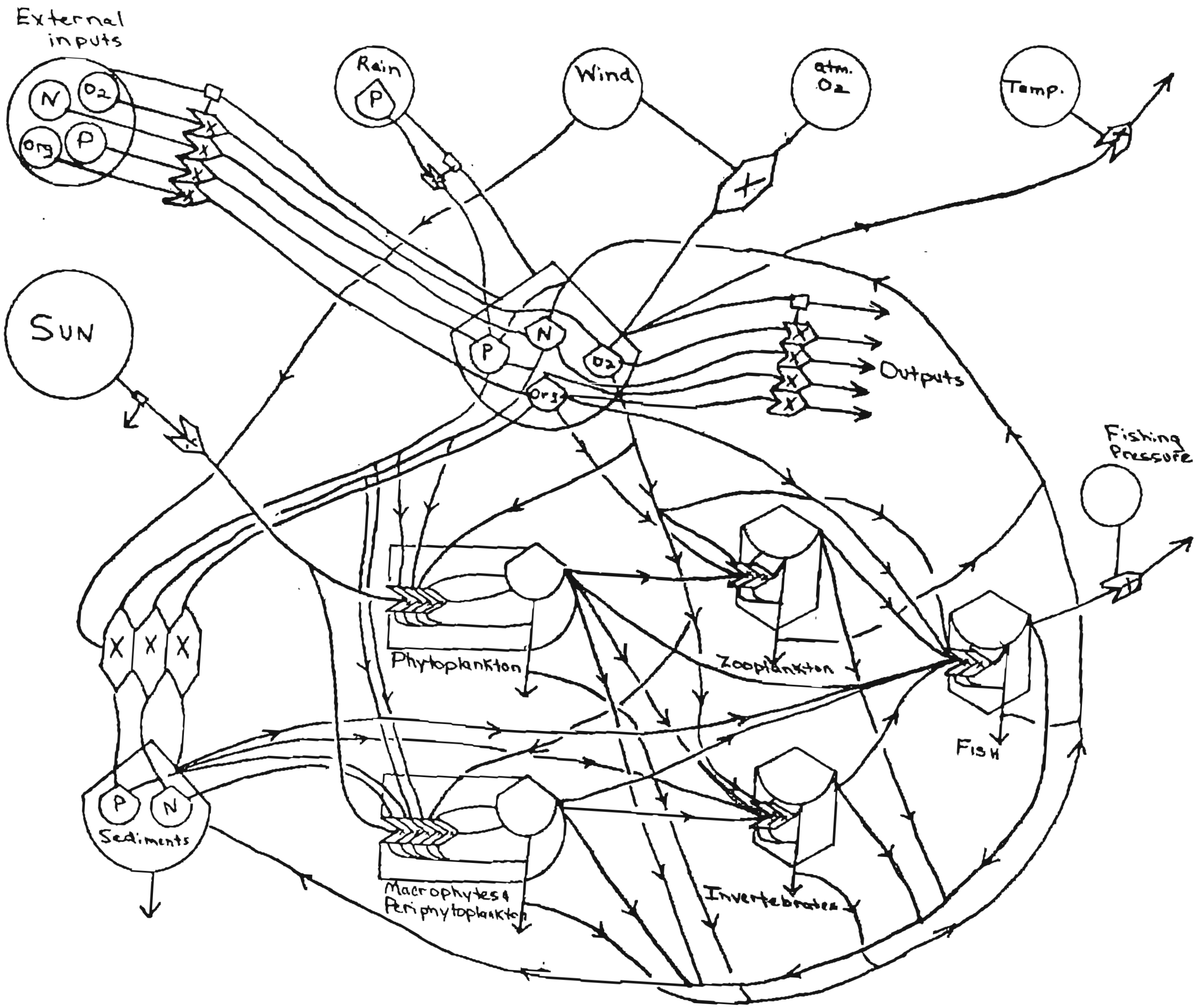


Figure 1 - General Lake Model

Submergent vegetation consists of species such as wild celery (*Vallisneria*), St. Johns Wort (*Hypericum*), coontail (*Ceratophyllum*), *Hydrilla*, and Naiads (*Najas*). They are habitually located in shallow water contours just beyond the zone of emergent vegetation and fade out when water becomes too deep for them to obtain adequate sunlight.

Water hyacinth (*Eichhornia*) doesn't need to remain rooted in order to grow and multiply and is often blown about by the wind. In nutrient rich water, water hyacinth grows at tremendous rates, forming large mats and shading out beneficial vegetation. Dying hyacinths produce large accumulations of organic buildup, which rob the water of oxygen making bottom areas unproductive for invertebrates and fish. Mat formation also interfers with the natural diffusion of oxygen between air and water, increasing the problem of low oxygen even more.

The phytoperiphyton includes algae often of the filamentous variety which grow on or around stems and leaves of aquatic vegetation. It probably is the primary food source of herbivorous invertebrates grazing on aquatic vegetation. When a lake is loaded at high nutrient levels, the filamentous algae type develop large "blooms" which rise to the surface buoyed up by entrapped oxygen. The oxygen which is produced during photosynthesis escapes to the air. When the bloom dies, oxygen is used up, often stressing or killing fish (E.P. Odum, 1959).

Phytoplankton associations are typically of one or two basic types: blue greens or an association of several forms not including blue greens. Blue green algae are of great importance, because under conditions of high nutrients, they produce great blooms. Many blue green species are resistant to grazing which allows for large biomass accumulations. Many species, such as Aphanizomenon, Anabaena and Coelosphaerium produce toxic substances when they decay and die. These algae are especially dangerous when they appear in blooms and are concentrated by wind action along a windward shore. They have been responsible for mammalian, avian and fish deaths. Cattle drinking the water with high concentrations may show signs of acute poisoning (Bennet, 1970). Blue green algae are utilized by very few consumers other than gizzard shad and threadfin shad.

The consumers consist of the zooplankton, invertebrates and fish. The zooplankton are comprised mainly of copepods, cladoceans (water fleas), ostracods, and rotifers. They are found in both the littoral and limnetic zones. Gliwicz (1969a) found that zooplankton derive their energy from small sized detrital particles and phytoplankton, especially nanoplankton. He also found that the detrital portion becomes increasingly important in eutrophic lakes as compared to oligotrophic lakes. He felt that this was because nanoplankton is replaced by larger blue green forms in eutrophic lakes, forcing the zooplankton community to feed more heavily on detritus. Hence, the zooplankton does not really keep up with increased production.

The invertebrate fauna is a diverse group composed of molluscus. insects, crustaceans, annelids, and nematodes. Kramler (1970) suggested that the benthic community derives about 70 percent of its energy requirement from detritus and 30 percent from algae. Numbers and diversity are usually higher in the littoral zone in comparison to the profundal area (Wegener and Williams, 1974; Holcomb, 1974; Ager and Kerce, 1974; Wilbur 1969). Vegetation provides food, cover, increased surface area, and oxygen for mobile phytophagus invertebrates. It stabilizes sediments and moderates wave-erosion and scouring action which reduces burrowing forms and their habitat. It serves as attachment for eggs and larvae. It also provides a resting place for semiaquatic forms.

From a fisheries viewpoint, there are three basic types of fish: forage species, trash species, and species that can be harvested by sportfishing. Forage species include a great diversity of species: minnows, top minnows, shiners and small shad. Most forage species are intermediate in the food chain, feeding on invertebrates and zooplankton (Table 1). There are a few species such as golden shiners, sailfin mollies, flag fish, gizzard shad, and threadfin shad that derive a substantial portion of their energy requirements from phytoplankton or algae. However, only the gizzard shad and threadfin shad seem to consume much detritus. Looking at their feeding habits tells why gizzard shad and threadfin shad are the major forage species of the limnetic zone; algae are abundant and there is little competition from other vertebrates. Being able to utilize blue green algae, they are one of the few species that can benefit from algal blooms.

Large gizzard shad are considered trash fish because they are too large for piscivorous fish to eat, do not take a fish hook and are of low quality as human food. Table 2 shows another reason for considering the gizzard shad as undesirable as they eat zooplankton which might go to more desirable species. Other trash fish include gar, bowfin, needlefish, large chubsuckers and large golden shiners. The first three are mainly piscivorous, competing directly with the bass. The latter two are much like the gizzard shad, in contributing very little to the system from man's viewpoint, yet taking their share of zooplankton and invertebrates and competing for space with more desirable species.

Table 1
Food Habits Of Forage Species

Species	Invertebrates	Algae Phytoplankton	Detritus	Forage	Zooplankton	Sources
Seminole killifish	100%					MacLane 1955, Grocki 1974 (unpublished data)
Golden topminnow	100%					MacLane 1955, Grocki 1974 (unpublished data)
Flagfish		100%				MacLane 1955
Pygmy killifish	40%	10%			50%	MacLane 1955
Bluefin killifish	80%	5%			15%	MacLane 1955, Harrington 1961
Mosquitofish	60%				40%	Harrington 1961, Flemes 1966, Barnichol 1941
Least killifish	40%	10%			50%	MacLane 1955
Sailfin molly	50%	50%				Harrington 1961, MacLane 1955
Brook silverside	30%	10%			60%	MacLane 1955
Notropis sp.	25%				75%	MacLane 1955, Marshall 1946
Goldenshiner	40%	40%			20%	Radcliffe 1931, Flemer 1966
Lake chubsucker	50%				50%	MacLane 1955, Ewers 1935
Pygmy sunfish	25%				75%	MacLane 1955
Bluespotted sunfish	25%				75%	MacLane 1955, Fox 1969, Cable 1947
Dollar sunfish	75%				25%	MacLane 1955

Table 1
(Cont.)

Swampdarter	50%				50%	MacLane 1955
Threadfin shad	45%	10%			45%	Swingle 1969, Hendricks, 1961
Gizzard shad		50%	25%		25%	Berry 1955, Kutkuhn 1958, Swingle 1969, Cramer 1970, Jude 1973
Brownbullhead	50%				50%	Keast 1966, Swenson 1954, Flemer 1966
White catfish	50%				50%	Stevens 1959, Miller 1966, Wolfe (unpublished data)
Channel catfish	90%	5%				Bailey 1948, Ewers 1935, Darnell 1958, Stevens 1959, Cross 1951, Ware 1966, Dendy 1946
Yellow catfish	50%	20%		30%		Flemer 1966, McClellan 1954
Pirate perch	75%			25%		MacLane 1955, Robinson 1975 (Unpublished data)
Chain pickeral	75%				25%	Meyers 1962, Flemer 1966, Buntz 1966, MacLane 1955
Bluegill	50%	2%			45%	Huish 1965, MacLane 1955, Gerking 1962, Cable 1947
Redear	100%					Huish 1965, Cable 1947, Fox 1969
Warmouth	100%					Reid 1949, Fox 1969, Huish 1965, Larimore 1957
Largemouth bass	33%			34%	33%	Chew 1970, Chew 1972, Clugston 1954, MacLane 1948, MacLane 1950, MacLane 1955
Black crappie	100%					Huish 1954, Reid 1950

Table 2
Food Habits Of Trash Species

Species	Inver-tebrates	Algae Phyto-plankton	Detri-tus	Forage	Zooplankton	Sources
Florida gar	10%			90%		Halloway 1954, Hunt 1960, Crumpton (unpublished data), Diana 1966, Lagler 1940
Bowfin	20%			80%		Lagler 1940, Lagler 1942, Scott 1938, Diana (unpublished data)
Gizzard shad		15%			85%	Berry 1955, Kutkuhn 1958, Swingle 1969 Cramer 1970, Jude 1973
Lake Chubsucker	50%	20%	30%			Ewers 1935, MacLane 1955
Needlefish				100%		MacLane 1955
Golden shiner	40%	40%			20%	Radcliffe 1931, Flemer 1966

Table 3 shows that the fish of greatest interest to man feed mainly on insects and forage fish. Bass, pickeral and crappies are nearly exclusively piscivorous, generally feeding on those species which are most abundant, easiest to catch, and large enough to be worth the energy expended to catch them. The food utilization data indicate the large food base available to the panfish, which is why they are usually so abundant.

Water enters the lake system from rivers, canals, creeks, runoff, rainfall, underground rivers, irrigation, and seepage outflows. Water leaves the system via rivers, canals, creeks, sinkholes, irrigation and evapotranspiration. Nutrients such as phosphorus and nitrogen are carried in and out by the water. Nutrients are removed when fish and invertebrates are harvested by man, migrating birds, and other animals such as racoons, snakes, frogs, and otters. Such sources also contribute nutrients back via excretions, especially in instances where birds nest in rookeries on the lake but feed elsewhere. Phosphorus, which is usually limiting in fresh water systems, and nitrogen are taken up by the primary producers (from both the water and the sediments), enter the sediments or are carried out of the system.

Organic matter may be carried into the lake via inflows or produced within the lake from dead plants and animals. Detrital particles are coated with bacteria and minute animal colonies increasing the nutrient value of the particle for the animal that feeds upon it.

