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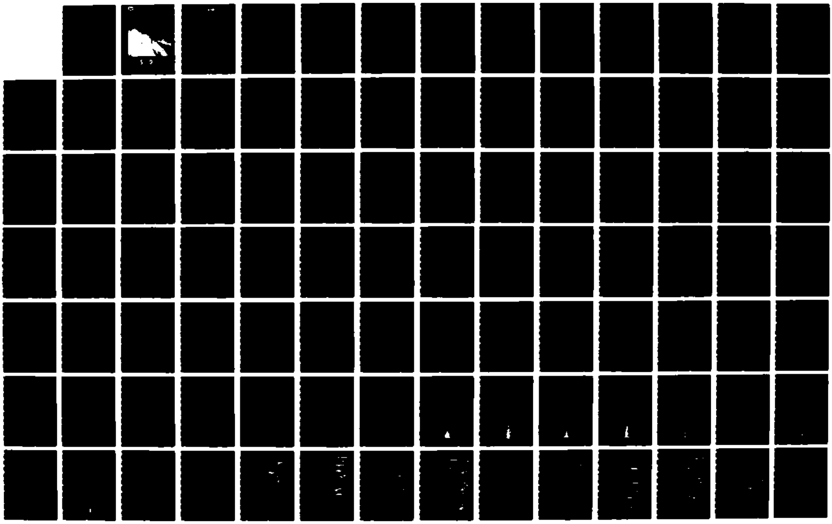

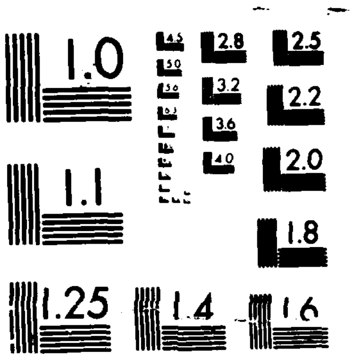

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Center Hill Reservoir Fishery Study–Water Level Effects

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The U.S. Army Corps of Engineers is considering the expansion of the generation capacity of several projects in the Cumberland River Basin. The expansion of the generation capacity might result in an operational change from a base-load regime to a peaking regime. Peaking operation yields much higher benefits to the public because it enables large power marketing systems to avoid the use of very costly power alternatives.

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The issue addressed herein is whether the newly proposed operation schedules would be expected to produce changes in the reservoir sport fisheries. Center Hill Reservoir was selected as a typical case for this study because it is a deep, steep-sided tributary storage reservoir which has considerable water level fluctuations. Center Hill also had a good fishery and water quality data base which could be used to show the effects of water level fluctuations.

This study used existing data to evaluate the water fluctuation effects on sport fish standing crops, catch rates, and water quality. Long-term changes in sport fish catch rates and water quality were also addressed. The study concluded with an outline of a monitoring system to evaluate the effects of water levels on sport fishing.

Attempts to correlate various parameters describing fluctuations in reservoir water levels with fish density, biomass, and creel catches indicated that water level fluctuations in steep-sided reservoirs have little effect on the sport fishery. The project involved 928 correlation attempts of which only 12% were significant at the 95% level. Of the 100 correlation tests between creel data and the ten hydrovariables, only 4% were significant. Thus, it appears that, with the exception of stable water levels during the May-June spawning season, fish management by water level fluctuation is not appropriate at Center Hill Lake.

The graphical analysis of the relationship between the rate of water level change in feet per day and the catch rates of several sport fish in numbers per hour, showed that fish are not caught as well when water levels are rising or falling. The best catches are made on days with stable water levels and/or rates-of-change less than 0.5 ft/day.

Long-term trends in the creel data were shown by changes in the catch of various sport fish. Crappie and white bass are no longer being creeled by fishermen on Center Hill Reservoir. The crappie decline began in 1978 and the white bass decline started in 1979. Smallmouth bass have declined since 1973, while Kentucky bass catch rates have increased dramatically since 1982. No specific trends were noted for largemouth bass, walleye, or bluegill.

Long-term trends in water quality showed that the levels of total nitrogen and phosphorus have decreased steadily since 1972. This trend is especially evident at the surface for spring nutrient concentrations. The total nitrogen has decreased from 0.7 mg/L to 0.3 mg/L and total phosphorus from 55 g/L to less than 10 g/L. These nutrient decreases may be related to declines in the catch of smallmouth bass, crappie, and white bass.

Water quality parameters were correlated with water levels and it was found that temperature and specific conductivity were negatively correlated with water surface elevation while dissolved oxygen, nitrogen, and phosphorus were positively correlated to the water surface elevation. There were cross-correlations between temperature, dissolved oxygen, pH, and specific conductivity.

Overall, it appears that Center Hill Reservoir is low in essential nutrients and that phosphorus is limiting productivity. The decline in nutrients has been followed by serious declines in the catch rates for crappie, white bass, and smallmouth bass while Kentucky bass catch rates have increased. It is concluded that manipulating water levels in Center Hill Reservoir cannot be used to manage the fishery except for stable levels during spawning. Sport fish catch rates decline whenever the lake surface is raised or lowered more than about one-half foot per 24-hour period.

The full and fair evaluation of the effects of water level fluctuations on sport fishing would require about five years of study which would include a careful fall rotenone study of the fish community and a special creel study. The creel study should focus on intended fish catches during productive fishing periods for sport fish of greatest importance to the fishery.

Center Hill Reservoir Fishery Study
Water Level Effects

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Table of Contents

Chapter Page

List of Tables

List of Figures

PART I: SYNOPSIS OF RESULTS

1. The U.S. Army Corps of Engineers is considering the expansion of the generation capacity of several projects in the Cumberland River Basin. The expansion of the generation capacity might result in an operational change from a base-load regime to a peaking regime. Peaking operation yields much higher benefits to the public because it enables large power marketing systems to avoid the use of very costly power alternatives.

2. The issue addressed herein is whether the newly proposed operation schedules would be expected to produce changes in the reservoir sport fisheries. Center Hill Reservoir was selected as a typical case for this study because it is a deep, steep-sided tributary storage reservoir which has considerable water level fluctuations. Center Hill also had a good fishery and water quality data base which could be used to show the effects of water level fluctuations.

3. This study involved using existing data to evaluate the water fluctuation effects on sport fish standing crops, catch rates, and water quality. Long-term changes in sport fish catch rates and water quality were also addressed. The study concluded with an outline of a monitoring system to evaluate the effects of water levels on sport fishing.

4. Attempts to correlate various parameters describing fluctuations in reservoir water levels with fish density, biomass, and creel catches indicated that water level fluctuations in steep-sided reservoirs have little effect on the sport fishery. The project involved 928 correlation attempts of which only 12% were significant at the 95% level. Of the

100 correlation tests between creel data and the ten hydrovariables, only 4% were significant. Thus, it appears that, with the exception of stable water levels during the May-June spawning season, fish management by water level fluctuation is not appropriate at Center Hill Lake.

5. The graphical analysis of the relationship between the rate of water level change in feet per day and the catch rates of several sport fish in numbers per hour, showed that fish are not caught as well when water levels are rising or falling. The best catches are made on days with stable water levels and/or rates-of-change less than 0.5 ft/day.

6. Long-term trends in the creel data show pronounced changes in the catch of various sport fish. Crappie and white bass are no longer being caught and creeled by fishermen on Center Hill Reservoir. The crappie decline began in 1978 and the white bass decline started in 1979. Smallmouth bass have declined since 1973, while Kentucky bass catch rates have increased dramatically since 1982. No specific trends were noted for largemouth bass, walleye, or bluegill.

7. Long-term trends in water quality show that the levels of total nitrogen and phosphorus have decreased steadily since 1972. This trend is especially evident at the surface for spring nutrient concentrations. The total nitrogen has decreased from 0.7 mg/L to 0.3 mg/L and total phosphorus from 55 μg/L to less than 10 μg/L. These nutrient decreased may be part of the cause for declines in the catch of smallmouth bass, crappie, and white bass.

8. Water quality parameters were correlated with water levels and it was found that temperature and specific conductivity were nega-

tively correlated with water surface elevation while dissolved oxygen, nitrogen, and phosphorus were positively correlated to the water surface elevation. There were cross-correlations between temperature, dissolved oxygen, pH, and specific conductivity.

9. Overall, it appears that Center Hill Reservoir is low in essential nutrients and that phosphorus is limiting productivity. The decline in nutrients has been followed by serious declines in the catch rates for crappie, white bass, and smallmouth bass while Kentucky bass catch rates have increased. It is concluded that manipulating water levels in Center Hill Reservoir cannot be used to manage the fishery except for stable levels during spawning. Sport fish catch rates are lowered whenever the lake surface is raised or lowered more than about one-half foot per 24-hour period.

10. The full and fair evaluation of the effects of water level fluctuations on sport fishing would require about five years of study which would include a careful fall rotenone study of the fish community and a special creel study. The creel study should focus on intented fish catches during productive fishing periods for sport fish of greatest importance to the fishery. The reservoir should not be in a changing state, as Center Hill now is, with respect to nutrients and catch rates.

PART II: INTRODUCTION, OBJECTIVES, AND SPECIFIC TASKS

11. As described in Part I, the Corps of Engineers are studying the feasibilty of changing the role of hydropower in the Cumberland River Basin from a regime currently involving mostly baseload to one

of peaking power production. There is concern regarding the fisheries aspects of this change, especially as evidenced by sport fishing success.

12. The broad objectives of this study were to use an existing situation, Center Hill Reservoir, to evaluate the effects of water level fluctuations on sport fish biomass, sport fish catch rate, and water quality conditions. An estimation of long-term trends in sport fish catch rates and water quality was another objective to be followed by a design for an ideal water level fluctuation effects monitioring program.

13. Specific tasks set forth for the study under the Scope-of-Work are listed below.

1) Water levels at Center Hill will be plotted and analyzed for the life of the project. A quantitative methodology will be developed to describe the fluctuations. The work of Ploskey, Aggus, and Nestler (1984) will be used as a model.

2) The morphological consequences of water level fluctuations, which impact upon fish habitat and food-chain species, will be determined.

3) Historical data on water quality will be analyzed to identify water level change effects on fishery-related water quality parameters (temperature, dissolved oxygen, pH, alkalinity, conductivity, dissolved solids, nitrogen, and phosphorus).

4) Long-term changes in temperature, pH, dissolved oxygen, nitrogen, and phosphorus will be analyzed and described for Center Hill Reservoir.

5) Available creel census data will be analyzed to determine trends in sport fishing success.

6) Fall cove rotenone data will be analyzed to identify periods of strong and weak year-classes for game and forage fish. Forage/predator relationships will be developed.

7) Information on water level fluctuations, water quality, fish populations and sport-fishing success will be correlated using multiple linear correlation methods and other techniques. The data analysis techniques of Plosky, Aggus, and Nestler (1984) will be used as the model for these studies.

8) The Ploskey, Aggus, and Nestler (1984) equations will be used to predict the consequences of an altered operational schedule for Wolf Creek Dam and lake Cumberland fisheries by September 15, 1985.

9) A feasible sampling schedule for future lakes, which would be a field assessment of water level fluctuations and sport-fishing success, will be developed with the goal of determining an ideal schedule of reservoir operation for fishery enhancement.

PART III: LITERATURE REVIEW

Center Hill Reservoir

14. Center Hill Reservoir is a flood control and power reservoir impounded by a dam at mile 26.6 on the Caney Fork River. The dam has a maximum height of 250 feet and a length of 2,160 feet. Electrical power is supplied by three 45,000 kw units for a total capacity of 135,000 kw. The estimated average yearly energy output is 351,000,000 kwh.

15. The reservoir has a drainage area of 2,174 square miles, total storage capacity of 2.092 million acre-feet, surface area (maximum) of 23,060 acres, shoreline length of 415 miles and is 64 miles in length. Flood control capacity is 762,000 acre-feet. The reservoir is located in Dekalb, Warren, White, and Putnam Counties of Tennessee about 20 miles from Cookeville.

16. Center Hill reservoir was authorized for flood control and hydroelectric power production. Flood storage capacity of 762,000 acre-feet is provided during the winter and spring months when the probability of heavy rainfall and flooding is highest. Through proper flow regulation, flooding is reduced in the drainage below the dam. In addition, the reservoir is operated as a unit in the comprehensive series of multipurpose reservoirs along the Cumberland River Drainage Basin which provide control of floodwaters along the Cumberland, lower Ohio, and Mississippi Rivers.

17. The Center Hill project has three 45,000 kw electric power generators which contribute substantially to the available electric power supply of the Upper Cumberland area. The reservoir volume between elevations 648 and 618 is allocated to power production and this volume of 492,000 acre-feet plus inflows allows an average of 351,000,000 kw hours of annual electrical output.

18. Storage between elevations 618 and 648 is allocated to power production and that between 648 and 685 is allocated to flood control. The potential for large variations in the lake levels is highest during the wet winter and spring seasons. Any water stored in the flood pool is evacuated as soon as possible to provide for future potential flood

events. During a "normal" year, a lake elevation of about 645.5 is achieved during May. Levels are then gradually lowered to about elevation 632 by November. The lake is then allowed to rise back to 645.5 during the wet winter and spring. This operation is supposed to make the best use of available water for hydropower generation and low-flow augmentation. It also allows a portion of the power pool to be used for the control of high flows. Lake levels are stabilized for a two to three week period in the spring to enhance fish spawning.

19. Temperature plots illustrated that temperature stratification of Center Hill Reservoir was occurring and that the pattern corresponded to classical horizontal isothermal layering (Gordon, 1976). An analysis of temperature changes with depth, length, and time suggested the following annual pattern. During the first of January to about mid-March, Center Hill reservoir was mixed vertically and no stratification was evident. A temperature of about 5°C was expected. During late March, warmer, less-dense inflows (10-11°C) spread out over the surface of the reservoir and resulted in the onset of stratification before the first of April. Much warmer inflows (15-20°C) coupled with more intense thermal heating by atmospheric heat exchange completed the stratification process by early May. Center Hill Reservoir then developed the classical three-tier thermal structure composed of a warm epilimnion, a thermocline, and a cold hypolimnion. The stratification is very stable and flow patterns shift to regions governed primarily by density differences.

A Literature Summary - Water Levels and Sport Fishing

20. The fisheries effects of fluctuating water levels in reservoirs have been studied and debated for decades. Over 400 reports, theses

and papers have been prepared on the topic and 367 of these were reviewed and annotated by Ploskey (1982). He reported that controlled manipulation of water levels has been recognized as one of the most valuable, practical and successful techniques for enhancing reservoir fisheries. However, uncontrolled or non-desirable fluctuations in water level can be detrimental, especially when fish are spawning. In general, the Ploskey review shows that high spring water levels produce good spawns of sport fish and forage fish and that fall drawdown increases survival and condition of sport fish by incrasing the amount of prey available to them.

21. Allen and Aggus (1985) reported on a workshop on the subject which was held in 1981. Over 60 people attended this workshop and made contributions to the report. The workshop summary reported that manipulation of water levels to enhance fisheries is usually based upon the timely flooding or dewatering of shoreline vegetation. This generally involves raising water levels during the spring season to enhance spawning and early survival of sport fish and forage fish. Pool levels are lowered during the summer to permit regrowth of vegetation in the fluctuation zone. Fall and winter drawdown is often recommended to concentrate sport fish and their prey as well as to control undesirable water plants. The summary stressed that planning for water level management should be site-specific and geared to the actual circumstances.

2. In 1983, Ploskey (1983) reviewed the effects of water level fluctuations on reservoir fisheries. The following paragraphs were taken from Ploskey's report:

Water-level changes alter trophic relations and regrowth of fish by regulating the input of allochthonous foods, the productivity or species composition of fish-food biota, or the availability and vulnerability of prey. Changes in water levels that significantly affect fish communities have three characteristics: they are of large magnitude, of long duration, and occur during at least part of the growing season. Feeding and growth of fish are not affected nearly as much by frequent (daily or monthly) fluctuations in water levels as by long-term (1-3 year) cycles of water levels. Low water during or after a spawning period, when food demands by the young-of-the-year fish are high, may severely reduce survival and annual production of an entire year class of fish.

23. Water level manipulation can provide fishery managers with a crude means of regulating structural complexity, and therefore, the predator-prey relations of littoral fish in reservoirs, by providing a more complex habitat at high elevations. Part of the success of drawdowns in improving sport-fishing is a result of an increase in the vulnerability of forage.

24. Reproduction of fish that spawn in the fluctuation zone of reservoirs is influenced by changes in water levels. Adverse effects on reproduction of near-shore spawning fishes are related to a loss of habitat by drawdown or shoreline modification, or mortality of eggs or young-of-the-year fish by exposure or suffocation with eroded sediments. The control of water levels during spawning is the most practical and

inexpensive method of producing fish. Controlling water levels may also be used to eliminate some undesirable fish.

25. Reproductive success of fish that spawn near shores in reservoirs is influenced by the time and duration of flooding and the type of substrate inundated. Water levels determine available refuge for young fish by inundating vegetation or receding from it, consequently, survival of these young fish is enhanced greatly when cover is abundant.

26. Knowledge of spawning and nursery requirements of various fish is essential for the development of effective strategies for water-level manipulation. Because time of spawning varies directly with temperature, temperature is more reliable than time of year as an index to spawning. In reservoirs dominated by warm-water species such as black bass, <u>Lepomis</u> sunfish, catfish, and crappies, virtually all important forage, sport, and commercial fish, spawning occurs at temperatures between 11 and 22°C. In reservoirs dominated by cool-water species such as northern pike, walleyes, saugers, and yellow perch, the temperature range for spawning is about 5 to 17°C.

