Special Publication SJ 87-SP3

ORANGE, LOCHLOOSA, AND NEWNANS LAKES:

A Survey and Preliminary Interpretation of Environmental Research Data.

by

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[Included under separate cover: A Categorized Bibliography of the Orange Creek Basin]

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Final Report: September, 1987

Prepared for:

St. Johns River Water Management District
Project: 15-200-33

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ABSTRACT

A reconnaissance profile is developed for Orange, Lochloosa, and Newnans Lakes, located in the Orange Creek basin in eastern and southeastern Alachua county, Florida. The objective is to integrate and summarize relevant scientific information concerning these lakes into a single reference in order to facilitate decision making processes in basin management. A second objective is to identify research and data collection needs essential for effective basin management.

Data and information from approximately 120 references relative to the basin are incorporated in a discussion of basin physiography and lake characteristics. The lakes can be broadly characterized as soft-water, eutrophic lakes. The flora and fauna of the three lakes are quite similar to one another and typical of enriched conditions.

Topics of special interest which may be considered in basin management are reviewed. First, reproducing populations of several state and federally listed threatened and endangered species inhabit and utilize the basin. This may require special management measures which focus on habitat preservation. Second, abundant growth of aquatic macrophytes limits the use of the lakes in the basin for fishing and water recreation. Basin management with the objective of maintaining or improving use of the lakes for recreation and sport fishing should incorporate measures to control primary production. The economic significance of these lakes for the region generated by these uses is an important consideration in this respect. Third, recent land-use considerations dealing with conservation of existing natural habitat and increased urban development pressure may be of concern in formulating a management plan.

Without major sources of cultural eutrophication in the basin, the most important factors in determining rates of primary production are runoff from the phosphate-rich soils and internal nutrient cycling between the sediment and water column in the lakes. Seasonal fluctuations in lake water level have a significant impact on nutrient cycling and may play an important role in periodic rejuvenation of these aquatic systems.

INTRODUCTION

Orange, Lochloosa, and Newnans Lakes, located in eastern and southeastern Alachua county, have long been recognized for their excellent bass fishing, tranquil aesthetic beauty, and productive wildlife habitat. These lakes annually attract many sportsmen, naturalists, tourists, and new residents. The watershed supports about 90% of the mammal, bird, reptile, and amphibian species that occur in inland north central Florida (Simmons, 1985), including many species of special interest such as bald eagle and osprey populations, woodstorks, sandhill cranes, bass, and alligators. In addition, because of the proximity of these lakes to the University of Florida, a variety of data has been gathered by researchers based in Gainesville.

In recent years, fundamental concerns have developed regarding excessive macrophyte growth, water quality changes, and subsequent ecological alterations in these lakes (Schramm et al., 1983; Shireman et al., 1983). Establishment of *Hydrilla verticillata* over large parts of Orange and Lochloosa Lakes may significantly reduce their value for fishing and water recreation (Krummrich, 1986b). This may cause economic hardship for many area residents (Delaney, pers. comm.). In addition, current proposals for urban and commercial development in the immediate area (Friends of Cross Creek, 1983, 1985) increase the potential for enhanced nutrient input, creating the possibility of further change in this ecosystem (FDER, 1987).

Considerable uncertainty exists regarding optimal development and management of watersheds such as this, especially for multiple uses. Relevant scientific information is widely scattered, not integrated on a systems level, and therefore difficult for water managers to comprehensively review. A need exists for a single reference of available information for the purpose of identifying specific problems and specific research needs, so that future management of this lake basin can be more effective.

The primary objective of this report is to develop such a single reference. Through a review of existing literature and an inventory of the existing data base, available research information is summarized and documented. This information can then be used to assess water resource conditions and problems. A secondary objective is to identify additional data collection needs that have a high probability of leading to improved basin management.

The report first describes the basin in terms of geomorphology, soils, and vegetation, and discusses hydrological considerations. After an inventory and interpretation of water quality data, the biology of the lakes is reviewed. Attention is given to temporal trends in water quality and in the structure and composition of biological communities. Topics of special concern such as wildlife in the basin, aquatic weed control, the economic significance of the lakes, and land-use issues are described. The nutrient dynamics and their impact on lake productivity are briefly reviewed and a conceptual model of lake management, based on periodic water level fluctuations is suggested and summarized. Finally, research needs are identified which will considerably enhance understanding of this basin and contribute to effective management.

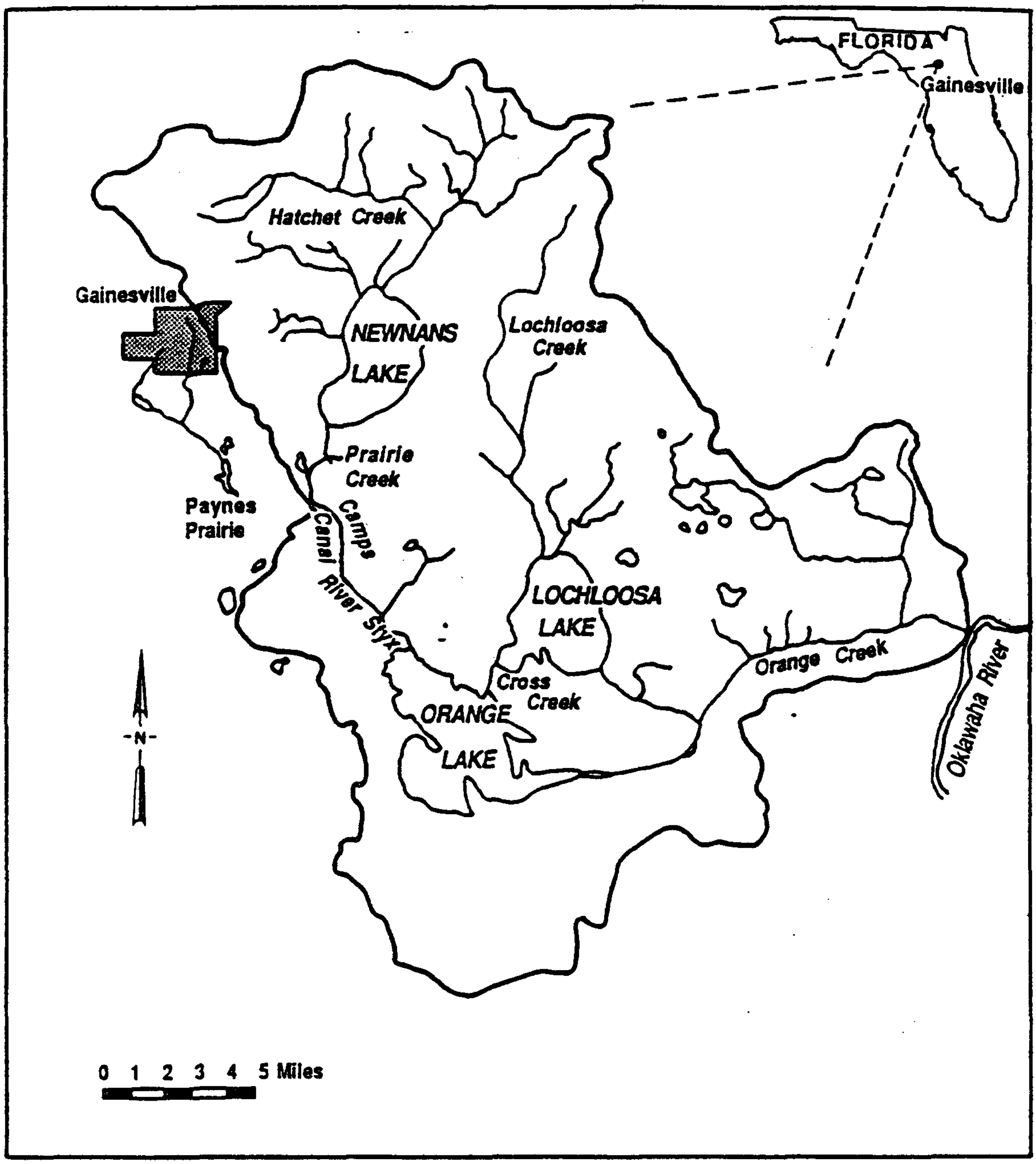

Figure 1. Drainage Map of Orange Creek Basin. (Adapted from Allen, 1986)

DESRIPTION OF THE BASIN

Orange, Lochloosa, and Newnans Lakes are the three main surface water bodies in the Orange Creek basin (see figure 1). This basin covers an area of 1040 km2 and falls within the topographical region of the state that is known as the Central Lowlands (Clark et al. 1964). The physiography of these lowlands is characterized by discontinuous highlands which form parallel ridges and are separated by broad valleys. The ridges are generally above the piezometric surface, while the valley floors are generally below it (White, 1970). Sinkhole lakes are common on the ridges, such as in the eastern part of the basin. Broad shallow lakes, such as the three lakes under study in this report, are common on the valley floors.

The geology of an area can influence soil development, drainage patterns, and the mineral composition of its surface waters. The geomorphology of this basin, described by Pirkle and Brooks (1959), is dominated by the Hawthorne formation. This formation is a marine deposit of Miocene age and consists of phosphatic sands, clays, and limestones. It is relatively impermeable compared to the underlying Ocala group and acts as a confining layer. It is exposed in the central and eastern parts of the basin, although the outcrop pattern of the various formations in this area is not documented identically in different publications (USDA-Soil Conservation Service, 1985; Brooks, 1981; Putnam et al.1969). The Ocala formation of older (Eocene) porous and permeable limestones is at the surface in the southern parts of the basin. It is the underlying, dominant component of the entire regional geology and constitutes the main part of the the Floridan aquifer. Because of its mixture of cavernous hard and soft limestone, which is approximately 98% calcium carbonate (USDA-Soil Conservation Service, 1985), the area can be described as generally having a karst topography. Features of such an area include sinkhole lakes, shallow erosion basins, filled and open sinks, and prairies. Younger deposits, consisting of sands and clayey sands overlie the Hawthorne formation in the northern part of the basin and in the River Styx-Orange Lake area (see figure 2).

The geologic formations are covered in most places by a thin veneer of sands and clayey sands. Most of these surface soils are nearly level to gently sloping. The drainage characteristics vary from moderately well drained on the upland soils to very poorly drained along the creek systems. Poorly drained to somewhat poorly drained flatwood soils of the Pomona-Wauchula-Newnans series are the dominant soils (USDA-Soil Conservation Service, 1985).

The physiography of the basin may be divided into two provinces as was first noted by Sellards (1912) and later refined by White (1970). These two provinces are; an upland plateau, north of Gainesville and which includes most of northeastern Alachua county, and a central and southern transitional area. The upland plateau is nearly level, sloping gently to the west, north, and east. Elevation ranges from about 135 to 180 feet above sealevel. In this plateau region, the aquifer is confined where it is overlain by the Hawthorne formation. It is therefore under artesian conditions and natural discharge from the aquifer occurs where the confining layer is thin or absent, such as at Magnesia Springs to the north of Lochloosa Lake (Pyne, 1985).

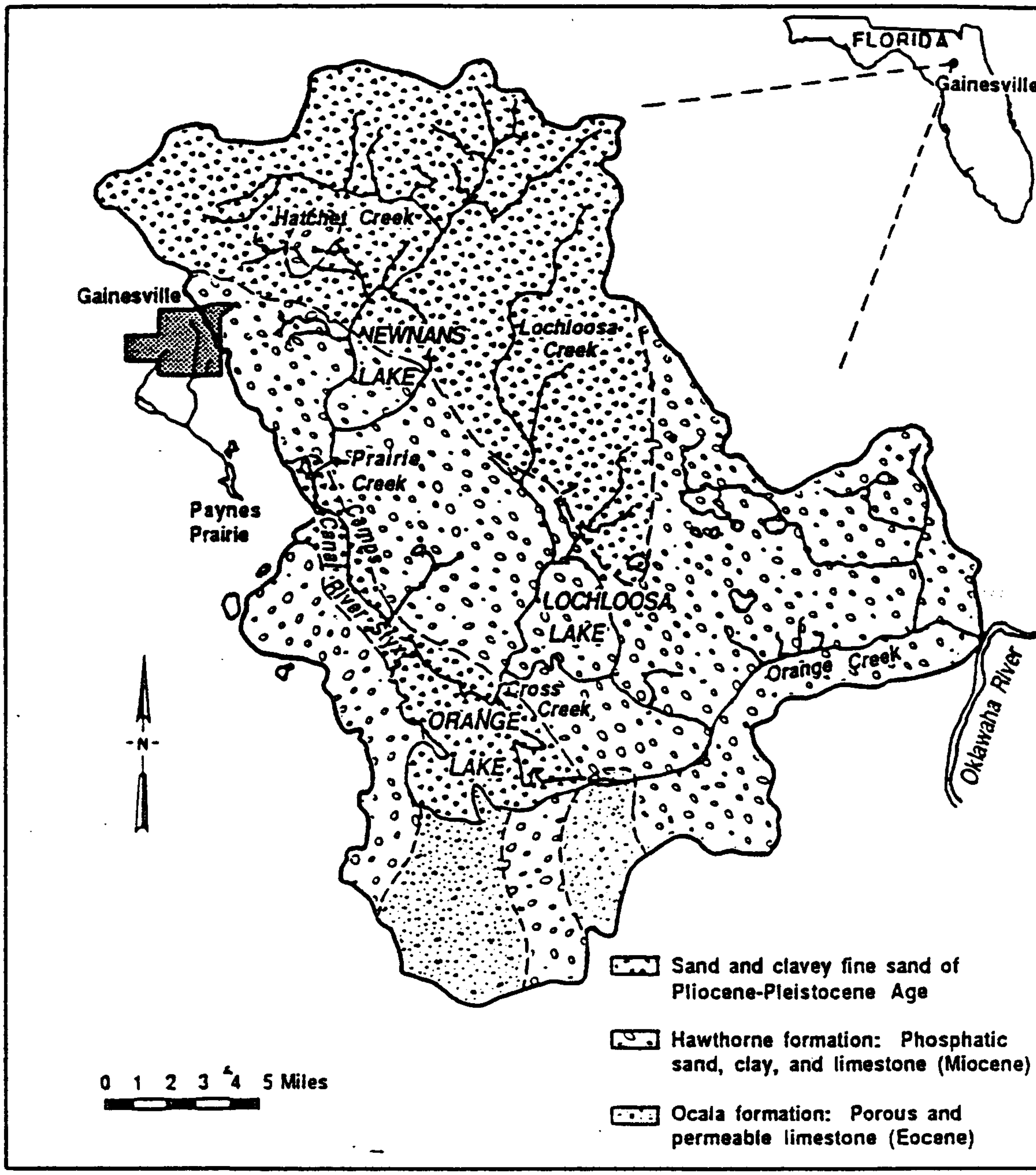

Figure 2. Geologic Map of Orange Creek Basin. (After Brooks, 1981)

The central and southern part is characterized by flat-bottom lakes, prairies, small streams, and erosional remnants of the plateau. Most of the surface topography is at an elevation of 65 feet MSL or less and the piezometric surface of the groundwater of the Eocene limestone roughly corresponds with the level of the depressions and lakes (Pirkle and Brooks, 1959). Consequently, natural infiltration and soil drainage is impeded in this portion of the area.

The poor drainage and small elevation gradients (usually less than 12 feet/mile) result in much sheetflow and poorly defined channels. Ponds and wetlands occur throughout the area. Surface flows, subsurface flows through slightly calcareous phosphatic sands, and direct rainfall are the major sources of water to the lakes in the basin, as was pointed out by Canfield (1981). He attributes the low mineral content of the lake waters to the generally reduced input from mineralized groundwater. Groundwater from deep aquifers apparently does not regularly enter the lakes (Deevey,1987). In addition, the highly colored, acidic nature of the inflow into the lakes significantly reduces the buffer capacity of this water.
Water from lakes in the Orange Creek basin is lost by drainage through underlying pervious sediments or solution cavities, evapotranspiration, and discharge in surface streams. Downward drainage often assumes unusual importance because of the high permeability of underlying materials (Deevey, 1987). Furthermore, high evapotranspiration losses are evident in Florida's climate. Of the 52 inches of rainfall received by the Orange Creek watershed annually only 5 inches leaves as surface drainage (Clark et al., 1964).

The lakes in the basin respond with little or no lag to monthly net precipitation, although annual and decade long variations in lake level appear to be driven by artesian pressure regulating downward leakage from the lakes (Deevey,1987). Mean precipitation for the Orange Creek basin is 52 inches per year. Annual variations can be significant. During the 80 year period of record for Gainesville, annual rainfall has occasionally fallen below 35 inches or exceeded 70 inches (Allen, 1986). About 52% of the total rain falls during the months of June, July, August, and September. October and November are the driest months. Average annual relative humidity is reported as 87% in the early morning and 55% during the middle of the day (Florida Statistical Abstracts, 1985).

Detailed information on vegetation and land-use in the basin can be found on maps produced by the Center for Wetlands at the University of Florida (1973) and in Brown (1985). The vegetation in the basin is dominated by forests, including large areas of commercial pinelands. The majority of the commercial forestry emphasizes medium rotation growth (20-30 years) of slash pine for the production of pulp (Schlitzkus, 1987). Extensive areas of undeveloped pine flatwoods occur, with riverine hardwood swamp and cypress along the water courses. Some of the surrounding forests are cleared for pasture and truck crops. Urban development is minor, although urban pressure from the Gainesville and Ocala areas is increasing. Figure 3 shows land-use and vegetation categories for the basin.

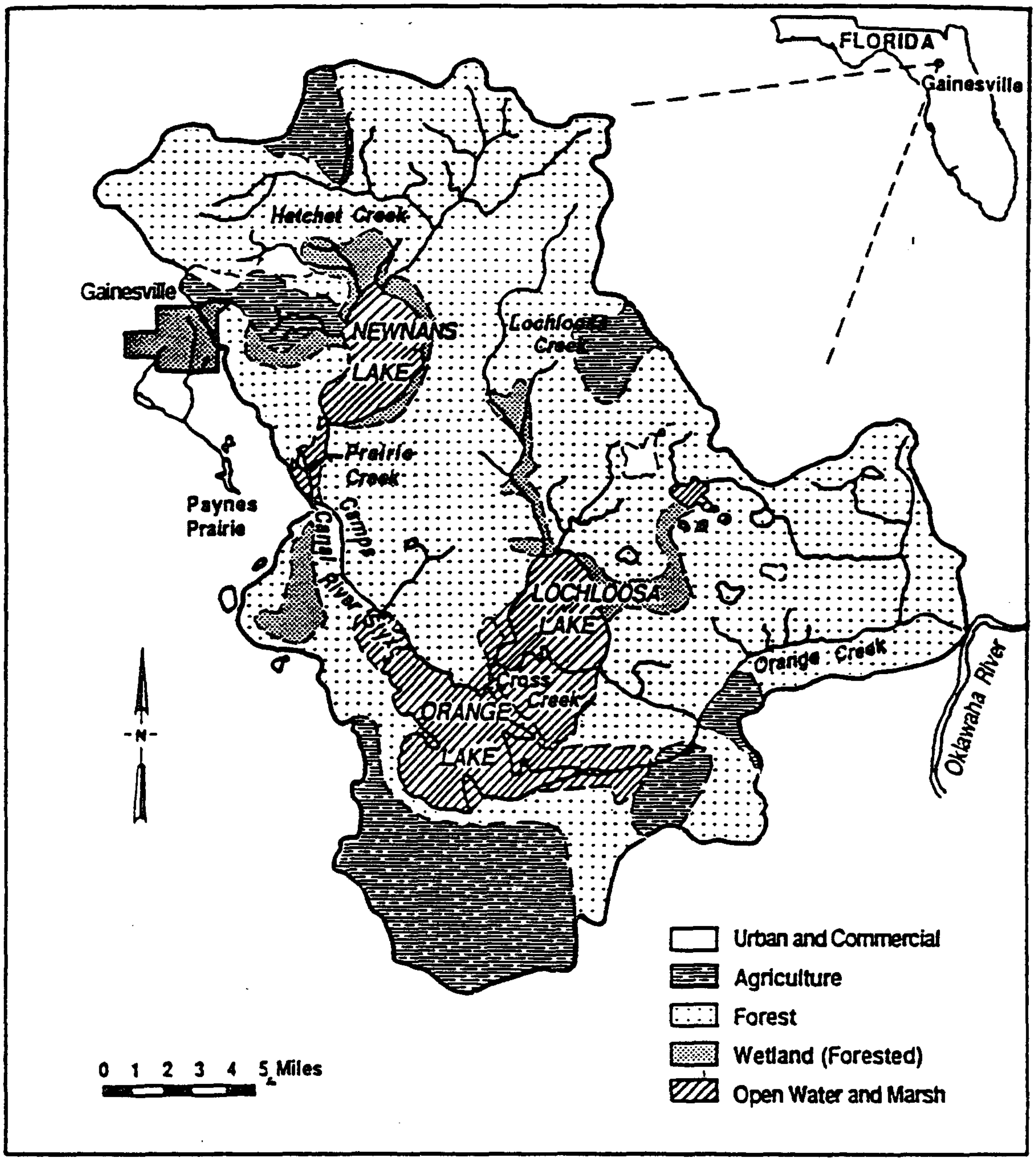

Figure 3. Land use and Vegetation of Orange Creek Basin.

DESCRIPTION OF THE LAKES
(Detailed discussions of the chemistry and the biology of the lakes follow in subsequent chapters).