Oxygen enters the system from the air during turbulence created by wind action and is produced as a by-product of photosynthesis. Oxygen is used by both producers and consumers. Producers respire about half

Table 3
Food Habits Of Harvestable Species

Species	Invertebrates	Algae Phytoplankton	Detritus	Forage	Zooplankton	Sources
Largemouth bass	5%			95%		Chew 1970, MacLane 1955, Chew 1972, Clugston 1954, MacLane 1948, MacLane 1950
Narmouth	50%			50%		Larimore 1957, MacLane 1955, Cable 194
Black crappie	10%			90%		Huish 1954, Reid 1950, Fox 1969
Redear sunfish	100%					Cable 1947, Fox 1969, Huish 1965, Wilbur 1969
Bluegill	70%	10%		20%		Cable 1947, Fox 1969, Huish 1965, MacLane 1955, Gerking 1962
Chain pickeral	5%			95%		MacLane 1955, Meyers 1962, Flemer 1966, Buntz 1966
Brown bullhead	80%			20%		Keast 1966, Swenson 1954, Flemer 1966
White catfish	75%	15%		10%		Stevens 1959, Miller 1966, Wolfe (unpublished data) MacLane 1955
Channel catfish	80%			20%		Bailey 1948, Ewers 1935, Darnell 1958, Denby 1946, Cross 1951, Stevens 1959
Yellow bullhead	50%	20%		30%		Flemer 1966, MacLane 1955, McClellan 1954

of the carbon that they fix (Jackson, 1969; Bayley, 1975). Bacterial action on organic matter utilizes oxygen. In deep regions of the lake, the hypolimnion may become oxygen deficient, producing an oxygen gradient. Sediments may accumulate via phytoplankton "fallout" and slower degradation rates (degradation is faster under aerobic conditions, because there are more decomposers; few organisms are capable of anaerobic degradation). Normally, sufficient oxygen is present throughout most of the water column, however large sewage inflows require oxygen to degrade them. Undesirable fish species which are able to tolerate low oxygen levels or gulp air such as gar and bowfin would be selected for, while gamefish with higher metabolic rates would be selected against.

Lastly, solar radiation drives the photosynthetic activity of the primary producers and determines the water temperature. Elevated temperatures increase evapotranspiration, decrease dissolved oxygen, and increase the metabolism and flows of the entire system.

Background

Lake Kissimmee was chosen for simulation because it is the last lake of the Kissimmee chain to receive water before it enters the Kissimmee River for delivery to Lake Okeechobee. Lake Kissimmee is located in western Osceola County, close to the eastern eage of Polk County. It is the largest and most southerly of the Kissimmee chain of lakes. Having the lowest surface elevation, water flows towards it from north, east, and west. Drainage is received from a multitude of headwater lakes, including Marion and Hatchineha to the north, Jackson to the east and Rosalie and Tiger to the west. It serves as the headwater for the now channelized Kissimmee River. Water levels are regulated by the Central and South Florida Flood Control District.

In 1964, water regulation structures were built by the Army Corps of Engineers to prevent flooding of the lake shore and the Kissimmee River. Natural lake fluctuations were 2.3 feet to 8.5 feet with a yearly average of 4.8 feet per year with surface area ranging from 22,500 - 83,500 acres. Twelve feet is the maximum range of recorded lake fluctuation. Historical high level since 1942 was recorded at 56.64 MSL (feet, mean sea level) and low was 44.2 MSL. Water levels are now scheduled to fluctuate from a high of 52.5 MSL to a low of 48.5 MSL. This corresponds respectively to a surface area of 40,000 acres at highpool stage around November 1 and begin dropping December 1, reaching the regulated low by June 1, in preparation for the summer hurricane season. Water levels gradually rise due to summer rainfall and runoff, returning the lake to its regulated high. However, the theoretical low of 48.5 MSL and high of 52.5 are seldom reached during the same year. Consequently, annual fluctuation is less than 3 feet rather than the scheduled 4 feet (Wegener, 1973).

Water levels are extremely important because the lakeward limit of perennial plants is determined to a great extent by the extreme lows of water fluctuation during the growing season. Germination of many emergent plants is stimulated when the water levels recede. Rooted emergent vegetation in Lake Kissimmee occupies those lakeward contours exposed by historical low water elevations. The area of the lake's littoral zone represents a considerable portion of the lake surface. At present regulation levels, about 26 percent of the lake's surface area is littoral zone. Fishery biologists (Wegener 1973; Holcomb and Barwick 1974) feel that the aquatic plants surrounding the lake are necessary to produce and maintain a dynamic sport fishery. The existence and well being of these plants are dependent upon adequate water level fluctuations.

The Florida Game and Fresh Water Fish Commission is presently conducting a five year study of the lake with hope that a drawdown (a drop in low pool stage to the historical low level) will result in increased littoral zone and increased fish production. A drawdown was partially successful (Wegener *et al.*, 1970-1974) in the management of Lake Tohopekaliga which is also regulated, and receives large inflows of secondary treated sewage. Lake Tohopekaliga was drawn down to its historical low level for six months, and then brought up slowly to its normal regulation level (Wegener, 1974). As a result, the littoral area increased from 9,000 acres to 10,500 acres, a 16 percent increase. Organic sediments that were exposed oxidized from 50-80 percent. Benthic invertebrates and fish populations doubled. Fishing success increased from 1.6 fish per man-hour effort to 2.0 fish per man-hour effort. Game fish were also larger, possibly because small fish normally protected in the shallower littoral zone were driven out into open water where they could be utilized by larger fish. However, improved water quality did not ensue, probably due to continuing large sewage inflows. Algal blooms, water hyacinths, and possibly the recently established *Hydrilla* may become increasingly severe problems (Wegener, 1973).

At the present, Lake Kissimmee's shoreline is mainly wet and dry prairie. Major land use at present is for cattle on improved and unimproved pasture. A few fish camps are located on the lake. Located on the southwestern shore is a small housing and trailer development. Future plans are for large areas to be developed around the lake for urbanization.

Lake Kissimmee Model

For simplicity and because of lacking data, a number of physical parameters were eliminated from the basic lake model, such as temperature, oxygen, wind and nitrogen. Seasonal temperature fluctuations were treated as the average temperature of 25°. Oxygen was considered to be sufficient for organisms living in the lakes, as no direct organic inflows such as sewage enter the lake and sediments are not unusually thick. No fish kills due to insufficient oxygen have been reported. Nutrients were considered to be uniformly distributed and available to producers so wind induced turbulence for mixing of nutrients was considered to be constant. Phosphorus, which is usually limiting in fresh water systems, was considered limiting in this system so the need to include nitrogen in the model was eliminated.

The model (Figure 5) has 3 forcing functions; sunlight, littoral zone area, and phosphorus inflows. Storages included primary producers, detritus(organic matter), invertebrates (benthic organisms and zooplankton), forage size fish (which also included young from the other fish compartments), trashfish, harvestable fish, and nutrients (phosphorus). Outflows from the system are nutrients lost through outflows and the removal of fish via sport fishing.

Lake Kissimmee receives a solar energy input of about 1.61×10^6 Kcal/m^2 yr. (U.S. Weather Bureau 1962-1972). Monthly averages range from 2920Kcal/m^2 for January and December to 5790 Kcal/m^2 for May. Theoretically, June would be expected to have the highest quantity of solar radiation during the year, but rainfall during this period, accompanied by cloudy skies is probably the reason for lower values during this month .

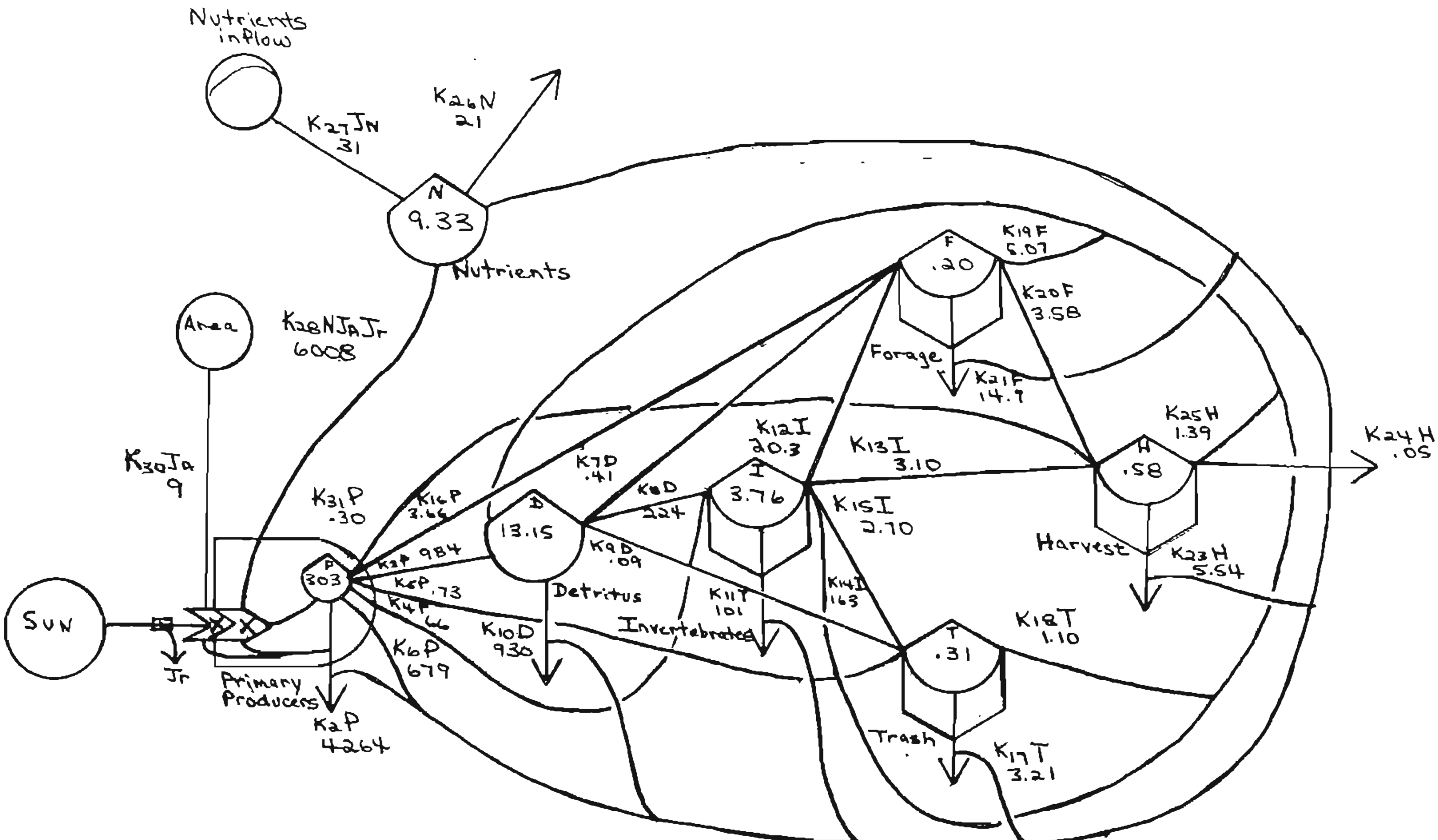


Figure 2 - Lake Kissimmee

Storages - x10^{8}gC

Flows - x10^{8}gC

Data collected by D.P.C. (Dye, 1975) indicate that phytoplankton production in the littoral zone represents about 10 percent of the lake's primary productivity. Including the primary productivity of littoral zone macrophytes, it appears correct to assume that about 85 percent of the lake's total primary production presently occurs in the littoral zone. Under regulated conditions, the lake's littoral zone encompasses a maximum area of 9,000 acres. Upon drawndown, the littoral zone area is potentially 20,000 acres, over a twofold increase. The drawdown was one variable in the model.

Primary producers were divided into three basic types: phytoplankton, macrophytes and phytoperiphyton. Standing crops were determined using unpublished data from the Florida Game and Fresh Water Fish Commission, 1975, and the U.S. Geological Survey, 1972. The data were available as number of cells per liter for August 1974, January 1975, and May 1972.

The data for the months of May and January were averaged to approximate the average standing crop over a year. The months of January and May best approximate the two extremes in the standing crop level. Conversion to weight was made using the conversion factor, $.23x10^6$ grams ashfree dry weight per cell (Jackson, 1969), a value obtained for the phytoplankton crop of Lake Onondaga, New York. The value obtained was multiplied by the area of the limnetic zone to get standing crop for the lake. Phytoplankton production was determined using unpublished chlorophyll a data from the Florida Game and Fresh Water Fish Commission 1975, Florida Department of Pollution Control 1973, and Kobeel, 1973. Data were available for the months of January 1975, October 1973 and November 1973. The yearly average chlorophyll was estimated to be slightly higher than October's value. Chlorophyll a was used in calculating carbon production using the formula, $P = P_r$ x chlorophyll a concentration x 3.7 where P_r = max production at radiation R (4020 Kcal/m^2 for October) and 3.7 was the amount of carbon fixed per mg of chlorophyll (Ryther and Yentch, 1957). As for biomass, phytoplankton production was considered limited to open water. Respiration was considered to be 40 percent of the gross production (Jackson, 1969). Leakage of organics was considered to be a fast recycle of nutrients and was estimated to be 17 percent of gross production (Fogg, 1965). Loss of nutrients was also assumed to occur due to respiration and was considered to be proportional to 1/100 of the carbon respired. This loss was considered to be a fast recycle of nutrients. Consumption by herbivores was determined by calculating the total algal-phytoplankton consumptive needs for each consumer group. The amount available to herbivores from phytoplankton was calculated first by determining how much non-blue green phytoplankton was available, 43 percent (Florida Game and Fresh Water Fish Commission 1975). Ten percent of this amount was deemed to be available which turned out to be about half of herbivore requirements. The remainder was estimated to be the amount of periphyton consumed. The approximate 20% left was considered to be going to detritus.