27. Harvest of fish is affected by many factors, some of which are influenced by water-level changes. Direct effects of water level fluctuations on angler harvest are rarely documented because of difficulties associated with quantifying short-term responses that are frequently determined by fish behavior. Because of the complexity of relations, observed

changes in harvest often cannot be readily explained by changes in water level alone. Some other factors that affect harvest are the standing crop; length, frequency distribution, and production of harvestable-size fish (as determined by reproductive success, growth, and recruitment); the local distribution of fish relative to anglers; and environmental conditions such as season and turbidity.

28. Jenkins (1967) examined relations between nine descriptive variables and the sport and commercial harvest of fish in 127 reservoirs and found that sport fish harvest per unit area was directly related to total dissolved solids, storage ratio, and shorline development and inversely related to reservoir age, area, and mean depth. Consequently, sport fish harvest should be highest in nutrient rich, productive reservoirs that entrain water for a year or more and that have a large littoral area relative to the area overlying deep water. Harvest of commercial fishes was inversely related to storage ratio, mean depth, shoreline development, and water level fluctuation; it was directly related to reservoir age. High commercial harvests are more common from old mainstream reservoirs that are not dendritic, but that are linear and shallow and exchange water rapidly.

29. Drawdown of water levels allows fishery managers to improve submerged structures in littoral areas or to alter the amount of structure available to fish. Fluctuating or reduced water levels in spring or early summer may not only be harmful to the reproductive success of fish but also could seriously reduce annual harvest by disrupting concentrations of fish or by limiting the access of anglers to the

lake. Because the growing season (spring, summer, and fall) is the most popular time for anglers, drawdown during this time would create much pressure from the anglers. Increases in turbidity resulting from changes in water levels may also adversely affect fisheries harvest. For example, the black bass is primarily a sight feeder and its sight impairment would consequently reduce its effectiveness in feeding.

30. Water levels should be steady or rising during spring and early summer to benefit spring-spawning fishes and high water levels should be maintained for as long as possible after spawning is complete to improve the survival of young fish. High water levels during reproduction periods result in enhanced reproduction of most fish as the expanded habitat is filled with young fish. A reduced area in fall presumably concentrates prey for predators and enhances the survival of yearling piscivores.

31. A report prepared by Ploskey, Aggus, and Nestler (1984) was intended to be used for predicting the effects of altering seasonal water levels in existing reservoirs. They studied hydropower storage reservoirs having characteristics such as extensive surface area, great depth, and being dendritic (having a high shoreline development index).

32. This particular report utilized multiple regression analyses of fish variables against hydrologic variables using the "maximum R^2 improvement" (MAXR) technique in the Statistical Analysis System Release. Criteria used to select the most appropriate regression equation generated by this procedure were: (a) level of significance of model and parameter estimates, (b) the change in mean square error (MSE), (c) the coefficient of determination (R^2), and (d) the logic of positive or negative correlations.

33. Two different strategies were used to describe the effects of fluctuating water levels on reservoir fish. In the first, a general description of the effects of fluctuating water levels on the entire reservoir fishery was obtained by examining the frequency with which the different hydrologic variables occur in the correlation matrix. The second approach described the reaction of species of fish to specific hydrologic variables as indicated by individual regression equations.

34. In the first approach, each independent water level variable was evaluated and examples of fishes that were positive or negative correlates to each independent variable were listed. Water level variables were ranked according to their relative importance by tallying the number of significant correlations at alpha = 0.05, counting the number of fish groups affected, and evaluating the consistency of positive or negative relations for different taxa. The consistency of positive or negative correlations was determined by examining the number of positive and negative correlations significant at the alpha = 0.20 level.

35. The second approach involved examining different species or groups of species and derived multiple regression equations that described relations between fish biomass or density and the independent variable or variables.

36. Conclusions in the Ploskey, Aggus, and Nestler report were that:

> Although the exact response mechanisms vary somewhat among species, effects of water level changes on many fishes can be predicted with relatively simple regression equations.

These equations can then be used by a biologist or engineer to estimate the effects on the reservoir fishery of altering seasonal water levels and reservoir operations in exisitng and proposed reservoirs. Additionally, these predictions can be used as guidelines to protect or enhance reservoir fisheries.

Hydrologic variables in hydropower storage reservoirs (as opposed to hydropower mainstream and flood control reservoirs) were the most consistent in terms of positive and negative effects on different fish, and effects were most consonant with prevailing hypotheses in the literature. More significant equations were obtained from this data set than from the others, probably because the sample was large (25 reservoir-years of data) and the most homogeneous with regard to morphometry, seasonal patterns of operation, and fish composition and abundance. The abundance of many fish in August was positively correlated with each of the four most important independent variables (i.e., mean spring area, annual change in area, mean summer area, and spring change in area). Above-average summer drawdowns usually resulted in below-average fish abundance in August. Results strongly suggest that reduced survival after hatching is more limiting to fish recruitment than poor spawning success in spring.

37. They concluded that the following hydrologic regime seems to increase the reproductive success of the majority of sport fish: (a) water is released more rapidly than usual in fall (during a wet fall)

and the extent of drawdown is increased, (b) below-average area in fall is maintained to permit the development of terrestrial vegetation in the drained zone, (c) water is retained in spring (above-average storage ratio) to make the average surface area in spring exceed the mean for the reservoir, and (d) water levels are kept above the average summer pool throughout summer. This regime does not necessarily mean that all species that comprise the collection group "sport fish" respond in the same way. It could mean that a few species that compose most of the numbers and biomass exhibit similar responses. Research has indicated that reproduction of some fish is adversely affected by the hydrologic regime stated above. Thus it is important to establish an optimum regime suitable for the enhancement of the largest number of sport fish species.

38. Ploskey, Aggus, and Nestler (1985) followed their previous work with an analysis of the effects of water levels on year-class development and the abundance of harvestable fish. As before, above-average water levels in the spring increased the production of the young-of-the-year fishes including both sport fish and forage fish. Above-average water levels in summer also provide more food and increase available refuge for young fish.

39. They reported that in years of high spring runoff, when reproductive success is high, one should hold summer and fall water levels as high as possible, consistent with other project purposes, to improve the condition and survival of YOY fish. They expected that winter drawdown would be advisable to concentrate the almost one-year old fish with available prey.

40. All of the previous references were involved with crops of fish and their condition. However, most fishermen are more concerned with fishing success rather than standing crop. One study covered the fishing success as a function of fall water level fluctuations. Laflin (1985) found that shoreline fish activity increased during either a slow rise or fall in the water level. Laflin also found that while maximum fishermen use occurred during stable water periods, maximum catch occurred during slow water level fluctuations. This is contrary to the knowledge that Kentucky fishermen believe that the lake drawdowns adversely affect fishing success. It should be noted that rises in level up to 1 foot in 15 days were stimulating while rises greater than 2 ft in 15 days rapidly decreased the catch. Black bass numbers along the shoreline decreased as the rate of drawdown increased beyond 2 ft in 15 days.

41. References on rapid, short-term fluctuations were scarce. Petr was reported by Ploskey (1983) to show that short-term fluctuations of water levels (days or weeks) have seldom been related to major changes in water chemistry or biological productivity. Ploskey also reported that Estes observed that growth rates of black bass and bluegill in a pumped storage lake were not related nor affected by weekly fluctuations of 6-8 feet.

Watauga Reservoir - A Related Study

42. A study somewhat similar to this was that of the Watauga Reservoir where the water level had to be lowered three times farther than usual during 1983 to permit legally required safety inspection of the

dam and to allow cleaning painting, and general maintenance of the turbine intake structure. Because drawdowns of this nature are relatively uncommon today and because a number of special circumstances were involved at Watauga, this operation was one of special interest. Even relatively small changes in the usual pattern of water levels in a reservoir can affect (beneficially or adversely) various uses of the water resource, the quality of water, and the characteristics of the habitat. Therefore, it was necessary to identify potential problems which might arise and measures to deal with those problems that could be prevented or reduced (Anon, 1983).

43. As the banks became exposed due to the drawdown, an ambitious shoreline planting program was launched which involved heavy fertilization and the planting of milo, winter wheat, winter rye, Japanese millet, and lespedeza. Because this vegetation was due to be inundated in the late spring of 1985, it should have had ample time to grow and reproduce. The vegetation should provide exceptionally good spawning grounds and protective cover for young fish in the reservoir.

44. During early planning for the drawdown, environmental engineers identified two major concerns which were the possible impacts on downstream municipal water supplies and potential hazards to fish populations. These concerns were mainly related to seasonal changes in the characteristics of deep reservoirs.

45. Deep reservoris in climates such as that of the Tennessee Valley have fairly uniform water quality during the colder months. Normally, temperatures are not sufficiently cold for long enough to form a lasting layer of minimum density water (ice) at the surface or a layer of maximum

density water (4°C) at the bottom. During the hot months, many deep reservoirs such as Watauga become thermally stratified which leads to changes in water quaity that must be understood and considered in planning reservoir operations to minimize effects on water use and aquatic life. This stratification process is described below:

> As the sun's rays penetrate and warm the surface water, it becomes less dense than the water beneath it. Wind and waves cause a limited amount of mixing, and conduction helps distribute some of the solar heat to deeper water, but complete vertical cycling ceases because the warmer and, therefore, lighter water, remains "floating" on top. Exposure to the air and photosynthesis by green plants growing in this sunlit zone provide plenty of dissolved oxygen. The depth of this fairly uniform upper layer of warm, well-lit, oxygen-rich water called the "epilimnion" varies greatly in different reservoirs, at different distances above the dam and at different times during the period of stratification.
>
> Below the epilimnion there is no source of energy sufficient to cause further vertical mixing. Temperature declines and density increases rapidly with increasing depth in an abrupt transition layer called the "thermocline." In some reservoirs, a large portion of the dead microscopic plants and animals, waste products, and other organic debris or "rainout" continually settling from the biologically productive epilimnion cannot sink past the thermocline. Light-weight material becomes suspended when it reaches the depth at which

the density of the colder water equals that of the sinking particles. Trapped there, these materials are decomposed by "aerobic" bacteria, which obtain life-sustaining oxygen from the surrounding water. Other processes make smaller but cumulative demands on the oxygen in the thermocline. Isolated from the air and from reoxygenation by photosynthesis, this layer of water may become severely depleted of dissolved oxygen.

Below the thermocline is the "hypolimnion," which extends all the way to the bottom. Temperature continues to decrease and density continues to increase with increasing depth in this layer of water, but the rate of change is much more gradual than in the thermocline. In Watauga and some other reservoirs, oxygen demands are lower in the upper and middle portions of the hypolimnion than in the thermocline. Much of the rainout that is heavy enough to settle through the thermocline is also heavy enough to settle all the way to the bottom, where aerobic decomposition and other processes contribute to the formation of another zone of oxygen depletion in the deepest part of the hypolimnion. In addition, reactions among chemical compounds exposed at the surface of the sediment layer may remove more (in some cases, all) dissolved oxygen from this bottom layer of water.

If sediment contains large amounts of iron and manganese, these metals remain in the insoluble form of oxidized compounds as long as the deep hypolimnion contains any dissolved oxygen. If this layer becomes devoid of oxygen, however, a different type of bacteria continues the process of organic decomposition. Under these conditions, iron and manganese compounds are stripped of their oxygen by "anaerobic" bacteria and by oxygen-stealing chemicals called "reducing agents." In their reduced or deoxidized state, iron and manganese become soluble in water. A pocket of water with high concentrations of dissolved metals can form, usually at the deepest part of the reservoir just upstream from the dam.

(In some other types of stratified reservoirs, oxygen may be depleted throughout the entire hypolimnion, only in a thin layer at some middle depth, or only in a thin layer directly above the sediment. Shallow reservoirs and those with rapid "flow-through" rates may seldom or never become stratified.)

These processes are reversed during "fall overturn" or "destratification." When shorter days, the lower angle of solar radiation, and the cooler temperatures of autumn chill the surface water just below it. The colder water sinks, and the somewhat warmer water rises to the surface, where it is reoxygenated and cooled until it in turn becomes more dense and sinks. As this vertical cycling continues to mix the reservoir, layer by layer, temperatures and oxygen levels eventually become nearly uniform at all depths. During the mixing process, when the deepest water containing dissolved metals eventually comes into contact with water containing dissolved oxygen, soluble iron and manganese are rapidly reoxidized to insoluble compounds and they settle back to the sediment from which they came.

46. There were questions and concerns regarding the effects of the drawdown at Watauga Reservoir. In general, the questions and concerns centered upon how the drawdown would affect the water quality above and below the dam. Because water is usually drawn primarily from the hypolimnion, the low temperatures typical of this layer would allow the development of a cold-water fishery downstream where none was previously possible. However, this cold water might adversely affect an existing warm water fishery, and it was possible that it would be suitable for neither cold nor warm water fisheries. Upstream of the dam, the concern was that the depletion of much of this cold water would harm fisheries common to areas within the hypolimnion (mainly trout and walleye).

47. A pocket of dissolved iron and manganese at the reservoir bottom could also cause problems during the drawdown. By the time destratification began mixing the reservoir, there would be much less water than usual in the upper layers, possibly too little to provide adequate dilution for the dissolved metals that would rise from the bottom with the water from the hypolimnion. Even if the concentration were diluted below toxic levels, the sudden oxygen demand created by the oxidation of iron and manganese might further deplete the supply of dissolved oxygen available for fish in an area extending some distance upstream from the dam.

48. The following is an explanation of the sampling that was peformed a year before the extensive drawdown to assess its potential problem and to prepare measures to minimize its effects:

> The areas of the reservoir sampled near the dam averaged about 67 meters (220 feet) deep at that stage of a normal fall drawdown. The epilimnion extended to a depth of about 12 meters (40 feet) with nearly a uniform temperature of 20°C and oxygen content of 7.5 mg/L. In the next six meters (20 feet), the thermocline, temperatures decreased rapidly to about 16°C and oxygen content dropped to about 1 mg/L. In the first 12 meters of the hypolimnion, temperatures declined more slowly to about 10°C and dissolved oxygen recovered rapidly to about 5 mg/L.
>
> A sonar depth recorder (fish finder) showed that nearly all of the large fish (presumably trout and walleye) were concentrated in the middle of the upper layer of the hypolimnion. This zone ranged from 20 to 27 meters (about 70 to 90 feet) below the surface; temperatures there ranged from 11 to 14°C and oxygen levels ranged from 4 to 5 mg/L.
>
> In the remaining 37 meters (more than 120 feet) of the hypolimnion, temperatures declined slowly to 6.5°C at the bottom. Oxygen levels first rose to 6.5 mg/L at about 53 meters (175 feet) below the surface, then dropped to a minimum of 2 mg/L at the bottom.

49. These results indicated that none of the potential problems associated with the planned drawdown would significantly affect pre-

existing water quality or aquatic life unless conditions in 1983 were much more severe than those measured in 1982.

Effects of Stage Fluctuation on Water Quality

Nutrients, Temperature, and Dissolved Oxygen

50. A shift from stable to fluctuating water levels can reduce the tendency for much of a reservoir to stratify. This possibility is even more likely if changes in water levels result from selective discharges from the hypolimnion or from rapid rates of discharge where complete water exchange occurs six or more times per year. The temperatures of inflowing waters tend to dominate the thermal regime of reservoirs as the retention time of water in the basin decreases.

51. Prolonged filling of reservoirs has been observed to contribute more toward increasing fish production than rapid filling. Short-term fluctuations of water levels (days or weeks) have seldom been related to major changes in water chemistry or biological productivity. By contrast, large seasonal or annual changes have the greatest effect because low water levels of sufficient duration provide time for exposed soils to aerate, which increases the availability of nutrients and time for herbaceous terrestrial plants to colonize exposed sediments. When dewatered areas with vegetation are flooded for at least three months of the growing season, aquatic animals and plants have enough time to fully colonize the areas and benefit from the nutrients available. Nutrient retention and biological production are high as reservoirs fill, because most inflowing nutrients and those within the basin are retained. By contrast, drawdowns during periods of low inflow flush nutrients downstream.

52. The greatest oxygen demands result from repsiration of microorganisms associated with the decay of organic matter in organically rich sediments, herbaceous vegetation, or leaf and grass litter. Demands are greatest in the metalimnion and upper hypolimnion in summer, whereas primary sources are in the epilimnion which is reaerated from the atmosphere and photosynthesis in the euphotic zone. Organic load and water temperature are the major factors controlling oxygen demand at various depths; however, basic morphometry and mixing determine whether the demand for oxygen will exceed the supply.

53. Nutrient loading and oxygen demands in shoreline areas are controlled by the number and characteristics (vegetation and geology) of inundated areas, as influenced by basin slope, frequency and height of water level fluctuations, and reservoir age. For example, changes in concentrations of oxygen and nutrients are greater and more rapid over gently sloping shores than over steep rocky ones, because more area is involved and growths of terrestrial vegetation are more dense. In older impoundments (greater than ten years), where nutrient concentrations at high elevations are less than at low elevations because of erosion, reduced water levels may increase nutrient concentrations and biochemical oxygen demands by recirculating previously eroded sediments. By contrast, in reservoirs less than ten years old, where concentrations of nutrients in sediments usually vary less with elevation than in older reservoirs, reduced water levels probably would not greatly alter nutrient input.

54. Some effects of drawdowns have been found to be beneficial. For example, drawdowns have been successfully used to consolidate and

aerate sediments. Consolidation may reduce turbidity after sediments are reflooded, while aeration remineralizes nutrients such as nitrogen and phosphorus and reduces the organic load of sediments by aerobic decay. Drawdown may also disrupt thermal stratification and increase the rate of oxidation and decay of organic matter in sediments at low elevations in the basin by providing oxygen for aerobic metabolism.