Newnans Lake is located approximately 5 miles east of Gainesville. It has a surface area of ca 7,200 acres and is a typical shallow basin lake. The maximum depth is not more than 12 feet and the mean depth is approximately 5 feet (Nordlie, 1976). The littoral zone around the open water area consists of cypress swamp. Similar to many other lakes in the region, it can be classified as a eutrophic, soft water lake (Canfield, 1981). A large drainage area north of the lake supplies inflow via Hatchet Creek, Gum Root Swamp, and several smaller creeks. The lake has a single major surface water outlet, Prairie Creek, which drains to the south. A dam was constructed at this outlet in 1967 to reduce natural seasonal water level fluctuations of the lake. This stabilized the water level at approximately 67-68 feet MSL. Prior to the construction of this dam, the lake level would fluctuate between 64 and 68 feet MSL, which caused seasonal exposure of littoral areas of the lake bottom.
Modification of the Prairie Creek dam in 1976 reintroduced limited fluctuations of the lake level in an effort to improve the condition of the lake with respect to algae and weed control. It is interesting to note that prior to the construction of Camp's Canal, in the early 1930-s, the surface outflow of the lake through Prairie Creek discharged into Paynes Prairie. The former owner of most of the prairie, Camp Ranch Inc., constructed an earthen dike and bypass canal around the eastern margin of the prairie to control flooding and to manage the land for cattle grazing. The dike directs the water around the prairie on a sluggish course to the River Styx and subsequently to Orange Lake.
Physical, chemical, and biological parameters of Newnans Lake were studied by Crisman (1986) during a four year period to characterize this system and to provide data for eutrophication management based on biocontrol. Two paleolimnological studies have been conducted at Newnans Lake. A pollen and diatom analysis on several sediment cores (Holly, 1976) indicated that the lake was formed between 5000 and 8000 years ago and that it has been eutrophic throughout its history. Flannery et al. (1982) documented chemical analyses data of surface sediments as part of a multi-lake survey.

Lochloosa Lake, located 15 miles southeast of Gainesville, has a surface area of ca. 5,600 acres, a mean depth of approximately 7 feet, and a maximum depth of 11 feet (Langeland, 1982). The lake is essentially undeveloped around its shoreline, which is characterized primarily by a relatively direct transition from lake to cypress wetland. It is a eutrophic, soft water lake (Canfield, 1981) with prevalent dense stands of aquatic macrophytes. A large drainage area to the north supplies water inflow through Lochloosa Creek. The majority of the surface outflow leaves the lake through Cross Creek. An undetermined amount of water drains slowly to Orange Creek through Lochloosa Slough in the southeastern corner of the lake. Historically, the stage of the lake has fluctuated between 54.1 and 61.9 feet MSL. The average lake level is currently at 58 feet MSL. In contrast with the extensive limnological data base for Orange Lake, few investigations have been conducted in Lochloosa.

Orange Lake is the largest of the three lakes discussed in this survey. Its water level has fluctuated considerably from year to year due to sinkholes that have opened up a number of times. Consequently, large changes in surface area have occurred. Reid (1950) reported a surface area of almost 14,000 acres and an approximate maximum depth of 30 feet. Deevey (1987) lists the lake size now as 8,636 acres with an average depth of 5.5 feet and a maximum depth of 12 feet. The residence time of the lake water is reported by him as 0.95 years. Orange Lake receives input from Newnans Lake through River Styx and from Lochloosa Lake through Cross Creek. The lake drains surficially through Orange Creek into the Oklawaha River, a tributary of the St. Johns River.

Lake levels have historically varied from a high of 61.0 feet in November, 1941 to a low of 49.8 feet MSL in August, 1956 (Pirkle and Brooks, 1959; Davis, 1973). In 1956, a sinkhole in the southwest section of the lake opened and 80% of the lake volume drained into the aquifer (Roland, 1957). An earthen dam was constructed around the sinkhole in an effort to isolate it from the lake and retard the loss of water. The sink eventually was closed and construction of a spillway in Orange Creek in the 1960-s further stabilized the lake level, which now averages 57.7 feet MSL. The wide fluctuation of past water levels has promoted the growth of dense hydrophytic plants along the shore.

The lake bottom is composed primarily of a layer of decaying organic material, often in excess of three feet thick, mixed with fine sediments. Shireman et al. (1983) report different compositions of the bottom substrate in different vegetational communities in the lake. Many limnological and fish & wildlife studies have been conducted in Orange Lake, the results of which will be reviewed in the next sections.

WATER QUALITY

Many independent investigations have documented water quality data for the Orange Creek basin. However, little long-term monitoring at frequent intervals has been done. The most significant water quality studies were carried out by Shannon (1970), the Florida Game and Fresh Water Fish Commission (Holcomb, 1968, 1969; Duchrow, 1970, 1971; Duchrow and Starling, 1972; Holcomb and Starling, 1973), Canfield (1981), and Crisman (1986). In addition, the U.S. Geological Survey (USGS) has monitored a number of water quality parameters at one station in each of the three lakes since the late 1950-s. However, sampling frequency was generally limited to once or twice per year. The Florida Department of Environmental Regulation (FDER) has sampled one station in Lochloosa and Newnans Lake with the same frequency since the mid 1970-s. These data can be accessed through the Environmental Protection Agency's (EPA) STORET system, a data base of sampling sites and their associated water quality data.
Following is a brief discussion of the water quality parameters and data collected in the three lakes by different workers. No attempt is made to include parameters which have only been collected in token numbers.

Temperature and dissolved oxygen. Oxygen is a fundamental parameter of lake water quality. Dissolved oxygen is not only essential to all aerobic aquatic organisms, its concentration also strongly effects the solubility of many inorganic nutrients. Solubility of oxygen is affected non-linearly by temperature, and increases considerably in cold water.
Temperature and dissolved oxygen data for Newnans, Lochloosa, and Orange are typical of shallow, eutrophic lakes in Florida. No significant thermal stratification occurs. Vertical changes in water column temperature rarely exceed 3 degrees Celsius, regardless of season. Winter minimum temperatures are always greater than 11 degrees Celsius, and summer maximum temperatures often exceed 30 degrees Celsius (Crisman, 1986; STORET). Pronounced water column changes in dissolved oxygen are common in all three lakes, particularly during summer and early fall. Daytime surface waters are often supersaturated, while the water column below three meters approaches anoxia as a result of intense decomposition in surficial sediments. The USGS reports an average of 6.76 (0.3-11.7) mg/l dissolved oxygen from 156 surface water measurements in Orange Lake between 1967 and 1985. Similar values are consistently found in the other lakes in the basin.

pH controls many processes in lakes, including the form and activity of many chemical species (nutrients, metals). The hydrogen ion activity in natural waters is governed to a large extent by the CO_2-HCO_3^--CO_3^{2-} buffering system.
No significant trend over time is documented in the literature for pH values in these lakes. Typical value ranges, as reported by Canfield (1981) and Nordlie (1976), are 7.0-8.0 for Orange, 7.3-7.4 for Lochloosa, and 6.3-7.5 for Newnans Lake, the latter being consistently more acid. Anoxic conditions in the bottom waters will produce a substantial decrease in pH values in the area of the sediment-water interface. The resulting change in redox state markedly increases the release of phosphates from the sediments.

Nitrogen is a major nutrient affecting productivity of plants and bacteria in fresh waters. Dominant forms include dissolved molecular N_2, ammonium (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-), and a large number of organic compounds of low nitrogen content. Water quality investigations routinely report total nitrogen, ammonium, and nitrate concentrations. The latter two are readily assimilated by plants. Nitrite is rapidly oxidized in the presence of oxygen and rarely accumulates. Its concentration is usually extremely low, unless high organic pollution is prevalent.

Nitrogen analyses are reported by Nordlie (1976) and Crisman (1986) for Newnans, Schramm et al.(1983), Shireman et al.(1983) and FDER (1987) for Orange, and by Putnam et al. (1969), Shannon (1970), and Canfield (1981) for all three lakes. Typical values for Newnans range from 0.85 to 1.50 mg/l total nitrogen, 0.03-0.80 mg/l NH_4^+, and 0.02-0.22 mg/l NO_3^-. These value ranges for Lochloosa are respectively 0.85-1.50, 0.11-0.22, and 0.01-0.03, while Orange Lake's values are 0.85-1.50, 0.05-0.36, and 0.02-0.25 mg/l. These concentrations underscore the eutrophic character of the lakes. For each lake, a comparison between recent data (Canfield, 1981) and earlier work (Shannon, 1970) shows similar value ranges. However, because of the lack of long-term data collection at frequent intervals, no sufficient data base exists to study trends.

Phosphorus is probably the most intensively studied element in fresh waters. Often it is the first nutrient to limit biological productivity, although nitrogen limitation in eutrophic systems in Florida is not uncommon (Canfield, 1983). Both total phosphorus and orthophosphate (PO_4^{3-}) concentrations are reported in limnological work. Orthophosphate is the only, directly utilizable form of soluble inorganic phosphorus.

A survey of the same studies which reported nitrogen concentrations indicates typical values for Newnans Lake of 0.023-0.082 mg/l total phosphorus and 0.006-0.080 mg/l PO_4^{3-}. For Lochloosa these values are respectively 0.018-0.059 and ca. 0.004. For Orange 0.010-0.057 and ca. 0.005 are usually reported. The three lakes obviously display similar phosphorus dynamics and the reported values are indicative of eutrophic conditions. Once again, no sufficient long-term data exist to document the magnitude or rate of change of eutrophication.

Chlorophyll *a* is the primary photosynthetic pigment. Its concentration in water is widely used in limnology as a measure for phytoplankton biomass. Because of the strong correlation between nutrient concentrations (total phosphorus and total nitrogen) and phytoplankton biomass, nutrient-chlorophyll *a* regression equations have gained acceptance as a tool for estimating the response of lakes to reductions or increases in nutrient loading rates (Dillon and Rigler, 1974).

Canfield (1981) documented chlorophyll *a* concentrations in Newnans of 38.0 (24.1-55.0) mg/m^3, in Lochloosa of 32.0 (24.7-44.9) mg/m^3, and in Orange of 35.4 (27.4-49.3) mg/m^3. These ranges indicate eutrophic conditions and are representative of data reported in other investigations. Chlorophyll *a* levels show definite seasonal trends. Peak concentrations occur during the summer, lowest concentrations generally occur during the winter. Substantial variations in chlorophyll *a* concentrations are also associated with the percentage of the lake volume occupied by aquatic macrophytes. Competition for nutrients by aquatic plants and epiphyton, reduction in nutrient cycling (because aquatic macrophytes reduce wind mixing), and increased sedimentation of planktonic algae (because macrophytes reduce water turbulence) all contribute to reduced chlorophyll a levels with an increase in plant communities (Canfield,et al., 1984). In the Orange Creek basin, with abundant and changing levels of aquatic macrophytes, chlorophyll a concentrations will, therefore, be highly variable and prediction of values based on nutrient-chlorophyll a models should include a term for the percentage of the lake's total volume occupied by macrophytes (PVI). PVI values reported for Newnans, Lochloosa, and Orange Lake are respectively 3.7, 48, and 79 (Canfield et al., 1984), but vary considerably during different times of the year or between years. The following best-fit multivariate regression equation is used by Canfield et al. (1984) to improve predictions of chlorophyll a concentrations:

$$\log CHLA = 1.02 \log TN + 0.28 \log TP - 0.005\ PVI - 2.08$$

Secchi Disk transparency is often measured as an index of lake trophic state. It is not only influenced by trophic state, but also by other factors such as inorganic turbidity and humic coloration of the water. It is measured, at mid-day, as the mean depth of the point where a weighted white disk, 20 cm in diameter, disappears when viewed from the shaded side of a boat, and that point where it reappears upon raising it after it has been lowered beyond visibility.
Typical values are 0.15-0.95 m for Newnans (Crisman, 1986), 0.50-1.0 m for Lochloosa, and 0.60-1.0 for Orange Lake (Canfield, 1981). Minimum values are generally found in the summer (increased algal productivity) and maxima occur in the winter. Because of the shallow depth and exposed character of the three lakes, wind action frequently results in resuspension of flocculent bottom materials. The wind is therefore a significant factor in reducing Secchi Disk readings.

Similarly, organic sediment disturbances contribute to high turbidity measurements in the three lakes. Turbidity is a measure of light scattering, which is affected by, essentially, any material in suspension. Values reported by USGS (STORET) for the early 1970-s range from 7.6 JTU for Orange, 24.0 JTU for Lochloosa, to 31.3 JTU for Newnans.

True color measures the selective absorption of light by dissolved solids. In the Orange Creek basin, color is largely a function of hydrology, i.e. inputs of highly colored water from the surrounding flatwoods and cypress. Seasonal changes in the input of water associated with rainfall patterns result in fluctuating values for water color. Particularly Newnans Lake is highly colored with values often in excess of 200 mg/l as Pt, with somewhat lower values for Orange and Lochloosa (Canfield, 1981).

The conductivity of lake water is a measure of its ability to carry an electrical current. When temperature effects are accounted for, it is a measure of the level of dissolved electrolytic ions. It is the reciprocal of the resistence of a solution to electrical flow and is often expressed in umhos/cm @ 25 degrees Celsius.
Typical conductivity values at that temperature are 45-73 for Newnans, 60-89 for Orange, and 71-96 umhos/cm for Lochloosa Lake (Shannon,1970). The slightly higher values for Lochloosa Lake are probably related to

increased calcium concentrations, which in turn can be linked to groundwater input from Magnesia Springs, to the north of the lake.

The higher calcium concentration in Lochloosa, relative to Newnans and Orange, produce higher values for hardness, a property of water caused by the presence of polyvalent metal ions (mainly calcium and magnesium ions). The source of most of the hardness in Florida waters is dissolution of mineral rocks, predominantly limestone. Therefore elevated total hardness is usually indicative of groundwater input into a lake.

The values for total hardness routinely documented for Lochloosa (30-32 mg/l as $CaCO_3$), Newnans (22-23), and Orange (24-26) are indicative of soft waters and suggest little groundwater input into the lakes.

Soft water lakes generally exhibit low alkalinity values. Alkalinity is a measure of the pH buffering capacity. Components in water responsible for alkalinity include carbonates, bicarbonates, phosphates, and hydroxides. These components tend to raise the pH and stabilize it. Alkalinity is reported in mg/l as $CaCO_3$ and the values typically found in the Orange Creek basin are indicative of lakes with poor buffering capacity. Mean alkalinities for Newnans, Lochloosa, and Orange are respectively 14, 23, and 18 mg/l as $CaCO_3$ (Canfield, 1981). Once again, these data indicate that the lakes do not receive direct inflow from underlying limestone formations, but receive the bulk of their water either directly from precipitation or from surface and subsurface runoff from the sandy, low calcareous soils.

In addition to the above mentioned "common" water quality parameters, different reseachers have analyzed and reported concentrations of various anions and cations (particularly metals) in the basin (Putnam et al., 1969; Shannon, 1970; Canfield, 1981; Shireman et al., 1983). EPA's STORET water quality data base provides additional information relative to these elements.

The average of total cadmium concentrations, measured in Orange Lake on 10 occasions from 1972 to 1985, exceeds water quality standards for Class III waters (recreation, fish, and wildlife) as specified in Chapter 17-3, Water Quality Standards, FDER. The average concentration reported is 1.3 ug/l (0.0-3.0) with the water quality standard set at 0.8 ug/l for fresh water with a hardness less than 150 mg/l as $CaCO_3$.

With the exception of one sample collection in Orange Lake (STORET, 04-11-85), no data are reported for concentrations of organic contaminants, such as pesticides.

Water Quality Data: Summary and conclusions

Many independent studies have reported water quality data for the Orange Creek basin. The lakes are broadly characterized as soft water, eutrophic lakes (Canfield, 1981). However, no sufficient long-term limnological data exist to document the magnitude or the rate of change of eutrophication. From the data present, particularly nutrient and Secchi Disk values, all three lakes have apparently been eutrophic at least since the mid 60-s. A summary of water quality data for the three lakes is given in table 1.

Table 1. Summary of water quality data for Newnans, Lochloosa, and Orange Lakes. Numbers in parentheses are the minimum and maximum values measured.

Parameter	Unit	Newnans			Lochloosa			Orange		
		Canfield 1981 1)	Shannon 1970 2)	GFC 1967-73 3)	Canfield 1981 1)	Shannon 1970 2)	GFC 1967-73 3)	Canfield 1981 1)	Shannon 1970 2)	GFC 1967-73 3)
pH		6.8 (6.7-6.9)			7.4 (7.3-7.5)		7.7 (6.7-8.9)	7.2 (7.0-8.0)		7.6 (7.0-7.8)
Tot.Alk.	mg/l CaCO3	14 (12-18)			23 (21-25)		23 (16-28)	18 (15-20)		17 (14-21)
Spec.Cond.	umhos/cm	59 (54-64)	60 (45-73)		77 (71-84)	87 (71-96)	105(94-115)	67 (60-72)	77 (60-89)	89 (76-100)
Tot.Hard.	mg/l CaCO3	22 (22-23)			31 (30-32)		32 (31-32)	25 (24-26)		23 (22-23)
Ca	mg/l		5.1 (3.5-7.0)			8.8(6.2-10.2)	9.5(6.7-15.0)		7.8 (5.8-9.0)	6.1 (5.2-7.2)
Mg	mg/l		1.4 (1.0-1.8)			2.4(1.5-3.4)	2.6 (1.9-3.5)		1.8 (1.4-2.2)	1.8 (1.6-1.9)
Na	mg/l	6.3 (5.4-7.7)	7.1 (6.0-8.4)		5.6(5.4-6.1)	7.4(6.0-8.7)	5.1 (4.1-6.0)	6.3 (5.9-7.2)	8.8 (8.3-9.1)	5.1 (4.2-5.8)
K	mg/l	0.4 (0.2-0.5)	0.5 (0.2-0.8)		0.3(0.1-0.4)	0.5(0.2-0.8)	0.6 (0.5-0.7)	0.2 (0.1-0.4)	0.7 (0.2-1.1)	0.6 (0.4-0.9)
Cl	mg/l	8.7 (8.0-9.3)			8.8(8.5-9.3)		10.0(9.0-11.0)	8.9 (8.5-9.3)		9.8(9.5-10.0)
Sulfate	mg/l	3.4 (0.0-9.6)			4.0(0.0-7.9)		2.7 (0.0-7.0)	4.2 (0.0-10.0)		0.4 (0.0-2.0)
Silica	mg/l	1.0 (0.5-1.7)			0.3(0.2-3.8)			0.4 (0.1-0.6)		
Tot.Fe	mg/l	0.36(0.30-0.46)			0.24(0.13-0.37)		0.30(0.17-0.42)	0.19(0.13-0.29)		0.14(0.08-0.20)
Tot.N	mg/l	1.30(0.88-1.50)	1.41(0.66-2.35)		1.20(0.88-1.50)	1.42(1.15-1.76)		1.10(0.88-1.20)	1.07(0.58-1.61)	
NH3-N	mg/l		0.36(0.03-0.80)			0.18(0.11-0.22)			0.15(0.05-0.36)	
NO3-N	mg/l		0.07(0.02-0.22)			0.02(0.01-0.03)			0.07(0.02-0.25)	
Tot.P	mg/l	0.05(0.02-0.08)	0.11(0.08-0.15)		0.04(0.02-0.06)	0.06(0.05-0.06)	0.14(0.13-0.18)	0.03(0.01-0.06)	0.06(0.04-0.08)	0.13(0.08-0.19)
Chl.a	mg/m3	38.0(24.1-55.0)	47.4(26.1-86.8)		32.0(24.7-44.9)	23.3(19.1-25.5)	22.9(8.0-32.1)	35.4(27.4-49.3)	15.6(11.9-20.6)	18.9 (6.4-35.3)
Color	mg/l Pt	93 (45-150)	189 (61-245)		61 (45-80)	116(90-157)		54 (35-80)	107 (41-179)	
Secchi	m	0.6 (0.5-0.7)	0.5 (0.4-0.6)		0.7(0.5-1.0)	0.9(0.8-0.9)	0.7 (0.5-0.9)	0.8 (0.6-1.0)	1.0 (0.8-1.2)	1.1 (0.9-1.5)

1) Canfield, 1981. Based on collections at 3 dates during Sep.1, 1979-Aug.30, 1980. At each date 3 mid-lake samples were taken (0.5 m deep). Each sample was analyzed separately.
2) Shannon, 1970. Sampling period June 69- June 70. Newnans and Orange - bi-monthly , Lochloosa - 3x; 3 stations were sampled and composited per collection date.
3) Florida Game and Fresh Water Fish Commission. Data are based on an average of values reported in 1968-73 water quality studies. References: Holcomb, 1968, 1969; Duchrow, 1970, 1971; Duchrow & Starling, 1972; Holcomb & Starling, 1973.

The mineral composition of the waters in the Orange Creek basin is to a large extent determined by the regional geology. High phosphorus concentrations in the lakes may be a direct consequence of the phosphate rich sands and clays of the dominating Hawthorne formation. High phosphorus concentrations, in turn, may contribute to elevated chlorophyll a levels, reduced Secchi Disk readings, anoxia in the lower water strata, and other limnological indications of eutrophy. This is true if the concentration of phosphorus in the lake water is limiting to these factors.

An assessment of the type of limiting nutrient(s) in the lake is important, because the control of inputs of a limiting nutrient may be used as a means by which to control primary production. Such an assessment is either done with enrichment bioassays or by computation of *in situ* nutrient ratios.
The ratio of N:P (in grams) in aquatic plant material is approximately 7:1 (Vallentyne, 1970). Using data from Canfield (1981), N:P values (in grams) in Newnans, Lochloosa, and Orange Lakes are respectively 26:1, 30:1, and 36:1. Schramm et al. (1983) documented an N:P ratio (in grams) for Orange Lake of 31.9:1. These results suggest phosphorus limitation of primary production despite the phosphate rich geology of the basin.

Significant changes in nutrient concentrations, reported during different studies, generally occurred in association with changes in water level. For instance, a rapid rise in water level (1978) resulted in high nutrient concentrations in Orange Lake (Shireman et al., 1983). Figure 4 depicts the relationship between concentrations of total nitrogen, total phosphorus and water level in Orange Lake for the period 1975-1985. Flooding of large areas of exposed lake bottom, containing oxidized sediments and decomposing plant material, may contribute substantial amounts of nutrients to the lake. In other words, lake hydrology, especially lake level fluctuations and, possibly hydraulic flushing rates, may be dominant factors in controlling nutrient concentrations.