Macrophyte biomass was estimated by assuming 50 percent _Panicum_, 5 percent _Scirpus_, 10 percent _Nymphaea_, 25 percent _Eichornia_ and 10 percent _Nuphar_ (Williams, 1975). These were converted to weight using 1,075 g/m^2 _Panicum_, 1,381 g/m^2 _Scirpus_, 256 g/m^2 _Nymphaea_, _Eichornia_ 2400 g/m^2 and Nuphar 84 g/m^4 (Polesine, 1972, Mitsch 1975). Littoral zone area was considered to be the area present between regulated high and regulated low. This value obtained 2.26×10^{10} gC/lake, falls within the range stated by Westlake, 1975 for emergent vegetation (using .2 - 10 x 10^3 g dry wt./m^2), which for Lake Kissimmee would be .364 - 18.2×10^{10} gC/lake.

Production was estimated using a value for marsh production of 27.3 g C/m^2/day (Bayley, 1975) which yielded an average production for the lake of $3.63x10^{11}$ gC/yr. Respiration was figured to be about 64 percent of the production (Bayley, 1975). Leakage was considered to be 10 percent of the gross production (Wetzel, 1965) and respiration was considered to recycle phosphorus proportionally. Direct consumption of macrophytes was assessed at zero and the remaining portion was deemed to go to detritus. Standing stock for periphyton was estimated to be 200 g C/m^2 (Westlake, 1965) for the littoral zone. Production was calculated to be 35 percent of the macrophyte production (Wetzel, 1965). Respiration was considered to release phosphorus in proportion to its rate. Herbivore consumption was determined by using the remainder needed after taking what was available from phytoplankton. The pathways for individual producers were totaled and treated in one compartment.

The storage of detritus was calculated to be the amount present in the sediments plus the amount occurring as suspended solids. Amount of sediment was calculated by assuming a one inch thickness over the area of the lake (Williams, 1975). The wet weight value of $.256x10^3$ g/m^3 was used for estimating sediment biomass for a one inch layer, also assuming 25 percent water and 50 percent carbon. This gives a value of 6.95 g C/m^2 for the sediment. Suspended detritus was calculated from DPC data for suspended solids and was figured to be 11.7g/m^3. Amount of detritus going into consumers was calculated using habit data for fish, invertebrate and zooplankton (Table 1, 2, 3, Kramler 1970; Gilwicz, 1969a). The net accumulation was considered to be minimal, so respiration was considered to be what was left over after consumers took their share.

Invertebrates were of two basic types: zooplankton and benthic invertebrates. As phytoplankton production in Lake Newnan, Florida, is similar to that of Lake Kissimmee, zooplankton standing crop for Lake Kissimmee, estimated using data from Lake Newnan, was 1.29 g C/m^2 (Nordlie, 1975). Respiration was determined to be 10 percent of the standing crop per day (McAllister, 1969). Production was considered to be 12 percent of the primary production (Welch, 1968) which agreed closely with other literature values (McAllister 1969; Richman, 1958). Ingestion was calculated by assuming 65 percent assimilation (Conover, 1964, 1965) or production/assimilation = ingestion. Egestion was figured as ingestion-assimilation, or 35 percent of ingestion. Phosphorus excretion was considered to be proportional to 1/100 of the carbon respired. Gliwicz (1969a) suggested that zooplankton derived about 80 percent detritus and 20 percent phytoplankton as their food supply in mesotrophic to eutrophic lakes. Data for benthic invertebrates were available in number per square foot. These were converted to weights using values from Anderson, 1975 and Jonasson, 1948. This value, 1.07 gC/m^2,however contained only those forms that would be obtained by using an Ekman dredge. Hence, it was decided to use some values from Eddy, 1963-2.0 gC/m^2 for the littoral and 1.26 gC/m^2 for the limnetic. This averaged out to be 1.45 gC/m^2 for the entire lake, which is probably a more reasonable estimate. Respiration was assessed to be 5 percent of the body weight per day (Prosser and Brown, 1961). Waters (1969) stated the turnover rate for invertebrates was about 4 times/year. This time the standing crop was estimated to be the net production per year. Respiration + net production = gross production.

Main source of food for benthic invertebrates was determined to be about 30 percent phytoplankton or periplankton and 70 percent detritus

(Welch, 1968; Winberg, 1970; Mann, 1964; Efford, 1969; Kajak, 1970). Assimilation was estimated to be 50 percent of that ingested (Kramler, 1970).

Fish were divided into three categories: forage, trash, and harvestable. Forage fish included all the small fish under 5 inches including young of the trash and harvestable fish, hence, all fish that would probably be routinely eaten. Harvestable fish consisted of adult bass, bluegill, ridear, warmouth, white catfish, channel catfish, and brown bullheads over 5 inches and pickeral over 6 inches. Trash fish included fish over 5 inches of gar, bowfin, gizzard shad and chubsucker and golden shiners over 6 inches. Average weight per size class per species was calculated from raw data supplied from the Florida Game and Fresh Water Fish Commission. The average pound per acre was calculated for each inch class. From these computations, weight per acre for each category could be used. Respiration was calculated for each size class using respiration equations for specific species (Winberg, 1966; Beamish, 1964; Saunders, 1962; O'Hara, 1968; Glass, 1968; Stogano, 1939; Johansen, 1970). For those species in which none of the above equations could be applied, the general respiration formula for fish, $Q = .307\ W^{.89}$ was used. Net production was figured to be 1.2 (standing crop) for harvestable fish, 1.6 for forage fish and 1.2 for trash fish (Gerking, 1966; Winberg, 1970; Mann, 1964). Assimilation rates were as follows: invertebrates 85 percent, fish 95 percent, phytoplankton 65 percent and detritus 50 percent (Mann, 1966; Winberg, 1956, Birge and Juday, 1922; Conover, 1964; Ivlev, 1939b).

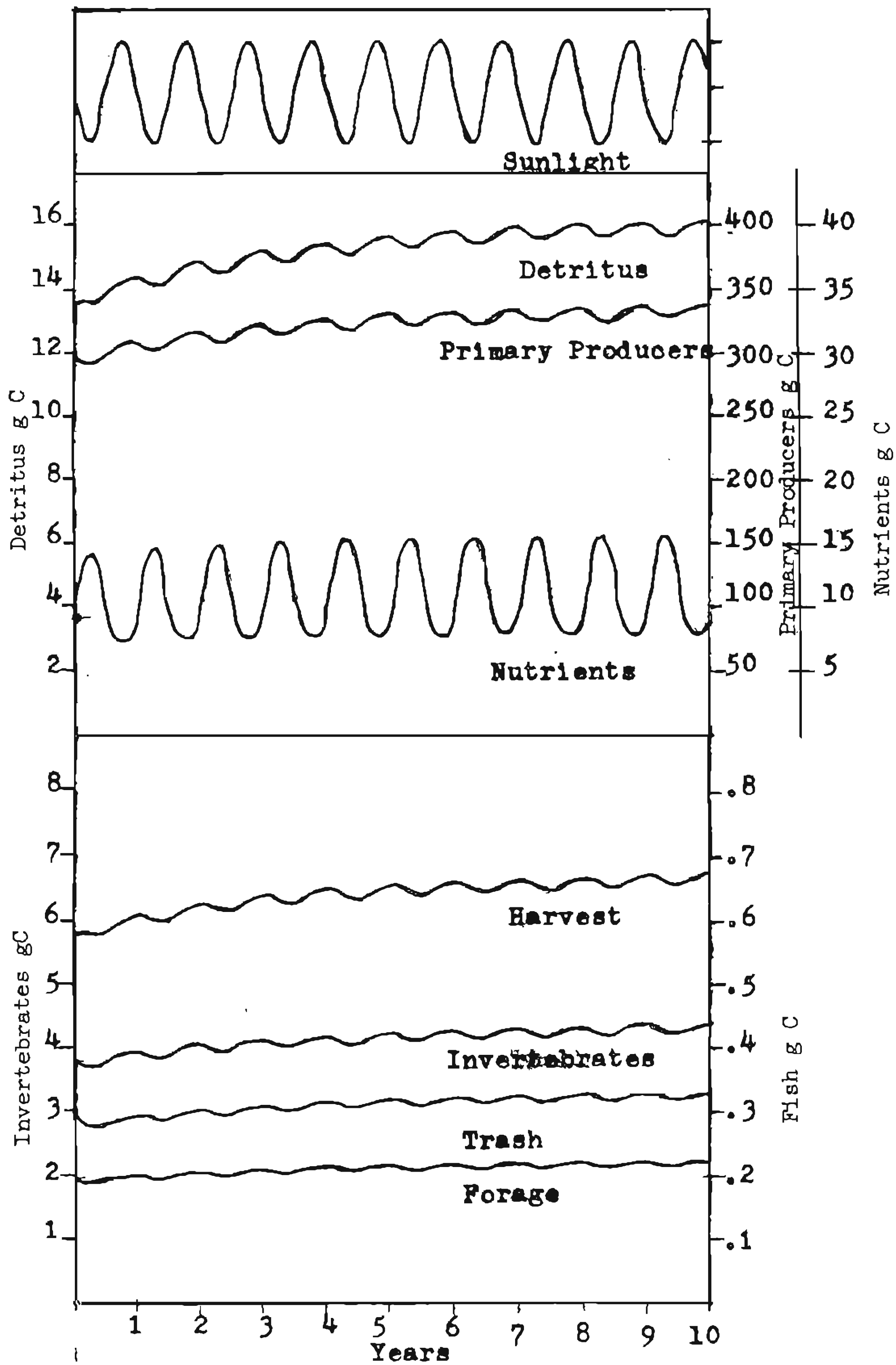
The percent consumption of invertebrates, forage fish, detritus and 1 production was determined for each fish. Species (adult and young) were accessed separately. The percent consumption was multiplied by the percent that species made up the category to obtain the total percent consumption for each category. Ingestion was calculated by using the formula:

$$I = P + R + \underbrace{(I)\left[\sum_{i=1}^{n} (\%\ x_i\text{consumed})(\%y_i\text{assimilated})\right]}_{E}$$

where I is ingestion, P its production, R is respiration and E is egestion. Excretion of phosphorus was assumed to be proportional to the respiration. Harvestable fish creeled were determined from unpublished data from the Florida Game and Freshwater Fish Commission.

Phosphorus storage, inflows and outflows, were determined by Shapiro (1975 unpublished data) using data from the Florida Game and Freshwater Fish Commission Water Quality Reports and the Department of Air and Water Pollution Control Quality Reports. It was assumed that all nutrients recycled were used. Phosphorus was expressed in carbon equivalent units assuming the relationship for biological material to be 100:1 of carbon to phosphorus. Yearly recycled phosphorus, 5.997x 108/gC/yr nearly equalled predicted primary production of 6,000x108 gC/yr, hence much confidence is placed in this calculated portion of the model. Nutrient inflows were very small, $31\text{x}10^8$ gC/yr, in comparison, hence it was assumed that at present conditions inflows basically equal outflows. Values were converted into grams carbon per year using the approximate dry weight content of biological matter to be 27.5 percent and assuming 50 percent of dry matter to be carbon (Gerking 1962; E.P. Odum, 1959).

Figure 3
Initial Conditions



An energese diagram was drawn showing the major energy pathways of the system. Flows for all the pathways were determined for Lake Kissimmee. Differential rate equations were determined for each storage. An analog diagram was drawn from the equations. The k-coefficients were determined for each pathway. Each flow was then amplitude scaled and time scaled by 290. The analog diagram was then patched to a Miniac board and run on an analog computer.

Results Model I

Figure 3 shows a projection of Lake Kissimmee for the next 10 years under present conditions with phosphorus inflows of $.31 \times 10^8$ grams per year, lake level regulation of the present four feet, and $.05 \times 10^8$ grams per year of fish harvested. Slight increases can be noted for all compartments. This would be because phosphorus inflows $.31 \times 10^8$g P/year exceed phosphorus outflows $.21 \times 10^8$g P/yr. Hence, about $.10 \times 10^8$g P/year are added to the lake per year. About $.05 \times 10^6$ grams of phosphorus per year are removed from the lake through fishing.

Figure 4 shows the theoretical effect of increasing phosphorus inflows threefold for a period of 10 years. All storages increase: primary producers increase 73 percent, detritus increases 89 percent. Figure 3 shows a projection of Lake Kissimmee for the next 10 years. Under present conditions with phosphorus inflows of $.31 \times 10^8$ grams phosphorus per year, lake level regulation of the present four feet, and 105 grams carbon per year of fish harvested, slight increases can be noted for all compartments, because phosphorus inflows (0.31×10^8 gP/yr.) are added to the lake and only about $.05 \times 10^6$ grams of phosphorus per year are removed through sport fishing.