Phytoplankton and Zooplankton

55. Productivity of reservoirs differs greatly seasonally and yearly due to variations in runoff from the drainage basin. High turbidity in inflowing water may limit productivity by reducing light, or if the retention time of water in the euphotic zone is low, phytoplankton may not have sufficient time to develop productive densities before being discharged through the dam.

56. Zooplankton and phytoplankton are rarely directly affected by changes in water level because they are suspended in the water column. Fluctuations in water levels have their greatest impact on zooplankton during the growing season primarily becuase the potential for production is low in winter due to low water temperatures. Because zooplankton concentrations are highest during the growing season and lowest in winter, the rapid discharge of water is more detrimental during summer than during winter. Because zooplankton usually are most abundant above a thermocline in the summer, discharge from the epilimnion would elimiante more biomass than would discharge from a greater depth. Water level changes that are small, rapid, or frequent have little effect on zooplankton because their productivity is mostly related to changes in trophic conditions (primary production and imput of detri-

tal foods). Zooplankton production may be increased substantially by increasing water levels during most of a single growing season and inundating terrestrial vegetation.

Benthos

57. Large seasonal changes in water levels are undoubtedly harmful to benthic populations in the fluctuation zone. Extensive winter drawdown reduces the production of benthos below its potential in the fluctuation zone in winter, spring, and perhaps early summer. The impact of changes in water levels on benthos is modified by basin morphometry and the frequency, timing, and duration of fluctuations. Slower drawdowns are less likely to harm benthos or young fish populations because neither are likely to suffer from exposure which is normally the case with rapid drawdowns. Because Center Hill Reservoir is generally a steep-sided, deep reservoir, its benthic populations are affected less by water level changes than other reservoirs that are shallow and gently sloping.

58. Inundating terrestrial vegetation, which is greatly lacking in Center Hill Reservoir, benefits benthos as they will thrive on terrestrial organic matter, then when this is consumed, their diets will shift to primary production and detritus (autochthonous foods).

Terrestrial Vegetation

59. Drawdown must occur during the growing season for the seeding of terrestrial plants to be a success.

> Herbaceous terrestrial plants that become established on suitable substrates after drawdown are beneficial. These

plants provide excellent spawning and nursery sites for many species of fish when inundated at the appropriate time. They also provide food and refuge for bacteria, zooplankton, benthos, and fish; substrates for attached algae; and nutrients for all aquatic plants.*

60. A potential danger of maintaining annual high water levels during the spawning season is that the higher lake level would no longer be effective for terrestrial vegetation if conditions became too wet. This could cause a retreat of the vegetation line which would result in conditions identical to those that existed prior to seeding. Thus, if seeding of terrestrial vegetation was an activity that could enhance the productivity of a reservoir, maintaining a higher lake level only every second or third year to give the vegetation time to recover should be considered (Lawrence, 1985).

61. A problem at Center Hill Reservoir would be to actually establish terrestrial vegetation. Because of the lake morphology and geology, it is doubtful that seeding would be of any benefit. The steep and rocky shoreline throughout the majority of the lake would render seeding efforts practically worthless. A possible alternative to enhance the productivity of Center Hill Reservoir would be to establish brushpiles and other structures in areas where accompanying vegetation or revegetation would not be likely.

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*Note: The literature presented in paragraphs 50 through 59 were taken from the literature review by Ploskey (1983).

Important Fisheries-Related Water Quality Parameters

Dissolved Oxygen

62. The presence of dissolved oxygen in bodies of water is of great importance and has received a great deal of attention over the years. Dissolved oxygen is needed for the maintenance of preferred aquatic life forms and as a terminal electron acceptor in the decomposition of organic materials. To be available for metabolic relationships the oxygen must not exist in a chemically combined form but must be held in simple solution. The amount of dissolved oxygen in simple solution is dependent upon four factors which are the temperature of the water, the partial pressure of the gas in the atmosphere above the water, the concentrations of dissolved salts in the water, and biological activity (Reid and Wood, 1976).

pH and Alkalinity

63. The pH and the range of its variations are dependent upon the buffering capacity within a lake. In water containing a bicarbonate in solution, for example, calcium bicarbonate, the pH is determined by the relation between CO_2 and carbonate, or more precisely by the H^+ ions arising from the hydrolysis of the bicarbonate. If some acid is added to this solution, a part of the bicarbonate is split off, which simultaneously combines with the acid. The free CO_2 released in its place is only weakly dissociated and increases the number of hydrogen ions only slightly. Thus, the hydrogen-ion concentration of the solution is altered very little. The decrease in the pH value thus brought about is very small in proportion to the amount of acid

added. Not until further additions have exhausted the bicarbonate will the reaction suddenly become strongly acidic. If, on the other hand, some alkali is added or the CO_2 is driven off, the shift of the reaction is likewise retarded because equilibrium CO^2 is continually split off from the remaining bicarbonate while the hydroxyl ions of the added alkali are bound in the precipitation of $CaCO_3$.

64. Accordingly, it is clear that the presence or absence of bicarbonates determines whether a water is alkaline or acid in its reactions. Since the point of neutrality brings about a sharp separation in the organic world in the sense that many species thrive only in alkaline or only in acid conditions, the content of calcium bicarbonate is a predominant factor in the composition of the organic community.

65. The natural solutions of calcium bicarbonate, which comprise the majority of natural waters, are continuously under the influence of plant and animal metabolism. The uptake and release of CO_2 alters the buffer mixture and disturbs the equilibrium. These interferences are profound and persistent, appearing to a greater or lesser degree in all habitable waters.

66. Consider the following equations which illustrate the interactions of CO_2, pH, and alkalinity.

(1) $CO_2 + H_2O \rightleftharpoons H_2CO_3$

(2) $H_2CO_3 \rightleftharpoons H^+ + HCO_3$

(3) $HCO_3 \rightleftharpoons H^+ + CO_3 =$

(4) $CO_3^= + Ca^{++} \rightleftharpoons CaCO_3$

CO_2 dissolves in H_2O forming carbonic acid which in turn ionizes to form a bicarbonate radical. If CO_2 is removed from the water, ionization of bicarbonate to carbonate occurs and the carbonate combines with Ca^{++} and precipitates out. If CO_2 is reintroduced into the system, then the equation force is reversed and Ca^{++} is brought back into solution (Ruttner, 1963).

67. In studies by Ruttner (1963) it was found that alkalinity in the epilimnion generally reached a late summer minimum and a spring maximum. This is caused by the removal of carbon dioxide by photosynthetic organisms in the epilimnion resulting in a shift to form CO_3 and the precipitation of Ca^{++} as $CaCO_3$. The $CaCO_3$ partially redissolves in the hypolimnion rich in free CO_2. Studies by Hutchinson (1960) showed that bicarbonate entered the bottom waters from the mud, thus enriching the hypolimnion. Another possible source of bicarbonate in the hypolimnion is the precipitation of $CaCO_3$ by bacterial action in the upper hypolimnion. The result is bicarbonate enrichment in the hypolimnion correlated with bicarbonate depletion in the epilimnion (Gnilka, 1967).

68. Contrary to studies by Ruttner, Gnilka (1967) found that there was an increase in pH as total alkalintiy increased from April through September 15 in Center Hill Reservoir. After that date, alkalinity increased while pH declined, indicating that bicarbonate was increasing more rapidly in late summer and early fall. The atypical late summer peak of alkalinity can best be explained by the influx of calcium rich waters from Great Falls Reservoir. Since water from Great Falls Reservoir is drawn off just above the thermocline, the penstock water is warm. As this water enters Center Hill Reservoir, it sinks to its own level near the thermocline, and bicarbonate and calcium diffuse into the epilimnion and hypolimnion.

Dissolved Solids and Specific Conductance

69. The total concentration of dissolved substances or minerals in natural waters is a useful parameter in describing chemical density and in measuring edaphic relationships that contribute to productivity within a body of water.

70. A measure of the total amount of ionized materials in water can be obtained through the determination of the electrical conductance of the solution. Commonly called specific conductance, this parameter closely approximates residues in solution and may be correlated with salinity. By definition, conductance is the reciporcal of the resistance measured between two electrodes separated by 1 cm and having a cross section of 1 sq cm. Conductivity is usually expressed as micromohs (reciprocal megohms) per centimeter at 25°C.

71. Most lakes occupying open basins have a total dissolved solids concentration of between 100 and 200 ppm. Evaporation from lakes in closed basins increases the concentration of dissolved solids, in some cases, to over 100,000 ppm.

72. The quantity and quality of dissolved solids often determine the variety and abundance of plants and animals in a given aquatic situation. Generally, the limiting nature of dissolved solids is essentially two-fold. First, the chemical density of the environment of aquatic organisms is a function of the total dissolved solids. According to principles of osmosis and diffusion, the water balance of plants and animals is governed by this enviornmental density factor. The second way in which dissolved solids influence the nature of the aquatic community relates to the supply of nutrients. The only source of nutri-

tionally important ions available to phytoplankton is the reservoir of matter dissolved in the water, and, in turn, the animal community is dependent upon the kinds and quantity of phytoplankton (Reid, 1961).

Nitrogen and Phosphorus

73. In natural waters the nutrients most frequently limiting algal growth are inorganic phosphorus and nitrogen. A cycle exists between bacteria and algae within natural waters that involves and explains the role of phosphorus and nitrogen as nutrients. Bacteria metabolize organic matter, releasing nitrogen, phosphorus, and carbon dioxide. Algae use these compounds, along with energy from sunlight, for photosynthesis, releasing oxygen into solution. Oxygen released by the algae is taken up by the bacteria, thus closing the cycle.

74. Nitrogen and phosphorus are introduced to surface waters from many sources. The most common natural origins are rainfall, runoff from fertile land, nitrogen fixation, and lake sediments. Nevertheless, the majority of nutrients entering surface waters come from man-generated wastes and runoff from agricultural land. Sixty percent of the phosphorus in domestic waste is from the phosphate builders used in synthetic detergents. Primary sources of nitrogen in domestic waste are feces, urine, and food wastes. Nitrogen and phosphorus contributions from agricultural land drainage vary from 3-24 lb of nitrogen and 0-15 lb of phosphorus per acre per year, depending on land use, fertilizer additions, topography, and hydrology.

75. Nutrient concentrations and loadings are closely related to the trophic level of lakes. The generally accepted upper concentration limits for lakes free of algal nuisances are 0.13 mg/L of inorganic

nitrogen and 0.02 mg/L of orthophosphate phosphorus at the time of spring overturn (Clark et al., 1977).

76. Because phosphorus is considered to be the major determinant of eutrophication and has been the focus of worldwide efforts to improve lake water quality, it will be discussed in more detail. The interpretation of the potential bioavailability of phosphorus forms indicates that some of the phosphorus entering lakes may have a limited effect on lake productivity. Some phosphorus sources, such as land runoff, are often high in particulate phosphorus, significant portions of which cannot be utilized in the growth of algae and higher plants. Based on existing information (mostly from Great Lakes studies), potentially bioavailable phosphorus in tributaries generally does not exceed 60% of the total phosphorus and is often considerably less. Whether potentially bioavailable particulate phosphorus actually becomes available in a receiving water depends upon factors such as the receiving water dissolved reactive phosphorus (DRP) concentration and the position (location) of the particle in the water.

77. Particulate phosphorus often comprises a high proportion of the total phosphorus input to lakes, and thus represents a major reservoir of phosphorus to organisms. The particulate phosphorus fraction can consist of inorganic, organic, and condensed forms. Of these, the inorganic fraction is most significant as a source of bioavailable phosphorus in most natural waters. The condensed particulate phosphorus compounds generally comprise a small proportion of the total particulate phosphorus pool. Organic phosphorus in eroded soil particles (the major source of particulate phosphorus in streams) is relatively stable,

and the fraction converted to DRP in natural waters is probably small. Organic and condensed phosphorus compounds in waste waters may be converted rapidly to inorganic phosphorus.

78. When developing a phosphorus management strategy for a whole lake or a portion of a lake, factors such as the DRP Concentration within the lake water and positional constraints should be considered in addition to the potential bioavailability of the total phosphorus sources. For example, in deep lakes with little reentrainment of sedimented particulate material back into the photic zone (water which is penetrated by at least 1% of available incident light), the opportunity for algal utilization of potentially bioavailable particulate phosphorus will be minimal (Armstrong et al., 1982).

PART IV: WATER LEVEL FLUCTUATIONS AND SPORT FISHING RELATIONSHIPS

Introduction

79. Sport fishermen have expressed concern for many years with the possible adverse effects of fluctuating water levels on fish populations. Fishermen rarely fish during rising or falling water, probably as a result of unsuccessful fishing trips in the past. A stable lake is always more attractive to sport fishermen.

80. There has been much recent interest in the effect of fluctuating water levels on the production and harvest of sport fishes (Allen and Aggus, 1983). Isolated but wide-spread studies have shown that fish populations in many lakes have benefitted from high water levels during the spawning season, low water levels during the summer growth period, and changes in rough fish ratios and predator-prey abundance attributed

to water level changes. However, there seems to be little consistency in these relationships between lakes of different types.

81. Ploskey et al. (1984) evaluated the effects of fluctuating reservoir water levels on the density and biomass of individual fish species in three types of reservoirs using correlation analyses. They generalized that reproductive success and survival of most important fish apparently was increased by above-average surface area in spring, summer, and fall, but extensive annual changes in surface area had a negative impact on sport-fish abundance. They reported the scarcity of quantitative data collected for four or more consecutive years from one reservoir is perhaps the greatest hinderance to statistical verification of cause/effect hypotheses that surpass simple testing for positive or negative effects.

82. The Tennessee Wildlife Resources Agency made available unpublished quantitative data on the numbers and biomass from cove rotenone studies made from 1957 to 1960. Additionally, TWRA provided creel census data for the years 1973 to 1985.

83. The U.S. Army Corps of Engineers had data available for determining the hydrologic variables used by Ploskey et al. (1984) for all years since Center Hill Reservoir was impounded.

84. This research project, commissioned and funded by the Nashville District, U.S. Army Corps of Engineers, was designed to related Center Hill fish production and harvest to the hydrologic variables tested by Ploskey et al. (1984) using the same techniques.

85. The major objective of the study was to correlate fish data from the cove rotenone samples for 1957 through 1960 with the ten previ-

ously considered hydrologic variables and to compare Center Hill results with the results of Ploskey et al. (1984).

86. A secondary objective was to correlate data from creel surveys of 1973 through 1985 with the same ten hydrologic variables.

Methods

Cove Rotenone Samples

87. One cove of 1.5 acres was sampled in August 1957, two coves totaling 4.6 acres were sampled in August 1958, five coves totaling 10.8 acres were sampled in 1959, and two coves totaling 5.7 acres were sampled in August 1960.

Fish Data

88. Fishes were collected and sorted by size. Fish density in number/acre and fish biomass in lbs/acre were determined by species. Data were grouped into three size classes (small, intermediate, and large) on the same basis as Ploskey et al. (1984).

89. Largemouth bass, smallmouth bass, spotted bass, white bass, channel catfish, flathead catfish, carp, and drum were classified as small (<3½ inches) and intermediate (3½ to 5½ inches).

90. White crappie, black crappie, rock bass, warmouth bass, bluegill, green sunfish, and longear sunfish were classified as small (<3½ inches) and intermediate (3½ to 5½ inches).

91. Redhorse and spotted suckers were classified as small (<3½ inches), intermediate (3½ to 12½ inches), and large (>12½ inches).

92. Walleye were classified as small (<5½ inches), intermediate (5½ to 12½ inches), and large (>12½ inches).

93. Threadfin shad were classified as small (<3½ inches), and large (3½ to 5½ inches).

94. Gizzard shad were classified as small (<4½ inches), intermediate (4½ to 9½ inches), and large (<9½ inches).

95. Assorted minnows of all sizes were included in one group.

Creel Data

96. The Tennessee Wildlife Resources Agency had a creel clerk stationed on Center Hill Reservoir on a year-round basis from 1973 through 1985. Monthly records of the catch by sport fishermen specifically fishing for certain species were available in terms of number of intented fish per hour and average weight of intented fish.

97. Creel records of average intented fish per hour were considered to be a measure of density and average weight of intented fish considered to be a measure of biomass. These data were treated as a group under the designation of "keeper" class.

98. Creel data were considered for the prime fishing seasons on Center Hill Reservoir. Black bass and white bass data were analyzed for March through May, while walleye data were analyzed for May through July.

Hydrologic Variables

99. The independent variables derived from surface area at the end of every month and monthly storage ratios (average monthly volume/total monthly discharge) as calculated by Ploskey et al. (1984) were used for correlations:

FSR (Fall Storage Ratio) = mean of monthly storage ratios in September and October of the previous year dA8-10 (Fall Change in Area) = difference in surface area on 31 July and 31 October of the previous year

FA (Fall Area) = mean of surface areas measured on 31 August, 30 September, and 31 October of the previous year

WSA (Winter-Spring Area) = mean of surface areas measured on 31 January, 28 February, and 31 March

SPSR (Spring Storage Ratio) = mean of monthly storage ratios in March, April, and May

dA3-5 (Spring Change in Area) = difference in surface area on 28 February and 31 May

SPA (Spring Area) = mean of surface areas measured on 28 February, 31 March, 30 April, and 31 May

dA6-8 (Summer Change in Area) - difference in surface area on 31 May and 31 August

SUA (Summer Area) = mean of surface areas measured on 31 May, 30 June, 31 July, and 31 August

dA/yr (Annual Change in Area) = maximum difference in area per year

A new parameter (Rate of Change) was calculated from Center Hill hydrologic records in terms of rise or fall in feet/week.