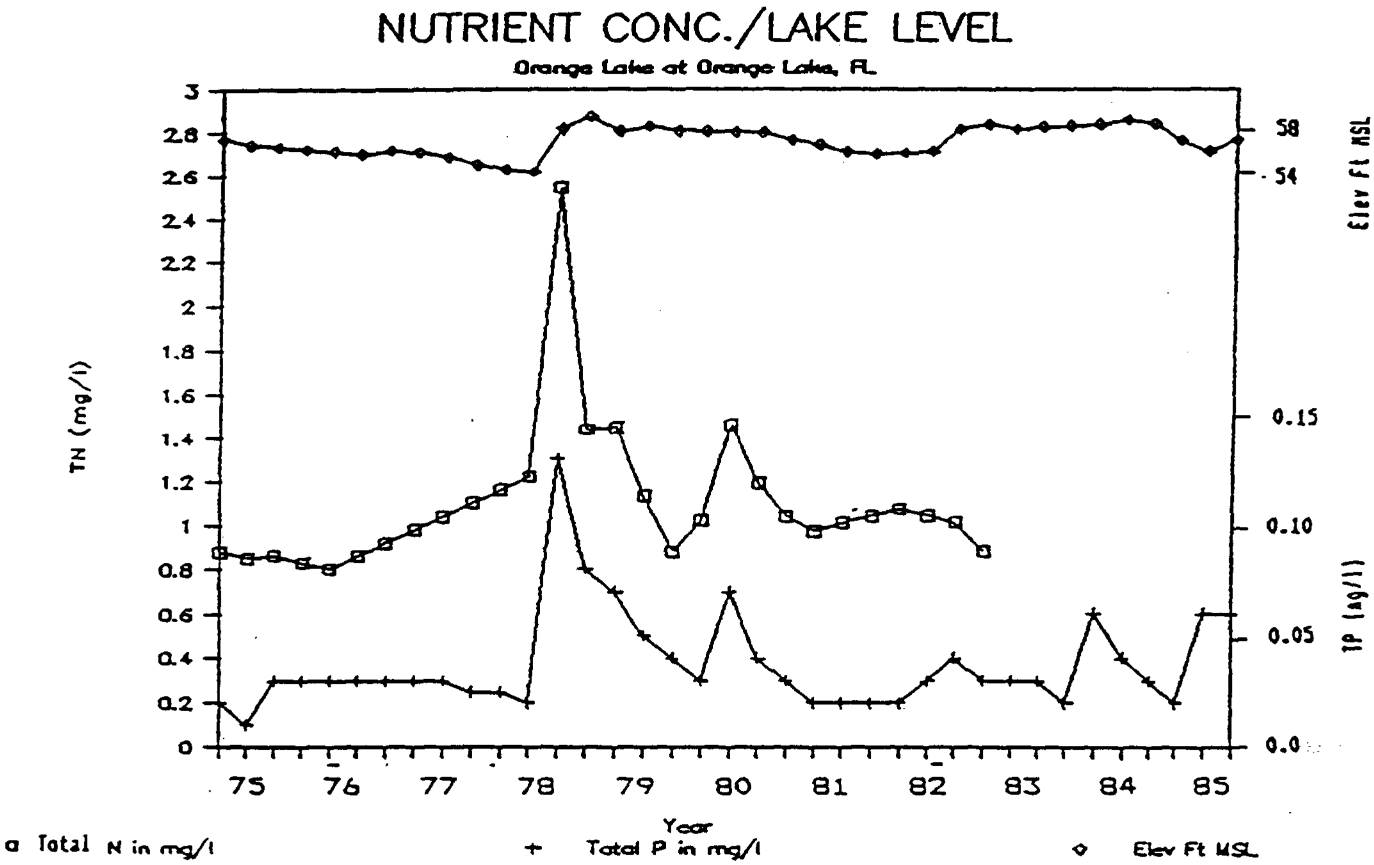

Figure 4. Relationship between concentrations of total nitrogen, total phosphorus, and water level in Orange Lake for the period 1975-1985. Graphs are based on 1-3 measurements per year at irregular time intervals. [Source of data: U.S.- Geological Survey]

BIOLOGY OF THE LAKES

The phytoplankton, microalgae of fresh water systems, consist of a very diverse assemblage of suspended, microscopic, autotrophic organisms. Many of these have different physiological requirements and vary in response to physical and chemical water quality parameters. Despite these differences, many phytoplankton species can co-exist in the same water body. Species composition of phytoplankton communities changes both in space (vertically and horizontally within a lake), as well as in time (seasonally) in response to changes in their aquatic environment.

Data on phytoplankton in Newnans Lake were published by Nordlie (1976) and Crisman (1986). In his two year study (1965-1966), Nordlie reported relatively high primary productivity of phytoplankton. Using two different techniques of measurements, mean values ranged from 0.64 to 1.10 gms.C/m2-day. These values are indicative of eutrophic conditions. An irregular pattern of productivity occurred during the study, but with generally higher values during the summer. The most common algal forms found in Newnans Lake were forms typical of enriched conditions. The dominant forms were blue-green algae. Nordlie (1976) reported Aphanizomenon holsaticum, Anacystis sp., and Anabaena flos-aque, while Crisman (1986) documented Spirulina sp. and Anabaena sp. with Microcystis sp. and Lyngbya sp. as subdominants. Several green algae, such as Ankistrodesmus falcatus and Pediastrum simplex, were often common forms too (Nordlie, 1976). Crisman (1986) noted a shift in the size distribution in the phytoplankton community of Newnans Lake during a one year monitoring study. Smaller forms appeared to dominate in fall and early winter, whereas larger forms were most common in summer.

No phytoplankton studies have been reported in Lochloosa Lake. Schramm et al.(1983) reported phytoplankton dynamics in Orange Lake in their comparative study of different vegetated habitats in the lake. Shireman et al.(1983) studied phytoplankton assemblages in Orange Lake in relation to abundance of aquatic macrophytes. Both researchers noted large seasonal fluctuations in algal biomass and density. The most abundant algae were blue-greens of the genera Lyngbya, Anabaena, Anacystis, Spirulina, and Oscillatoria. Other dominants included Coelastrum, Ankistrodesmus, Staurastrum, Scenedesmus (green algae), and the diatom Melosira (Shireman et al.1983). Schramm et al.(1983) documented higher density of phytoplankton in areas with decreased macrophyte biomass.
No dramatic differences in phytoplankton communities are found between the lakes. The species and the dynamics reported are typical of eutrophic conditions. Data from Langeland (1982) suggest that the assimilation of phosphorus by the macrophyte community limits phytoplankton production. A general relationship between chlorophyll a, as a measure of phytoplankton productivity, nutrients and the percentage of a lake's volume occupied by aquatic macrophytes was established by Canfield et al.(1984). For Florida lakes, as was noted previously, open water chlorophyll a, and thus phytoplankton biomass, decreases with increased aquatic macrophytes.

Aquatic macrophytes, macroscopic forms of aquatic vegetation, are either rooted or free-floating. The rooted plants can be emergent, floating-leaved, or submersed and are restricted to littoral areas of the lake.

Aquatic macrophytes can have a major impact on productivity, nutrient cycling, mixing patterns, and other aspects of the metabolism of a lake system. Excessive growth of aquatic plants can lead to interferences with the use of a lake for domestic, recreational, navigational, or agricultural purposes. The Orange Creek basin is subject to dramatic infestations of aquatic macrophytes, particularly as a result of the introduction of two exotics; the water hyacinth (Eichhornia crassipes) and hydrilla (Hydrilla verticillata). Specifics pertaining to aquatic plant control will be discussed in a later paragraph.

Newnans Lake exhibits relatively steeper shoreline gradients than Orange Lake. Consequently, its littoral zone is dominated by cypress and by a smaller fraction of herbaceous marsh. Newnans has alternated between phytoplankton and floating macrophyte domination. Crossman (1956), Crider (1972), and Smith (1974) documented that hyacinth growths have, at times, covered a large portion of the open area of the lake. The presence of numerous snail shells in the soft sediment of the lake - shells of snails not now common, and of forms that would be expected to inhabit vegetation- suggest that rooted macrophytes were common at times (Nordlie, 1976).
Presently, Newnans Lake has moderate levels of aquatic macrophytes and is dominated by algae. Garren (1982) did a macrophyte survey of the lake in 1981 and found a fairly rich flora consisting of four species of emergents, two species of floating-leaved, four species of free-floating, and three species of submersed plants. Included in his survey were Typha (cat-tail), Nelumbo (american lotus), Taxodium (cypress), Eichhornia (water hyacinth), Pontederia (pickerel weed), Althernanthera (alligator weed), Salvinia, Ceratophyllum (coontail), Najas (southern naiad), and Hydrilla. Over the decades, the extent of the aquatic macrophyte community in Newnans Lake has been determined by aquatic plant control practices and lake level fluctuations.

Aquatic plant control programs and hydrology also have a major impact on the aquatic macrophyte community in Lochloosa Lake. Little information has been documented on macrophyte community changes in the lake. Hinkle (1987) reports hydrilla cover since its introduction in 1974. Hydrilla levels steadily increased until 1983, when 65% of the lake was covered with this plant. Since that time, applications of herbicides have periodically reduced hydrilla biomass. Langeland (1982) studied submersed macrophyte dynamics in Lochloosa and reported averages of 114 gms.dry wt./m2 and 100 gms.dry wt./m2 of submersed macrophyte biomass in respectively January-February and September-October, 1981. He also noted that the variability of submersed macrophyte biomass had little or no positive relationship to hydrosoil chemical composition. Availability of nutrients in the water column and light penetration appear to be the major factors influencing overall submersed macrophyte cover. Similar to Newnans, the relatively steeper shoreline gradient in Lochloosa results in a cypress dominated littoral zone with less marsh than is found in Orange Lake.

Orange Lake supports a variety of plant communities. Extensive research has been done in the lake on the fish distribution among different plant habitats (Durant, 1980; Conrow, 1984), on the relative ecological value of common aquatic plants (Schramm et al., 1983), and on the effects of vegetation fluctuations on the aquatic environment (Shireman et al., 1983). The characteristic species in Orange Lake's plant communities include spatterdock (Nuphar luteum), panic grasses (Panicum spp.), pickerel weed (Pontederia lanceolata), hydrilla (Hydrila verticillata), water hyacinth (Eichhornia crassipes), cabomba (Cabomba caroliniana), coontail (Ceratophyllum demersum), blatterwort (Utricularia inflata), and southern naiad (Naias guadalupensis).

The percent coverage of the lake area by aquatic plants varies considerably from year to year. Durant (1980) reported that in 1977 open water only comprised 5% of the total lake area. Surfaced hydrilla, spatterdock, and spatterdock-hydrilla communities accounted for 93% of the total lake area at that time. During a more recent investigation by Conrow (1984), open water had increased to an estimated 40 to 50% of the lake area. The wide fluctuations in the extent of macrophyte cover in Orange Lake is not only influenced by aquatic weed control practices, but is also a function of water level fluctuation, substrate composition, shoreline gradient, and time of the year.

Early desciptions of the plant life in Orange Lake were given by Reid (1950, 1952). He documented sparse native submergents (mostly coontail) and widespread emergents such as panic grasses and floating nymphaea in some of the open water areas. The littoral zone and marshes consisted of a diverse assemblage of plants. He mentioned coontail, najas, nymphaea, arrowhead (Sagittaria spp.), and other native species. He also described the fairly unique phenomenon of floating islands in Orange Lake. These islands vary in size from a few square feet to several acres and usually support abundant stands of vegetation with roots penetrating a rather dense matrix of decaying plant detritus of peat-like nature (Reid, 1952). Bird Island, a 2 to 3 acre island in the southwestern portion of the lake and an Audubon sanctuary since 1910 (Pearson, 1941), is one of the better developed floating islands. Reid proposed several explanations for the origin of the floating islands. They vary from the influence of extreme water level fluctuations on dense tangled masses of vegetation, to the buoyancy offered by air chambers in the roots of island vegetation, to the upward movement of large root systems as a result of accumulation of decomposition gasses.

One of the most obvious aspects of Orange Lake plant life is the widespread occurrence of the exotic Hydrilla verticillata. The spread of this fast growing plant varies considerably from year to year and it occurs both in extensive monocultures, as well as in other plant communities. Hydrilla was first reported in Orange Lake in 1974. Hinkle (1987) described the wide fluctuations in hydrilla cover, which were largely a result of aquatic macrophyte control and lake level fluctuations. In 1976 and 1977, nearly 80% of the lake was covered with hydrilla. Following the near drought conditions that occurred in 1977, the water level in Orange Lake increased 5.7 feet during the Spring of 1978 (Shireman et al., 1983). Hydrilla coverage decreased to less than 5% in 1978 because of this rapid rise in water level and a concurrent algae bloom, resulting from a large influx of nutients from the watershed and a release of nutrients from previously exposed lake bottom. The bloom reduced bottom light levels to a value below which hydrilla could not survive. When the bloom disappeared in 1979, viable hydrilla tubers began germinating again. Herbicide treatments with fluridone (Sonar) in 1983, 1984, 1986, and 1987 produced substantial declines in hydrilla accumulations.

Allen (1986) gives the following descriptions of the major plant communities in Orange Lake.

* Panic grass: Maidencane (Panicum hemitomon) and knotgrass (Panicum geminatum) are the dominant plant species of this community. The panic grass community is usually found in association with a firm bottom substrate. It occupies approximately two percent of the surface area of the lake and occurs primarily along the eastern portion. Distribution is usually in linear bands approximately 10 to 15 meters offshore from the spatterdock (Nuphar luteum) dominated floating aquatic community.

* Floating aquatic: Though more properly classified as an emergent species, spatterdock is included in this group because of the above water similarity of it's growth form with other floating aquatic species. This plant is the dominant species within this community, however water hyacinth coverage in some years can be extensive. Other commonly occurring plants include pickerel weed, salvinia, and azolla (Azolla caroliniana).. A significant feature of this community is the presence of the large spatterdock rhizomes that protrude from the bottom. These rhizomes provide important attachment sites for aquatic organisms and serve as important nesting areas for largemouth bass (Bruno, 1984).

* Emergent marsh: The dominant plants in this community include saw grass (Cladium jamaicense), arrowhead (Sagittaria sp.), smartweed (Polygonum sp.), primrose willow (Ludwigia leptocarpa), wax myrtle, and red maple (Acer rubrum). This community covers over 30% of the lake and it occurs in two principal areas -the mouth of River Styx, and at the southwestern part of the lake known as P-G Run. In some areas open water pockets are interspersed within this community.

* Bottomland hardwood hammock: This community occurs as a wetland transition association along the shoreline margins. It contains a wide variety of species with dominants including red maple (Acer rubrum), water tupelo (Nyssa aquatica), swamp black gum (Nyssa sylvatica var. biflora), sweetgum (Liquidambar styraciflua), bald cypress (Taxodium distichum), pop ash (Fraxinus caroliniana), Florida elm (Ulmus floridana), and cabbage palm (Sabal palmetto).

Surprisingly few studies have focused on the periphyton in this basin. Periphyton, although variously used, usually refers to microfloral growth on plant substrate. The periphyton communities have been recognized as major contributors to the productivity of aquatic ecosystems, as well as providing food for invertebrate grazers. Carter (1982) examined periphyton assemblages on two submersed and two emergent macrophytes from Orange Lake, using a new technique designed for direct microscopic observation. Both hydrilla and coontail supported high densities of diatoms of the genus Fragilaria (in the order of 200 cells/m2). Spatterdock supported mostly Cocconeis sp. (diatom), while panic grasses had high levels of periphytic Stigeoclonium sp. (green algae). Schramm et al.(1983) found abundant periphyton in Orange Lake. The greatest abundance was noted on submersed vegetation (in the order of 50-150 mg chl.a/kg wet weight plant), intermediate abundance on floating plants, and lowest abundance on emergents. High temporal variation in total periphyton biomass was observed. In addition to surface area per unit weight of the host macrophyte, periphyton abundance is likely to be influenced by season, age of host macrophyte, and nutrient availability in the surrounding water.

The zooplankton is an extremely diverse group of animals, that are suspended in water and subject to dispersal by turbulence and other water movements. The planktonic protozoa have limited locomotion, but the rotifers, cladoceran and copepod microcrustaceans often migrate vertically in standing waters. Zooplankton form the main pathway of energy transfer between algal primary productivity and small and large fish in aquatic ecosystems. Additionally, some function as decomposers, recycling nutrients in detritus and the sediments to primary producers.

Zooplankton studies in Newnans Lake were carried out by Nordlie (1976), Beaver (1980), Bays (1983), and Crisman (1986). Nordlie (1976) reported zooplankton assemblages from the lake dominated by cladocerans. He considered rotifers, and the two subclasses of crustaceans, the cladocerans and the copepods. Zooplankton community composition and biomass were highly variable, although the forms encountered were generally typical of eutrophic conditions. Rofifers, for instance, demonstrated an erratic pattern of abundance and diversity. Keratella was most consistently present, while Filinia longiseta was more abundant but intermittently present. Polyarthra sp. and Conochilus sp. were also occurring. Common cladocerans included Bosmina longirostris, Eubosmina tubicen, Diaphanosoma brachyurum, Ceriodaphnia lacustris, Daphnia ambigua, with Holopedium amazonicum only intermittently present. Copepod assemblages were dominated by Diaptomus floridanus with Mesocyclops edax less abundant. The community diversity patterns in the zooplankton displayed not more than 6 species of rotifers present at any one time in other than token numbers, not more than 6 species of cladocera, and not more than 3 species of copepods. The typical diversity consisted of only 1 to 3 species of rotifers, 2 to 4 of cladocera, and 1 to 2 of copepods in any one set of collections.
Beaver (1980) and Crisman (1986) paid particular attention to the community dynamics of ciliated protozoans. They reported relatively high abundance and biomass of ciliates, especially small-bodied Scuticociliatida, in Newnans Lake and other eutrophic systems. It was suggested that ciliated protozoans are valid indicators of trophic state for Florida lakes (Beaver and Crisman, 1982). Crisman (1986) reported rotifers to be most abundant in Newnans Lake during his 1979-1982 investigation. Species composition of the zooplankton community generally agreed with Nordlie's (1976) findings. Once again, a very erratic pattern of abundance and diversity was found.

No zooplankton data have been reported in the literature for Lake Lochloosa. Three independent studies addressed zooplankton communities in Orange Lake. Watkins et al.(1983) found a great diversity of zooplankton, particularly of crustaceans, in vegetated areas. Rotifers, on the other hand, were most common in the non-vegetated, limnetic region. Common rotifers included Monostyla sp. and Keratella

cochlearis; common cladocerans were Diaphanosoma brachyurum and Camptocercus rectirostris. These species are all familiar forms of productive Florida waters.
Both Schramm et al.(1983) and Shireman et al.(1983) also reported numerical dominance of rotifers in the open water and crustacean dominance in the vegetated littoral zone. Copepods were the most abundant crustaceans. Again, large temporal variations in zooplankton densities were encountered. Higher densities were consistently collected in the open water. In this light, Schramm et al. (1983) pointed out that zooplankton density was inversely related to macrophyte biomass.

Very little work in the Orange Creek basin has been done on community assessments of benthic invertebrates, an extremely diverse group of organisms attached to or resting on the bottom, or living in the bottom sediments. The difficulty of obtaining quantitative samples, the tedious separation of benthos from the substrate in which they live, and the considerable confusion surrounding details of their taxonomy all contribute to a still very incomplete description of benthic animals in the literature. For lake management this deficiency is particularly critical, because benthic invertebrates can be valuable in pollution studies. They are relatively long-lived, sensitive to pollution, and are usually abundant and widespread. Biological integrity of benthic invertebrate communities is incorporated in the State of Florida Water Quality Standards (FDER; Chapter 17-3).

For the three lakes discussed in this report, benthic invertebrate data have been reported only for Orange Lake. Both Shireman et al.(1983) and Schramm et al.(1983) pointed out that aquatic vegetation is an important factor in determining benthos density and biomass. The greater biomass and diversity of benthos in Orange Lake's vegetated habitat appears to be a result of increased habitat diversity -as compared to open water areas- and increased food supply (in the form of plant litter and periphyton) for the benthos. The low densities and biomass of benthos in open water habitat is likely due to the thick muck and silt layer, and oxygen deficiency, found on the bottom. Midges of the genera Chironomis and Chaoborus, oligochaetes (segmented worms), and gastropods (e.g. snails) were most abundant. Densities ranged from ca 300 ind./m2 in the open water areas to more than 1000 ind./m2 in dense maidencane-hydrilla habitat. The different species in the genus Chironomis (midges) can provide valuable data on the pollution history of a lake through paleontological investigations of their chitin body parts, which preserve well in the sediments (Binford et al., 1983).

The subject of fish biology and the fish fauna of lakes is an enormous field to which much attention has been devoted. Fish are an integral component of the fresh water ecosystem. For instance, a shift of fish species feeding on larger sized food organisms to planktivorous species can have a substantial impact on the composition and productivity of zooplankton communities. This change can, in turn, influence the species composition of the phytoplankton and therefore the productivity at the primary level.
Another conspicuous example occurs during eutrophication of a lake. In Florida, an increase in the trophic state of a lake is generally associated with a gradual decline in predatory gamefish populations

(such as largemouth bass) and an increase in planktivorous fish (such as gizzard shad and the exotic species Tilapia) (Kautz, 1980). Concurrently, a decrease in species diversity is observed.
Several fish studies have been conducted in the Orange Creek basin. The large majority of these have focused on fish communities in Orange Lake, which has a national reputation as an excellent sport fishing lake. In addition, the Florida Game and Fresh Water Fish Commission performs annually a thorough survey of fish fauna in many of the regional lakes.