The theoretical effect of a threefold increase in phosphorus inflows over a ten year period is seen in Figure 4. All storages increase:

Figure 4 X 10^8 g C

Increased Nutrients (3X)

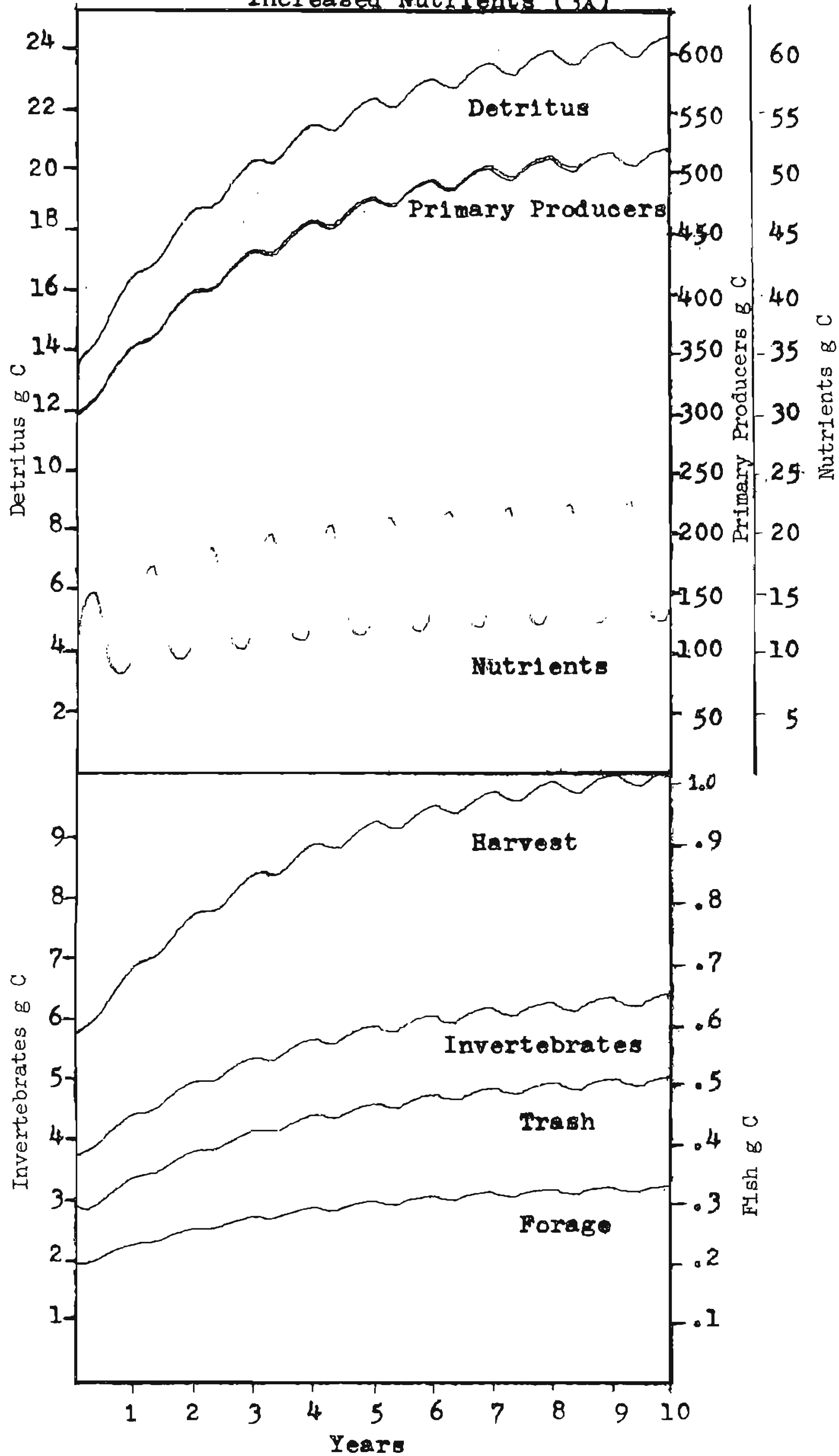


Figure 5
Drawdown X 10^8 g C

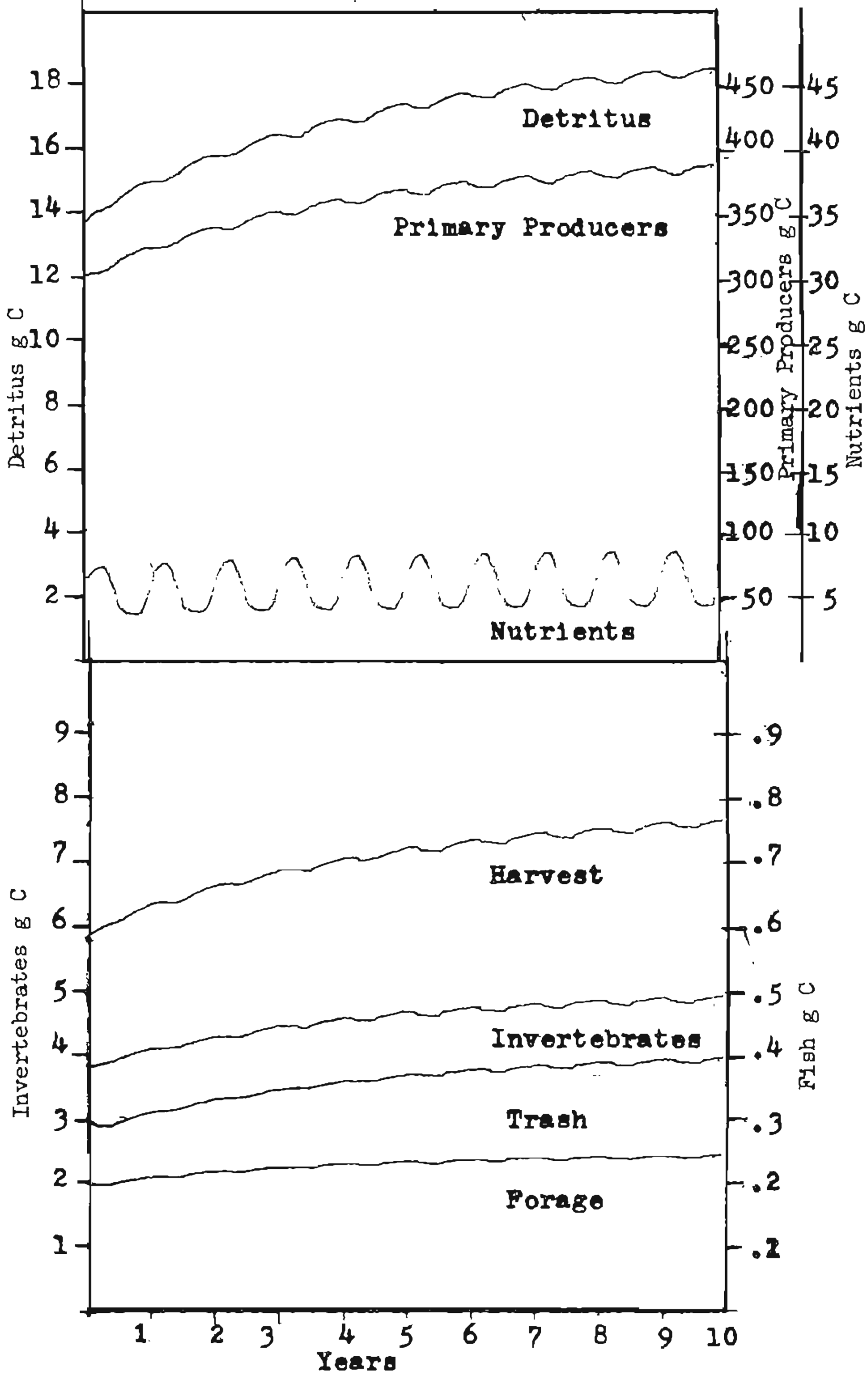


Table 4. Results of Lake Kissimmee Simulations

	Initial Conditions	10 years Present conditions		Drawdown		Increased nutrients 3x		Drawdown increased nutrients 3x		Increased fishing pressure 10x Drawdown increased nutrients 3x	
		change	%change	change	%change	change	%change	change	%change	change	%change
0 1 Producers	303.00	333	9.8%	375	23.8%	525	73%	600	98%	550	81%
Detritus	13.20	15.50	9.8%	19.00	44%	25.0	89%	28.0	110%	23.0	74%
Nutrients	9.33	12.50	30.4%	6.00	-37%	17.5	88%	10.0	7%	10.0	7%
Harvest	0.58	0.65	12.1%	0.75	29.4%	1.0	72%	1.40	140%	1.35	133%
Forage	0.20	0.23	15%	0.24	20%	0.43	110%	0.39	95%	0.38	90%
Trash	0.31	0.32	3.2%	0.40	29%	0.50	61%	0.62	100%	0.58	87%
Invertebrates	3.76	4.30	14.9%	4.90	30.4%	6.50	73%	7.70	100%	7.50	99%

primary producers increased 73 percent, detritus increased 89 percent, the nutrient pool increased 88 percent, forage fish increased 110 percent, trash fish increased 61 percent , harvestable fish increased 72 percent, and invertebrates increased 73 percent. Detritus buildup estimated to be about .09 inch/year. When storages increase at different rates, the structure of the system begins changing because flow rates depend on storages. From Table 4, it can be noted that nutrients increased at a higher rate than the primary producers, 88 percent - 73 percent, respectively.

Drawndown (Fig. 5) resulted in an increase in all compartments, from 20-44 percent, but the nutrient storage was reduced 37 percent. The detritus storage may be slightly high, with possibly more being oxidized and recycled into nutrients. It is possible that natural lake fluctuations direct nutrients back into structure (emergent plants), providing food and habitat for consumers. Hence, the model shows what might be expected, increased primary producers. Increased producers provide food and habitat for consumers to increase. Detritus production increases because primary production increases. Nutrients decrease because they are incorporated by plants. Figures 6a and 6b show the drawndown plus a threefold nutrient increase. All compartments went up dramatically indicating that the system is nutrient limited. Since the nutrient storage increased by 7 percent, it is suspected that algal blooms might occur. This instance is analagous to Lake Tohopekaliga in which a drawdown increased the littoral zone, the invertebrate population and the fish, but did not bring a halt to algal blooms. Decreased nutrient inputs are the only way to reduce high nutrient storages.

Conclusions

1. Lake Kissimmee is nutrient limited.
2. Small increases in nutrient loading rates seem to have a marked impact on the production of the system.
3. Drawndown seems to have a positive effect in increasing harvestable fish production and decreasing nutrient storages.
4. Increased fishing pressure does not appear to significificiently affect desirable fish or the system as a whole.

Figure 6a X 10^8 g C

Drawdown and Increased Nutrients (3X)

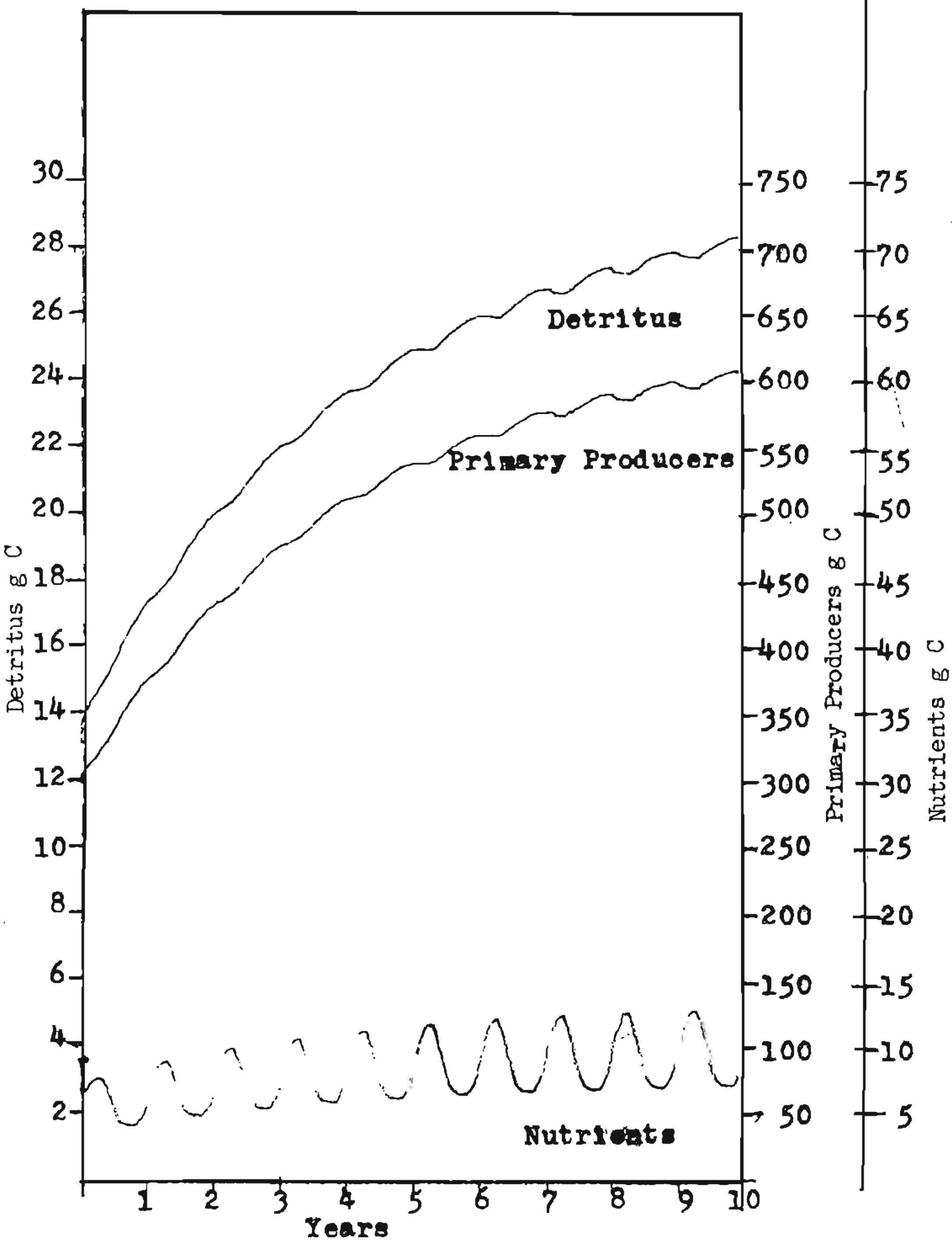


Figure 6b

Drawdown and Increased Nutrients (3X)