Statistical Methods

100. All correlations were completed by VAX/VMS version V3.6 on the TTU research VAX system using VMS 3.x Version of the Statistical Analysis System Release 4.10.

101. Rotenone sample data on density and biomass were correlated with the ten hydrologic variables. Correlation coefficients (r) were considered significant at Alpha = 0.05.

102. Creel data on numbers/hour and pounds/hour for non-intented species and numbers/hour and average weight of intented species were correlated with the ten hydrologic variables. Correlation coefficients (r) were considered significant at Alpha = 0.05.

103. All correlation coefficients were tested at Alpha = 0.05. Significant "r" values are listed in tabular form for discussion purposes.

Summary of Hydrovariables

104. When the significant "r" values for both density (numbers) and biomass (weight) correlations are grouped in Table 7 certain relationships appear.

105. There were no differences in the numbers of significant correlations between small (35), intermediate (33), and large fish (38) out of a total of 106. There were no differences between the numbers of significant correlations between density (51) and biomass (55).

106. If the number of significant correlations is considered as an indication of the cause-effect relationships between the tested hydrovariables and fish density and biomass, neither size of the fish (small, intermediate, or large) nor which fish parameter measured (density or biomass) makes a difference in Center Hill Reservoir.

107. When hydrovariables are ranked by number of significant correlations (density and biomass) in Table 7, it appears that SPA is the most important to small fishes and SUA is inconsequential. All the SPA correlations were positive indicating a direct relationship: the higher the Spring Area, the greater the density and biomass of small fish in the fall samples. This reflects the fact that higher water provides more spawning area and greater escape cover for small fish during the time when they are most vulnerable to predation.

Table 1

Significant "r" Values for Small Fish Density (Number/Acre)
for 1957-1960 Correlated with Hydrologic Variables
and Tested at Alpha = 0.05

Species:	FSR	dA-810	FA	WSA	SPSR	dA3-5	SPA	dA6-8	SUA	dA/yr
Black Bass:										
LMB	-	-	-	0.961	-	-	-	-	-	-
SPB	-	-	-	-	-	-	0.916	0.878	-	-
SMB	-	-	-	-	-	-	-	-	0.988	-
Other Sunfish:										
Bg	-	-	-	-	-	-	0.962	-	-	-
GS	0.975	-0.957	-	-	-	-	-	-	-	0.897
LS	-	-	-	-	-	-0.906	0.901	-	-	-
WMB	-	-0.932	-0.903	-	-	-	-	-	-	0.964
WC	-	-	-	-	-	-	0.928	-	-	-
BC	-0.948	-	-	-	-	-	-	-	-	-
Catfish:										
CC	-	-	-	-	-	-	-	-	-	-
FC	-	-	-	0.984	-	-	-	-	-	-
Forage Fish:										
TShad	-	-	-	0.891	-	-	-	-	-	-
AsstMin	-	-	-	-	-	-	0.955	-	-	-

$r_{tab(DF=3,\ Alpha\ =\ 0.05)} = 0.878$

Table 2

Significant "r" Values for Small Fish Biomass (Pounds/Acre) for 1956-1960 Correlated with Hydrologic Variables and Tested at Alpha = 0.05

Species:	FSR	dA8-10	FA	WSA	SPSR	dA3-5	SPA	dA6-8	SUA	dA/yr
Black Bass										
LMB	-	-0.891	-	0.938	-	-	-	-	-	-
SPB	-	-	-	-	-	-	-	-	-	-
SMB	0.914	-	-	-	0.895	-	-	-	-	-
Other Sunfish:										
Bg	-	-	-	-	-	-	0.901	-	-	-
GS	0.993	-0.965	-0.933	-	-	-	-	-	-	0.937
LS	-	-	-	-	-	-0.912	0.908	-	-	-
WMB	-	-0.885	-0.926	-	-	-	-	-	-	0.945
Catfish:										
CC	-	-	-	-	0.988	-	-	-	-	-
FC	-	-	-	-	-	-	-	-	-	-
Forage Fish:										
TShad	-	-	-	-	0.889	-	-	-	-	-
AsstMin	-	-	-	-	-	-	0.993	-	-	-

$r_{tab(DF=3,\ Alpha=0.05)}=0.878$

Table 3

Significant "r" VAlues for Intermediate Fish Density (Number/Acre)
for 1957-1960 Correlated with Hydrologic Variables
and Tested at Alpha = 0.05

Species:	FSR	dA8-10	FA	WSA	SPSR	dA3-5	SPA	dA6-8	SUA	dA/yr
Black Bass:										
LMB	-	-	-	-	-0.921	-	-	0.933	-	-
SPB	-	-0.8977	-	0.951	-	-	-	-	-	-
SMB	-	-	-	-	-	-	-	-	-	-
Other Sunfish:										
Bg	-	-	-	-	-	-	-	-	-	-
GS	-	-	-	-	-	-	-0.988	-	-	-
LS	0.973	0.949	0.959	-	-	-	-	-	-	-9.939
WMB	-	-	-	-	-	-0.913	-	-	-	-
WC	-0.940	-	-	-	-	-	-	-	-	-
RB	-	-	-	-	-	-	-	-	-	-
Catfish:										
CC	-0.935	-	-	-	-	-	-	-	-	-
FC	-	-	-	-0.905	-	-0.969	-	-	-	-
Forage Fish:										
GShad	-	-	-	-	-	-	-	-	-	-
TShad	-	-0.958	-	-	-	-	-	-	-	0.961
Other:										
WB	-	-	-	-	-	-	0.930	-	-	-
D	-	-	-	-	-0.951	-	-	-	-	-

$r_{tab(DF = 3, Alpha = 0.05)} = 0.878$

Table 4

Significant "r" Values for Intermediate Fish Biomass (Pounds/Acre)
for 1957-1960 Correlated with Hydrologic Variables
and Tested at Alpha = 0.05

Species:	FSR	dA8-10	FA	WSA	SPSR	dA3-5	SPA	dA6-8	SUA	dA/yr
Black Bass:										
LMB	-	-	-	0.970	-	-	-	-	-	-
SPB	0.923	-0.984	-	-	-	-	-	-	-	0.952
SMB	-	-	-	-0.957	-	-	-	-	-	-
Other Sunfish:										
Bg	-	-	-	-	-	-	-	-	-	-
GS	-	-	-	-	-	-	-0.963	-	-	-
LS	-	-	-	-0.954	-	-	-	-	-	-
WMB	-	-	-	-	-	-	-	-	-	-
WC	-	-	-	-	-	-	-	-	-	-
RB	-	-	-	-	-0.897	-	-	-	-	-
Catfish:										
CC	-	-	-	-	-	-	-	-	-	-
FC	-	-	-	-	-	-0.893	-	-	0.913	-
Forage Fish:										
GShad	-	-	-	-	-	-	-	-	-	-
TShad	0.882	-0.950	-	0.905	-	-	-	-	-	0.905
Other:										
WB	-	-	-	-	-	-	0.972	-	-	-
D	-	-	-	-	-	-	-	-	-	-

$r_{tab(DF = 3, Alpha = 0.05)} = 0.878$

Table 5

Significant "r" Values for Large Fish Density (Number/Acre) for 1957-1960 Correlated with Hydrologic Variables and Tested at Alpha = 0.05

Species:	FSR	dA8-10	FA	WSA	SPSR	dA3-5	SPA	dA6-8	SUA	dA/yr
Black Bass:										
SMB	-	-	-	-	0.946	-	-	-	-	-
Other Sunfish:										
Bg	-	-	-	-	-	-	-	-	-	-
GS	-	0.894	-	-	-	-	-	-	-	-0.881
LS	-	-	-	-	-	-	-	-	-	-
WC	-0.968	-	-	-	-	-	-	-	-	-
BC	-	-	0.930	-	-	-	-	-	-	-
RB	-	-	-	-	-	-	-	-	-	-
Catfish:										
CC	-	-	-	-	-	0.971	-	-	-	-
FC	-0.939	-	-	-	-	-	-	-	-	-
Forage Fish:										
GShad	-	-	0.915	-	-	-	-	-	-	-0.890
Other:										
D	-	-	-	-	-	0.880	-	-	-0.946	-
C	-	-	-	-	-	-	-0.995	-	-	-
GR	-	-0.900	-0.956	-	-	-	-	-	-	0.958

$r_{tab(DF = 3,\ Alpha = 0.05)} = 0.878$

Table 6

Significant "r" Values for Large Fish Biomass (Pounds/Acre) for 1957-1960 Correlated with Hydrologic Variables and Tested at Alpha = 0.05

Species:	FSR	dA8-10	FA	WSA	SPSR	dA3-5	SPA	dA6-8	SUA	dA/yr
Black Bass:										
SMB	-	-	-	-	0.905	-	-	-0.949	-	-
Other Sunfish:										
Bg	-	-	-	-	-	-	-	-0.879	-	-
GS	-	-	-	-	-	-	-	-	0.971	-
LS	-	-	-	-	-	-	-	-	-	-0.894
WC	-0.989	0.909	-	-	-	-	-	-	-	-
BC	-0.940	0.924	0.974	-	-	-	-	-	-	-0.930
RB	-	-	-	-	-0.909	-	-	-	-	-
Catfish:										
CC	-	-	-	0.942	-	0.972	-	-	-	-
FC	-0.943	-	0.914	-	-	-	-	-	-	-
Forage Fish:										
GShad	-	-	0.933	-	-	-	-	-	-	-0.901
TShad	-	-	-	0.975	-	-	-	-	-	-
Other:										
D	-	-	-	-	-	-	-	-	-0.992	-
C	-	-	-	-	-	-	-0.953	-0.910	-	-
GR	-	-	-	-	-	-0.968	-	-	-	-

$r_{tab(DF = 3,\ Alpha = 0.05)} = 0.878$

Table 7

Importance of Hydrologic Variables Expressed as Number of Significant Correlations and Ranked

Hydrovariable:	Significant Correlation (Number)	Significant Correlation (Weight)	Ranked Variable	Significant Correlation (Total)
Small Fish:				
FSR	2	2	SPA	8
dA8-10	2	3	dA8-10	5
FA	1	2	FSR	4
WSA	3	1	WSA	4
SPSR	0	3	dA/yr	4
dA3-5	1	1	FA	3
SPA	5	3	SPSR	3
dA6-8	1	0	dA3-5	2
SUA	1	0	dA6-8	1
dA/yr	2	2	SUA	1
Totals:	18	17		35
Intermediate Fish:				
FSR	3	2	WSA	6
dA8-10	3	2	FSR	5
FA	1	0	dA8-10	5
WSA	2	4	SPA	4
SPSR	2	1	dA/yr	4
dA3-5	2	1	SPSR	3
SPA	2	2	dA3-5	3
dA6-8	1	0	FA	1
SUA	0	1	dA6-8	1
dA/yr	2	2	SUA	1
Totals:	18	15		33
Large Fish:				
FSR	2	3	FA	6
dA8-10	2	2	dA/yr	6
FA	3	3	FSR	5
WSA	0	2	dA8-10	4
SPSR	1	2	dA3-5	4
dA3-5	2	2	SPSR	3
SPA	1	1	dA6-8	3
dA6-8	0	3	SUA	3
SUA	1	2	WSA	2
dA/yr	3	3	SPA	2
Totals:	15	23		38
Grand Totals:	51	55		106

108. Small fish were least affected by dA6-8 and SUA. The smaller fish would not have been present during June through August of the previous year, but their parents probably were. Lack of effect by SUA probably indicates the small fish have reached a size large enough by late spring to not be affected by water levels.

109. Intermediate fish were most affected by WSA and least affected by dA/yr. Large fish were most affected by FA and dA/yr and least affected by SPA.

110. The ranking of hydrovariables by total number of significant correlations (Table 8) shows that FSR, dA8-10, SPA, and dA/yr have the greatest and equal effect on fish density and biomass. The fish were least affected by dA6-8 and SUA.

Species Susceptibility

111. When fish species were ranked by the number of significant correlations with the hydrovariables by size (Table 9) certain relationships appear.

112. Of the small fish, green sunfish were affected most by the tested hydrovariables, while crappies and catfish were affected the least.

113. Among intermediate fish, threadfin shad were most susceptible, while bluegill and gizzard shad were the least. Among large fish, black crappie were most susceptible, and bluegill, longear sunfish, rock bass, and threadfin shad the least.

114. When fish species were ranked by the number of significant correlations with the hydrovariables for all fish (Table 9) the suscepti-

Table 8

Hydrovariables for All Fish Ranked by Number of Significant Correlations

Ranked Hydrovariable	Significant Correlation (Total)
FSR	14
dA8-10	14
SPA	14
dA/yr	14
WSA	12
FA	10
SPSR	9
dA3-5	9
dA6-8	5
SUA	5

Table 9

Fish Species Susceptibility as Measured by Number of Significant Correlations and Ranked

Significant Correlations	Number	Weight	Total	Ranked Species	Total
Small Fish:				GS	7
Black Bass				WMB	6
LMB	1	2	3	LS	4
SPB	2	0	2	LMB	3
SMB	1	2	3	SMB	3
Other Sunfish				SPB	2
Bg	1	1	2	Bg	2
GS	3	4	7	TShad	2
LS	2	2	4	AsstMin	2
WMB	3	3	6	WC	1
WC	1	nt	1	BC	1
BC	1	nt	1	CC	1
Catfish				FC	1
CC	0	1	1		
FC	1	0	1		
Forage Fish					
TShad	1	1	2		
AsstMin	1	1	2		
Total	18	17			
Intermediate Fish				TShad	6
Black Bass				SPB	5
LMB	2	1	3	LS	5
SPB	2	3	5	FC	4
SMB	0	1	1	LMB	3
Other Sunfish				GS	2
Bg	0	0	0	WB	2
GS	1	1	2	SMB	1
LS	4	1	5	WMB	1
WMB	1	0	1	WC	1
WC	1	0	1	RB	1
RB	0	1	1	CC	1
Catfish				D	1
CC	1	0	1	Bg	0
FC	2	2	4	GShad	0
Forage Fish					
GShad	0	0	0		
TShad	2	4	6		
Other					
WB	1	1	2		
D	1	0	1		
Total	18	15			

Table 9 (continued)

Significant Correlations	Number	Weight	Total	Ranked Species	Total
Large Fish				BC	5
Black Bass				GShad	4
SMB	1	2	3	GR	4
Other Sunfish					
Bg	0	1	1	GS	3
GS	2	1	3	WC	3
LS	0	1	1	CC	3
WC	1	2	3	FC	3
BC	1	4	5	D	3
RB	0	1	1	C	3
Catfish				Bg	1
CC	1	2	3	LS	1
FC	1	2	3	RB	1
Forage Fish					
GShad	2	2	4		
TShad	nt	1	1		
Other					
D	2	1	3		
C	1	2	3		
GR	3	1	4		
Total	15	23			
All Fish		GS	12		
		LS	10		
		TShad	9		
		FC	8		
		SPB	7		
		SMB	7		
		WMB	7		
		LMB	6		
		BC	6		
		WC	5		
		CC	5		
		GShad	4		
		D	4		
		GR	4		
		Bg	3		
		C	3		
		RB	2		
		AsstMin	2		
		WB	2		

bility of different species to being affected by these hydrovariables is indicated.

115. Green sunfish had the most correlations and white bass the fewest. There was no pattern to indicate a consistent cause/effect relationship between any of the hydrovariables and any of the fish species tested.

Ranking of Hydrologic Variables

116. When both density and biomass for all fish from the rotenone samples were ranked according to the number of significant correlations, the following pattern resulted.

Table 10

Significant Correlations/Total Correlations
for all Rotenone Studies

	Numbers	Weight	Total
Small	18/130 (13.8%)	17/110 (15.5%)	35/240 (14.6%)
Intermediate	13/150 (12.0%)	15/150 (10.0%)	33/300 (11.0%)
Large	15/130 (11.5%)	23/140 (16.4%)	38/270 (14.1%)
Total	51/410 (12.0%)	55/400 (13.8%)	106/810 (13.0%)

117. Only 13% of the 810 correlations calculated from the rotenone data were significant at Alpha = 0.05. This small percentage seems to indicate that the hydrologic variables tested had little effect on either the density or biomass of Center Hill Reservoir fishes in general.

Discussion

118. Neither density (fish/hour) nor biomass (average weight) of black bass, crappie, nor white bass from the March through May creel

samples showed correlation with any of the ten hydrovariables (Table 11).

119. Walleye density (fish/hour) from the May through July creel samples showed significant, negative correlation at Alpha = 0.05 with the Fall Change in Area (dA8-10), the difference in surface area on 31 July and 31 October of the previous year. In this analysis, this indicated a drop in the lake level and the concurrent reduction in surface area during September and October of the previous year resulted in a decrease in walleye density and conversely a rise resulted in an increase in density. This is the reverse of what would be expected when a drop in water should result in concentration of prey and better survival during the early fall.

120. Walleye average weight in the creel was negtively correlated with the Annual Change in Area (dA/yr). However, these fish were caught in the first half of the year, so this correlation based on the whole year's hydrovariable was disregarded (Table 12).

121. Average weight of black bass caught from September through November was negatively correlated with the Fall Storage Ratio (FSR) of the previous year. This indicates that lower water during the previous fall season resulted in heavier fish the next year. This phenomenon reflects the concentration of forage fish with the resultant improvement in feeding conditions.