Fish investigations started in Newnans Lake in the mid 50-s. Berry (1955) investigated the age structure, growth, and food habits of the gizzard shad, the principal fish in this eutrophic lake. In a study on phytoplankton and zooplankton communities of three central Florida lakes, Nordlie (1976), reported eight species of fish in Newnans Lake, which rely to some extent on zooplankton as a food source. Without having the intent of providing a comprehensive list of species, he listed gizzard shad (*Dorosoma cepidianum*), threadfin shad (*D. petenense*), seminole killifish (*Fundulus seminolis*), brook silverside (*Labidesthes sicculus*), bluegill (*Lepomis macrochirus*), black crappie (*Pomoxis nigromaculatus*), largemouth bass (*Micropterus salmoides*), and golden shiner (*Notemigonus chrysoleucas*).
Fish population data and fish management practices are documented in annual surveys from the Florida Game and Fresh Water Fish Commission. For instance, Vaughn (1972) pointed out that, in the mid 50-s and early 60-s, Newnans Lake was treated repeatedly with rotenone to reduce gizzard shad populations and improve sport fishing in the lake. Another attempt to improve sport fishing was undertaken in 1965, when 5,000 fingerling channel catfish were introduced. Vaughn (1972) also described seven years of blocknet data in Newnans (1965-1971) to compare fish populations pre and post lake level stabilization (initiated with the construction of the Prairie Creek dam in 1966). He noted an increase in standing crop of fish, but a stabilization of the bass population and concluded that the changes in the fish community followed the classical pattern of a fish community in a lake affected by accelerated eutrophication. In the early and mid 70-s, the Game and Fresh Water Fish Commission started a striped bass and sunshine bass stocking program in the lake (GFC, file records).
In a later survey, Krummrich et al.(1980) compared 1972-1975 data with 1979 data with the objective of assessing the effect of a 2-2.5 feet fluctuation in Newnans lake water level. This fluctuation was initiated through modifications in the Prairie Creek dam in 1976, in response to a growing concern over the water quality degradation and declining sport fish populations. He observed an increase in average standing crop of fish (from 49 lbs/acre in 1972-75 to 144 lbs/acre in 1979 for limnetic and littoral areas combined) and an increase in the pounds of harvestable sport fish (from 12 lbs/acre in 1972-75 to 58 lbs/acre in 1979 -combined habitats).
Recent data (Krummrich, 1986a) indicate 308 lbs/acre of total standing crop in littoral areas, and 69 lbs/acre in deep water for an average of 170 lbs/acre of total standing crop in combined habitat.
The annual surveys are the single source of information on fish populations in Lochloosa Lake. Data reported for Lochloosa parallel the findings in Orange Lake which will be discussed below.

A broad array of scientific investigations involving fish communities has been conducted in Orange Lake. The close proximity of several academic and governmental research institutions, particularly the different research centers at the University of Florida, and, perhaps more so, the national reputation of Orange Lake as excellent sport fishing lake, definitely contribute to this research interest. In one of the earliest accounts of the fish community in Orange Lake, Reid (1950) described a total of 37 species. Durant (1980) gave a listing of scientific and common names of fishes collected in the fall of 1977 in the lake. Table 2 gives a comparison of both surveys.

Durant (1980) concluded from his study that the habitat type significantly influenced the distributiuon of fish species. The amount and structure (growth form) of vegetation communities influenced the density, biomass, and number of species of fish. Increased amounts of vegetation increased the value of these parameters except biomass which decreased. Open water and spatterdock (Nuphar luteum) habitats contained the greatest fish biomass, while spatterdock-hydrilla, surfaced hydrilla, and spatterdock habitats contained the greatest number of fish. Based on his investigations, Durant concluded that if the hydrilla growth was to remain widespread in the lake, it would be likely that the number of large adult centrarchids (such as largemouth bass) would decrease, while the total number of fish and the diversity would remain high. If hydrilla was partially controlled, so that the open water area in the center of the lake increased or large open areas were created elsewhere in the lake, it would increase the number and biomass of large adult fish with little effect on total number or species diversity.

Significant differences with respect to fish biomass, density, and species composition in different plant communities were also noted by Schramm et al. (1983). Unlike Durant (1980), they documented low biomass values including low biomass of harvestable sport fish in open water areas. Spatterdock-hydrilla habitat appeared optimal for nesting and feeding. They concluded that the positive relationship between plant biomass and fish density/biomass was largely a result of an increase in food resource provided by the plant, particularly the epiphytic macroinvertebrate abundance. Additionally, the most desirable habitats for sport fish such as bluegill, largemouth bass, and chain pickerel contained dense emergent vegetation interspersed with patches of submersed and floating macrophytes.

The ecological impact of aquatic macrophyte control was investigated by Shireman et al. (1983). With respect to Orange Lake fish communities, their findings were in line with Schramm et al.(1983). Increased hydrilla coverage resulted in increased species diversity, densities, and total biomass, mostly because of increases in the population densities of small littoral fishes, such as bluefin killifish, golden topminnows, and bluespotted sunfish. At high hydrilla levels, these fish become a major biotic component. Sport fish populations undergo shifts in length frequency distributions, with the distributions becoming skewed toward small to intermediate sized individuals. This appears to cause an overall stunting of the sport fish population. Immediate changes in fish communities as a result of a reduction in hydrilla density can not be adequately assessed, because it takes probably three to five years for fish populations to adapt and stabilize after macrophyte removal.

Table 2. A listing of scientific and common names of fishes collected in Orange Lake during the fall of 1977, and a comparison with those collected by Reid (1950). (Adapted from Duránt, 1980).

Common name	Scientific name	Collected 1977	Reid 1950
Florida gar	Lepisosteus platyrhinsus Dekay	*	*
Bowfin	Amia calva Linneaus	*	*
American eel	Anguilla rostrata (Lesueur)	*	*
Gizzard shad	Dorosoma cepedianum (Lesueur)	*	*
Threadfin shad	Dorosoma petenense (Gunther)		*
Redfin pickerel	Esox americanus americanus Gmelin	*	*
Chain pickerel	Esox niger (Lesueur)	*	*
Golden shiner	Notemigonus crysoleucas(Mitchill)	*	*
Pugnose minnow	Notropis emiliae (Hay)		*
Taillight shiner	Notropis maculatus (Hay)	*	*
Lake chubsucker	Erimyzon sucetta (Lacepece)	*	*
Unidentified catfish	Ictalurus sp.		*
Yellow bullhead	Ictalurus natalis (Lesueur)	*	*
Brown bullhead	Ictalurus nebulosus (Lesueur)	*	*
Tadpole madtom	Noturus gyrinus (Mitchill)	*	*
Pirate perch	Aphredoderus sayanus (Gilliams)	*	*
Golden topminnow	Fundulus crysotus (Gunther)	*	*
Lined topminnow	Fundulus lineolatus (Agassiz)		*
Seminole killifish	Fundulus seminolis Girard	*	
Flagfish	Jordanella floridae Goode & Bean	*	*
Pygmy killifish	Leptolucania ommata (Jordan)		*
Bluefin killifish	Lucania goodei Jordan	*	*
Mosquitofish	Gambusia affinis (Baird & Girard)	*	*
Least killifish	Heterandria formosa Agassiz	*	*
Sailfin molly	Poecilia latipinna (Lesueur)	*	*
Brook silverside	Labidesthes sicculus (Cope)	*	*
E'glades pygmysunfish	Elassoma evergladei Jordan	*	*
Banded pygmysunfish	Elassoma zonatum Jordan		*
Blackbanded sunfish	Enneacanthus chaetodon (Baird)		*
Bluespotted sunfish	Enneacanthus gloriosus (Holbrook)	*	*
Banded sunfish	Enneacanthus obesus (Girard)		*
Redbreast sunfish	Lepomis auritus (Linnaeus)	*	
Warmouth	Lepomis gulosus (Cuvier)	*	*
Bluegill	Lepomis macrochirus Rafinesque	*	*
Dollar sunfish	Lepomis marginatus (Holbrook)	*	*
Redear sunfish	Lepomis microlophus (Gunther)	*	*
Spotted sunfish	Lepomis punctatus (Valenciennes)	*	*
Largemouth bass	Micropterus salmoides (Lacepede)	*	*
Black crappie	Pomoxis nigromaculatus (Lesueur)	*	*
Swamp darter	Etheostoma fusiforme (Girard)	*	*

Conrow (1984) conducted a study on habitat preferences and seasonal succession of early life stages of fishes in Orange Lake and emphasized the importance of the littoral zone as spawning, nursery, and feeding grounds for many species of sport and forage fishes. Accordingly, establishment of desirable aquatic vegetation in littoral zones should be an important objective for fisheries managers.

Related to this, Bruno (1984) conducted a detailed study of the habitat preferences of nesting largemouth bass. Habitat features, such as plant species and substrate characteristics were found to significantly influence nesting preferences. Even though most nests were found in habitat dominated by spatterdock, this appeared to be a consequence of the limited availability of optimum nesting habitat which was the hard substrate found in panic grasses. Nesting bass utilized the hard, abundant rhizomes in the spatterdock communities as alternative nest sites. An important implication of Bruno's study is that spraying of aquatic weeds can have a negative impact on vegetation used for spawning. Consideration, therefore, should be given to spawning season and vegetation associations when designing spraying programs for aquatic vegetation control on Orange Lake.

Again, annual fish management reports and surveys from the Florida Game and Fresh Water Fish Commission provide a wealth of information on fish community dynamics in the lake. Several interesting observations have been made. Cole and Greek (1967) and Fletcher and Vaughn (1968) both observed that control of the nutrient influx and periodic oxidation of the littoral bottom with a fluctuating water level would be of benefit to the fishery. Krummrich (1986a) demonstrated that, on a lake-wide basis, pounds and numbers of harvestable sport fish have been consistently lower since 1977, a year of heavy hydrilla infestation, than the 1975 pre-hydrilla levels. He concluded (Krummrich, 1986b), based on many years of fish survey data, that widespread hydrilla is poor habitat for the production of harvestable sport fish. Recommended optimum habitat features for Orange Lake include little or no floating vegetation, maintenance of healthy spatterdock and maidencane (panic grasses) acreages and only a narrow perimeter of hydrilla outside existing marsh.

TOPICS OF SPECIAL INTEREST

Wildlife in the basin

The Orange Creek basin contains about 90% of the mammal, bird, reptile, and amphibian species that occur in inland north central Florida (Simmons, 1985). The size of the basin, its diversity of habitats, high concentrations of fish and other prey organisms, and relatively low levels of cultural disturbance contribute to the continuation of these rich communities. A wide spectrum of wildlife is present in the basin, from game species to non-game wildlife, animals which face neither consumption nor extinction, to species which are threatened or endangered and may be close to extinction.

Threatened or endangered species in the Orange Creek Basin

An important aspect of the ecological significance of the basin is the occurrence of reproducing populations of several state and federally listed threatened and endangered species (Table 3). The low level of human disturbance, the abundance of food and prey organisms in this productive environment, and the availability of suitable nesting sites all contribute to a high quality habitat in which these protected species are able to survive. Efforts to preserve these species and the biological integrity of their habitat are widespread and require strong consideration in the development of basin management guidelines. Following is a brief description of the status and needs of listed species in the Orange Creek Basin.

The Florida black bear is Florida's largest land mammal, yet despite its size it is rarely observed in the wild (Brady and Maehr, 1985). Their need for large areas of undisturbed land with mast producing flatwood and hardwood communities makes the black bear populations vulnerable. Increased cultural disturbance and the conversion of natural forests with diverse vegetation types to slash pine plantations significantly reduces bear habitat (Maehr and Brady, 1984).
Bears observed in the basin are restricted to undisturbed densely vegetated bayheads and bottom land hardwood habitat. Individuals that are observed are probably territory seeking young adults, that have dispersed from a larger core population such as that which exists in the Ocala National Forest (Allen, 1986).

Only about two dozen wood stork rookeries still exist in the United States, all but two of which are in Florida. The actual number of storks nesting in north Florida is poorly documented. The most successful rookery in the basin is located in the headwater swamp of the River Styx. This rookery has been active since at least 1910 (Simmons, 1985) and fluctuates annually between total failure and 100 active nests. A second, much smaller rookery in the basin is located in a swamp on the northeast side of Newnans Lake. This colony, which was first observed in 1972, may be a "satellite" of the larger and more active River Styx colony (Nesbitt, 1973). Wood storks are highly social birds that nest in colonies and roost and forage in flocks. They feed predominantly on small freshwater fish. Because of their specialized

Table 3. Several of the species which are officially listed as threatened, endangered, or of special concern (SSC) that inhabit the Orange Creek Basin (after Allen, 1986).

Common name	Designation	Status
Florida Black Bear (*Ursus americanus floridanus*)	Threatened	Occasional
Wood Stork (*Mycteria americanus*)	Endangered	Breeding
Bald Eagle (*Haliaeetus leucocephalus*)	Threatened	Breeding
Sandhill Crane (*Grus canadensis pratensis*)	Threatened	Breeding
Little Blue Heron (*Florida caerulea*)	SSC	Breeding
Snowy Egret (*Egretta thula*)	SSC	Breeding
Louisiana Heron (*Hydranassa tricolor*)	SSC	Breeding
Limpkin (*Aramus gaurauna*)	SSC	Breeding

"grope" feeding technique, storks feed most efficiently when fish densities are high (Allen, 1986). Nesting coincides when rainfall and temperature are likely to yield high fish densities in drying pools, ditches or swampy depressions, such as in spring and summer, when high evapo-transpiraration rates are important in promoting a favorable environment (Ogden, 1971). If the water level remains high during the usual dry season or fails to rise in the wet season, the stork will not nest (Kahl, 1964).

The Orange Creek basin supports an outstanding bald eagle population. Collopy and Bohall-Wood (1986) report a total of 24 active nests in eastern Alachua and northern Marion counties. The Florida Game and Fresh Water Fish Commission, which has monitored eagle nest productivity on Orange Lake since 1973 documents 11 active nests along the lake's shoreline in 1985, with a productivity value of 1.08 young per nest. This is slightly higher than the state-wide average of 0.9 (Allen, 1986).

The bald eagle is probably one of our most conspicuous endangered species and has been protected by the federal Endangered Species Act, Bald Eagle Act, and Migratory Bird Treaty Act. In Florida they are classified as a threatened species which means that the eagles require

rigorous protection, but are not in immediate danger of extinction. Experiments are now underway to determine how the species can be safely relocated from Florida to areas of suitable habitat in other southern states and re-establish eagles throughout their former range (Collopy and Bohall-Wood, 1986). Eagle nests from Orange Lake and two other Alachua County sites are currently being utilized as donor nests to evaluate the feasibility of this program.
In Florida bald eagles lay their eggs between late November and early February. Hatching takes 35 days. Most pairs produce two eggs per season, with the offspring leaving the nest 10 to 12 weeks after hatching. Eagles nesting in north Florida use nesting sites in live pine and cypress trees in a fairly open situation (Nesbitt et al., 1975). They generally nest in close proximity to open water, reflecting the dependence of bald eagles on fish, water fowl, and shore birds as primary foods. Both the abundance of food in the productive waters of the Orange Creek Basin and the relatively low levels of cultural disturbance contribute to the success of this species in this area.

Open prairies and pond edges in the basin support both the resident Florida and the migrating sub-species of the <u>sandhill crane</u>. Data for Orange Lake and its attendant marshes indicate a resident population size of about 30-50 pairs. Approximately 1000 to 1200 migratory sandhill cranes use the lake on an annual basis (Allen, 1986). Reduced vegetation height through grazing, fire , or water management is important in attracting cranes (Nesbitt, 1977).

Of the many bird species that inhabit and utilize the Orange Creek Basin, three wading birds (<u>little blue heron</u>, <u>snowy egret</u>, and <u>tricolored heron</u>) and the <u>limpkin</u> are listed as State Species of Special Concern. The primary reason for their listing is the loss of nesting and feeding habitat throughout their range (Allen, 1986).
The large areas of freshwater marsh in the basin support established populations of these species of special concern. Bird Island, part of an Audubon sanctuary in the southwest portion of Orange Lake, is especially significant as nesting and feeding habitat for these species, as well as many other water birds. The number of birds using this rookery is high, but fluctuates considerably at times. Allen (1986) recently reported 150 pairs of little blue heron, 0-50 pairs of snowy egret, and 150 pairs of tricolored heron, in addition to nesting pairs of many other species such as white ibis, cattle egret, anhinga, and great egret. The entire basin provides important nesting and feeding grounds for the limpkin, little blue heron, snowy egret, and tricolored heron. Food availability and water level fluctuations appear to be the major factors in determining colony sites (Ogden et al.,1980).

Game and non-game wildlife

The wildlife fauna of the basin is varied and abundant. Extensive species lists of mammals, birds, reptiles, and amphibians inhabiting and utilizing the basin are given by Simmons (1985).

Of the mammals, the raccoon, opossum, marsh rabbit, river otter, cotton rat, armadillo, and various squirrels are most conspicuous. A large number of other species also occur, such as the bobcat, gray fox, striped skunk, and several species of bats.

The basin supplies ample opportunity for recreational hunting. Important game species are deer, hogs, wild turkey, ducks, and quail. The upland areas of hammock are particularly important feeding areas for deer and turkey. Since 1980, the Florida Game and Fresh Water Fish Commission has administered a program of experimental alligator harvest in the basin. From 1981 to 1984 nesting has increased approximately 59% on Orange Lake, despite an estimated 15% annual harvest of adult alligators including mature females (Woodward, 1985). The dense emergent and floating marsh found in this lake provide excellent habitat for hatchlings and assure high survival rates of young alligators. 1984 Estimates of the number of harvestable alligators (larger than 1.2 m) for Orange, Lochloosa, and Newnans lakes are 1361, 321, and 403 respectively (Woodward, 1985).

The large areas of wetlands and marshes support outstanding populations of wading birds and waterfowl species including the great blue heron, great egret, little blue heron, white ibis, least bittern, limpkin, tricolored heron, anhinga, wood duck, common moorhen, double-crested cormorant, and many others. Marsh areas are important wintering habitat for ring-necked ducks, blue-winged teal, mallard, and purple gallinules (Mulholland and Percival, 1982; Jeske and Percival, 1987). Simmons (1985) lists some 230 species of birds for the Lochloosa Wildlife Management Area, a 31,000 acres tract of land within the basin. Collopy (1984) reports a minimum of 43 and 29 breeding pairs of ospreys on Newnans and Orange Lake respectively. Healthy populations of ospreys, red-shouldered hawks, and barred owls inhabit the River Styx, Prairie Creek, and Lochloosa Creek areas.

Many species of amphibians and reptiles inhabit the basin. Among the numerous amphibians, frogs of the genus Hyla such as the green treefrog, squirrel treefrog, and the barking treefrog are conspicuous. Bullfrogs of the genus Rana occur in enormous numbers and are commercially harvested, particularly on Orange Lake. Many species of salamanders, newts, sirens, and toads complete the varied amphibian community in the basin. In addition to the american alligator, the most common reptiles include turtles (such as the Florida softshell turtle, stinkpot, red-bellied turtle, and the Florida cooter) and many snakes (including the Florida banded water snake, black racer, diamondback rattlesnake, water mocassin, green water snake, and the yellow ratsnake).

Aquatic plant control

Aquatic plant accumulations cause very serious economic and environmental problems in many regions of the United States and other countries. Florida's subtropical climate and abundant fresh water resources provide ideal conditions for growth and reproduction of aquatic plants. An increase in cultural eutrophication and the introduction of exotic plants such as hydrilla (Hydrilla verticillata) and water hyacinth (Eichhornia crassipes) have contributed to dramatic increases in aquatic weed problems in our state.

Both exotics have caused severe problems in the Orange Creek basin. They drastically restrict navigational and recreational uses of the lakes, degrade their aesthetic value, and outcompete more desirable native plants. Today, hydrilla growth is particularly widespread in Orange and Lochloosa Lakes. Without chemical control practices hydrilla would restrict fishing, boating, and other recreational activities in the lakes. Fish camp operators are very concerned about their lakes and future as camp operators (Delaney, pers. comm.; Westergard, pers. comm.).

All three lakes have a long history of excessive algae and macrophyte growth, typically associated with highly eutrophic systems. Newnans Lake has alternated between algal and macrophyte dominations. Goin (1943) and Crossman (1956) pointed out that hyacinth growths have at times covered a large fraction of the open area of the lake. Putnam et al.(1969) noted profuse algal blooms in 1968 and made mention of the considerable difficulty encountered in controlling water hyacinths. Extensive control programs would keep the plants confined to the cypress areas surrounding the lake, though large rafts of hyacinths occasionally were moved about by winds over the open water. Presently, Newnans Lake has considerably fewer macrophytes than the other large lakes in the basin.

In Lochloosa, and particularly in Orange Lake, widespread growth of aquatic plants cause the most severe problems. Hydrilla especially reduces the lakes' value for fishing, produces economic hardship for fish camp owners and local businesses, and makes the lakes inaccessable to outboards. Hydrilla was first discovered in Orange Lake in the fall of 1974. In only two years the plant cover increased to approximately 80% of the surface of the lake. In 1977, the U.S. Army Corps of Engineers designed and conducted a mechanical removal program for hydrilla and maintained 150 acres of water in useable condition for a four month period (McGehee, 1979). In 1978, a dramatic reduction in hydrilla occurred, caused by a rapid water level increase of more than 5 feet during the spring. Concurrently, heavy blooms of planktonic algae reduced the amount of light available for hydrilla growth. Significant declines of hydrilla also occurred in 1983, 1984, and 1986 as a result of herbicide treatments with fluridone (Sonar).

In 1975, hydrilla was introduced to Lochloosa Lake by boat traffic through Cross Creek. Hydrilla growth rapidly increased until 1983 when fluridone was first applied. With the exception of 1985 and the first half of 1986, when the expiration of the fluridone label prevented use of this product, hydrilla levels have been kept under control through regular herbicide applications. A summary of acreage estimates for hydrilla in Orange and Lochloosa Lakes is given in table 4 and figure 5 (after Hinkle, 1987).

Table 4. Hydrilla acreage estimates since its introduction.