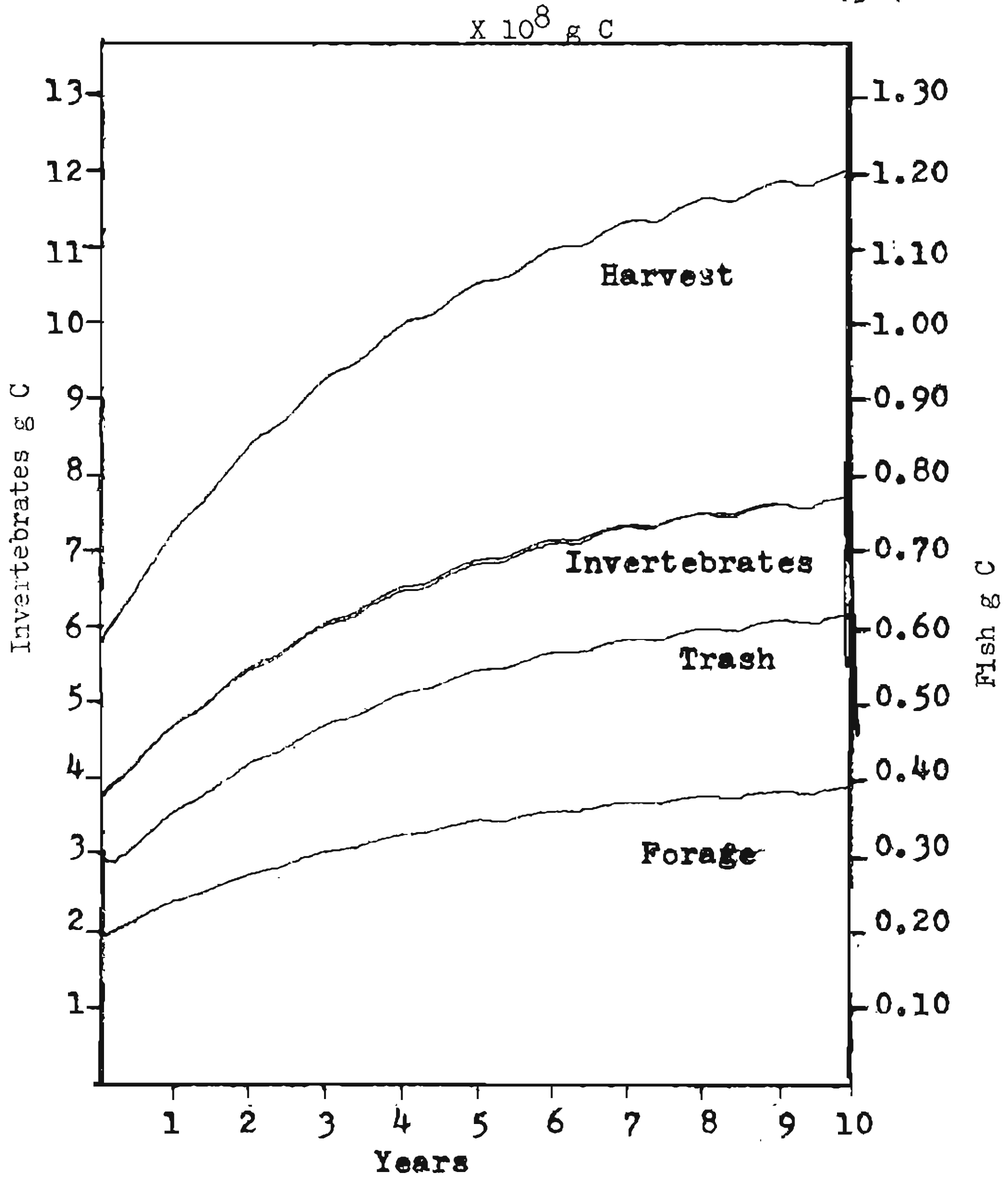


Figure 7a

Drawdown, Increased Nutrients, (3X), and Increased Fishing Pressure (10X)

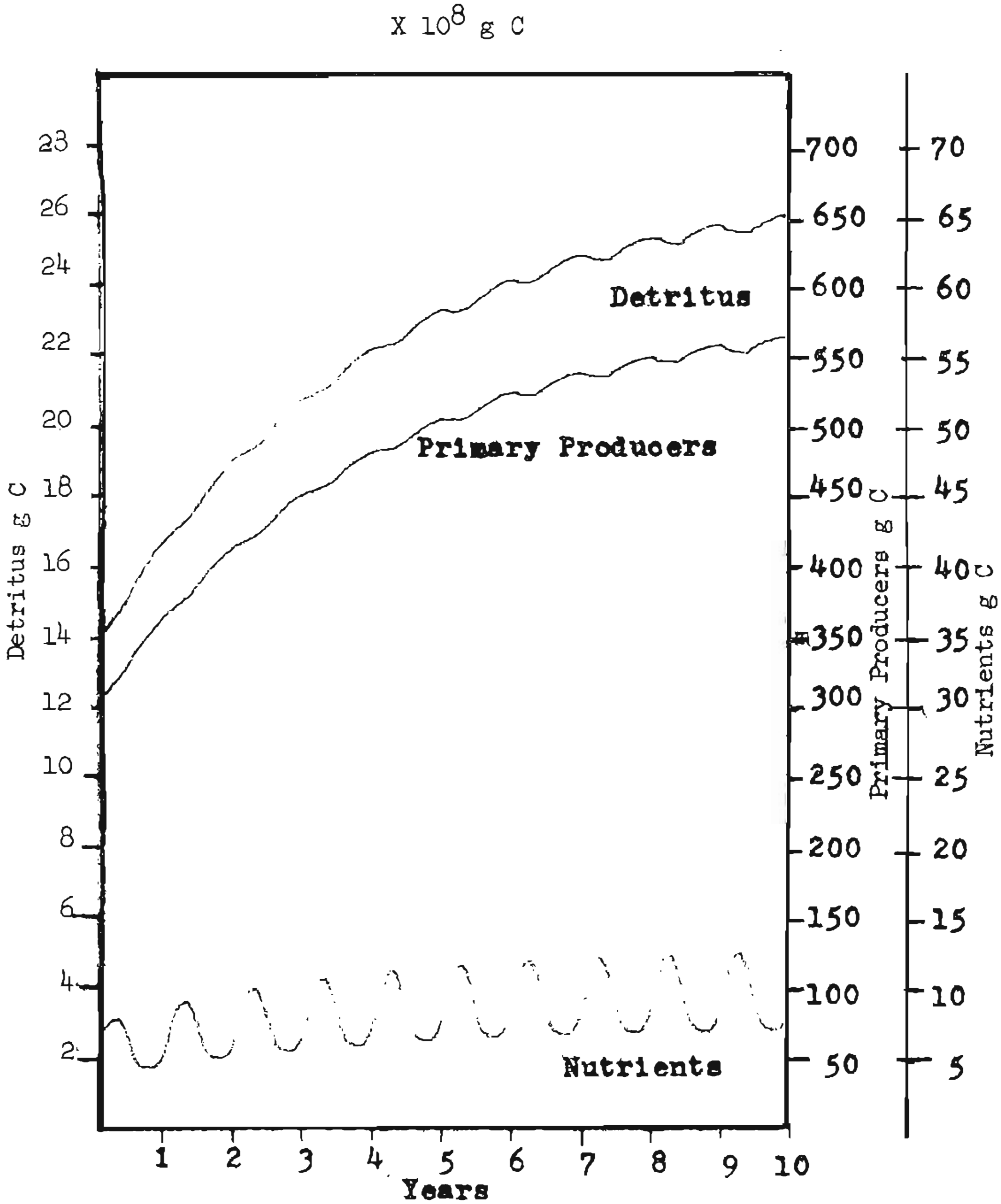


Figure 7b

Drawdown, increased nutrients (3X) and Increased fishing pressure (10X)

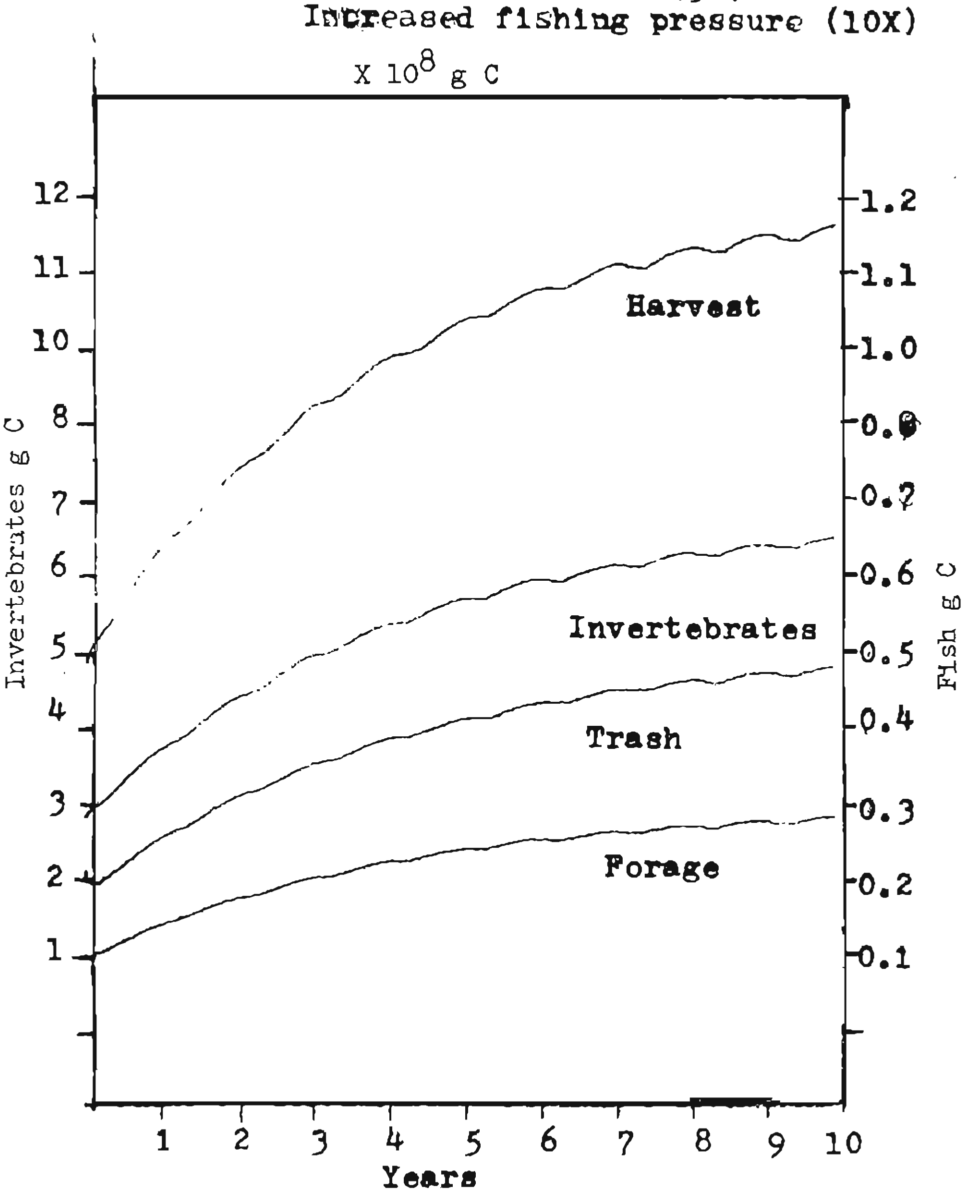


Table A-1 Storages/Lake

Description of Model Components

Storage	Value	Description	Calculation	Source
P	$303x10^8$gC	Primary Producers	1. P = Phytoplankton + Macrophytes + Periphyton 2. Phytoplankton = (#/liter)($.23x10^{-6}$gC/cell) (ave. depth water)(area limnetic) Macrophyte = Σ [(% coverage)(gC/m^2 for plant)] [area littoral] 3. Periphyton (400 g dry wt/m^2)(area littoral) (.50%C)	Wegener and Williams 1975, U.S.G.S. 1972, Jackson 1969, E.P. Odum 1959, Westlake 1965, Polesine 1972, Williams 1975, Mitsch 1975
D	$13.15x10^8$gC	Detritus	1. (organics in water)(average depth) x (ave. area of lake) + (density of carbon)(2/3 dry wt)(50% carbon)(area of lake)	Fla. Dept. Pollution Control 1973
I	$3.76x10^8$gC	Invertebrates	1. I = zooplankton + macroinvertebrates 2. (1.29 gC/m^2)(area lake) = zooplankton 3. Macroinvertebrates = (2.0 gC/m^2) (area littoral) + (1.26)(area limnetic)	Nordlie 1975, Frey 1963, Wegener and Williams 1975, Anderson 1975, Jonasson 1948
F	$.2x10^8$gC	Forage Fish	Calculated from raw data. (ave. wt/littoral acre)(area littoral) + (ave. wt/acre limnetic) (area limnetic)	Wegener and Williams 1975, Wegener et al., 1973
T	$.31x10^8$gC	Trash Fish	Calculated from raw data. (ave. wt/littoral acre)(area littoral) + (ave. wt/acre limnetic) (area limnetic)	Wegener and Williams 1975, Wegener et al., 1973

Table A-1 (Cont.) Storages /lake

Storage	Value	Description	Calculation	Source
H	$.58 \times 10^8$ gC	Harvestable species	(ave. wt/acre littoral)(area littoral) + (ave. wt/acre limnetic)(area limnetic)	Wegener and Williams 1975, Wegener et al, 1973
N	9.33×10^8 gC	Phosphorus	(g P/lake)(100gC/gP)	Shapiro 1975, Fla. Dept. Pollution Control 1973

Flows

Table A-2 - Description of model components x 10^8 grams C/lake yr.