122. The average weight of black bass caught from September through November was negatively correlated with the summer change in Area (dA6-8). This probably was the result of concentrated forage fish just prior to the time these bass were caught (Table 13).

Table 11

Black Bass, Crappie, and White Bass (Number/Hour and Pounds/Hour) in Creel Samples During March through May, 1975 through 1985, Correlated with Hydrologic Variables and Tested at Alpha = 0.05

Variable	Mean	Standard Deviation	Minimum	Maximum
BB35NO	0.20172727	0.08491536	0.11100000	0.34300000
BB35WT	1.60100000	0.17560581	1.30700000	1.92700000
C35NO	0.95563636	0.84422240	0.00000000	3.08100000
WB35WT	0.50163636	0.20448974	0.00000000	0.77400000
WB35NO	1.02290909	0.69827050	0.00000000	2.39100000
WB35WT	1.14490909	9.56273536	0.00000000	1.88900000
FSR	24.26718182	24.68713447	7.04600000	74.13000000
dA8-10	785.75454545	589.02526323	-458.00000000	1720.00000000
FA	16666.72727273	566.87531097	15678.00000000	17485.00000000
WSA	17243.45454545	965.44283763	15748.00000000	19105.00000000
SPSR	6.00790909	3.28975587	2.73000000	14.09300000
dA3-5	-916.49636364	795.56700174	-2332.00000000	0.00000000
SPA	17723.45454545	552.67175858	16991.00000000	18713.00000000
dA6-8	1146.50000000	677.36681643	575.10000000	2390.00000000
SUA	17402.36363636	278.55134993	16892.00000000	17894.00000000
dA/yr	3995.53636364	1611.98231645	2196.50000000	6720.00000000

Pearson Correlation Coefficients/N = 11

	BB35NO	BB35WT	C35NO	C35WT	WB35NO	WB35WT
FSR	-0.56031	-0.13218	-0.51819	-0.41620	-0.54420	-0.26889
dA8-10	-0.57542	-0.25821	-0.56461	-0.18426	-0.28446	-0.28205
FA	0.44981	-0.13320	0.27682	0.24053	0.26438	0.55547
WSA	0.37280	-0.15432	0.16553	0.06365	0.23205	0.12802
SPSR	-0.09516	0.20818	-0.07472	0.33974	0.14331	-0.01424
dA3-5	-0.08387	-0.26614	-0.38093	0.03485	-0.41191	0.10418
SPA	0.25908	-0.42034	-0.05404	0.02001	0.04331	0.19032
dA6-8	-0.47838	-0.46579	-0.16522	-0.08299	-0.15438	0.19868
SUA	-0.03011	0.11570	-0.02215	-0.11399	-0.31388	-0.25287
dA/yr	-0.01514	-0.51629	-0.21370	-0.56444	-0.14449	-0.97925

$r_{\text{tab(DF = 10, Alpha = 0.05)}} = 0.576$

No significant correlations between these data.

Table 12

Walleye (Number/Hour and Pounds/Hour) in Creel Samples During May through July, 1974 through 1985, Correlated with Hydrologic Variables and Tested at Alpha = 0.05

Variable	Mean	Standard Deviation	Minimum	Maximum
W57NO	0.18133333	0.07501555	0.08500000	0.32000000
W57WT	1.83800000	0.41959158	0.96700000	2.37200000
FSR	24.12791667	23.54320244	7.04600000	74.13000000
dA8-10	795.84166667	562.69954918	-458.00000000	1720.00000000
FA	16693.33333333	548.29625922	15678.00000000	17485.00000000
WSA	17304.75000000	944.68562592	15748.00000000	19105.00000000
SPSR	5.84508333	3.18696993	2.73000000	14.09300000
dA3-5	-841.63833333	801.65189713	-2332.00000000	0.00000000
SPA	17721.08333333	527.01586285	16991.00000000	18713.00000000
dA6-8	1087.67500000	677.22886440	440.60000000	2390.00000000
SUA	17406.50000000	265.97453740	16892.00000000	17894.00000000
dA/yr	4068.09166667	1557.37990312	2196.50000000	6720.00000000

Pearson Correlation Coefficients/N = 12

	W57NO	W57WT
FSR	-0.51077	-0.08515
dA810	-0.66565*	-0.18065
FA	0.50304	-0.27064
WSA	0.26287	-0.41708
SPSR	-0.12164	0.35815
dA3-5	-0.08149	-0.22941
SPA	0.35603	-0.31119
dA6-8	0.06331	0.02617
SUA	0.14589	0.21023
dA/yr	-0.00491	-0.58367*

*Significant: $r_{tab(DF = 11, Alpha - 0.05)} = 0.553$

Two significant correlations.

Table 13

Black Bass (Number/Hour and Pounds/Hour) in Creel Samples During September through November, 1974 through 1984, Correlated with Hydrologic Variables and Tested at Alpha = 0.05

Variable	Mean	Standard Deviation	Minimum	Maximum
BB911NO	0.19618182	0.07053342	0.10600000	0.29100000
BB911WT	1.48009091	0.31899074	0.94300000	1.90400000
FSR	19.58227273	18.35648711	7.04600000	72.38000000
dA8-10	767.28181818	580.97081135	-458.00000000	1720.00000000
FA	16729.45454545	559.88308845	15678.00000000	17485.00000000
WSA	17355.09090909	973.76716463	15748.00000000	19105.00000000
SPSR	5.53463636	3.14647016	2.73000000	14.09300000
dA3-5	-900.12363636	813.48591613	-2332.00000000	0.00000000
SPA	17761.63636364	532.74032562	16991.00000000	18713.00000000
dA6-8	1119.28181818	700.93947502	440.60000000	2390.00000000
SUA	17421.36363636	273.67947410	16892.00000000	17894.00000000
dA/yr	4237.91818182	1512.37349277	2196.50000000	6720.00000000

Pearson Correlation Coefficients/N=11

	BB911NO	BB911WT
FSR	0.15103	-0.58234*
dA8-10	-0.32589	-0.15151
FA	0.45597	0.07801
WSA	0.35019	-0.14501
SPSR	-0.40224	0.36976
dA3-5	0.46783	-0.50643
SPA	0.42997	-0.45506
dA6-8	0.16445	-0.58381*
SUA	0.29707	-0.52316
dA/yr	0.39500	-0.33553

Significant: $4_{(DF = 10,\ Alpha = 0.05)} = 0.576$
Two significant correlations.

123. Table 14 shows that of the non-intented bass, only the weight of spotted bass was correlated with the Rate of Change. If ROC affected weight of fish, there would be more correlations.

124. Table 15 shows no significant correlations between non-intented crappie, walleye, or white bass and the Rate of Change. Table 16 shows that of the intented black bass, crappie, walleye, and white bass, only the numbers (density) of white bass were significantly correlated with Rate of Change. A rapidly changing lake level might affect white bass numbers because this species moves over large distances and could compensate by movement for drastic changes in level.

125. Of the 100 correlation tests between creel data and the ten hydrovariables, only four were significant. This figure of 4% indicates there is little or no relationship between the parameters tested.

126. Of the 18 correlation tests between creel data covering eleven years and the Rate of Change, only two were significant. This is 11% and indicates little or no relationship between the parameters tested.

Summary

127. This project involved 928 correlation analyses of fish density and biomass with various parameters describing fluctuations in reservoir water levels. Only 112 tests showed significant correlation between the variables tested. An overall percentage of 12% indicates that water level fluctuations in steep-sided reservoirs such as Center Hill have little effect on density or biomass of any of the fish species tested.

Table 14

Non-Intented Bass (Largemouth, Smallmouth, and Spotted) Per Month in Creel Samples Between July 1973 and June 1985 Correlated with Average Monthly Rate of Change (Feet/Week) and Tested at Alpha = 0.05

Variable	Mean	Standard Deviation	Minimum	Maximum
ROC	0.18145833	4.35491218	-9.30000000	37.00000000
LMBNO	0.03279861	0.02863530	0.00000000	0.14400000
LMBWT	0.05468056	0.05227933	0.00000000	0.27800000
SMBNO	0.05158333	0.04196860	0.00000000	0.21700000
SMBWT	0.08320139	0.06777282	0.00000000	0.29500000
SPBNO	0.02456250	0.02875547	0.00000000	0.14500000
SPBWT	0.03054861	0.03388191	0.00000000	0.21900000

Pearson Correlation Coefficients/N = 144

	ROC
LMBNO	0.03023
LMBWT	0.03899
SMBNO	0.03255
SMBWT	0.14714
SPBNO	0.13320
SPBWT	0.18473*

$r_{tab(DF = 143, Alpha = 0.05)} = 0.175$

One significant correlation.

Table 15

Non-Intented Crappie, Walleye, White Bass, and Bluegill (Numbers and Pounds)
Per Month in Creel Samples Between July 1973 and June 1985
Correlated with Average Monthly Rate of Change
(Feet/Week) and Tested at Alpha = 0.05

Variable	Mean	Standard Deviation	Minimum	Maximum
ROC	0.18145833	4.35491218	-9.30000000	37.00000000
CRNO	0.09433333	0.16163743	0.00000000	1.07600000
CRWT	0.04953472	0.09633021	0.00000000	0.80500000
WNO	0.03626389	0.03637143	0.00000000	0.15700000
WWT	0.06793056	0.06662279	0.00000000	0.31500000
WBNO	0.04010417	0.08576392	0.00000000	0.77000000
WBWT	0.04416667	0.07963360	0.00000000	0.57600000
BGNO	0.14154167	0.18740584	0.00000000	0.89800000
BGWT	0.04509722	0.05774193	0.00000000	0.29500000

Pearson Correlation Coefficients/N = 144

	ROC
CRNO	-0.06344
CRWT	-0.05826
WNO	-0.04765
WWT	-0.04299
WBNO	0.11762
WBWT	0.16475
BGNO	-0.12048
BGWT	-0.11165

$r_{tab(DF = 143, Alpha = 0.05)} = 0.175$
There were no significant correlations between these variables.

Table 16

Intented Black Bass, Crappie, Walleye, and White Bass (Number/Hour) in Creel Samples from July 1974 through June 1985 Correlated with Average Monthly Rate of Change (Feet/Week) and Tested at Alpha = 0.05

Variable	Mean	Standard Deviation	Minimum	Maximum
ROC	0.10090909	4.02160092	-9.30000000	37.00000000
IBNO	0.17989394	0.09779362	0.00000000	0.45800000
ICNO	0.80483333	1.01568474	0.00000000	5.53200000
IWNO	0.13934091	0.12135795	0.00000000	0.48000000
IWBNO	0.22961364	0.51972843	0.00000000	3.33300000

Pearson Correlation Coefficients/N = 132

	ROC
IBNO	0.0132
ICNO	-0.07751
IWNO	0.02453
IWBNO	0.18883*

$r_{tab(DF = 131, Alpha = 0.05)} = 0.177$
One significant correlation.

PART V: FISHING SUCCESS UNDER VARIOUS RATES OF WATER LEVEL CHANGE IN CENTER HILL LAKE

Introduction

128. The Nashville District, U.S. Army Corps of Engineers, are conducting a study of the feasibility of changing the operation of hydropower systems at Center Hill, Dale Hollow, and Wolf Creek Dams. If hydropower operations are changed to a peaking power regime, the question of the reglationship between water level fluctuations and sport fishing success is foremost in the minds of sport fishermen.

129. Fishermen typically desire stable water levels and regard sudden rises and falls in water surface elevations as precursors of poor fishing. Most area fishermen feel that dropping lake-levels certainly produce poor fishing as sport fish avoid the bank areas and suspend in deep water; fish suspended are less likely to "bite" according to local legend.

130. Laflin (1985) conducted a study of water level fluctuations on the sport fishery of Barren River Lake in Kentucky from 1974 to 1981. Her abstract is quoted as follows:

> The effects of various water level fluctuation rates during the fall drawdown on abundance and harvest of fish in shoreline areas and the overall sportfish harvest were sudied in 1974-1981 at Barren River Lake, a 10,000 acre flood control reservoir. Shoreline fish activity increased during either a slow rise or fall in the water level. Black bass occurrence was greatest during a 2-foot decline below summer pool or

a 1- to 2-foot rise in water levels during a 15-day period. Sunfish and catfish were more prevalent during stable water levels. Crappie ramined relatively unaffected by water level rises, but a rapid decrease from 1 to 2 feet resulted in the number of crappie increasing in shoreline areas. Maximum fisherman-use occurred during stable water level periods; however, maximum fisherman-catch occurred during slow water level fluctuations. White bass and crappie harvest were highest during stable water levels. Maximum water levels within ±2 feet of summer pool were preferred by fishermen. Total harvests of black bass and sunfish were higher when the water level exceeded summer pool at some time during the fall drawdown period. A slow drawdown of 1 to 2 feet per 15-day period resulted in the greatest occurrence and harvest of sportfish in shoreline areas. Although greatest fisherman-use of the shoreline areas occurred during a very slow drawdown, a more rapid drawdown resulted in a high catch rate.

131. Because of a lack of general information on the effects of water level fluctuations on sport fishing success and the possibility that such effects were site specific, we decided to look into this situation beginning with Center Hill Lake, Tennessee.

Methods of Analysis

132. Creel data were obtained from the Tennessee Wildlife Resources Agency for the period of July 1973 through June 1985. These data in-

cluded all fishermen interview summaries and were used to compute the sport fish catch in numbers per hour. The catch rates were averaged on a daily basis. Average catches of largemouth, smallmouth, Kentucky, and white bass, crappie, walleye, and bluegill were developed. Thus, a good data base on the rate of sport fishing success on a daily average basis was developed which covered a complete and recent time period.

133. Water level changes for each day were determined from computer tapes of daily water surface elevations from 1973 to 1985 which were supplied by the Nashville District, U.S. Army Corps of Engineers. Increases in elevation were considered positive and decreases negative, i.e., "+" equals a rise and "-" equals a fall in water level. The range of water level changes ranged from -4.0 to +4.0 feet per day. These data points were sorted and plotted on a VAX 11/785 computer interfaced with a Cal-Comp plotter and Regis software.

Results and Discussion

134. Eight plots were prepared, one for each species, which showed the relationship of the catch rate in number/hour and the rate of water level change. The water level change rate was held constant at -4 to +4 ft/day on all graphs. The graphs were expected to show a Christmas tree spread of data if the changes in water levels did decrease the catch rate. For example, the highest catch rates would occur at the 0.0 rate of change (stable pool) and decrease with rises and falls in pool elevations.

135. This analysis considered only water level fluctuations as the causative agent in fishing success or failure. Other factors such as season, moon phases, and weather were not considered. In essence,

the hypothesis tested: is water level fluctuation the single most important factor in fishing success on a daily basis?

Largemouth Bass

136. Figure 1 shows the catch of largemouth bass as a function of water level change rates. The best catches were made at relatively stable water levels of -0.5 to +0.5 ft/day. The poorest catches were evident at the greatest fluctuations. Occasional fair catches are made on rising waters but falling levels decrease the success rate.

Smallmouth Bass

137. Figure 2 shows the effects of changing water levels on smallmouth bass success. Poor fishing is evident at the higher rates of rise and at dropping levels greater than one ft/day.

Kentucky Bass

138. The best catches of Kentucky bass are on stable pools. Success declines dramatically on dropping pools and whenever a rise of more than two ft/day occurs as shown by Figure 3.

Walleye

139. The best catches are on stable pools and pronounced decrease in success occurs whenever pool levels fluctuate. Figure 4 shows one of the better "Christmas-tree" data patterns.

White Bass

140. Figure 5 shows that white bass also are best caught on stable pools and that both drops and rises cause the success rate to dramatically decline. No white bass were caught at rises or falls above 1.5 ft/day.