Year	Orange Lake Acres	Orange Lake % of lake	Lochloosa Lake Acres	Lochloosa Lake % of lake
1974	50	0.4	0	0.0
1975	270	2.1	2	0.0
1976	10000	78.7	30	0.5
1977	10000	78.7	150	2.6
1978	500	3.9	1075	18.8
1979	2200	17.3	2680	47.0
1980	5350	42.1	2800	49.1
1981	2920	23.0	3150	55.2
1982	6000	47.2	3700	64.8
1983	1150	9.0	1750	30.7
1984	460	3.6	413	7.2
1985	3500	27.5	4500	78.9
1986	6305	49.6	4500	78.9
1987	2538	20.0	570	10.0

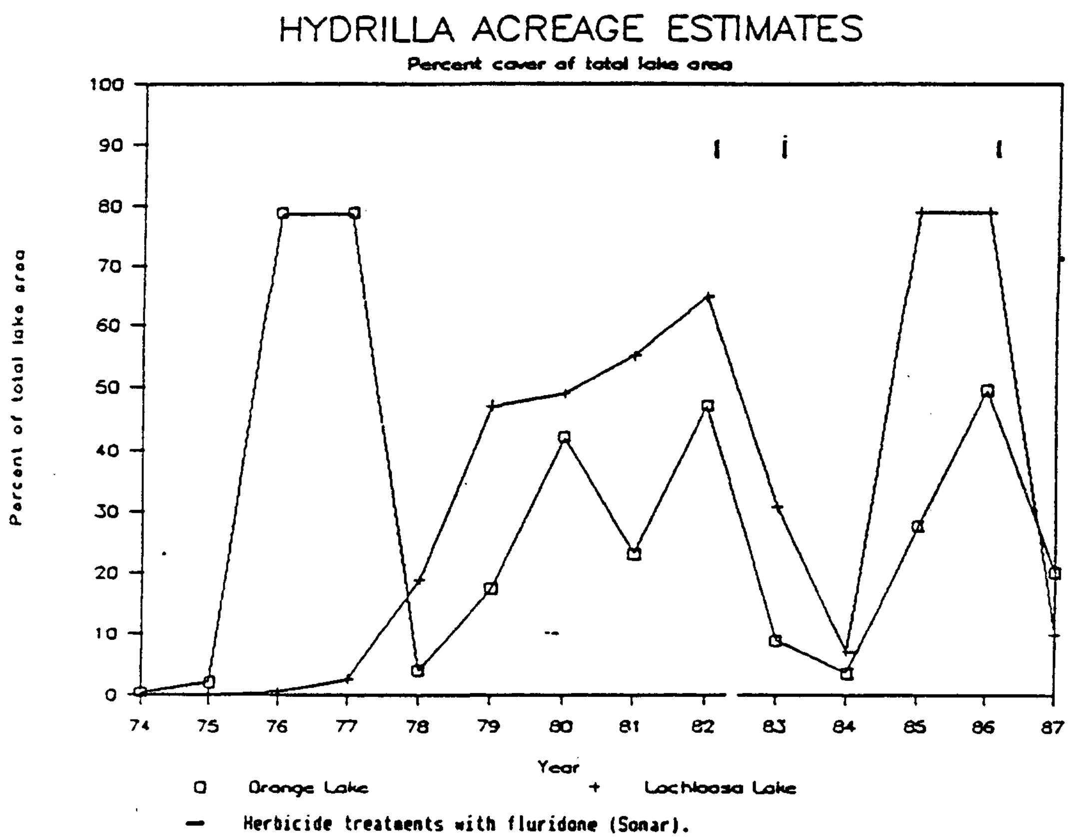

Figure 5. Orange and Lochloosa lakes 1974-1987: Hydrilla acreage estimates as percent cover of total lake area.

There are several reasons why hydrilla is difficult to control in lakes. First, hydrilla is a submersed species and grows under water where dilution of herbicides requires higher application rates. Secondly, the profuse vegetative reproduction and regrowth capabilities of hydrilla allow it to outcompete other species. Haller (1976a) describes the growth dynamics of this species and emphasizes the production of underground tubers, which are unaffected by chemical control methods and remain viable for many years. Chemical treatments essentially shear and kill most of the plant biomass in the water column, leaving viable plant crowns, rhizomes, stolons, and plant fragments on the bottom as a source of regrowth (Haller, 1971, 1979). The rate of regrowth depends on local conditions of turbidity and water temperature, but often three chemical treatments per year were required for satisfactory hydrilla control. [Since the use of Sonar (below) the frequency of spraying has been substantially reduced]. Additionally, hydrilla has very low light requirements for photosynthesis. It is able to outcompete other (native) species in conditions of low irradiance, such as during regrowth from the hydrosoil at the bottom of a lake (Van et al., 1976; Bowes et al. 1977).

Present control techniques for hydrilla in Orange and Lochloosa Lakes involve an annual application (during the spring) of the herbicide Sonar on a series of small plots in each lake. Total treatment acreage for 1986 was 150 acres in Orange and 300 acres in Lochloosa.

Sonar, which contains the active ingredient fluridone, is credited with clearing up large patches of hydrilla. It requires fewer applications than previously used chemicals and degrades hydrilla more slowly, reducing oxygen depletion, which could lead to fish kills. It is the first herbicide that has been specifically developed under EPA guidelines for submersed macrophyte control. A restriction attached to the approval of the use of Sonar was that it only be applied to part of a lake at a time and that it not be applied to waters used for crayfish farming, since this crustacean was not tested for tolerance levels. The management objective in the aquatic plant control program is to keep the hydrilla growth at a minimal level while allowing more desirable native plants to become re-established in the lake (Hinkle, 1987). The St. Johns River Water Management District, in cooperation with the Department of Natural Resources, spent ca $410,000 during FY 1986 on weed control in both lakes. For FY 1987 a $460,000 management program is planned.

Several researchers have documented findings on the applicability of other approaches to aquatic plant control in the basin. Decisions involved in the management of aquatic macrophytes include an evaluation of the effectiveness of the method, the availability of equipment and personnel, and the intended use of the water. Options for Lochloosa and Orange include:

1. Terminate all aquatic plant control practices. The rapid increase in hydrilla cover on both lakes during the 10 month gap in the state's ability to use Sonar effectively demonstrates the fate of the lakes with such an approach.

2. Introduce mechanical removal of hydrilla. Mechanical harvesting is generally a very expensive method for managing aquatic macrophyte problems (Sutton and Portier, 1983); however, utilization of harvested hydrilla plants may help mitigate these costs (Bagnall et al., 1973). Also, the expense per acre of mechanical removal techniques is reduced when plant growth is widespread. In such a case, the costs are competitive with most chemical control methods (McGehee, 1979). Benefits generally associated with mechanical harvesting include an immediate removal of the nuisance vegetation, the absence of long-term impacts of added chemicals to the aquatic system, and the elimination from the aquatic ecosystem of nutrients contained in the plants. Macrophytes high in nutrient content, therefore, may best be controlled with mechanical methods. In comparing Lake Okeechobee data from Sutton and Portier (1983) with Lochloosa data from Langeland (1982), it appears that hydrilla has average nitrogen content, but relatively high phosphorus concentrations.

A significant problem with mechanical removal of hydrilla is the ability of the plant to regenerate rapidly from fragments, as was discussed earlier. The good accomplished by opening the water body by mechanical means needs to be weighed against the potential acceleration of the spread of the plant over the remaining areas.

3. Biological control of hydrilla. Research is in progress on the effectiveness of several insect species in eliminating or reducing hydrilla accumulations (Buckingham, 1986). Promising results have been established in biocontrol with sterile specimens of the grass carp (<u>Ctenopharyngodon idella</u>). This voracious herbivore can consume massive amounts of all types of aquatic vegetation. However, serious questions remain before grass carp can be applied to large lake systems. First, it has been impossible to "manage" the species such that it only controls a portion of the submersed macrophytes, instead of total elimination of all vegetation from the ecosystem. Secondly, the effect of adding approximately 20 grass carp (suggested initial stocking rate - Sutton et al., 1986) to the carrying capacity of native fish communities is unknown. Of particular consideration here is the fact that introduced specimens need to be 0.5 kg or larger to reduce predation losses (Sutton et al., 1979) and may grow at a rate of 0.9 kg/month. And thirdly, grass carp is suspect of having a considerable effect on phytoplankton abundance and on nutrient cycling (sediment disturbance).

4. Continue the current program of herbicide applications. For the moment, the annual applications of Sonar are giving the water managers a fairly reliable means of controlling hydrilla in large lakes. However, several concerns remain. Chemical control does not remove nutrients from the lake, but causes large amounts of decaying organic material to accumulate on the lake bottom. Drastic changes in the benthic environment ard accelerated release of plant nutrients through microbial decomposition are the result. More extensive testing of the effect of fluridone and its breakdown products on fish, particularly Florida's native fish, and invertebrates, should be done to eliminate concern regarding long-term toxic effects.

5. Physical control in the form of lake level fluctuations. As was discussed earlier, lake levels in the basin have been stabilized since the mid 1960-s with the construction of two spillways at the outflows of Newnans and Orange Lakes. Many effects contributing to accelerated eutrophication have been observed in Florida associated with such stabilized lake levels. The rapid accumulation of organic detritus and unconsolidated muds, the loss of important rooted wetland vegetation in the peripheral area of the lake, and the concentration of nutrient-rich organics are some of these effects. Because of the profuse vegetative reproduction and regrowth capabilities of hydrilla, a periodic lowering of the water table will only provide partial management results, while timing of low water should specifically be tied to preceed new tuber formation (October). Additionally, water levels should be raised fast enough to rapidly shade new hydrilla growth. Timed chemical applications in combination with water level fluctuations deserve closer study. An added advantage of water level fluctuations is that periodic exposure of littoral lake bottom may improve substrate and may eliminate nutrients through oxidative processes and wind action.

Economic significance of the lakes

Newnans, Lochloosa, and Orange Lakes are nationally recognized as excellent sport fishing lakes. Orange Lake, in particular, attracts recreational fishermen from all over the U.S. In 1963, the Florida Game and Fresh Water Fish Commission in conjunction with the Alachua Board of County Commissioners, designated the lakes as fish management areas. Since then, a continuing program of fishery improvement and management has been conducted on the lakes, including the stocking of sunshine bass, construction of boat ramps, installation of fish attractors, and the performance of fish population studies to determine management needs and management effectiveness.

The sport fishing expenditures for Orange and Lochloosa for 1985 have been estimated in excess of $5,600,000, with a non-resident contribution of approximately $3,200,000 (Milon et al., 1986). Values in this economic analysis were derived by multiplying total number of fishing trips and the average trip expenditures per person. No data are available for Newnans Lake. The ten fish camps on Orange, five on Lochloosa, and two on Newnans Lake, provide a variety of services including lodging, guides, boat ramps, boat and motor rental, tackle, and live bait. The sport fishing in the basin is characterized as a year round fishery, with a significant spring peak.

Creel surveys in Orange Lake from August 1977 to December 1978 indicate catches per person per hour in between 0.91 to 1.18, and bass harvests in between 0.32 and 0.44, with a high of 0.98 bass per hour during the fall of 1977 (Krummrich et al., 1979). Recently, combined values for Orange and Lochloosa of 0.80 catch per person per hour and bass harvests of 0.25 per person per hour were reported (Milon et al., 1986). These fishing success rates are comparable to previously reported values from other popular Florida bass fishing lakes, such as Lake Okeechobee, and are high in comparison to other north-central Florida sites (Milon et al., 1986).

With an increase in aquatic macrophytes in open water areas the fish community in the that portion of the lake appears to change quantitatively and qualitatively and resembles that of shoreward littoral areas. Ever since the 1977 infestation of hydrilla, pounds and numbers of harvestable sport fish have been lower than the 1975 pre-hydrilla values (Krummrich, 1986a). Figure 6 illustrates the relationship between hydrilla cover and pounds of harvestable sport fish for Orange Lake from 1975 to 1984. Additionally, an expanding population puts increased pressure on the fishery resources of the lakes (Delaney, pers. comm.). The presence of high quality habitat for nesting and feeding and access to that habitat for fishermen are important factors for productive fisheries and, therefore, prevent economic hardship for a significant number of area residents and businesses.

In addition to fishing, the lakes are also used for commercial frogging and alligator harvesting. Orange Lake is the most popular and productive lake in the basin for recreational and commercial frog harvesting. Estimated peak season use generally ranges from 80-100 boat nights per month. The estimated value of the frogmeat is $100,000 annualy.

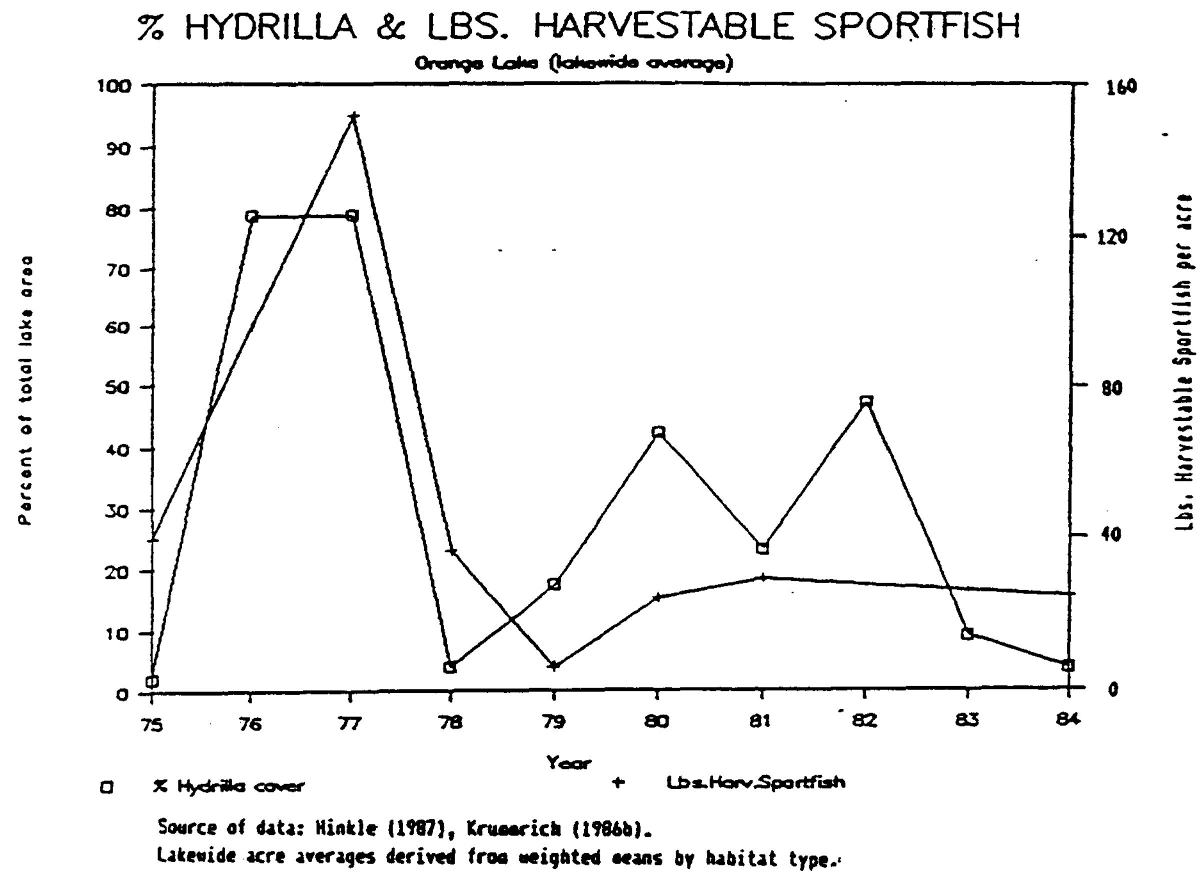

Figure 6. Relationship between hydrilla cover (as percent of total lake area) and pounds of harvestable sport fish for Orange Lake from 1975 to 1984.

Beginning in 1980, the Florida Game and Fresh Water Fish Commission started an experimental alligator harvest program in several area lakes. Newnans, Lochloosa, and Orange were included in the experimental program with a planned removal of 15% of the alligators of harvestable size (4 feet and larger) each year. Alligator hunting is only allowed during a selected few days every year and is closely monitored by the Game Commission. It provides revenue for the (mostly) local hunters in the form of the sale of meat and hides. Total commercial value of the harvest from 1982 to 1985 was approximately $240,000 (Allen, 1986).

With the importance of recreational sport fishing and hunting opportunities, the economy of a large part of the basin is centered mainly on providing goods and services to meet the demands of visiting sportsmen. In the Orange Lake area alone, some 60 acres of recreational area provide 174 campsites, 15 boat ramps, and 287 marine slips (Allen, 1986). Sound management of the basin is the single most important factor in maintaining or enhancing the health of this economy.

Furthermore, the Cross Creek area, in between Lochloosa and Orange Lakes, is recognized nationally for its cultural, historical, and natural-scenic significance. The residence of Pulitzer Prize winning author Marjorie Kinnan Rawlings is officially listed on the National Register of Historic Places and is maintained by the Department of Natural Resources as a state historic site. It attracts 15,000 visitors each year (Allen, 1986).

Land-use considerations

There are no major sources of cultural eutrophication present in the Orange Creek basin. As was outlined earlier, the watershed of the three lakes is dominated by natural and commercial forest land. Data for land-use in the watersheds of the three lakes are summarized in table 5 (Huber et al., 1982).

Table 5. Land-use data for Lochloosa, Newnans, and Orange Lakes (values in percentage of total water area).

	Urban	Forest	Agriculture	Water	Wetland
Lochloosa	1.2	71.0	12.9	10.8	4.1
Newnans	8.6	75.6	7.7	8.0	0.1
Orange	4.7	56.6	25.7	9.2	3.8

* Data are for 1982 when a significant portion of the Orange Lake watershed was still in citrus production.

Few people live directly on the lakes. Some of the smaller towns release some sewage into the lakes. For instance, the community of Cross Creek is served by a small (5,000 gallons/day design capacity) sewage treatment plant, which discharges aerated effluent into Cross Creek. Such discharge is presumably extremely small compared to natural loadings of nutrients from the phosphate rich watersheds. [If we assume that the effluent contains up to 10 mg P/l, a discharge of 5,000 gallons/day generates ca. 190 grams P/day, i.e. 69,000 grams P/year. With a lake surface area of 4,900 ha., such load equals 0.00141 grams P/m2.year, which is 0.16 % of the total annual load of 0.890 grams P/m2.year as computed in the next chapter.]

The development potential and pressure is, however, high in the basin. Proposals for large scale urban development on holdings surrounding Lochloosa Lake and the community of Cross Creek were submitted in 1982. This Development of Regional Impact (DRI) was to involve most of the eastern and northern shore of Lochloosa Lake and approximately 30% of the Orange Lake shore. The plan called for ca 30,000 units on ca 5,000 acres (Barnes, pers. comm.). In response to initiatives from a local citizens' group, the State of Florida agreed, in 1983, to attempt to purchase the lands involved through funds from the Conservation and Recreation Lands (CARL) aquisition committee (Friends of Cross Creek, 1983).

Smaller developments have continuously been proposed in the immediate vicinity of Cross Creek. Again, citizens' input resulted in an amendment to the county land-use plan providing for restricted development based on environmental assessments (Friends of Cross Creek, 1985; Alachua Co. Depart. of Planning and Development, 1985).

Recently, the Environmental Regulation Commission of the State of Florida approved the designation of Orange Lake, Cross Creek, and the River Styx as Outstanding Florida Waters (OFW). This designation will protect these habitats in numerous ways. First, it will help prevent the lowering of existing water quality characteristics within these waters. With their current classification as Class III waters (recreation, fish, and wildlife), regulatory permits can legally be issued to lower water quality down to the minimum standards for that classification. The OFW designation prevents the lowering of existing water quality with respect to new discharges of stormwater, pollutant discharge activities, and dredge and fill (FDER, 1987). Secondly, special recognition of these waters allows the Florida Department of Community Affairs and the North Central Florida Regional Planning Council to consider these waters as significant resources. This will elevate the level of agency review when impacts of future land development projects in the watersheds of these lakes are being considered. Finally, an OFW designation increases the public's appreciation and stewardship of a resource that has been given formal recognition (Allen, 1986).

Within the last year efforts have also been undertaken to increase the public's awareness and appreciation for the Prairie Creek ecosystem. This creek system, a hydrologic connection between Newnans Lake, Paynes Prairie, and Orange Lake , is proposed to be incorporated in a project of environmental protection. This plan would create a loop of parks, and multi-purpose trails, including canoe trails, that would preserve a large part of southeastern Alachua County. A request for acquisition by the State of Florida under the Conservation and Recreation Lands program (CARL) of approximately 3,000 acres of uplands, wetlands, and floodplain along Prairie Creek has been submitted recently (Hamann and Brown, 1987).

NUTRIENT DYNAMICS IN THE BASIN

Primary productivity in lake ecosystems is the rate at which solar energy is stored by photosynthetic activity of algae and plants in the form of organic substances. In comparison to other macro-nutrients required by biota, phosphorus is least abundant and commonly is the first element to limit primary productivity (Wetzel, 1983). However, the phosphate-rich geology of the Orange Creek Basin enhances the availability of this nutrient to the lakes. Particularly after storms and increased runoff other elements, such as nitrogen, may therefore temporarily replace phosphorus as the major limiting factor.

Management measures designed to limit the biomass of algae and aquatic plants should primarily focus on controlling the availability of phosphorus and nitrogen. Attention should not only be given to control of external nutrient income, i.e. point and nonpoint sources, but also to internal nutrient supply. Indeed, in these shallow lakes with high ratios of bottom sediment to lake volume, the dynamic stores of phosphorus in the sediments that interact with the water column can be a major contributing factor to high nutrient concentrations and plant biomass.

While the sedimentation rate of phosphorus and its release from bottom substrate (i.e. internal loading of phosphorus) are very difficult to quantify practically, inputs of phosphorus and nitrogen from the surrounding watershed into a lake (i.e. external loading) can readily be estimated with the use of export coefficients (Huber et al., 1982). Such an approach attempts to relate the land-use surrounding a water body to the nutrient flux into the water. Specific export coefficient values (usually in units of mass/area/time) are assigned to each land-use, and the appropriate coefficient can then be multiplied by the area of land-use to arrive at a loading in units of mass/time. Total nutrient loading to a lake can be calculated by summing the results over all land uses. Export coefficients can produce a reasonable estimate of phosphorus and nitrogen loading to a lake, and at a comparatively low cost. Validation of export coefficients with field measurements of several storm inputs will significantly reduce the degree of uncertainty of the computed loading values.

As an example of the above described technique, nitrogen and phosphorus loading into Orange Lake is computed below. Computation of land-use data was based on Huber et al. (1982) and Department of Environmental Regulation/Department of Administration - Division of State Planning digitized land-use data bases. Selection of export coefficients was limited to Florida case-studies and followed work by Baker et al. (1981), Reckhow et al. (1980), and Shahane (1982).