Flow	Value	Description	Calculation	Source
$K_1NJ_AJ_r$	6000	Gross production	1. ($2.2\ gC/m^2day$)(area limnetic) (365 days/yr) = phytoplankton 2. ($27.3\ gC/m^2day$)(365 days/yr) (area littoral) = macrophyte 3. (35%)(macrophyte production) 4. Σ 1 + 2 + 3	Wegener and Williams 1975, Kabrel 1973, Fla. Dept. Pollution Control 1973, Duchrow 1971, 1972, Bayley 1975, Wetzel 1965
K_2P	4264	Respiration of Producers	1. Phytoplankton - 40% gross 2. Macrophytes - 65% gross 3. Periphyton - 65% gross	Jackson 1969, Bayley 1975
K_3P	984	Production into detritus	Calculated as what is left over after other flows are subtracted assuming steady state.	
K_4P	66	Production into invertebrates	Zooplankton - 20% ingestion Invertebrates - 30% ingestion	Welch 1968, Winberg 1970, Mann 1964, Efford 1969, Kajak 1970, Gliwicz 1969a, Conover 1964, Conover 1965
K_s	.73	Production into trash fish	Calculated from Table 2 - (ingestion)(frequency of ingestion)	See Table 2
K_6P	697	Leakage of nutrients	17% of gross production for phytoplankton 10% of gross production of macrophytes + periphyton	Fogg 1965, Wetzel 1965
K_7D	.41	Detritus into forage fish	Calculated using food habit data (ingestion)(% of diet)	Table 1

Table A-2 (Cont.) Description of Model Components x 10^8 grams C/lake yr.

Flow	Value	Description	Calculation	Source
K_8D	224	Detritus into invertebrates	Calculated assuming zooplankton - 80% ingestion invertebrates - 70% ingestion	Welch 1968, Winberg 1970, Mann 1964, Efford 1969, Kajak 1970, Gliwicz 1969a, Conover 1964, Conover 1965.
K_aD	.09	Detritus into trash fish	Calculated from Table 2 (ingestion)(frequency ingestion)	See Table 2
$K_{10}D$	930	Respiration of detritus	Calculated by assuming steady state that detrital buildup is minimal hence whatever is left over from consumers.	
$K_{11}I$	101	Invertebrate respiration	Zooplankton - 10% standing crop/day Invertebrates - 5% of weight per day	MacAllister 1968, Prosser and Brown, 1961
$K_{12}I$	20.27	Forage fish consumption of invertebrates	Calculated using food habit data Table 1	Table 1
$K_{13}I$	3.1	Harvest fish consumption of invertebrates	Calculated using food habit data Table 3	Table 3
$K_{14}I$	163	Invertebrate egestion	Calculated assuming 35% ingestion is egested for zooplankton, 50% assimilation for invertebrates	Conover 1964, Conover 1965, Kramler 1970

Table A-2 (Cont.) Description of Model Components x 10^8 grams C/lake yr.

Flow	Value	Description	Calculation	Source
$K_{15}I$	2.7	Trash fish consumption of invertebrates	Calculated using food habit data, Table 2.	Table 2
$K_{16}P$	3.66	Primary production consumed by forage fish	Calculated using food habit data, Table 1.	Table 1
$K_{17}T$	3.21	Trash fish respiration	Calculated using respiration formula for specific species for each size class. General formula $Q = .307\ W^{.89}$ used when no other formula available.	Winberg 1966, Beamish 1964, Saunders 1962, O'Hara 1968, Glass 1968, Stoganov 1939, Johansen 1970.
$K_{18}T$	1.10	Trash fish egestion	Calculation by assuming assimilation of 5% invertebrates, 95% fish, 65% phytoplankton, and 50% detritus. Consumption determined using food habit Table 2.	Mann 1966, Winberg 1956, Birge and Juday 1922, Conover 1964, Ivler 1939b, Table 2
$K_{19}F$	5.07	Forage fish egestion	Calculated as $K_{18}T$	Same as above ($K_{18}T$)
$K_{20}F$	3.58	Forage fish ingestion by harvest fish	Calculated using food habit, Table 3.	Table 3
$K_{21}F$	14.90	Forage fish respiration	Calculated as $K_{17}T$	Same as $K_{17}T$
$K_{22}F$	.79	Forage fish consumption by trash fish	Calculated using food habit data, Table 2	Table 2
$K_{23}H$	5.54	Harvest fish respiration	Calculated as $K_{17}T$	Same as $K_{17}T$

Table A-2 (Cont.) Description of Model Components x 10^8 grams C/lake yr.

Flow	Value	Description	Calculation	Source
$K_{24}H$	.05	Fish removed via fishing	Calculated from expanded Crude census	Wegener and Williams 1975
$K_{25}H$	1.39	Egestion by harvest fish	Calculated as in $K_{18}T$	Same as $K_{18}T$
$K_{26}N$	21	Phosphorus going out of system	Calculated by Larry Shapiro	Shapiro, L. 1975
$K_{27}N$	31	Phosphorus coming into system	Calculated by Larry Shapiro	Shapiro, L. 1975
$K_{28}NJ_AJ_r$	6008	Nutrient uptake by producers	Assumed to be proportional to 1/100 of carbon fixed.	
$K_{30}J_A$	9	Area of littoral zone (area between high and low levels).		Wegener et al., 1973

Differential Rate Equations for Storages

$$\mathring{P} = k_1 NJAJr - K_{16}P - k_3P - k_4P - k_5P - k_{31}P - k_2P - k_6P$$

$$\mathring{D} = k_3P + k_{19}F + k_{25}H + k_{18}T + k_{14}I - k_7D - k_8D - k_9D - k_{10}D$$

$$\mathring{I} = k_8D + k_4P - k_{11}I - k_{12}I - k_{13}I - k_{14}I - k_{15}I$$

$$\mathring{F} = k_{16}P + k_7D + k_{12}I - k_{19}F - k_{20}F - k21F - k_{22}F$$

$$\mathring{H} = k_{20}F + k_{13}I + k_{31}P - k_{23}H - k_{24}H - k_{25}H$$

$$\mathring{T} = k_{22}F + k_{15}I + k_9D + k_5P - k_{18}T - k_{17}T$$

$$\mathring{N} = k_{27}JN + k_2P + k_6P + k_{10}D + k_{11}I + k_{21}F + k_{17}T + k_{23}H - k_{26}N - k_{28}NJAJr$$

LITERATURE CITED

Ager, Lothian, and K.E. Kerce. 1971. Vegetational changes associated with water level stabilization in Lake Okeechobee, Fla. Proc. of the 24th Ann. Conf. S.E. Assoc. of Game and Fish Comm. 338-351.

Allen, H.L. 1969. Chemo-organotrophy in epiphytic bacteria with reference to macrophytic release of dissolved organic matter in The structure and function of fresh-water microbial communities, John Cairns, Jr, ed. Amer. Microsc. Soc. Symp. Res. Div. Monog. 3, Virginia Polytechnic Inst.

Anderson, J. 1975 (unpublished data).

Anderson, R.D., and F.F. Hooper. 1956. Seasonal abundance and production of littoral bottom fauna in a southern Michigan lake. Amer. Microscop. Soc., Trans. 75: 259-270.

Bailey, P.M., and H.M. Harrison, Jr. 1948. Food habits of the southern channel catfish (Ictalurus lacustric punctatus) in the Des Moines River, Iowa. Trans. Fish Soc. 75:11-138.

Barnickol, P. G. 1941. Food habits of Gambusia affinis from Reelfoot Lake, Tennessee, with special reference to malaria control. J. Tenn. Acad. Sci. 6(1):5-13.

Baudouin, M.F., and O. Ravera. 1972. Weight, size, and chemical composition of some freshwater zooplankters: Daphnia hyalina (Leydig). Limnol. and Oceanogr. 17:645-649.

Bayley, S. 1975 (unpublished data).

Beamish, F.W.H. 1964. Seasonal changes in the standard rate of oxygen consumption of fishes. Can. J. Zool. 42:189-194.

Beamish, F.W.H. 1964. Respiration of fishes with special emphasis on standard oxygen consumption in fishes II. Influence of weight and temperature on respiration of several species. Can. J. Zool. 42:177-188.

Beamish, F.W.H., and P.S. Mookherjii. 1964. Respiration of fishes with special emphasis on standard O_2 consumption. I Influence of weight and temperature on respiration of goldfish, Carassius auratus L. Can. J. Zool. 42.

Bennett, G.W. 1962. Management of artificial lakes and ponds. Reinhold Corp., N. Y. 283 pp.

Berg, A., and E. Grimaldi. 1966. Ecological relationships between planktophagic fish species in the Lago Maggiore. Verh. Internat. Verein. Limnol. 16:1065-1073.

Berry, F.H. 1955. Age, growth, and food of the gizzard shad, Dorosoma cepedianum (Lesueur) in Lake Newnan, Fla. U. of Fla. (unpublished Masters thesis).

Birge, E.A., and C. Juday. 1922. The inland lakes of Wisconsin. The plankton. Part I. Its quality and chemical composition. Bull. Wisc. Geol. Nat. Surv. 64:1-222.

Bishop, J. W. 1968. Respiratory rates of migrating zooplankton in the natural habitat. Limnol. and Oceanogr. 13:58-62.

Bray, J.R. 1962. Estimates of energy budgets for a Typha (cattail) marsh. Science. 136:1119-1120.

Buntz, J. 1966. Stomach analysis of chain pickeral (Esox niger) of South Central Florida. Proc. of the 12th Ann. Conf. S.E. Assoc. of Game and Fish Comm. 315-318.

Carlander, K.D. 1955. The standing crop of fish in lakes. J. Fish Res. Bd. Canada. 12(4):543-570.

Carlander, K.D. 1970. Handbook of freshwater fishery biology. Vol. 1. Iowa State Press, Ames.

Central and South Florida Flood Control District (unpublished data).

Chable, Alphonse. C.1947. A study of the food habits and ecological relationships of the sunfishes of N. Fla. (unpublished Master's thesis, Univ. of Fla.).

Chew, R.L. 1967. Lake Fishery Investigations. Completion report for D-J Project F-17-R (mimeo). Fla. Game and Fresh Water Fish Comm., Tallahassee.

Chew, R. 1970. Early Life History of Largemouth Bass. Job. Completion report D-J F-24-R (mimeo). Fla. Game and Fresh Water Fish Comm., Tallahassee. 135 pp.

Chew, R.L., S. Babcock, S. McKinney. 1972. Largemouth Bass Invest. Ann. Prog. Report. D-J F-24-S (mimeo.). Fla. Game and Fresh Water Fish Comm., Tallahassee. 59 pp.

Clugston, J.P. 1964. Growth of the Fla. Largemouth Bass, Micropterus salmoides floridamus (LeSueur) and the Northern Largemouth Bass, M. s. salmoides (Lacipide), in Subtropical Florida. Trans. Am. Fish Soc. 93(2):146-154.

Cohn, M.F. 1958. Feeding in Daphnia. Ph.D. dissertation, Yale Univ.

Comita. G.W. 1964. The Energy Budget of Diaptomus Siciloides, Lilljeborg Verh Internat. Verein. Limnol. 15:646-653.

Comita, G.W. 1965. Oxygen Uptake in Diaptomus siciloides, Liljeborg. Limnol. and Oceanogr. 10:466-468.

Comita, G.W. 1968. Oxygen consumption in Diaptomus. Limnol. and Oceanogr. 13:51-57.