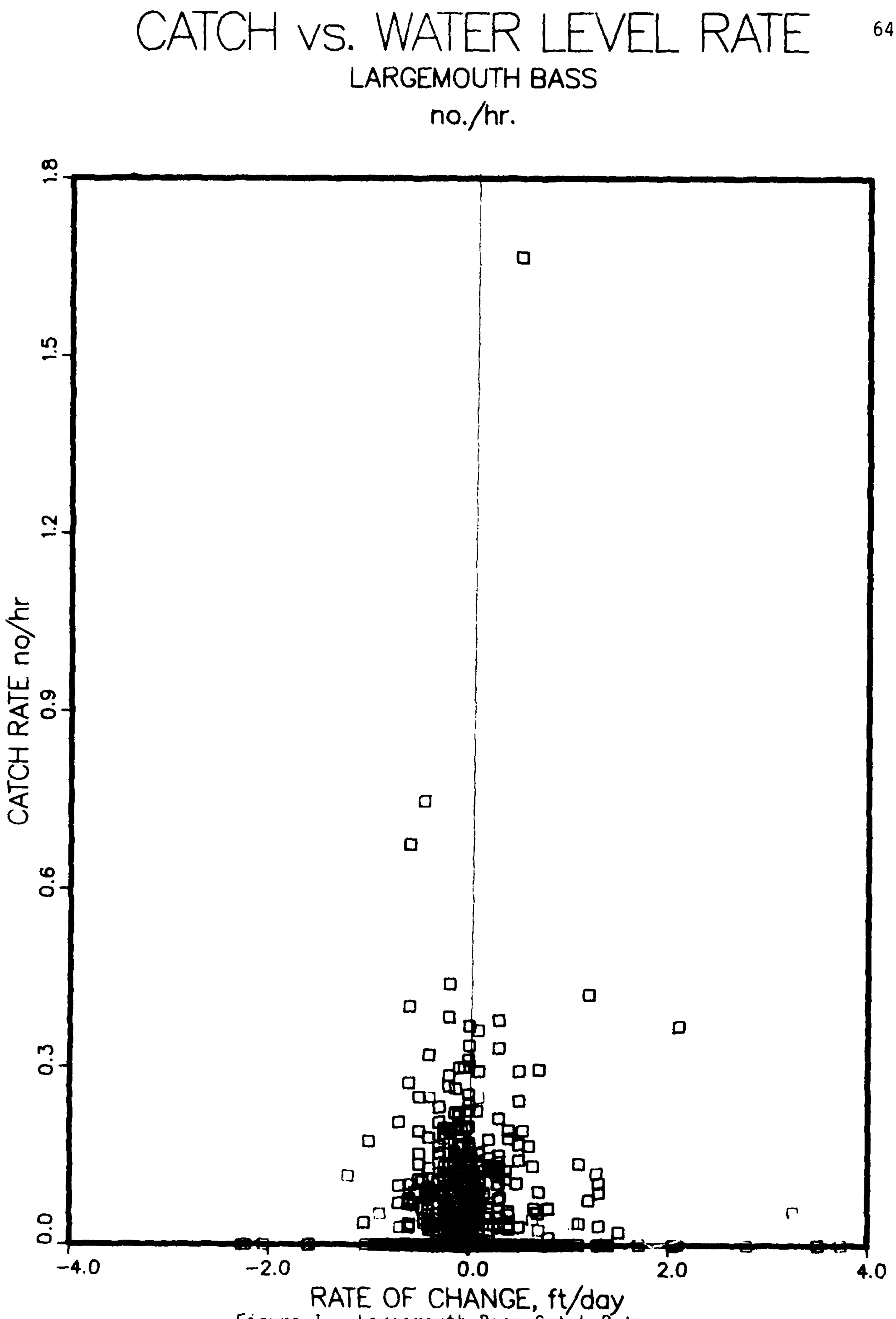


Figure 1. Largemouth Bass Catch Rate as a Function of Water Level Change

Hill Lake

CATCH vs. WATER LEVEL RATE

SMALLMOUTH BASS

no./hr.

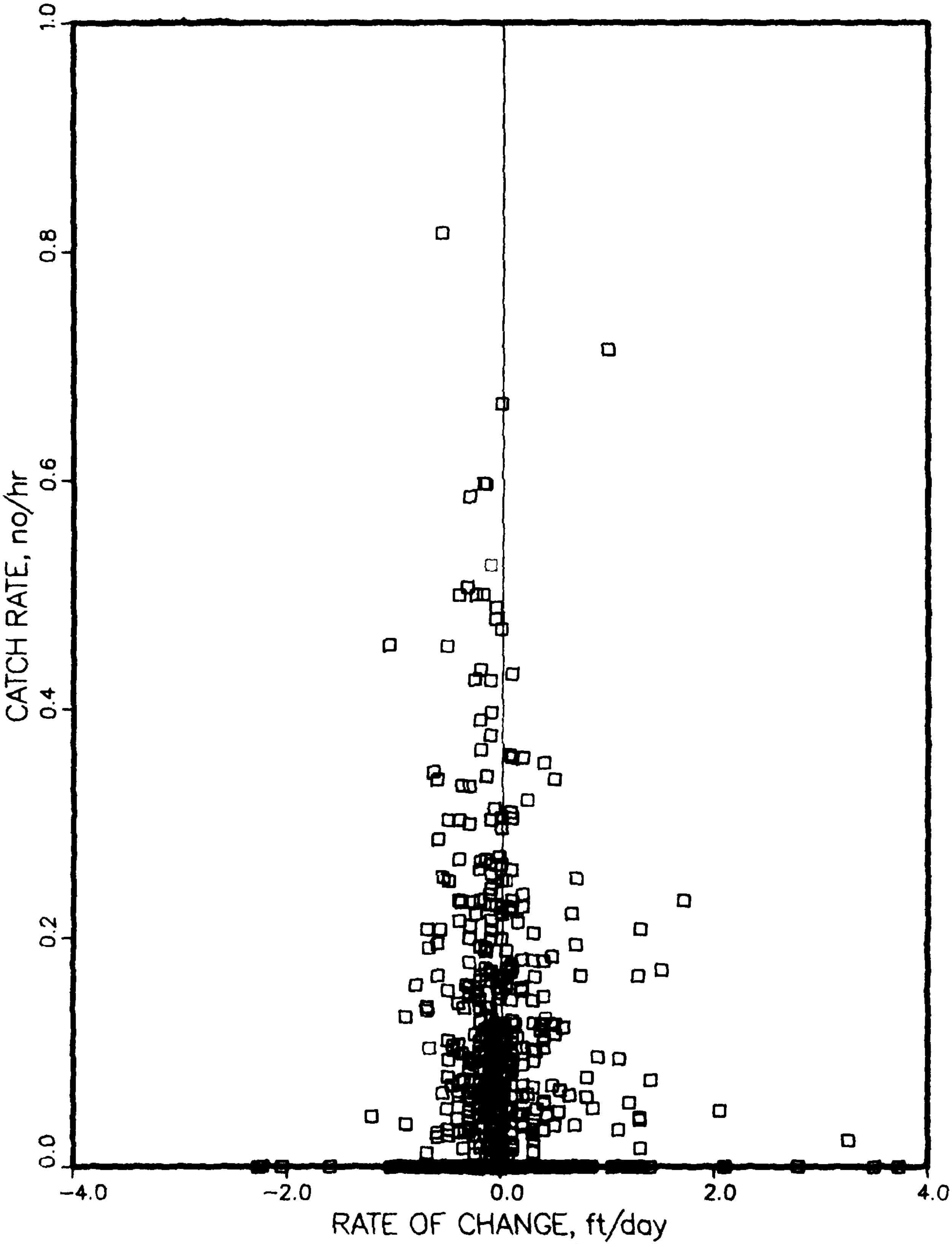


Figure 2. Smallmouth Bass Catch Rate as a Function of Water Level Change

Center Hill Lake

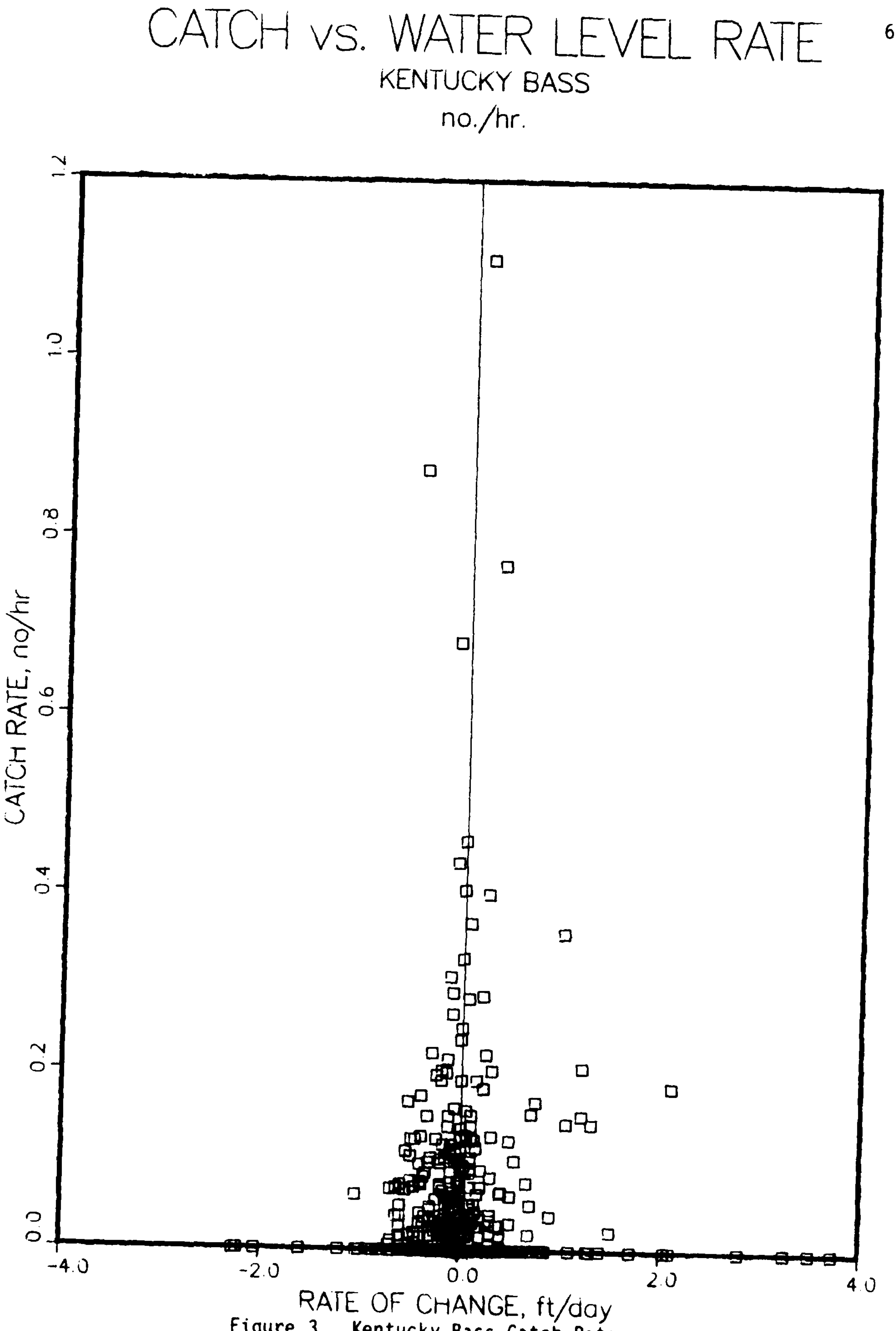


Figure 3. Kentucky Bass Catch Rate as a Function of Water Level Change

Center Hill Lake

CATCH vs. WATER LEVEL RATE

WALLEYE

no./hr.

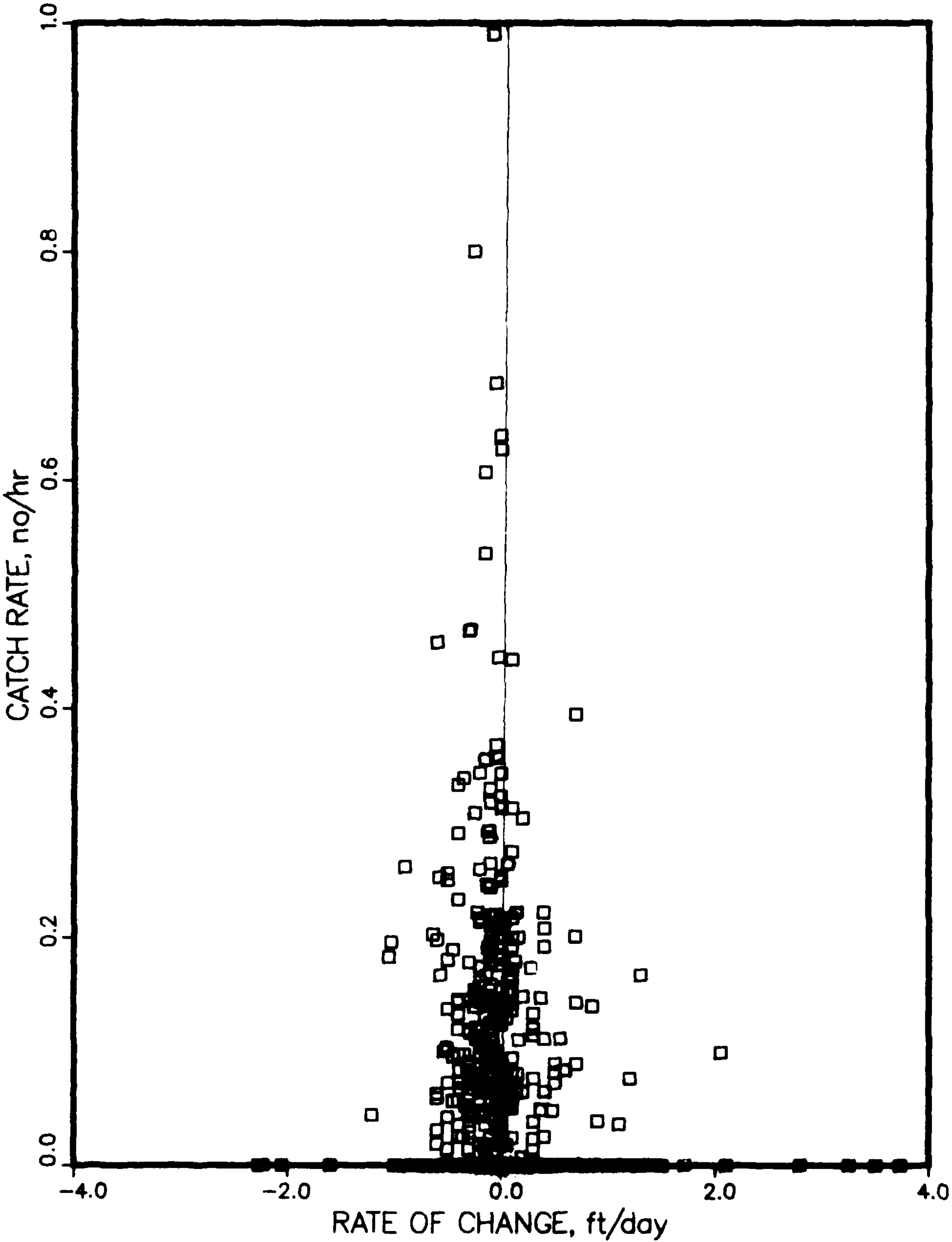


Figure 4. Walleye Catch Rate as a Function of Water Level Change

Center Hill Lake

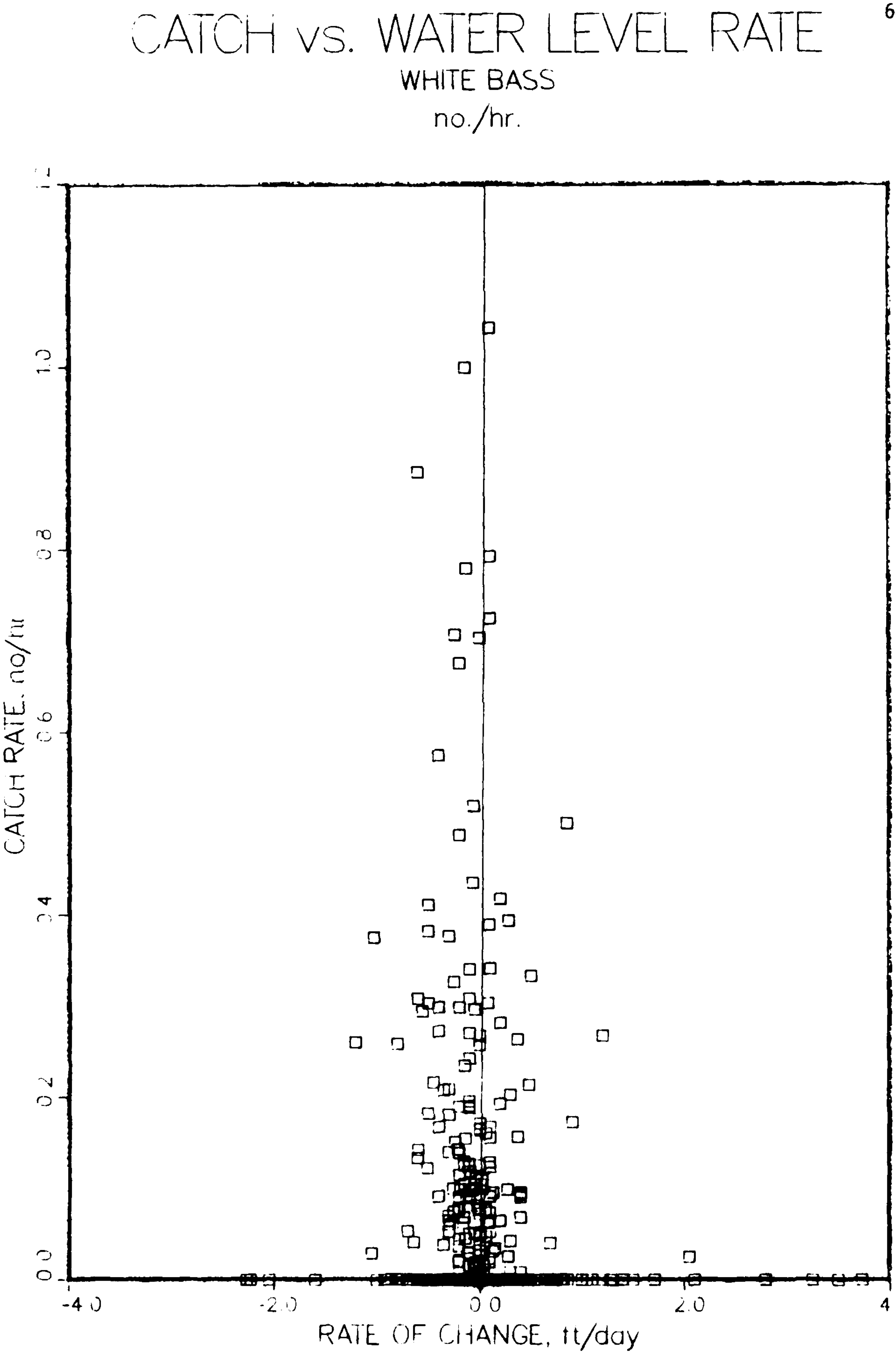


Figure 5. White Bass Catch Rate as a Function of Water Level Change

Center Hill Lake

White Crappie

141. Figure 6 shows that white crappie react similarly to white bass. The best catches were at stable water levels.

Black Crappie

142. Black crappie are not often caught on Center Hill Lake. Figure 7 shows, however, that the catch response is similar to white crappie but some fish are caught at moderate rises.