The effects of septic tanks on nutrient loading to lakes (STI) can be highly variable. For the scope of this analysis, the effort necessary to quantify their influence was not seen to be justifiable. In order to estimate inputs from septic tanks the following information needs to be determined; 1) watersheds where septic tanks are in use, 2) number of septic tanks in each watershed, 3) fraction of year that system is in use, 4) number of people using the system, 5)proximity of system to water body, and 6) soil type and condition.

Mass loading equation

$$M=(Ec_{u} \times A_{u})+(Ec_{f} \times A_{f})+(Ec_{ag} \times A_{ag})+(Ec_{wl} \times A_{wl})+(Ec_{at} \times A_{w})+STI+PSI$$

			g/m2-yr	n
M	= total mass loading (kg/yr)			
Ec_{u}	= export coefficient for urban areas (kg/ha-yr)	nitrogen: phosphorus:	0.57 0.082	10 13
A_{u}	= area of urban land-use (ha)			
Ec_{f}	= export coefficient for forest areas (kg/ha-yr)	nitrogen: phosphorus:	0.22 0.032	4 6
A_{f}	= area of forest land-use (ha)			
Ec_{ag}	= export coefficient for agricultural areas (kg/ha-yr)	nitrogen: phosphorus:	2.06 0.067	13 14
A_{ag}	= area of agricultural land-use (ha)			
Ec_{wl}	= export coefficient for wetlands (kg/ha-yr)	nitrogen: phosphorus:	0.55 0.025	1 1
A_{wl}	= area of wetlands (ha)			
Ec_{at}	= coefficient for atmospheric input (kg/ha-yr)	nitrogen: phosphorus: (state averages)	0.75 0.051	
A_{w}	= area of water (ha)			
STI	= septic tank input (kg/yr)			
PSI	= point source input (kg/yr)			

[n=number of reported export coefficients. Values used are median values (minimum bias for skewed data) of these reported coefficients]

No significant municipal or industrial point source discharges (PSI) exist in the watershed.

Orange Lake contributory drainage basin: land-uses

	Acres	ha	%
Urban	10,701	4,510	4.7
Forest	130,352	55,050	56.6
Agriculture	59,181	25,000	25.7 *
Water	21,252	8,980	9.2
Wetland	8,671	3,660	3.8
Total	230,157	97,200	100.0

* Data are for 1982 when a significant portion of the Orange Lake watershed was still in citrus production.

Substituting the export coefficients and land-use data in the mass loading equation:

nitrogen

$$M_n = (0.57 \times 4,510)+(0.22 \times 55,050)+(2.06 \times 25,000)+(0.55 \times 3,660)+(0.75 \times 8,980)$$
$$= 74,929.7 \text{ g.ha/m2-yr} = 749,297 \text{ kg/yr}$$

With a lake surface area of 4,900 ha; nitrogen load = 15.29 g/m2-yr.

Contributions from different land-uses in g/m2-yr:

Urban	:	0.52
Forest	:	2.47
Agriculture	:	10.51
Wetland	:	0.41
Atmospheric	:	1.38
Total	:	15.29

phosphorus

$$M_p = (0.082 \times 4,510)+(0.032 \times 55,050)+(0.067 \times 25,000)+(0.025 \times 3,660)+(0.051 \times 8,980)$$
$$= 4,355.9 \text{ g.ha/m2-yr} = 43,559 \text{ kg/yr}$$

With a lake surface area of 4,900 ha; phosphorus load = 0.890 g/m2-yr.

Contributions from different land-uses in g/m2-yr:

Urban	:	0.075
Forest	:	0.360
Agriculture	:	0.342
Wetland	:	0.019
Atmospheric	:	0.094
Total	:	0.890

Thus, the ratio of inputs of nitrogen vs phosphorus from the surrounding watershed into the lake is 15.29/0.890 = ca 17:1. Comparing this ratio with the ratio of N:P in aquatic plant material of 7:1 (Vallentyne, 1970) suggests, once again, phosphorus limitation of primary production despite the phosphate rich geology of the basin.

In a comparison with 325 lakes in Florida (Huber et al., 1982) such phosphorus and nitrogen loadings would rank Orange Lake at approximately the 50th percentile. Use of these export rates to determine the trophic state of a lake, or to predict a new steady-state phosphorus concentration in the lake after a land-use or management change, requires knowledge of the annual hydrologic budget. However, no detailed water budget has been developed for Orange Lake. [A crude estimate of such a budget can be made using data presented by Deevey (1987) and Huber et al. (1982).]

Such nutrient-water models are widely used in lake management and restoration work. The most commonly employed approaches are the models of Dillon and Rigler (1974) and of Vollenweider (1975; 1976). To improve their predictive capability for Florida lakes, Baker et al. (1981) suggested revised criteria based on observations in 40 Florida lakes.

The above mentioned models differ mainly in the way the internal phosphorus cycling between sediment and water is estimated. As was noted earlier, the contribution of phosphorus to the lake by the sediments may be significant in the shallow Orange Creek Basin lakes. In addition, the anoxic conditions in the hypolimnia of these lakes further enhance phosphorus release from the sediments. (Cooke et al., 1986).

Without excessive nitrogen and phosphorus loading from external sources, and without any significant point source input, to affect primary productivity management of the lakes in the basin should focus on control of internal nutrient cycling. Several management strategies are available to deal with the loose, flocculent type of bottom substrate that is prevalent in this basin and which is often an important source of nutrients to the water column. Re-introduction of seasonal water level fluctuations is an inexpensive and commonly suggested management practice in these cases (Cooke et al., 1986). Periodic exposure of the lake bottom in the littoral zones consolidates and dries the substrate and creates the opportunity for removal of nutrients by oxidative processes, mechanical means, or wind action. It may improve future fish habitat, since hard bottom seems to be preferred nesting habitat for largemouth bass (Bruno, 1984). Seasonal water level fluctuations are also important for optimal nesting and feeding habitat of several species of birds in the basin. The wood stork, for instance, will not nest if the water level remains high during the usual dry season or fails to rise in the wet season (Kahl, 1964).

Total removal of waterflow obstructions at the outlet of lakes in the basin may increase hydraulic flushing and decrease accumulation rates of organic detritus and unconsolidated mud on the lake bottom. The spillways at the outflow of Newnans and Orange Lakes may have promoted such accumulation of flocculent sediments, increased internal nutrient supply, and decreased the lake depth. Relatively simple aggregated computer models, which evaluate the impact of lake level stabilization, demonstrate such trends in Orange Lake (see appendix A).

The nutrient dynamics of the lakes in the Orange Creek Basin indicate a naturally productive environment. Seasonal changes in water level change the availability of nutrients periodically and, as such, may play an important role in keeping these aquatic systems at an earlier successional stage.

CONCEPTUAL MODEL OF LAKE MANAGEMENT

Some of the findings and processes discussed in the previous sections can be summarized in a conceptual model of lake management. Such a model illustrates the interdependence of these processes and suggests a problem-solving management alternative based on given information and hypotheses, which need to be field tested. As such, this model assists in identifying research needs that have a high probability of leading to improved basin management. These research needs are outlined in the next chapter.

Figure 7 shows a conceptual model of lake management using periodic lake level fluctuations. It focuses on multiple management objectives including improved fish habitat, water quality, and reduced algae and weed infestations. The model is an imperfect and abstract representation of the actual web of processes in the lake systems.

The positive impact of water level fluctuations on fish standing crop has been documented for different lakes in the southeastern U.S. (Lantz et al., 1964; Wegener and Williams, 1974). Richardson (1975) reported enhanced spawning of sport fish after a temporary water level drawdown and contributed this to a consolidated and rejuvenated littoral substrate.

Loose, flocculent sediments are common in eutrophic systems. They can represent a significant source of turbidity, and can release nutrients to the water column. Exposure of littoral lake sediments to the air may bring about oxidation of organic matter and subsequent nutrient release to the water column at reflooding (Wegener and Williams, 1974; Harris and Marshall, 1963). Fox et al. (1977) performed studies on Lake Apopka sediments and presented strong support that no significant decomposition of organic matter in sediment occurs during drying. Further studies on this issue are needed. At low water levels, sediments can be removed by bulldozer in stead of the more expensive hydraulic dredge operation. Also, at that time, repair or construction of docks, placement of rip-rap on banks, maintenance of dams, and removal of stumps and litter can be carried out more effectively.

The effect of water level fluctuations on nuisance aquatic vegetation can be highly species specific. This is an important consideration for the lake manager. Some plants are unaffected or may even thrive under such management. Especially with infestations of hydrilla, it is essential that timing of low water should preceed new tuber formation (which starts in October) and that water levels can be raised fast enough to shade out new hydrilla growth. Chemical spot treatment of new hydrilla growth may be needed.

The impact of dam construction on hydraulic flushing of the lakes and, indirectly, on rates of accumulation of organic detritus and unconsolidated mud on the lake bottom, may be important in correcting lake problems. The disappearance of a true pelagic area in Orange Lake may be the result of a decrease in depth, providing an opportunity for hydrilla (low light requirements!) to invade rapidly. A study of the sedimentation record will produce valuable information on accumulation rates of bottom materials and may be useful to test such a hypothesis.

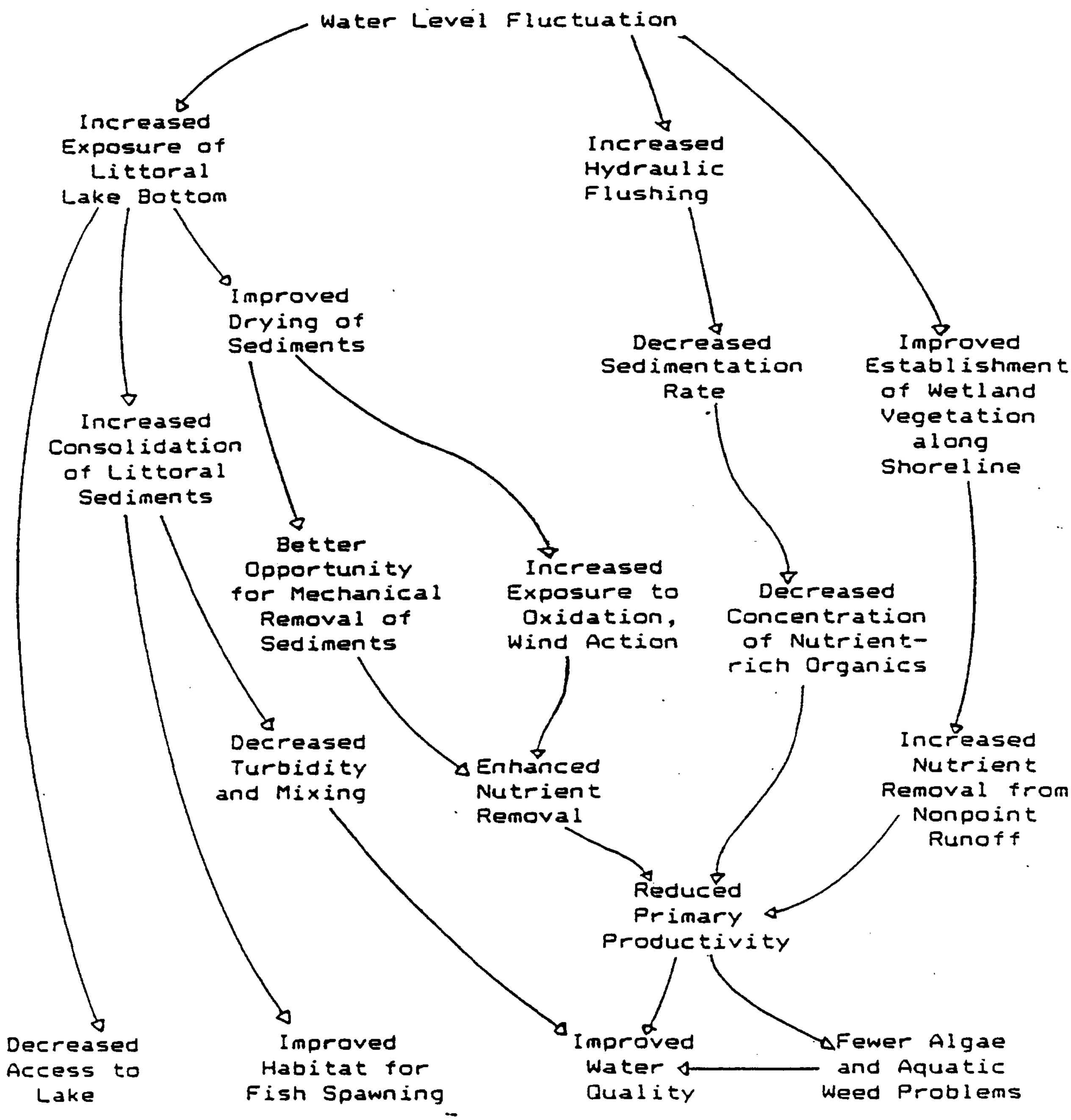

Figure 7. Conceptual model of lake management using periodic lake level fluctuations.

Water level stabilization substantially reduces forested wetlands along the lake margin (Odum, pers. comm.). Wetland trees need an environment in which the waters rise and fall with season. With so little wetland to absorb the nutrients, nutrient-rich runoff from the watershed enters the lake unimpeded and may contribute to accelerated eutrophication. Again, this hypothesis deserves closer study.

Lake level fluctuation is a procedure which is unquestionably among the least expensive in lake management. It has been used successfully to reduce problems with algae and certain aquatic macrophyte accumulations. Its use can also reduce the cost of other procedures such as sediment removal and reduce the frequency and extent of herbicide applications. Additionally, research has demonstrated that fluctuating water levels are essential to maintaining vegetation to support a substantial water fowl community (Kadlec, 1962). The inconvenience of decreased lake access during periods of low water can be reduced with floating platforms at the end of boat docks and timing of low water during a period of little recreational activity.

SUMMARY AND DISCUSSION OF RESEARCH NEEDS

1. A reconnaissance profile is developed for Orange, Lochloosa, and Newnans Lakes, located in the Orange Creek basin in eastern and southeastern Alachua County, Florida. The purpose of this profile is to integrate and summarize relevant scientific information regarding these lakes into a single reference in order to facilitate decision making processes in basin management. A second objective is to identify research and data collection needs that have a high probability of leading to improved basin management.

2. The lakes can be classified limnologically as eutrophic, soft water lakes. The geomorphology of the basin, dominated by phosphatic sands, clays, and limestone, and its hydrologic behavior, with generally poor drainage and small elevation gradients, largely determine the mineral composition and trophic state of the lake waters. Without major sources of cultural eutrophication present in the basin, management of primary production in the lakes should focus on control of internal nutrient cycling.

3. Even though many independent investigations have reported water quality data for the Orange Creek basin, little long-term monitoring at frequent intervals has been done to document the magnitude or rate of change of eutrophication. From the data present, it appears that the lakes have been eutrophic for many decades. However, from field observations it is clear that the lakes have changed significantly in character over the last two decades, particularly with respect to aquatic plant growth. Research should focus on physical, chemical, and morphometric alterations in the lakes over time and establish causative relationships between these alterations and the management problems which the lakes now experience.

4. Past lake conditions, including many of these alterations, can be reconstructed based on interpretations of the sedimentary record. Through a detailed study of the mineralogy and structure of the lake sediments, their organic and inorganic constituents, and the morphological remains of organisms preserved in the sediments, an interpretation of past trophic conditions is possible. Several paleolimnological techniques are available to determine the age of sedimented materials and sedimentation over time. The latter can be related to the rate of loss of volume, i.e the rate of eutrophication. These stratigraphic methods are not only useful to evaluate rates of change in trophic state, and nutrient and ionic loadings; they are helpful in the development of predictive lake management models, because they can assist in reconstructing the reasons for past changes in lake biota.

5. The finding, in several studies, that lake hydrology (especially water level fluctuations) has a substantial impact on nutrient concentrations in the lake water is of considerable importance in the development of management strategies. With the introduction of lake level stabilization, through the construction of spillways in the 1960-s, water quality and quantity aspects of the lake ecosystems were changed. Long-term lake level stabilization leads to effective elimination of the seasonal floodplain. This, in turn, allows nutrient-

rich runoff from the watershed to enter the lakes unimpeded and may explain patterns of increased primary productivity. The general concept of pulse stability, first introduced by Odum (1969), as a dominant force in holding ecosystems in a younger successional stage through seasonal fluctuations in water level, is an established concept in systems ecology and lake management. Additionally, the impact of dam construction on hydraulic flushing of the lake and, indirectly, on rates of accumulation of organic detritus and unconsolidated muds on the lake bottom, is important in correcting lake management problems. The disappearance of a true pelagic area in Orange Lake may be the result of accelerated accumulation of bottom material. The resulting decrease in depth provides an opportunity for hydrilla (low light requirements) to rapidly invade. Again, a study of the sedimentation record will produce valuable information to test such a hypothesis.

6. The observed changes in fish community structure are of immediate and direct concern, particularly for the economic well-being of the area. In addition to the above recommended investigations, programs of fish improvement and fish population studies should continue and should be promoted. Current chemical application practices for hydrilla accumulations provide temporary (ca. one year) control of large acreages at an economically reasonable cost. A long-term successful lake management program should, however, also incorporate concepts of pulse stability. An investigation of these concepts in the Orange Creek basin is a first step toward such a management program.

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APPENDIX A

ORANGE LAKE, FLORIDA:

Minimodels for evaluating the impact of lake level stabilization on plant biomass and the long-term effectiveness of three commonly used biomass reduction methods.

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December, 1986

ABSTRACT

The effect of water level stabilization on lake plant biomass production was studied with the use of a relatively simple aggregated computer model of Orange Lake, Florida. Additional runs were performed to evaluate the long-term impact of herbicide application, mechanical plant removal, and increased fish harvesting on plant biomass. In a 25 year simulation, lake level stabilization (initiated after 12 years) resulted in significant increases in lake plant biomass and phosphorus concentrations. At the same time net community production in the wetland around the lake halted. Simulated herbicide spraying and mechanical plant harvesting resulted in substantial short-term decrease of vegetational biomass, but did not provide long-term reductions. Ultimate increase in plant biomass following herbicide application over and above increase without herbicide spraying is observed and may be caused by increased lake phosphorus concentrations following spraying and decomposition of organic matter. Even a large increase in fishing pressure, and therefore an increase in removal of phosphorus did not significantly affect standing crop of water plants.

INTRODUCTION

An overabundance of aquatic macrophytes in lakes may produce a decrease in the value of the lake for fishing and water recreation (Cooke et al., 1986). In the case of Orange Lake, Florida, which is the subject of this minimodel simulation, this may resulted in economic hardship for area residents (Delaney, pers. comm.) and the use of a program of repeated herbicide applications and mechanical plant removal as control strategies (Shireman, et al., 1983; Hinkle, 1976; Haller, 1976).

With the construction of a fixed-crest dam at the outflow of Orange Lake (4900 ha) in 1963, fluctuations in water level were minimized, which reduced wetland areas around the lake. With the disappearance of these wetlands, a zone which can filter nutrient-rich runoff from the watershed is lost. The hypothesis in this minimodel research project is that elimination of such wetlands around Orange Lake, through water level stabilization, results in increased plant biomass production in the lake. Other research has documented similar effects associated with stabilized lake levels in Florida. The rapid accumulation of organic detritus and unconsolidated muds, and the concentration of nutrient-laden wastes have been reported (Holcomb and Wegener, 1971; Johnson-Grocki, 1975; Cooke, et al., 1986). Massive growth of the aquatic macrophyte _Hydrilla verticillata_ has been documented for Orange Lake since the mid 70-s (Krummrich, et al., 1985).

In addition, this model evaluates the effect of three commonly used plant biomass reduction strategies. Both herbicide spraying and mechanical plant removal have been used in Orange Lake in an effort to reduce widespread macrophyte growth. Neither method has provided long-term control at a justifiable level of expense (Haller, 1976). The use of extensive fish harvesting may be an alternative management strategy, since harvest of fish represents removal of phosphorus containec in the fish. The impact of this management strategy on lake plant biomass is evaluated in this simulation.