Confer, J.L. 1972. Interrelations among plankton, attached algae and the phosphorus cycle in artificial open systems. Ecol. Monogr. 42:1-23.

Corner, E.D.S., C.B. Conely, S.M. Marshall. 1967. On the nutrition and metabolism of zooplankton. V, Feeding efficiency of Calanus finmarchicus. J. Marbiol. Ass. U.K. 47:259-270.

Cramer, J.D., and G.R. Marzolf. 1970. Selective predation on zooplankton by gizzard shad. Trans. Am. Fish Soc. 99:320-332.

Creitz, G.I., and F.A. Richards. 1955. The estimation and characterization of plankton populations by pigment analysis. III, A note on the use of "Millipore" membrane filters in the estimation of zooplankton pigments. J. Marine Res. 14:211- 213.

Crisp, D.T. 1962. Estimates of the annual production of Corixa germari (Fieb.) in an upland reservoir. Arch. Hydrobiologie. 58:210-223.

Cross, F.B. 1951. Early limnological and fish population conolitions of Canton Reservoir, Oklahoma, with special reference to carp, channel catfish, largemouth bass, green sunfish and bluegill, and fishery management recommendations. Ph.D. thesis, Okla. A.M. Coll. 92 pp.

Crumpton, J.E. 1971. Food habits of longnose gar (Lepisosteus osseus) and Florida gar (Lepisosteus platyrhincus) collected from five control Florida lakes. Proc. 24th Ann. Conf. S.E. Assoc. of Game and Fish Comm. 419-423.

Cummins, K.W. R.R. Costa, R.E. Rowe, G.A. Moshiri, R.M. Scalon, and R.K. Zajdel. 1969. Ecological energetics of a natural population of the predaceous zooplankter Leptodera kindii Foche (Cladoera) Oikos 20:189-223.

Darnell, R.M. 1958. Food habits of fishes and larger invertebrates of Lake Pontchartrain, Louisiana, an esturine community. Inst. Mar. Sci. 5:353-416.

Darnell, R.M. 1964. Organic detritus in relation to secondary production in aquatic communities. Verh. int. Ver. Limnol. 15:462-470.

Dendy, J.S. 1946. Food of several species of fish, Norris Reservoir, Tennessee. J. Tenn. Acad. Sci. 21(1):105-127.

Diana, Michael C. The diet of bowfin in central Fla. (unpublished data).

Diana, M. 1966. The diet of longnose gar (Lepisosteus osseus) in Lake Griffin before, during, and after a selective rotenone treatment with differences in male and female diets (mimeo.). Fla. Game and Fresh Water Fish Commission.

Dodson, S.I. 1972. Mortality in a population of Daphnia rosea. Ecology. 53:1011-1023.

Duchrow, R.M. 1971. Water quality investigations. Ann prog. rept. D-J project F-21-5 (mimeo.). Fla. Game and Fresh Water Fish Comm., Tallahassee. 156 pp.

Duchrow, R.M. 1972. Water quality investigations. Ann prog. rept. D-J project F-21-6 (mimeo.). Fla. Game and Fresh Water Fish Comm., Tallahassee. 153 pp.

Edmondson, W.T. 1957. Trophic relations of the zooplankton. Trans. of Amer. Micros. Soc. 76(B):225-245.

Edmondson, W.T. 1961. Secondary production and decomposition Verh. int. Ver. Limnol. 14:316-339.

Efford, I.E. 1969. II Lakes. I America energy transfer in Marion Lake, British Columbia; with particular reference to fish feeding. Verh. Internat. Verein. Limnol. 17:104-108.

Ewers, L.A. and M.W. Boesel. 1935. The food of some Buckeye Lake fishes. Trans. Am. Fish Soc. 65:57-70.

Flemer, D.A. and W.S. Woolcott. 1966. Food habits and distribution of the fishes of Lachahoe Creek, Virginia. With special emphasis on the bluegill Lepomis M. Macrochims. Rafenesgur Chesapeake Sci. 7(2):75-89.

Florida Dept. of Pollution Control 1973 (unpublished data).

Fogg, G.E., C. Nalewajko and W.D. Watt. 1965. Extracellular products of phytoplankton photosynthesis. Proc. Roy. Soc, B. 162:517-534.

Foreman, M. H. 1953. A limnological study of the population of Daphnia dentifera (Cladocera) in Hall Lake, Washington. M.S. Thesis. Univ. of Washington.

Fox, R.S., III. 1969. A study of the life history of the centrarchid Enneacanthus gloriosus (Holbrook) near the southern limit of its range. U. of Fla. (unpublished Masters thesis).

Frey, D. G. 1963. Limnology in North America. University of Wisconsin Press, Menasha. 734 pp.

Gerking, S.D. 1952. The protein metabolism of sunfishes of different ages. Physiol. Zool. 25:358-72.

Gerking, S.D. 1954. The food turnover of a bluegill population. Ecology. 35:490-8.

Gerking, S.D. 1955a. Influence of rate of feeding on body composition and protein metabolism of bluegill sunfish. Physiological Zoology. 28(4):267-282.

Gerking, S.D. 1955b. Endogenous nitrogen excretion of bluegill sunfish. Physiol. Zool. 28:283-9.

Gerking, S.D. 1962. Production of food utilization in a population of blue gill sunfish. Ecol. Monographs. 32:31-78

Glass, N. 1968. The effect of time of food deprivation on the routine oxygen consumption of large-mouth black bass (Micropteus salmoides). Ecology. 49:340-343.

Gliwicz, Z.M. 1967. The contribution of nanoplankton in pelagial primary product on in some lakes with varying trophy. Bull. Acad. Pol. Sci. Ser. Sci. biol. 15:343-347.

Gliwicz, Z.M. 1968. The use of anesthizing substances in studies on the food habits of zooplankton communities. Ekol. pol. Ser. A. 16:279-295.

Gliwicz, Z.M. 1969. The food sources of lake zooplankton. Ekol. pol. Ser. B. 15:205-223.

Grocki, D.R. 1975 (unpublished data).

Hall, D. 1964. The dynamics of a natural population of Daphnia. Verch. int. Ver. Limnol. 15:660-664.

Hargrave, B.T. and G.H. Gun. 1968. Phosphorus excretion by zooplankton. Limnol. and Oceanogr. 13:332-342.

Harrington, R.W., Jr. and E.S. Harrington. 1961. Food selection among fishes invading a high subtropical salt marsh: from onset of flooding through the progress of a mosquito brood. Ecology. 42(4):646-66.

Hayne, D.W. and Ball, R.C. 1956. Benthic productivity as influenced by fish predation. Limnol and Oceanogr. 1:162-175.

Hendricks, L.J. 1961. The threadfin shad, Dorosoma petenense. Calif. Fish Bull. 113:93-4.

Hestand, R.S. and C.C. Carter. 1974. The effects of a winter drawdown on aquatic vegetation in a shallow water reservoir. Hyacinth Control Journal. 12:9-12.

Hestand, R.S., B.E. May, D.P. Schultz, and C.R. Walker. 1973. Ecological implications of water levels on plant growth in a shallow water reservoir. Hyacinth Control Journal. 11:54-58.

Hillbricht-Ilkowska, A. and A. Karabin. 1970. An attempt to estimate consumption, respiration, and production of <u>Leptodora kindtic</u> (Focke) in field and laboratory experiments. Pol. Arch. Hydrobiol. 17(30):81-86.

Hillbricht-Ilkowska, A. and Weglenska, T. 1970. Some relations between production and zooplankton structure of two lakes of a varying trophy. Pol. Arch. Hydrobiol. 17:233-240.

Hobbie, J. E. 1969. Heterotrophic bacteria in aquatic ecosystems; some results of studies with organic radioisotopes in the structure and function of fresh-water microbial communities. Ed. by John Cairns, Jr. Amer. Microsc. Soc. Symp. Res. Division Mngr. 3. Virginia Polytechnic Institute.

Hobbie, J.E. and C. C. Crawford. 1969. Respiration corrections for bacterial uptake of dissolved organic compounds in natural waters. Limnol. and Oceanogr. 14:528-532.

Holcomb, D. 1967b. Water quality study. Ann. prog. rpt. D-J project F-21-1. (Mimeo.). Fla. Game and Fresh Water Fish Comm. Tallahassee. 17 pp.

Holcomb, D. 1968. Water quality study. Ann. prog. rpt. D-J project F-21-2. (Mimeo.). Fl. Game and Fresh Water Fish Comm. Tallahassee. 105 pp.

Holcomb, D.E. and D.H. Barwick. 1974. Oklawaha Basin Fisheries. Invest. ann. prog. rpt. D-J project F-30-1. Fl. Game and Fresh Water Fish Comm. (Mimeo.) Tallahassee. 174 pp.

Holcomb, D. and W. Wegener. 1971. Hydrophytic changes related to lake fluctuation as measured by point transects. Proc. 25th Ann. Conf. S.E. Assoc. Game and Fish Comm. 570-583.

Holloway, A.D. 1954. Notes on the life history and management of the shortnose and longnose gars in Fla. waters. J. Wildl. Mgmt. 18(4):438-48.

Huish, M.T. 1954. Life history of the Black Crappie of Lake George, Fla. Trans. Am. Fish Soc. 83:176-193.

Huish, M.T. 1957. Food habits of three centrarchidae in Lake George, Fla. Proc. 11th Ann. Conf. S.E. Assoc. of Game and Fresh Water Fish Comm. pp. 293-302.

Hunn, J.B. 1967. In Fish Physiology Vol. 1. 1969. Ed. by W.S. Hoar and D.J. Randall. Acad. Press New York pp. 151.

Hunt, B.P. 1960. Digestion rate and food consumption of Fla. gar, warmouth and largemouth bass. Trans. Amer. Fish Soc. 86:206.

Hutchinson, G.E. 1957. A treatise on limnology. V. 1. Wiley, New York. 1015 pp.

Ivanova, M.B. 1970. Relations between the food concentration, filtration rate and effectiveness of oxygen utilization by Cladocera. Pol. Arch. Hydrobiol. 17:161-168.

Kajak, L. 1970. Some remarks on the necessities and prospects of the studies on biological production of freshwater ecosystems. Pol. Arch. Hydrobiol. 17:43-54.

Jackson, D.F. 1969. Primary productivity studies in Onodaga Lake, N.Y. Vern. Internat. Ver. Liminol. 17:86-94.

Johansen, K., D. Hanson, and C. Lenfant. 1970. Respiration in a primitive air breather, <u>Amia Calva</u>. Respiration Physiology. 9:162-174.

Jónasson, Pétur M. 1948. Quantitative studies of the bottom fauna of the river Susaa. Folia Limnol. Scandinavica. 4:204-284.

Juday, C. 1940. The annual energy budget of an inland lake. Ecology. 21:438-450.

Juday, C. and E.A. Birge. 1931. A second report on the phosphorous content of Wisconsin lake waters. Trans. Wisc. Acad. Sci. 26:353-382.

Jude, D.J. 1973. Food and feeding habits of gizzard shad in Pool 19, Mississippi River. Trans. Am. Fish Soc. 102(2):378-384.

Kabiel, R. 1973. Orange County pollution control (unpublished data).

Kajak, Z. 1970. Some remarks on the necessities and prospects of the studies on biological production of freshwater ecosystems. Pol. Arch. Hydrobiol. 17:43-54.

Kajak, Z. and J.I. Rybak. 1966. Production and some tropic dependences in benthos against primary production and zooplankton production of several Masurian lakes. Verk. Int. Verein. Limnol. 16:441-451.

Keast, A. and D. Webb. 1966. Mouth and body form relative to feeding ecology in the fish fauna of a small lake, Lake Opinicon, Ontario. J. Fish Res. Bd. Can. 23(12):1845-74.

Klekowski, R.Z. 1970. Bioenergetic budgets and their application for estimation of production efficiency. Pol. Arch. Hydrobiol. 17:55-80.

Kramer, R.H. and L.L. Smith, Jr. 1960b. Utilization of nests of large mouth bass, Micropterus salmoides, by golden shiners, Notemigonvs Crysoleucas.. Copeia. 1:73-74.

Kutkuhn, J.H. 1958. Utilization of gizzard shad by game fishes. Proc. Ia. Acad. Sci. 65:571-79.

Kutkuhn, J.H. 1958. Utilization of plankton by juvenile gizzard shad in a shallow prairie lake. Trans. Am. Fish Soc. 87:80-103.

Kuznetsov, S.I. 1968. Recent studies on the role of microorganisms in the cycling of substances in lakes. Limnol. and Oceanogr. 13:211-224.

Lagler, K.F. and F.V. Hubbs.. 1940. Food of the long-nosed gar (Lepisosteus osseus oxyurus) and the bowfin (Amia calva) in southern Michigan. Copeia. 1940(4):239-41.

Lagler, K.F. and V.C. Applegate. 1942. Further studies on the food of the bowfin (Amia calva) in southern Michigan with notes on the inadvisability of using trapped fish in food analysis. Copeia. 1942:190-91.

Larimore, R.W. 1957. Ecological life history of the warmouth (Centrarchidae). Ill. Nat. Hist. Suw. Bull. 27(1):1-83.