Bluegill

143. Figure 8 shows that bluegill are not caught at falling pools above 0.5 ft/day. Rises up to 2 ft/day produce scattered catches, but above 2 ft/day, no bluegill were caught.

Summary

144. Most of the highest catch rates of sport fish on Center Hill Reservoir occur when the pool is stable or fluctuates less than 0.5 ft/day. Success is poorer on falls above 0.5 ft/day and is very poor on falls greater than 1 ft/day. Rises up to 1 ft/day can produce fair catches while rises above 2 ft/day usually produce no fish. This pattern is shown by Table 17.

Creel Data Trends for Center Hill Reservoir

145. The creel data for the Center Hill Reservoir were analyzed for long term trends over the period from 1973 to 1985. The catch rates for several sport fish in numbers per hour were plotted as a

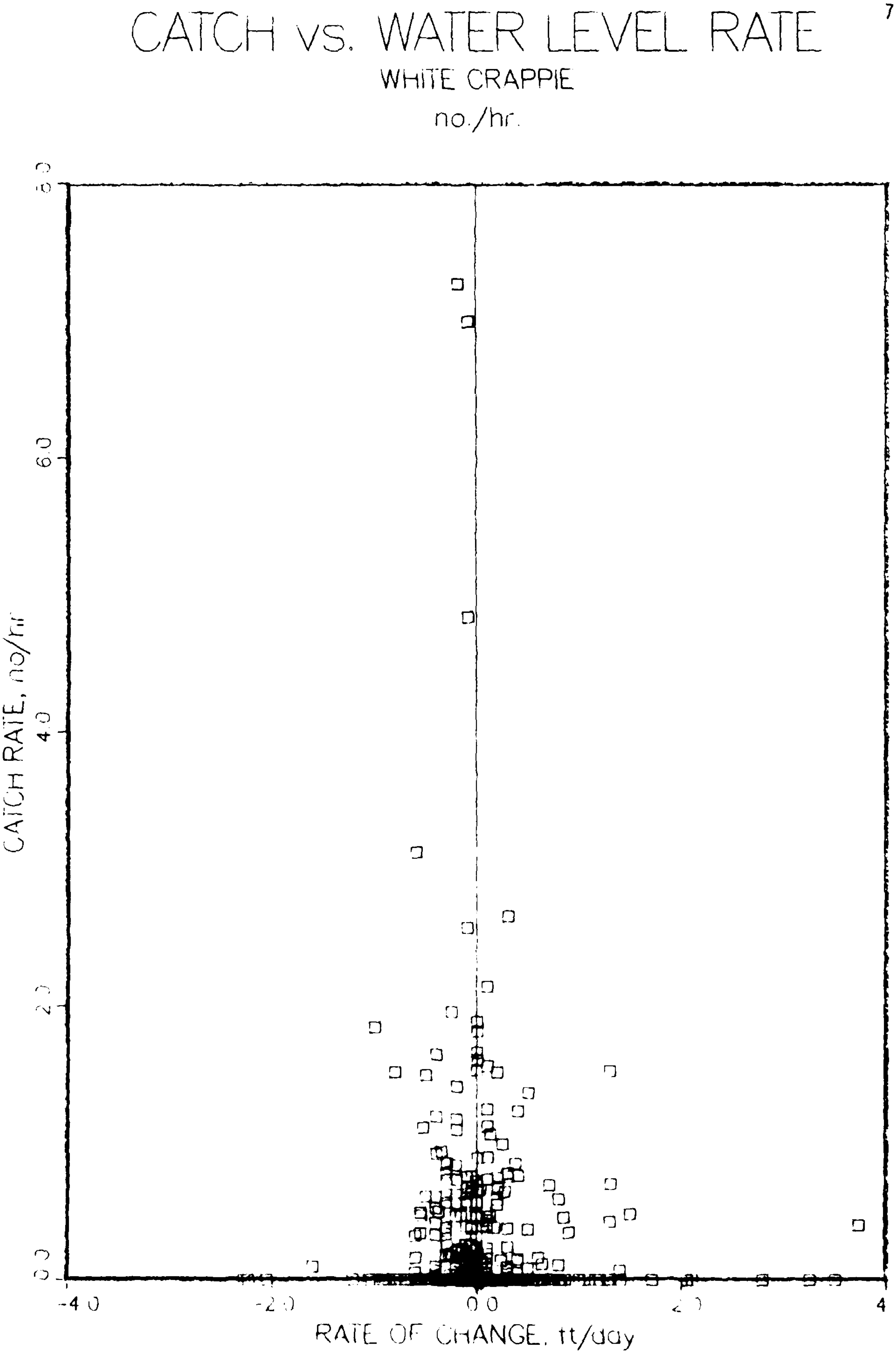


Figure 6. White Crappie Catch Rate as a Function of Water Level Change

Center Hill Lake

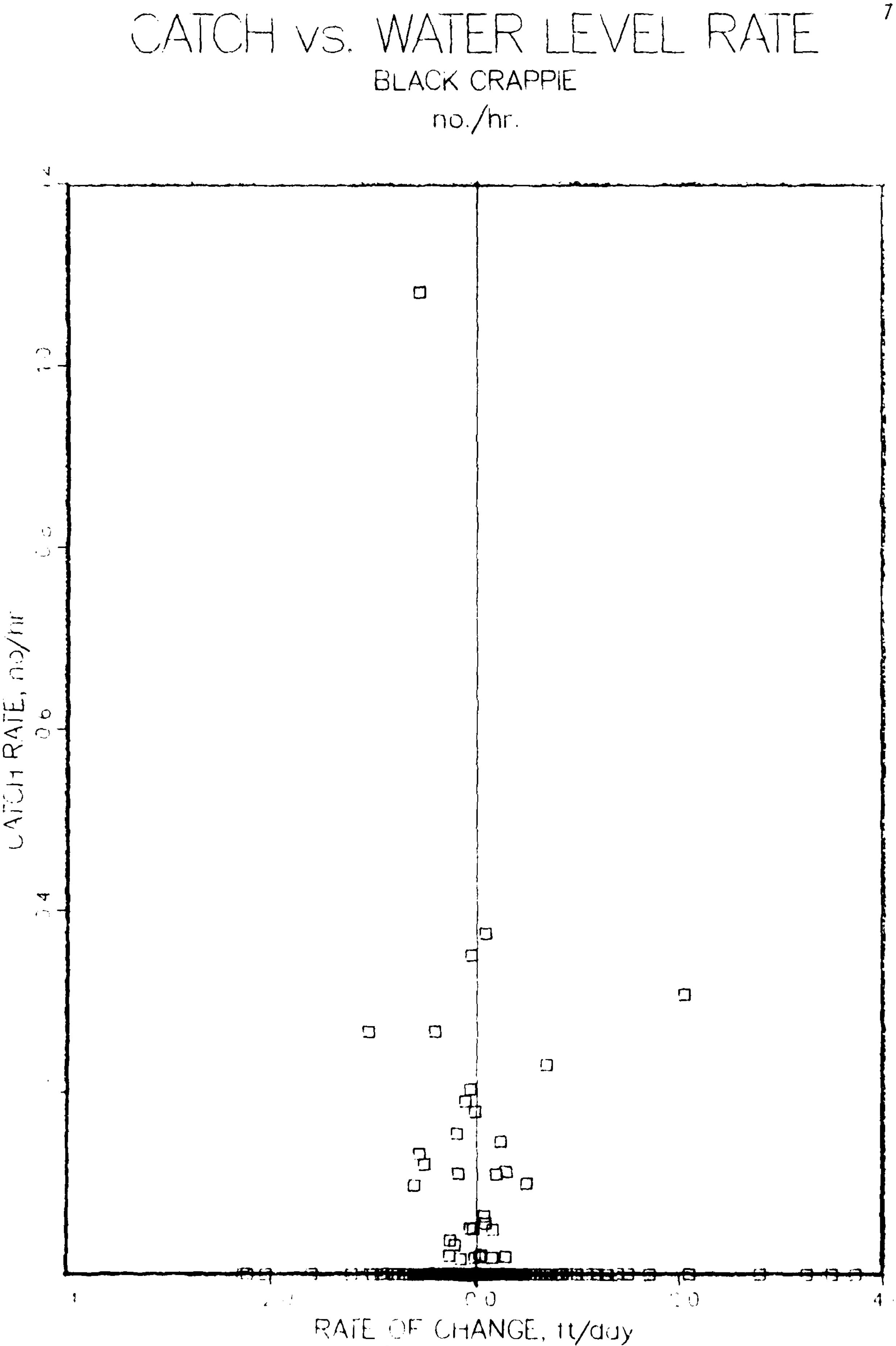


Figure 7. Black Crappie Catch Rate as a Function of Water Level Change

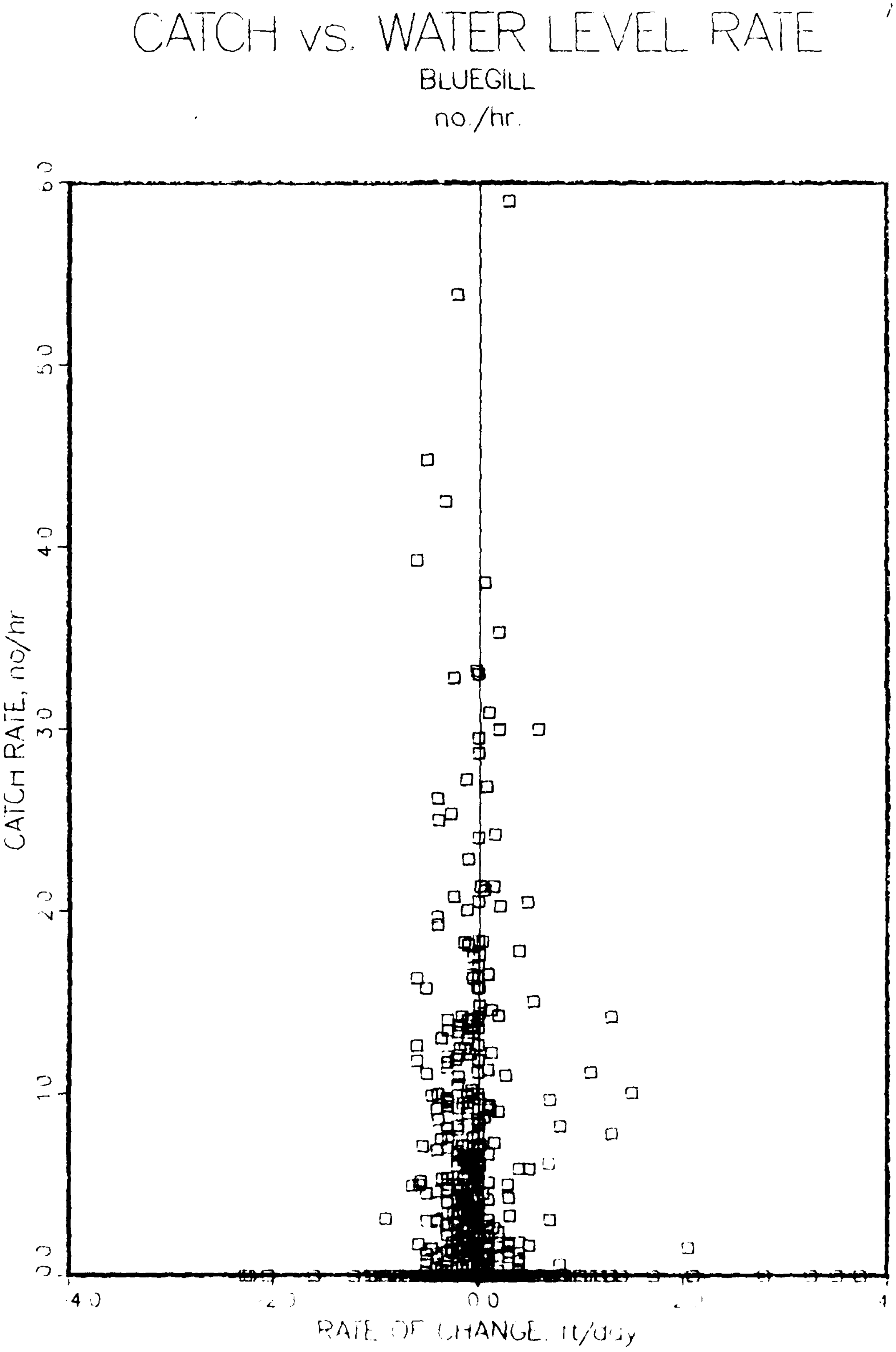


Figure 8. Bluegill Catch Rate as a Function of Water Level Change

Hill Lake

Table 17

Effect of Water Level Fluctuations Upon Several Species of Sport Fish in Center Hill Reservoir

Fish Species	Stable Levels 0-0.5 ft/day	0-1 ft/day Fall	0-2 ft/day Rise	>1 ft/day Fall	>2 ft/day Rise
Largemouth	Best	Fair	Poor	Poor	Poor
Smallmouth	Best	Good	Fair	Poor	Poor
Kentucky	Best	Poor	Fair	None	None
Walleye	Best	Good	Fair	Poor	None
White Bass	Best	Good	Fair	Poor	None
White Crappie	Best	Good	Fair	Poor	None
Black Crappie	Fair	Poor	Fair	None	None
Bluegill	Best	Good	Fair	None	None

Best = best fishing success
Good = good fishing success
Fair = fair fishing success
Poor = poor fishing success
None = no catch situation

regular creel extends from July 1973 to June 1985 and the intented creel from July 1974 to June 1985. The plots are presented as Figures 9 to 19 and are discussed in the following paragraphs.

Creel Results

Intented Black Bass

146. There has been very little change in the catch rate for intented black bass over the 1974 to 1985 periods as shown by Figure 9. Fishing for black bass was best in 1974 through 1976, declined slightly from 1977 to 1981, and has recovered since 1981.

Largemouth Bass

147. The regular creel for largemouth bass is shown by Figure 10. Although there are annual differences, no long term trends are apparent.

Smallmouth Bass

148. The regular creel for smallmouth bass is shown by Figure 11. Smallmouth catch rates have declined almost steadily over the period of record. Fishing for smallmouth was poor during 1984 and early 1985. Success was also fairly poor during 1979 and 1980.

Kentucky Bass

149. The regular creel for Kentucky bass is shown by Figure 12. In the long-term, Kentucky bass catch rates increased dramatically beginning in 1982 and this trend appears to continue through 1985. Catch rates were also very good in 1975 and 1976. It appears that the decline in smallmouth in the creel is being offset by increased numbers of Kentucky bass.