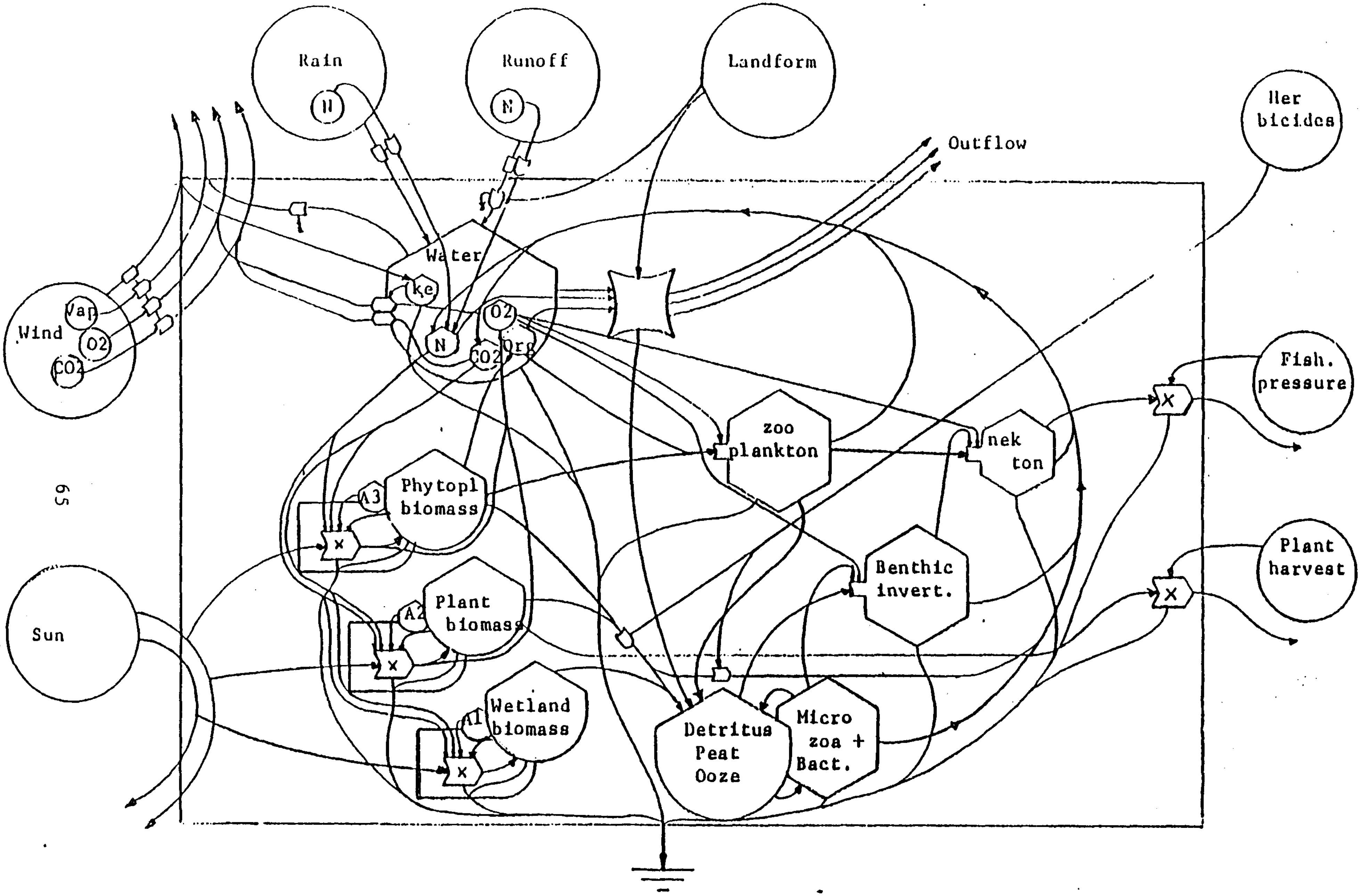

Figure 1. Energy diagram of Orange Lake

STRUCTURE OF THE MODEL

The relationships of sources, processes, and products for a relatively simple lake model are given in an energy language diagram (figure 1). The structure of the model simulated in this study is an aggregation of this diagram and is represented in figure 2. Solar energy is used in the production of plant organic matter in both the lake and the wetland. The relative areas of the wetland and the lake, as controlled by water level fluctuations, are simulated with the use of the area components A1 and A2 (A1+A2=100%). Rythmic seasonal fluctuations in A1 and A2 are represented by a sine-wave. Pathways for the accumulation of peat and bottom sediments from lake and wetland production are given. The flow of organic matter from the wetland to the lake storage is illustrated as a constant drain (zero-order kinetics). The wetland storage delivers a constant flow in proportion to the fixed surface of interaction (Mitsch, 1975). Phosphorus is received from rainfall, runoff, and decomposition of organic matter and is used in the production of water plants and wetland vegetation or is lost through outflow. Heat sinks, which show the energy lost in processes and depreciations are illustrated.

Energy system diagrams for simulation of a single herbicide application, a mechanical plant removal program, and increased fish harvesting are given in figures 3, 4, and 5. Switch symbols are incorporated to indicate that the processes involved are turned on and off relative to a pre-set threshold value. The actual computer programs, simulated in BASIC on an IBM-PC, are given in the appendix.

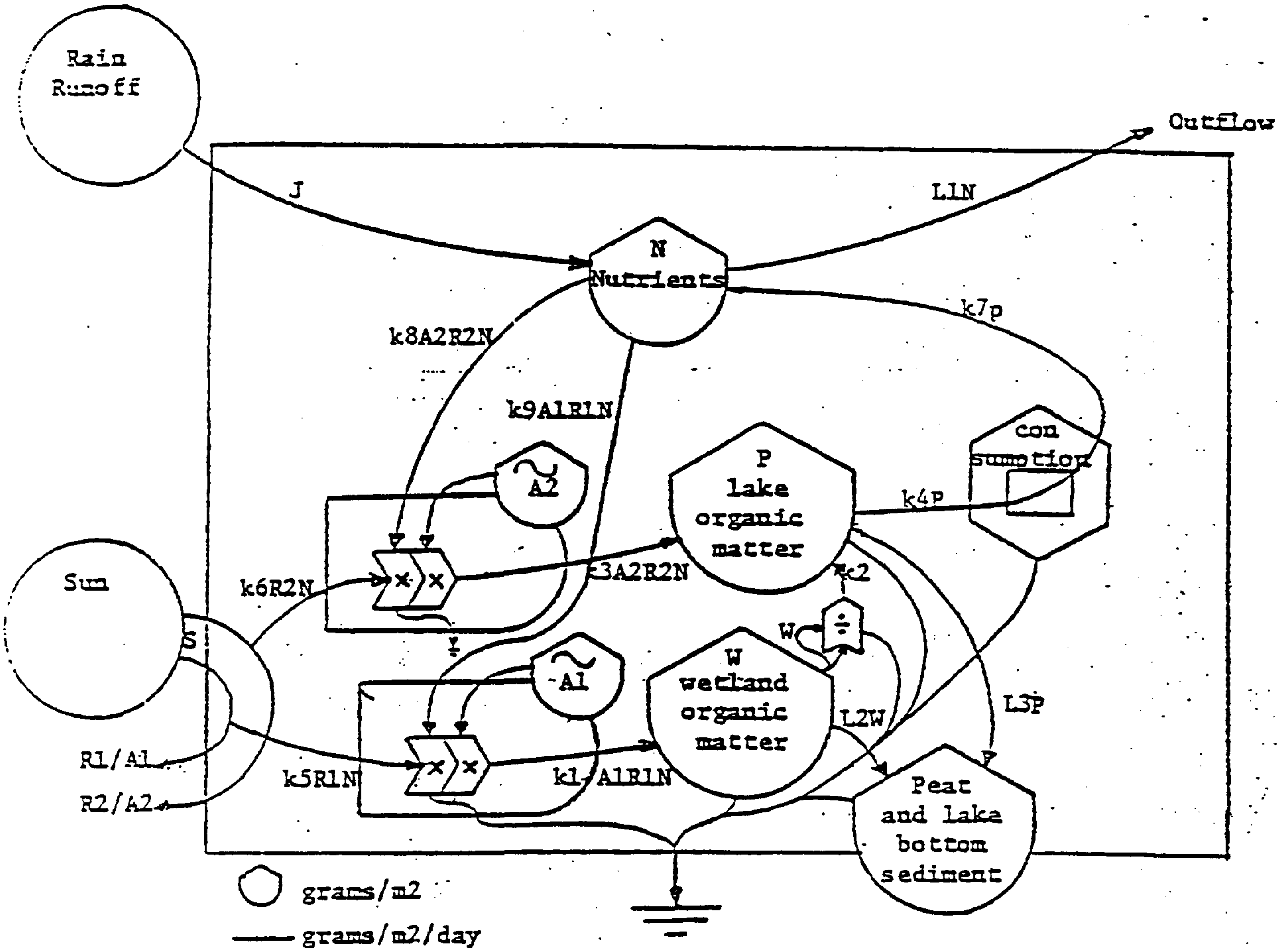

Figure 2. Aggregated diagram of Orange Lake as used in this study.

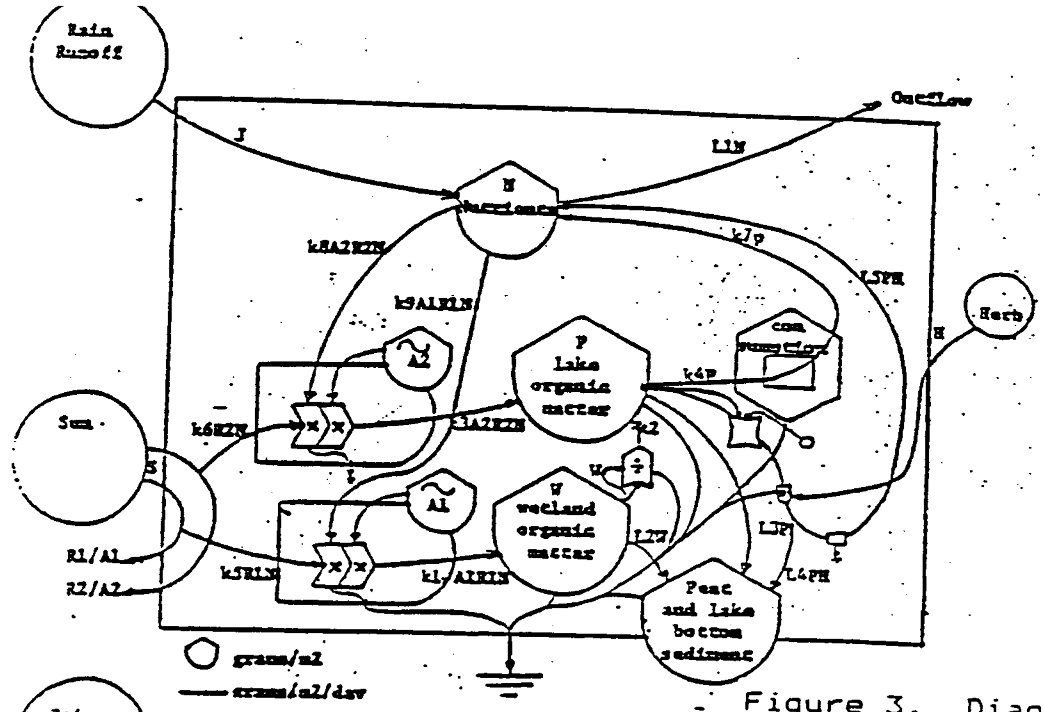

Figure 3. Diagram showing herbicide applica

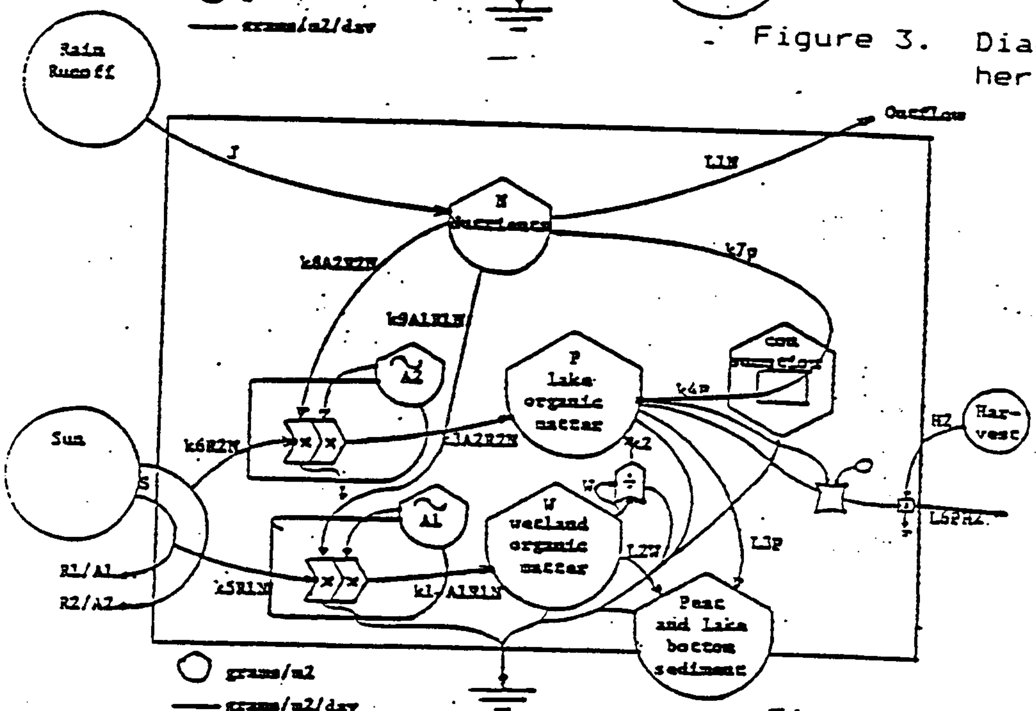

Figure 4. Diagram showing plant removal.

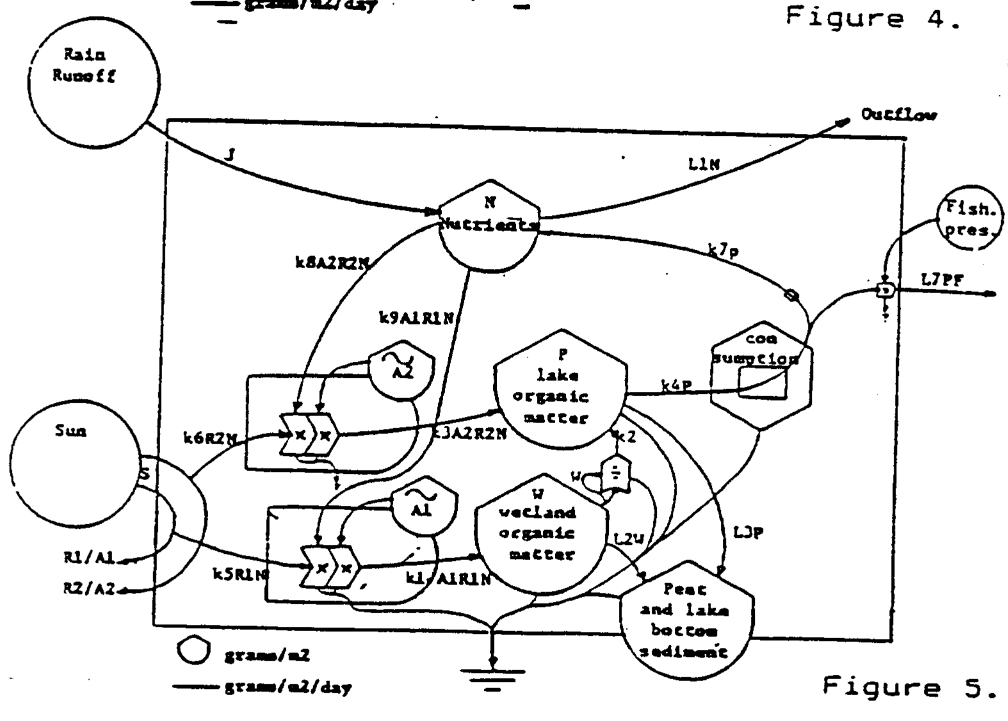

Figure 5. Diagram showin

MODEL QUANTIFICATION

Initial conditions

Value	Description	Units	Source
S = 4000	Light on pond	Kcal/m2/day	Average solar energy for North-central Florida (Fontaine, 1978)
R1= 50	Unused light (wetl.)	Kcal/m2/day	Odum, 1985
R2= 600	Unused light (lake)	Kcal/m2/day	Odum, 1985
N = 10	Phosphorus	g/m2	Odum, 1985
A1= 30	Area wetland	%	Estimate of initial condition
A2= 70	Area lake	%	ditto
W =40000	Wetland organic m.	g/m2	ditto
P = 1000	Lake organic m.	g/m2	ditto
J = .0005	Phosphorus in rain and runoff	g/m2/day	Fontaine, 1978

Equations

With the use of figure 2, equations for the simulation of lake level stabilization can be developed as follows;

A1 = 25+25*SIN(T/51)

A2 = 100-A1

R1 = S/(1+k5*N)

R2 = S/(1+k6*N)

DW = k1*A1*R1*N-k2-L2*W

DP = k3*A2*R2*N+k2-k4*P-L3*P

DN = J+k7*P-k8*A2*R2*N-k9*A1*R1*N-L1*N

The equations for area 1 and area 2 are not involved in the programs for evaluating the three plant biomass control strategies. In these cases, simulations are started after lake level stabilization has been put into effect.

The effect of the application of herbicides is mathematically given by the subtraction of a flow from the lake biomass production storage (i.e. reduction of life plant material) and the addition of a flow to the phosphorus storage (i.e. generation of phosphorus through increased decomposition);

DP = k3*A2*R2*N+k2-k4*P-L3*P-L4*P*H

DN = J+k7*P-k8*A2*R2*N-k9*A1*R1*N-L1*N+L5*P*H

H is a factor used to express the impact of the herbicide application.

Similarly, mechanical plant removal is represented by subtraction of a flow from the lake plant biomass storage;

DP = k3*A2*R2*N+k2-k4*P-L3*P-L6*P*H2

H2 is a factor used to express the impact of plant removal.

Stepped-up fish harvesting is simulated with the decrease of the flowpath from plant biomass through consumption/decomposition to the phosphorus storage. In essence, the fish harvest is represented by removal of phosphorus embodied in the fish. The equation for the phosphorus tank is then as follows;

DN = J+k7*P-L7*P*F-k8*A2*R2*N-k9*A1*R1*N-L1*N

F represents fishing pressure.

Actual values used in the simulation are given in figure 6.

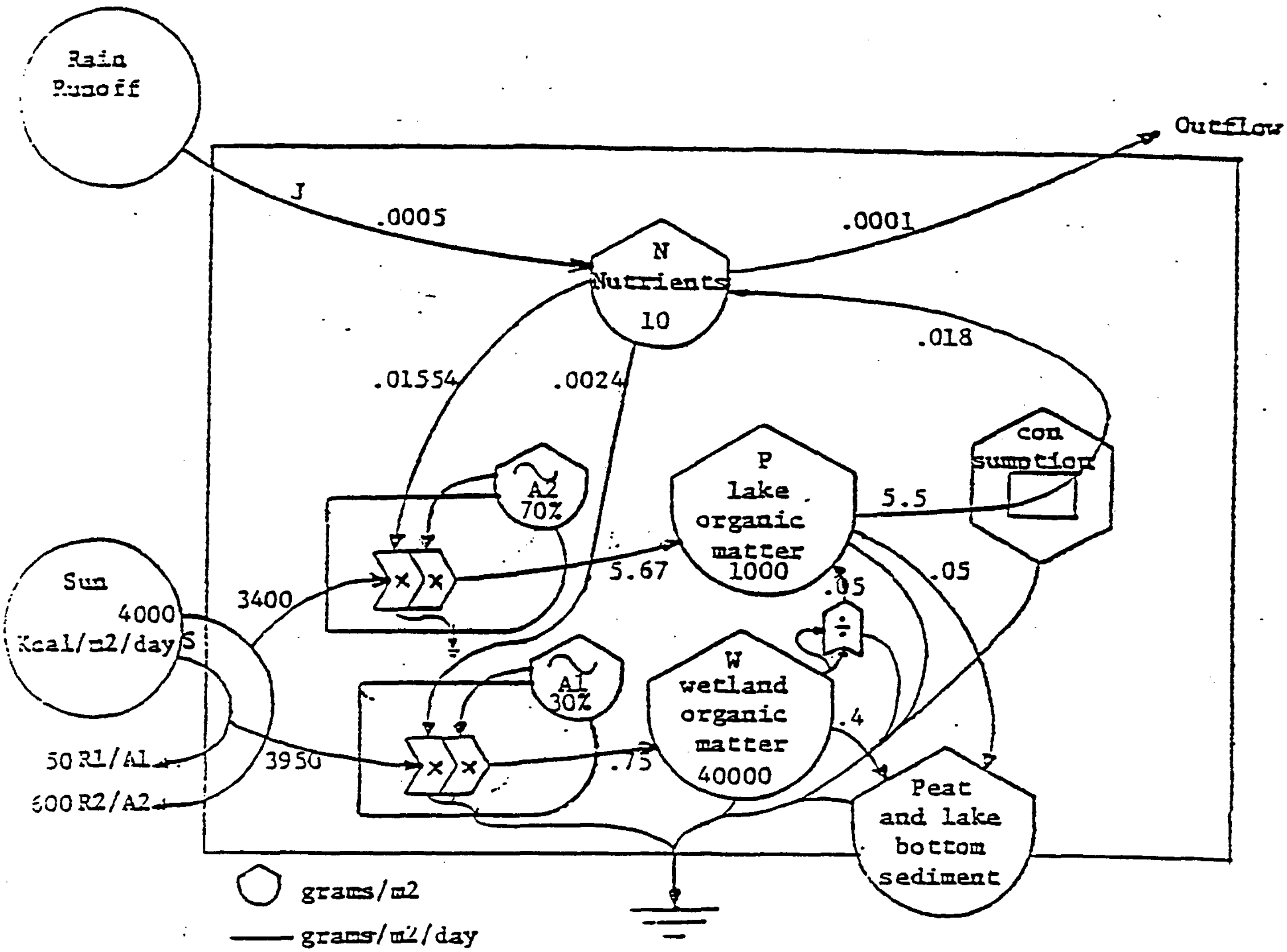

Figure 6. Energy diagram with flow values used in simulation.

Calculations of coefficients at steady state (calibration)
(calculations according to initial conditions as earlier reported)

Calibrated Flow value (g/m2/day)	Source	Coefficient	Value used in simulati
k1*A1*R1*N= .75	Wetzel, 1983	k1= .00005	.00005
k2W/W = .05	Mitsch, 1975	k2= .05	.05
k3*A2*R2*N= 5.5	Wetzel, 1983	k3= .0000131	.0000135
k4*P = 5.5	Steady state estimate	k4= .0055	.0055
k5*R1*N =3950	Odum, 1985	k5=7.9	7.9
k6*R2*N =3400	Odum, 1985	k6= .57	.57
k7*P = .017	Odum, 1985	k7= .000017	.000018
k8*A2*R2*N= .015	Odum, 1985	k8=3.57E-08	3.70E-08
k9*A1*R1*N= .002	Mitsch, 1975	k9=1.30E-07	1.60E-07
L1*N = 5E-04	Odum, 1985	L1=5.0E-05	1.0E-05
L2*W = .7	Steady state estimate	L2=1.75E-05	1.0E-05
L3*P = .05	Steady state estimate	L3=5.0E-05	5.0E-05
Flow values used in additional runs; At the time of herbicide application and plant removal: P=1500			
L4*P*H =11.25	Based on estimate that herbicide kills 47.5 kg/acre/day (H=150)	L4=5.0E-05	5.0E-05
L5*P*H = .225	2% of killed plants immediately converted into phosphorus	L5=1.0E-06	1.0E-06
L6*P*H2 =65	Based on 100mT/acre/yr. plant removal(for 1 yr)	L6= .00058 (H2=75)	.00058
L7*P*F =9.2E-6	Fish yield data from Orange Lake (Allen,1986) P content fish (Shapiro, 1975)	L7=9.2E-09 (P=1000) (F=1)	9.2E-09

RESULTS AND DISCUSSION

Figure 7 shows the impact of eliminating seasonal water fluctuations on wetland and lake plant biomass production and on nutrient concentrations (25 year scale). Lake level stabilization is initiated after 12 years by reducing A1 (area wetland) to 5% of the total area. Prior to stabilization lake plant biomass fluctuates with the season, increasing during the wet season when lake area (A2) is large. After the lake level is stabilized, vegetational biomass in the lake more than doubles in a period of 13 years (from approximately 700 tO 1500 g/m2). Further development of wetland biomass is halted, whereas phosphorus concentrations increase, presumably as a result of surging decomposition of lake organic matter.