Lean, D.R.S. 1973. Movements of phosphorous between its biological importent forms in lake water. J. Fish Res. Bd. Can. 30(10):1525-1536.

Lean, D.R.S. and F.H. Rigler. 1973. A test of the hypothesis that abiotic phosphorous complexing influences phosphorous kinetics in lake water. Limnol. and Oceanogr.

Lindeman, Raymond L. 1942. The trophic-dynamic aspect of ecology. 23:399-418.

McAllister, C.D. 1969. Aspects of estimating zooplankton production from phytoplankton production. J. Fish Res. Bd. Can. 26:199-220.

McAllister, C.D., N. Shah, and J.D.H. Strickland. 1964. Marine phytoplankton photosynthesis as a function of light intensity: a comparison of methods. J. Fish Res. Bd. Canada. 21(1):151-181.

McClellan, W.G. 1954. A study of the southern spotted channel catfish, Ictalurus punctatus (Rafinesque). M.S. thesis N. Texas St. Coll. 69pp.

McLane, W.M. 1948. The seasonal food of the largemouth bass, Micropterus salmoides floridanus (LeSeur) in the St. Johns River, Welaka, Fla. Quart. Jour. Fla. Acad. Sci. 10(4):103-138.

McLane, W.M. 1950. Notes on the food of the largemouth bass, Micropterus salmoides floridanus (LeSeur), in a Fla. lake. Quart. Jour. Fla. Acad. Sci. 12(3):195-201.

McLane, W.M. 1955. The fishes of the St. John's River system. U. of Fla. (unpublished Doctoral thesis).

Main, R.A. 1953. A limnological study of Chaoborus (Diptera) in Hall Lake, Washington. M.S. Thesis, Univ. of Washington.

Mann, K.H. 1964. The pattern of energy flow of the fish and invertebrate fauna of the River Thames. Verh. Internat. Ver. Limnol. 15:485-495.

Mann, K.H. 1965. Energy transformation by a population of fish in the river Thames. J. Anim. Ecol. 34:253-275.

Marshall, N. 1946. Studies on the life history of Notropis chalybeus (Cope). Quart. Journ. Fla. Acad. Sci. 314:163-188.

Marshall, S.M. and A.P. Orr. 1961. On the biology of Calanus finmarchicus XII. The phosphorus cycle: excretion, egg producton, autolysis, with an addendum "The turnover of phosphorus by Calanus finmarchicus," by R.J. Conover. J. Marine Biol. Assoc. U.K. 41:463-488.

Martin, J.H. 1968. Phytoplankton-zooplankton relationships in Narragansett Bay. III. Seasonal changes in zooplankton excretion rates in relation to phytoplankton abundance. L. and O. 13:63-71.

Meehean, O.L. 1942. Fish populations of five Florida lakes. Trans. Amer. Fish Soc. 71:184-194.

Meyers, C.D. and R.J. Muncy. 1962. Summer food and growth of chain pickeral, Esox niger in brackish waters of the Swern River, Maryland. Chesapeake Sci. 3(2):125-8.

Miller, R.B. 1941. A contribution to the ecology of the Chironomidae of Costello Lake, Algonquin Park, Ontario. Univ. Toronto Studies, Biol. Ser. 49:1-63.

Miller, R.R. 1960. Systematics and biology of the gizzard shad (Dorosoma cepedianum) and related fishes. Fish Bull. U.S. 60(173):371-392.

Miller, E.E. 1966. White catfish. Calif. Dept. Fish Game, Inland Fisheries Mngt., ed. A. Calhoun. 430-440.

Mitsch, W.J. 1975. System analysis of nutrient disposal in cypress wetlands and lake ecosystems in Florida. Ph.D. thesis, University of Florida.

Nordlie, F. 1975. (unpublished data).

Odum, E.P. 1971. Fundamentals of Ecology. W.B. Saunders Co. Philadelphia. 574 pp.

O'Hara, J. 1968. The influence of weight and temperature on the metabolic rate of sunfish. Ecology. 49(1):159-161.

Parker, R.A. and R. Helm. 1965. The relationship between inorganic phosphate uptake and oxygen consumption by Daphnia schodleri Sars. Ecology. 46(6):881-882.

Parmalee, P.W. and W.E. Klippel. 1974. Freshwater mussels as a prehistoric food source. American antiquity. J. of the Soc. for Am. Archaeology. 39(3):421-434.

Penfound, W.T. 1956. Primary production of vascular aquatic plants. Limnol. Oceanog. 1:92-101.

Peters, R. and D.L. Lean. 1973. The characterization of soluble phosphorus released by limnetic zooplankton. Limnol. Oceanogr. 18:270-279.

Peters, R.H. and F.H. Rigler. 1973. Phosphorus release by Daphnia. Limnol. and Oceanogr. 18(6):821-839.

Pieczynska, E. 1970. Periphyton in the trophic structure of freshwater ecosystems. Pol. Arch. Hydrobiol. 17:141-147.

Pieczynska, E. and W. Szczepanska. 1966. Primary production in the littoral of several Mazurian lakes. Verh. int. Ver. Limnol. 16:372-379.

Polisini, J.M. and C.E. Boyd. 1972. Relationships between cellwall fractions, nitrogen, and standing crop in aquatic macrophytes. Ecology. 53:484-488.

Pomeroy, L.R. 1960. Residence time of dissolved phosphate in natural waters. Science. 131:17312.

Prosser, C.L. and F.A. 1961. Comparative animal physiology. Second edition. Saunders, Philadelphia. 688 pp.

Radcliffe, L. 1931. Propagation of minnows. Trans. Am. Fish. Soc. 61:131-138.

Reid, G.K. 1950. Food of the black crappie *Pomoxis nigromaculatus* (LeSueur) in Orange Lake, Florida. Trans. Amer. Fish Soc. 79:145-154.

Richman, S. 1958. The transformation of energy by *Daphina pulex*. Ecol. Monogr. 28:272-291.

Richman, S. 1966. The effect of phytoplankton concentration on the feeding rate of *Diaptomus oregonensis*. Verh. Int. Ver. Limnol. 16:392-398.

Rigler, F.H. 1956. A tracer study of the phosphorus cycle in lake water. Ecol. 37:550-562.

Rigler, F.H. 1961. The uptake and release of inorganic phosphorus by Daphnia magna Straus. Limnol. Oceanogr. 6:165-174.

Rigler, F.H. 1964. The phosphorus fractions and the turnover time of inorganic phosphorus in different types of lakes. Limnol. Oceanogr. 9:511-518.

Richer, W.E. 1949. Utilization of food by bluegills. Invest. Indiana Lakes and Streams. 3:313-318.

Robinson, C. 1975. (unpublished data).

Ryther, J.H. and C.S. Yentsch. 1957. The estimation of phytoplankton production in the ocean from chlorophyll and light data. Limnol. Oceanogr. 2(3):281-286.

Saunders, R.L. 1962. The irrigation of the gills of fishes II. Efficiency of oxygen uptake in relation to respiratory flow, activity, and concentrations of oxygen and carbon dioxide. Can. J. Zool. 40:637-653.

Schindler, D.W. 1968. Feeding, assimilation and respiration rates of *Daphina magna* under various environmental conditions and their relation to production estimates. J. Anim. Ecol. 37:369-385.

Schneider, R.F. 1962. Seasonal succession of certain invertebrates in a northwestern Florida lake. Quart. J. Fla. Acad. Sci. 25(2):127-141.

Scott, W. 1938. The food of *Amia* and *Lepisosteus*. Invest. Ind. Lake Streams. 1:112-115.

Shapiro, L. 1975 (unpublished data).

Slobodkin, L.B. 1959. Energetics in *Daphnia pulex* populations. Ecol. 80:232-243.

Slobodkin, L.B. 1960. Ecological energy relationships at population level. The Am. Nat. XCIV:213-236.

Smirnov, N.N. 1962. Eurycercus lamellatus (O.F. Muller) (Chydoridae, Cladocera): Field observations and mitrition. Hydrobiologia. 20:280-294.

Spector, William S. 1956. Handbook of Biological Data. W.B. Saunders Co. Philadelphia.

Spodniewska, I. 1967. Dynamics of the abundance and biomass of phytoplankton in lakes Mikolajskie and Taltowisko. Ekol. pol. Ser. A. 15:139-153.

Stevens, R.E. 1959. The white and channel catfishes of the Sastee Cooper Reservoir and tailrace sanctuary. Proc. S.E. Assoc. Game Fish Comm. 13:203-219.

Stewart, W.D.P., T. Mague, G.P. Fitzgerald and R.H. Burris. 1971. Nitrogenose activity in Wisconsin lakes of differing degrees of entrophication. New Phytol. 70:497-509.

Swenson, E. A., Jr. 1954. Analysis of the fish population of two farm ponds in central New York. M.S. thesis St. Univers. N.Y. Coll. Forestry. 100 pp.

Swingle, H.A. 1969. Production of the threadfin shad Dorosoma petenense. Proc. of the 23rd annual conf. S.E. Assoc. of Game and Fish Comm. 407-421.

Tucker, A. 1957. The relation of phytoplankton periodicity to the nature of the physicochemical environment with special reference to phosphorus. Am. Midland Naturalist. 57:300-370.

U.S. Geological Survey. 1972. (Unpublished data).

U.S. Weather Bureau. 1962-1972. Climatological Data National Summary.

Vollenweider, R.A. 1969. Eutrophication of waters. Mitt. Vereindt. Gewass-Schutz. 1(2):4-5.

Vollenweider, R.A. and O. Ravera. 1958. Preliminary observations on the oxygen uptake by some freshwater zooplanktons. Verk. int. Ver. Limnol. 13:369-380.

Ware, F.J. 1966. The food habits of channel catfish in South Florida. Proc. of the 12th Ann. Conf. S.E. Assoc. of Game and Fish Comm. 283-287.

Ware, F.J. 1974. Lake management and research. Final prog. report D-J project F-12-1S. (Mimeo.). Fl. Game and Fresh Water Fish Comm. Tallahassee. 94 pp.

Waters, T.F. 1969. The turnover ratio in production ecology of fresh water invertebrates. The Am. Nat. 103:173-185.

Watt, W.D. 1966. Release of dissolved organic material from the cells of phytoplankton populations. Proc. Roy. Soc. B. 164:521-551.

Watt, W.D. 1969. Extracellular release of organic matter from two freshwater diatoms. Ann. Bot. 33:427-437.

Wegener, W. and D. Holcomb. 1972a. Water level manipulation. Ann. prog. rpt. Job. No. 1, fish population studies. D-J project F-29-1. (Mimeo.). Fl. Game and Fresh Water Fish Comm. Tallahassee. 35pp.

Wegener, W. and D. Holcomb. 1972b. An economic evaluation of the 1970 fishery in Lake Tohopekaliga, Florida. Proc. 26th Ann. Conf. S.E. Assoc. Game and Fish Comm. 628-634.

Wegener, W. and V. Williams. 1975. (unpublished data).

Wegener, W., V. Williams, J. Buntz. 1973. Preliminary fish population investigations on lakes Kissimmee and Hatchineha, Osceola County, Florida. Florida Game and Fresh Water Fish Commission (mimeo.). 20 pp.

Wegener, W., V. Williams and D. Holcomb. 1973. Sampling shallow water fish populations using the Wegener Ring. Proc. 27th Ann. Con. S.E. Assoc. Game and Fish Comm. 663-674.

Welch, H.E. 1968. Relationships between assimilation efficiencies and growth efficiencies for aquatic consumers. Ecology. 49:755-759.

Westlake, D.F. 1963. Comparisons of plant productivity. Biol. review. 38:385-425.

Westlake, D.F. 1965. Some basic data for investigations of the productivity of aquatic macrophytes. In C.R. Goldman (ed.) the Primary Productivity in aquatic Environments. Mem . Dst. Ital. Idrobiol., 18 Suppl., University of Calif. Press, Berkeley.

Wetzel, R.G. 1964. Primary productivity of aquatic macrophy es. Verh. int. Ver. Limnol. 15:426-436.

Wetzel, R.G. 1965. Techniques and problems of primary productivity in higher aquatic plants and periphyton. 251-267.

Wetzel, R. 1969. Excretion of dissolved organic compounds by aquatic macrophytes. Biosci. 19:539-540.

Wilbur, R.L. 1969. The redear sunfish in Florida. Fla. Game and Fresh Water Fish Comm. Tallahassee Fish Bul. No. S, 64 pp.

Williams, Vincent 1975 (private communication).

Winberg, G.G. 1956. Rate of metabolism and food requirements of fishes. Belorussian State Univ., Minsk. 251 pp.

Winberg, G.G. 1960. Rate of metabolism and food requirements of fishes. Fish Res. Bd. Can. Trans. Series #194.

Winberg, G.G. 1968. The methods for the estimation of production of aquatic animals. Minsk, Izd. "Vysejsaja Skola."

Wolfe, J.C. The food habits of Ictaluridae in North Florida. (unpublished data).

Yentsch, C.S. and D.W. Menzel. 1963. A method for the determination of phytoplankton chlorophyll and phaeophyton by fluorescence. Deep Sea Res. 10:221-

Zicker, E.L., Berger, K.C. and A.D. Hasler. 1956. Phosphorus release from lake muds. Limnol. and Oceanogr. 1:296-303.