The simulation in figure 8 starts at the time the water control structure is put in place and the lake level is stabilized. The impact of a herbicide application is shown when lake biomass has approached 1500 g/m2. Quantification is based on an estimate that the chemical kills 47.5 kg of plant material/acre/day (11.25 g/m2/day), 2% of which is immediately converted into phosphorus through microbial decomposition. It is demonstrated that within 1.5-2 years lake plant biomass has reached pre-application levels again. Concurrent plotting of plant biomass without herbicide treatment shows lower long-term values than with a herbicide application (resp. 1540 and 1600 g/m2, 13 years after spraying). This increased biomass after chemical treatment may be caused by excess nutrients generated through stepped-up decomposition.

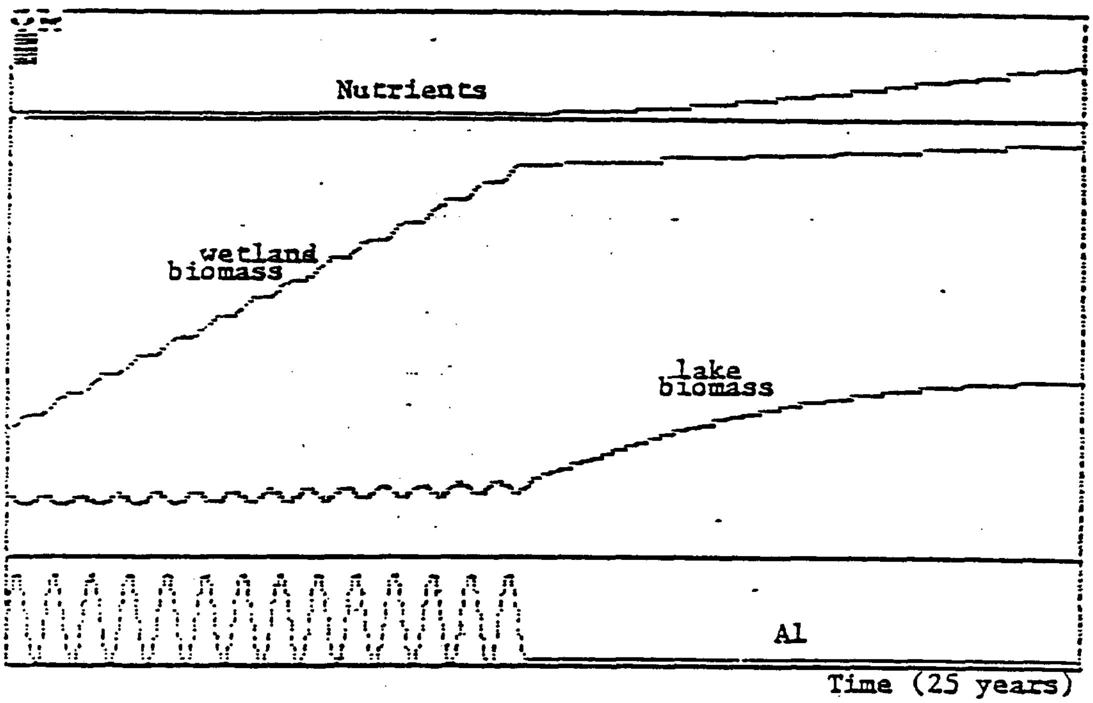

Figure 7. Output of lake level stabilization run.

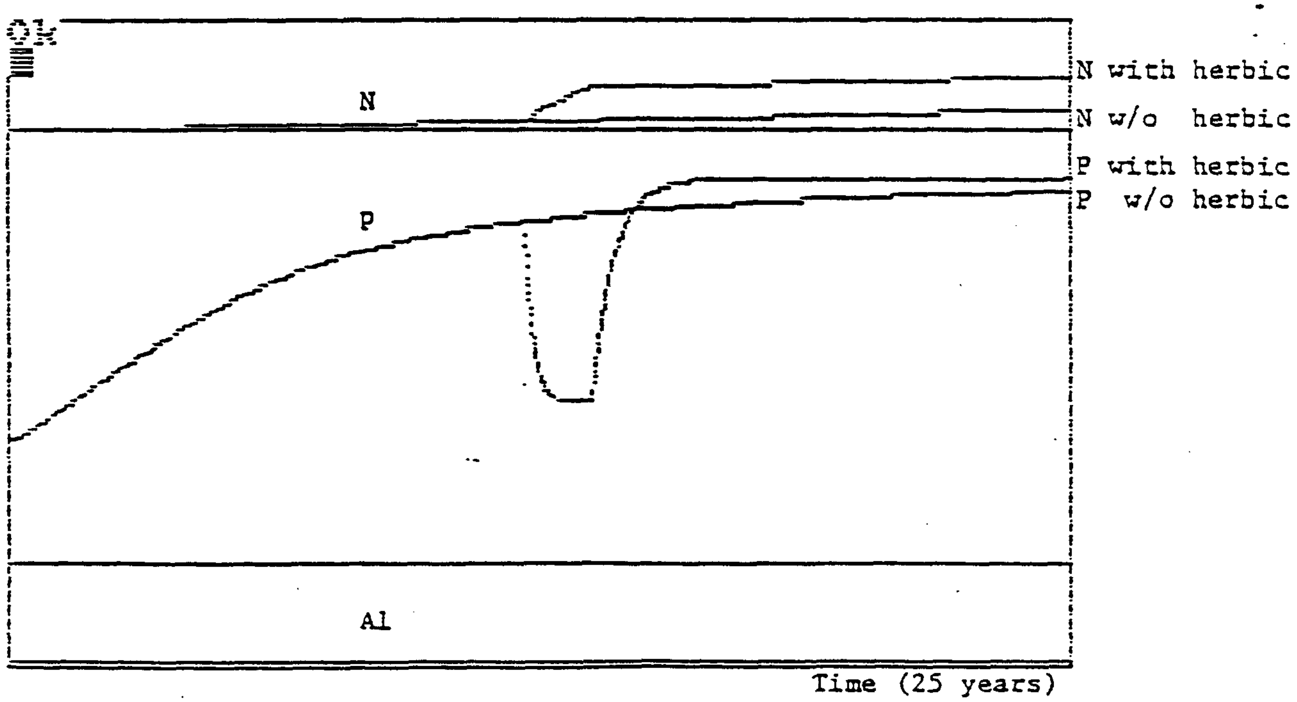

Figure 8. Output of herbicide application run.

The same time scale, 25 years, is applied to figure 9. Again, the simulation starts with lake level stabilization at t=0. The effect of a mechanical plant harvest program is indicated after 12 years. The program is calculated to remove approximately 100mT/acre/yr for 1 year (65g/m2/day), although similar patterns can be demonstrated with different harvest intensities. The plant removal program is discontinued after lake plant biomass has been reduced to approximately 200 g/m2. In the next 4 years, plant biomass gradually increases to pre-harvest levels. Unlike the herbicide simulation, no substantial increase in phosphorus concentrations is generated; nutrients embodied in the plants are harvested.

The effect of increasing fishing pressure on lake plant biomass production, over a 25 year time period with stabilized water levels, is indicated in figure 10. The production curve is actually a family of curves each representing an increase of 10x the current fishing pressure. No significant reduction in lake plant biomass is produced. Current fishing pressure was calculated with recent harvest data and creel surveys for Orange Lake (Allen, 1986). Nutrient content of the fish was computed after Shapiro (1975).

SUMMARY

The impact of water level stabilization on lake plant biomass and the long-term effectiveness of three biomass reduction methods was evaluated with the use of a simple aggregated computer model of Orange Lake, Florida. Eliminating seasonal fluctuations of the lake level resulted in accelerated lake plant biomass production. A single application of herbicides was ineffective for any period longer than

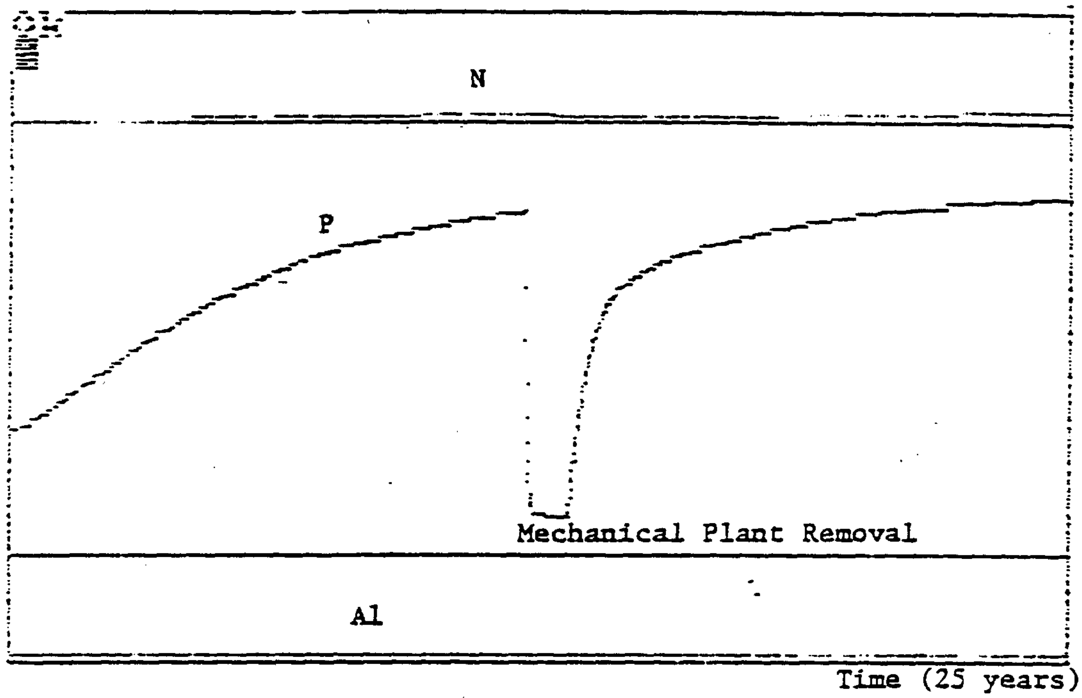

Figure 9. Output of mechanical plant removal run.

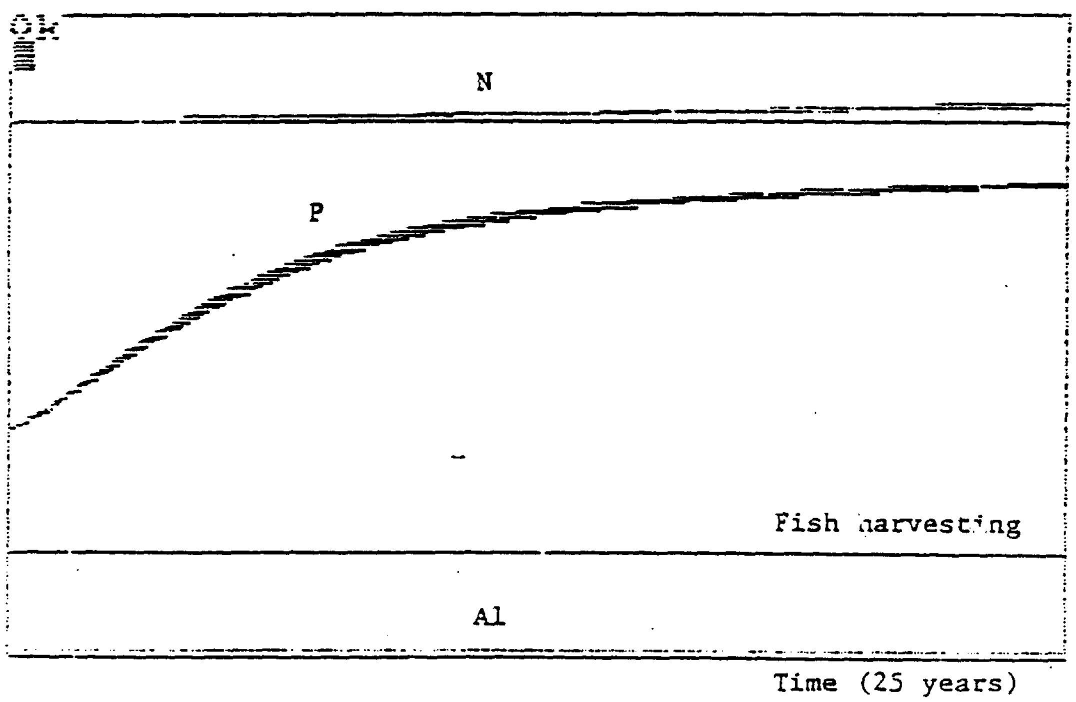

Figure 10. Output of fish harvesting runs (family of curves).

1.5 years and resulted in increased plant biomass as compared to no treatment during a 25 year simulation. Similarly, a single mechanical plant removal program did not produce long- term reduction of aquatic plant biomass. An advantage of mechanical plant removal is that no excessive nutrient accumulation occurred; nutrients were in effect harvested.

Likewise, nutrients were removed with fish harvesting techniques. However, even a large increase in fishing pressure did not significantly reduce plant biomass.

None of the evaluated management strategies provide long-term reductions in aquatic plant biomass with single applications. Herbicide spraying and plant harvesting programs may be effective when carried out at regular time intervals. The use of a model of energy and economics is valuable in analyzing such management. Maintaining a seasonal pattern of water level fluctuations, and thereby maintaining a productive wetland fringe around the lake may be an effective strategy for limiting lake plant production. This management option should be further tested in theory and in the field.

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```
. REM ibm - hans gottgans ees 5007
3 REM drywat 1 - lake level stabilization
. CLS
. SCREEN 1,0: COLOR 0,0
10 LINE (0,0)-(320,180),3,B
20 LINE (0,30)-(320,30)
30 LINE (0,150)-(320,150)
35 LINE (0,180)-(320,180)
45 REM scaling factors
50 I=10
55 A0=2
58 REM 25 year scale
60 T0=28.5
70 W0=30
80 N0=1
90 P0=30
100 REM initial conditions
105 J=.0005
107 S=4000
110 N=.85
115 P=500
120 W=1000
125 A1=30
130 A2=70
140 REM coefficients
145 K1=.00005
150 K2=.05
155 K3=.0000135
160 K4=.0055
165 K5=7.9
170 K6=.57
175 K7=.000018
180 K8=3.7E-08
185 K9=1.6E-07
190 L1=.00001
195 L2=.00001
197 L3=.00005
200 REM plotting
205 PSET (T/T0,30-N/N0),1
210 PSET (T/T0,150-W/W0),2
215 PSET (T/T0,150-P/P0),3
220 PSET (T/T0,180-A1/A0),1
227 REM initiate lake level stabilization
228 IF T/T0>155 GOTO 295
230 REM equations
231 A1=25+25*SIN(T/51)
232 A2=100-A1
240 R1=S/(1+K5*N)
245 R2=S/(1+K6*N)
250 DW=K1*A1*R1*N-K2-L2*W
255 DP=K3*R2*A2*N+K2-K4*P-L3*P
260 DN=J+K7*P-K8*N*R2*A2-K9*N*R1*A1-L1*N
265 REM change equations
270 W=W+DW*I
275 P=P+DP*I
280 N=N+DN*I
285 T=T+I
290 IF T/T0<320 GOTO 200
295 A1=5
296 A2=95
300 R1=S/(1+K5*N)
305 R2=S/(1+K6*N)
310 DW=K1*A1*R1*N-K2-L2*W
315 DP=K3*R2*A2*N+K2-K4*P-L3*P
320 DN=J+K7*P-K8*N*R2*A2-K9*N*R1*A1-L1*N
325 REM equations
330 W=W+DW*I
335 P=P+DP*I
340 N=N+DN*I
345 T=T+I
350 IF T/T0<320 GOTO 200
```

```
1 REM ibm - hans gottgens ees 5007
2 REM drywet2 - herbicide application
3 CLS
4 SCREEN 1,0: COLOR 0,0
10 LINE (0,0)-(320,180),3,B
20 LINE (0,30)-(320,30)
30 LINE (0,150)-(320,150)
35 LINE (0,180)-(320,180)
45 REM scaling factors
50 I=10
55 A0=2
59 REM 25 year scale
60 T0=28.5
65 REM q,b represent p,n in repeat run
70 Q0=15
75 B0=6
80 N0=6
90 P0=15
100 REM initial conditions
105 J=.0005
107 S=4000
110 N=.85
115 P=500
118 Q=500
119 B=.85
125 A1=5
130 A2=95
135 H=0
140 REM coefficients
145 K1=.00005
150 K2=.05
155 K3=.0000135
160 K4=.0055
165 K5=7.9
170 K6=.57
175 K7=.000018
180 K8=3.7E-08
185 K9=1.6E-07
190 L1=.00001
195 L2=.00001
197 L3=.00005
198 L4=.00005
199 L5=.000001
200 REM plotting
205 PSET (T/T0,30-N/N0),1
215 PSET (T/T0,150-P/P0),3
218 PSET (T/T0,150-Q/Q0),3
219 PSET (T/T0,30-B/B0),1
220 PSET (T/T0,180-A1/A0),1
227 REM initiate herbicide impact
228 IF T/T0>155 THEN H=150
229 IF T/T0>175 THEN H=0
230 REM equations
240 R1=S/(1+K5*N)
245 R2=S/(1+K6*N)
246 R3=S/(1+K6*B)
247 R4=S/(1+K5*B)
250 DQ=K3*R3*A2*B+K2-K4*Q-L3*Q
255 DP=K3*R2*A2*N+K2-K4*P-L3*P-L4*P*H
260 DN=J+K7*P-K8*N*R2*A2-K9*N*R1*A1-L1*N+L
262 DB=J+K7*Q-K8*B*R3*A2-K9*B*R4*A1-L1*B
265 REM change equations
270 Q=Q+DQ*I
272 B=B+DB*I
275 P=P+DP*I
280 N=N+DN*I
285 T=T+I
290 IF T/T0<320 GOTO 200
```

```
1 REM ibm - hans gottgens EES 5007
2 REM drywet3 - mechanical plant removal
3 CLS
4 SCREEN 1,0: COLOR 0,0
10 LINE (0,0)-(320,180),3,B
20 LINE (0,30)-(320,30)
30 LINE (0,150)-(320,150)
35 LINE (0,180)-(320,180)
45 REM scaling factors
50 I=10
55 A0=2
58 REM 25 YEAR SCALE
60 T0=28.5
80 N0=6
90 P0=15
100 REM initial conditions
105 J=.0005
107 S=4000
110 N=.85
115 P=500
125 A1=5
130 A2=95
135 H2=0
140 REM coefficients
145 K1=.00005
150 K2=.05
155 K3=.0000135
160 K4=.0055
165 K5=7.9
170 K6=.57
175 K7=.000018
180 K8=3.7E-08
185 K9=1.6E-07
190 L1=.00001
195 L2=.00001
197 L3=.00005
198 L6=.00058
200 REM plotting
205 PSET (T/T0,30-N/N0),1
215 PSET (T/T0,150-P/P0),3
220 PSET (T/T0,180-A1/A0),1
227 REM initiate 1 year plant removal program
228 IF T/T0>155 THEN H2=75
229 IF T/T0>168 THEN H2=0
230 REM equations
240 R1=S/(1+K5*N)
245 R2=S/(1+K6*N)
255 DP=K3*R2*A2*N+K2-K4*P-L3*P-L6*P*H2
260 DN=J+K7*P-K8*N*R2*A2-K9*N*R1*A1-L1*N
265 REM change equations
275 P=P+DP*I
280 N=N+DN*I
285 T=T+I
290 IF T/T0<320 GOTO 200
```

```
1 REM ibm - hans gottgens EES 5007
2 REM drywet4 - fish harvesting
3 CLS
4 SCREEN 1,0: COLOR 0,0
5 LINE (0,0)-(320,180),3,B
10 LINE (0,30)-(320,30)
30 LINE (0,150)-(320,150)
35 LINE (0.180)-(320,180)
45 REM scaling factors
50 I=10
55 A0=3
65 REM 25 YEAR SCALE
70 T0=28.5
80 N0=6
90 P0=15
100 REM initial conditions
105 J=.0005
107 S=4000
110 N=.85
115 P=500
125 A1=5
130 A2=95
134 REM current fishing pressure
135 F=1
140 REM coefficients
145 K1=.00005
150 K2=.05
155 K3=.0000135
160 K4=.0055
165 K5=7.9
170 K6=.57
175 K7=.000018
180 K8=3.7E-08
185 K9=1.6E-07
190 L1=.00001
193 L2=.00001
197 L3=.00005
199 L7=9.2E-09
200 REM plotting
205 PSET (T/T0,30-N/N0),1
215 PSET (T/T0,150-P/P0),3
220 PSET (T/T0,180-A1/A0),1
230 REM equations
240 R1=3/(1+K5*N)
245 R2=3/(1+K6*N)
255 DP=K3*R2*A2*N+K2-K4*P-L3*P
260 DN=J+K7*P-L7*P*F-K8*N*R2*A2-K9*N*R1*A1-L1*N
265 REM change equations
275 P=P+DP*I
280 N=N-DN*I
285 T=T+I
290 IF T/T0<320 GOTO 200
 REM increase fishing pressure x10
 F=F*10
 N=.85:P=500
 T=0
 IF F<=1 GOTO 200
```