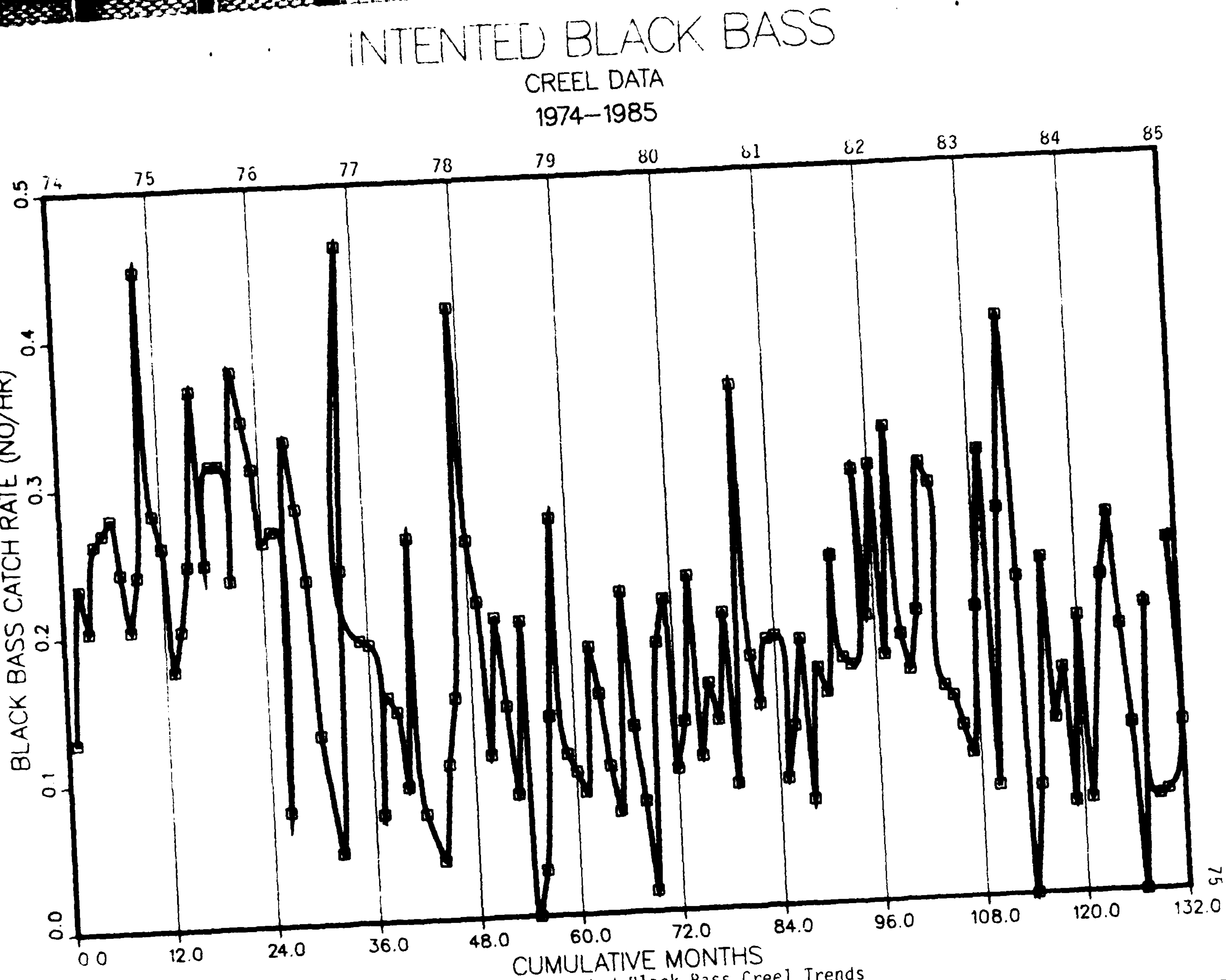


Figure 9. Intented Black Bass Creel Trends

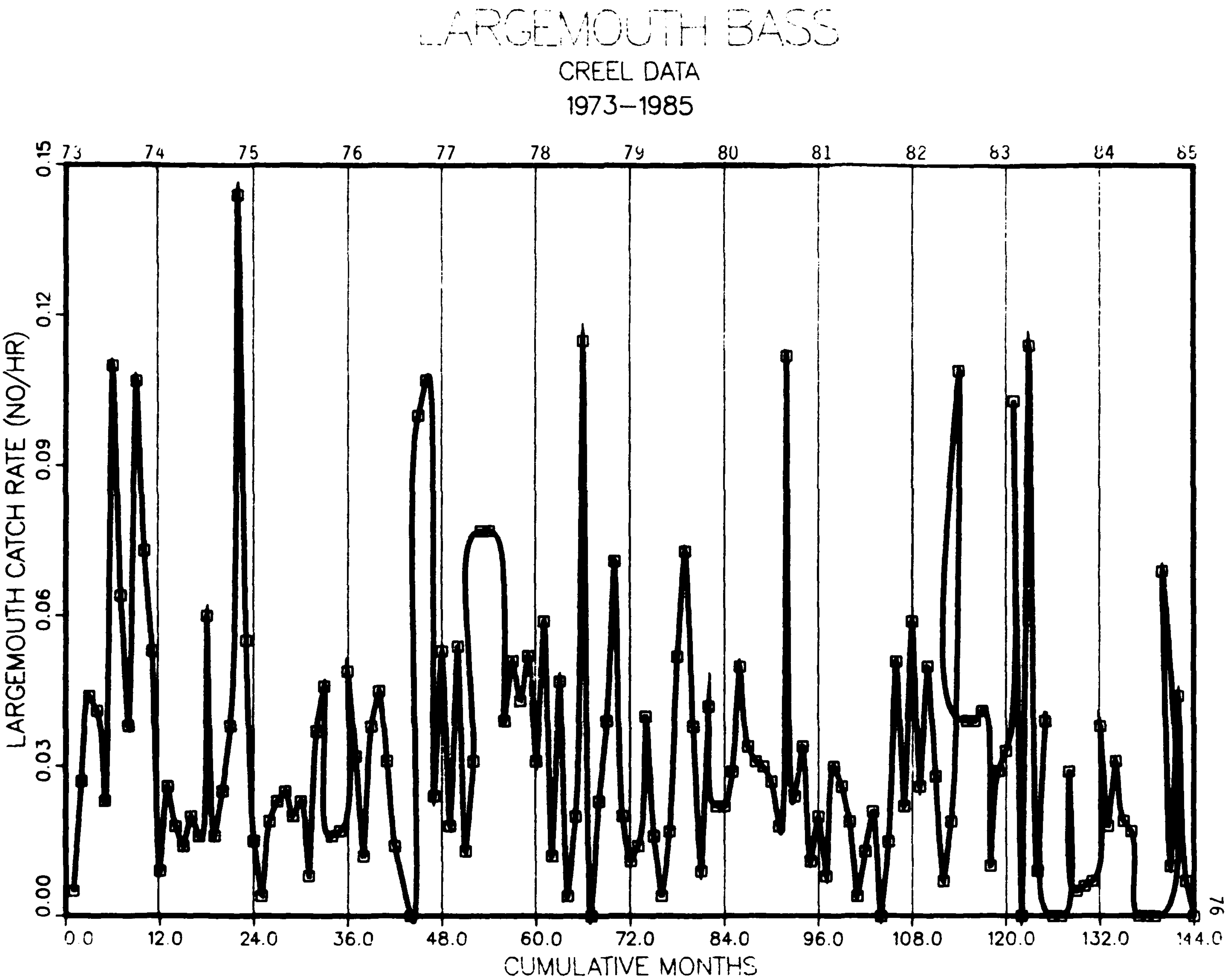


Figure 10. Largemouth Bass Creel Trends

CENTER HILL LAKE

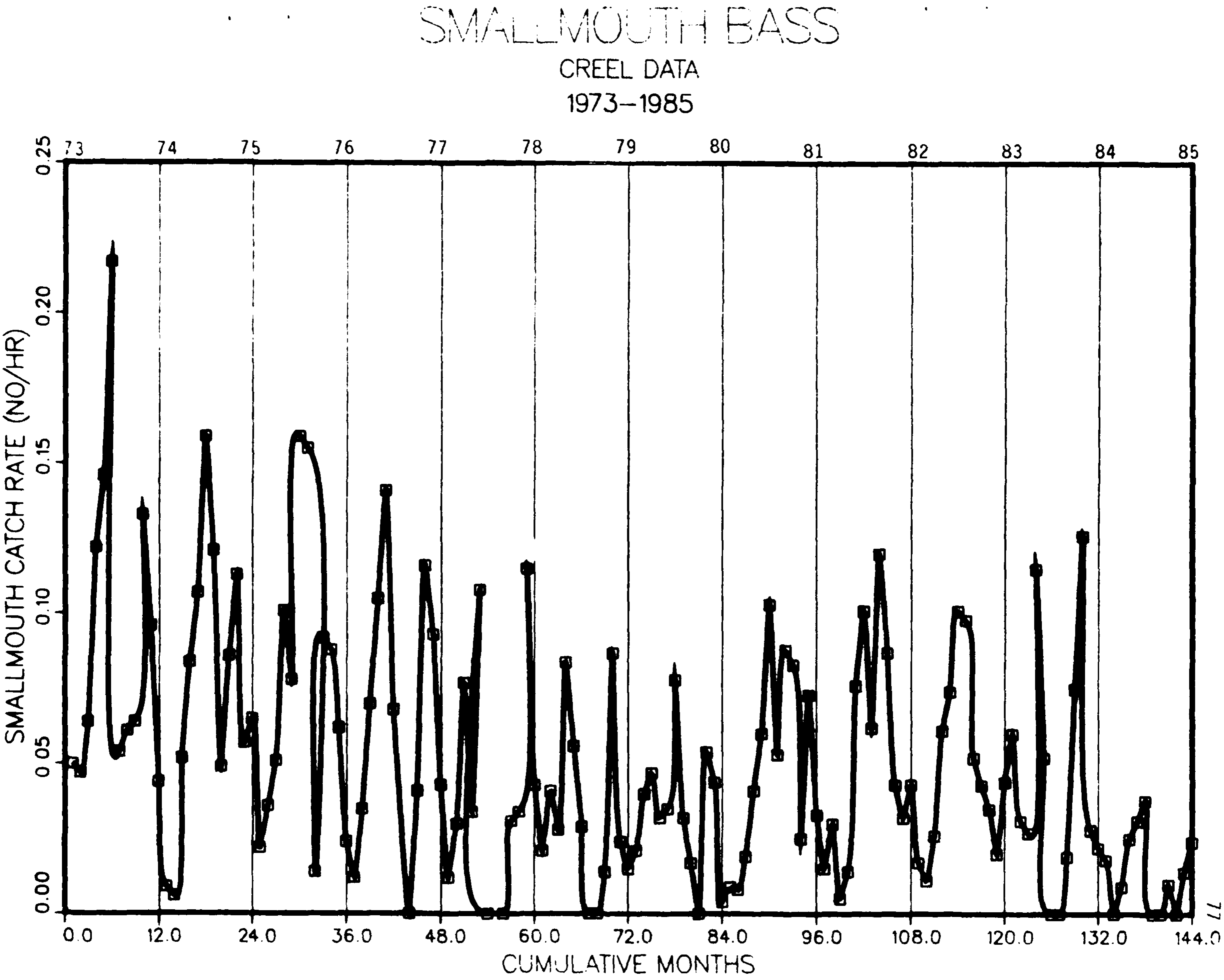


Figure 11. Smallmouth Bass Creel Trends

CENTER HILL LAKE

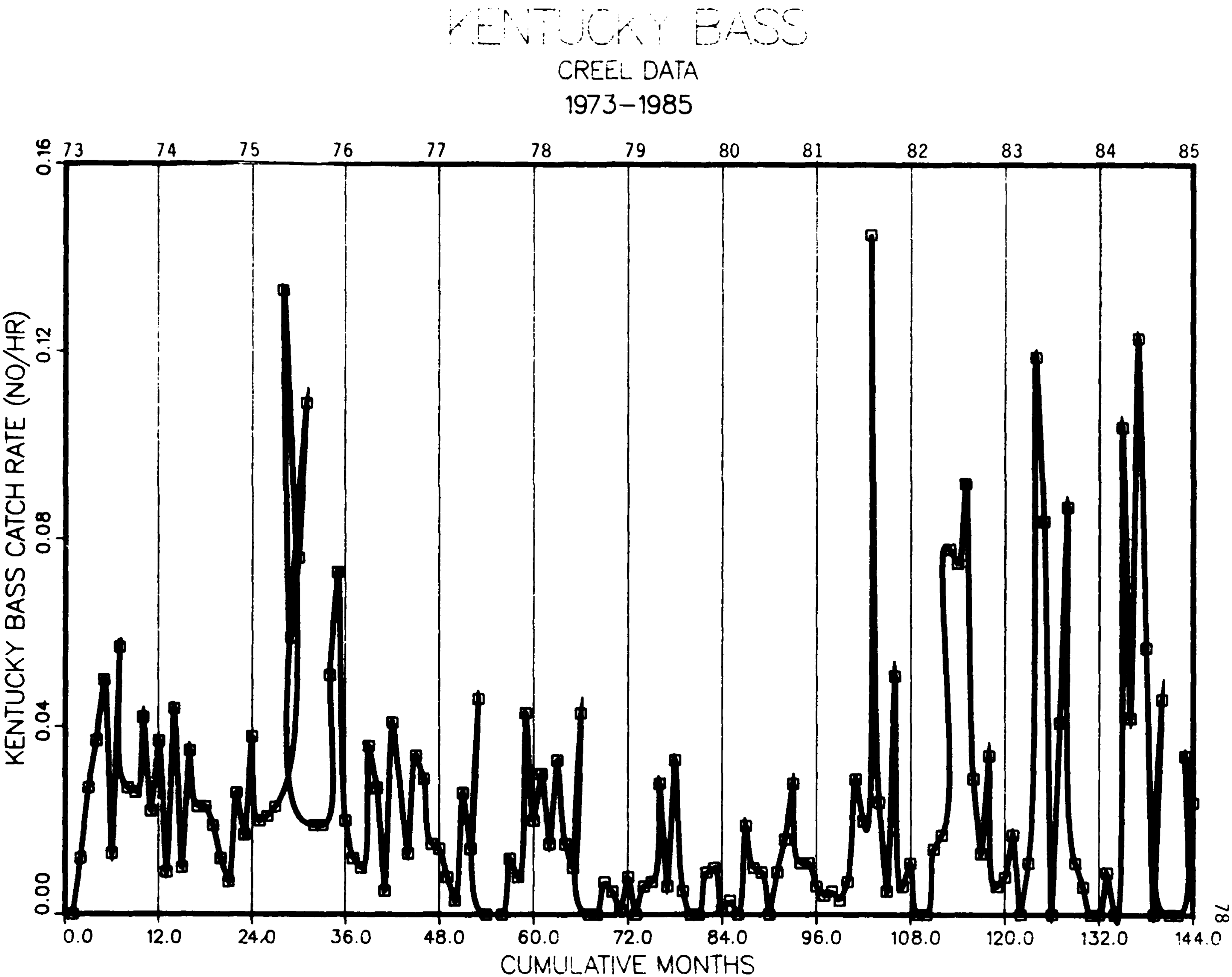


Figure 12. Kentucky Bass Creel Trends

Bluegill

150. The regular creel for bluegill is shown by Figure 13. Peak catch rates of bluegill have increased since 1978 and fishing looks good for this species. However, there are more zeros during 1983 to 1985 than in all previous years. Thus, the differences in the peaks and valleys is more pronounced than in most earlier years.

Intented Walleye

151. The intented walleye creel is shown by Figure 14. There do not appear to be any trends in the intented walleye catch rate. Low catches were made between 1980 and 1982, and again in 1984. Some of the best catch rates were observed in 1985.

Walleye

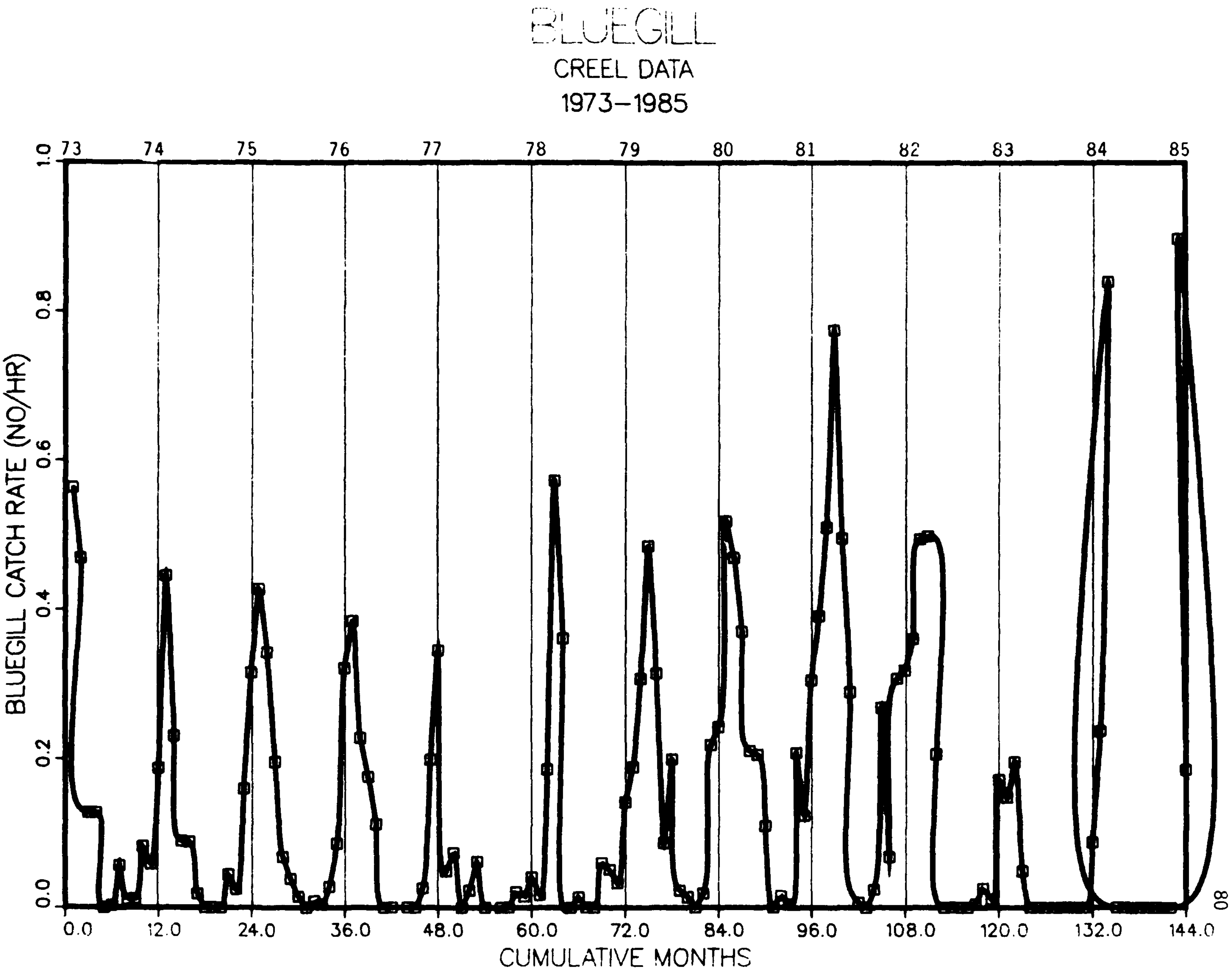
152. The regular walleye creel is shown by Figure 15. The catch rates are relatively constant from year to year. The slightly lower catches during 1981 correspond to the intented creel. There were more zeros in the creel during 1983-1985 than previously.

Intented Crappie

153. The intented crappie creel is shown by Figure 16. Crappie catches were moderate from 1974 to 1977 then increased to good catches during 1977-1978. Beginning in 1978, catches rapidly declined to almost nothing in 1985. In 1983 to 1984, no crappie appeared in the creel except on two occasions.

Crappie

154. The regular crappie creel is shown by Figure 17. Crappie catches were very low in 1973 but increased substantially by 1978. Again,



CENTER HILL LAKE

Figure 13. Bluegill Creel Trends

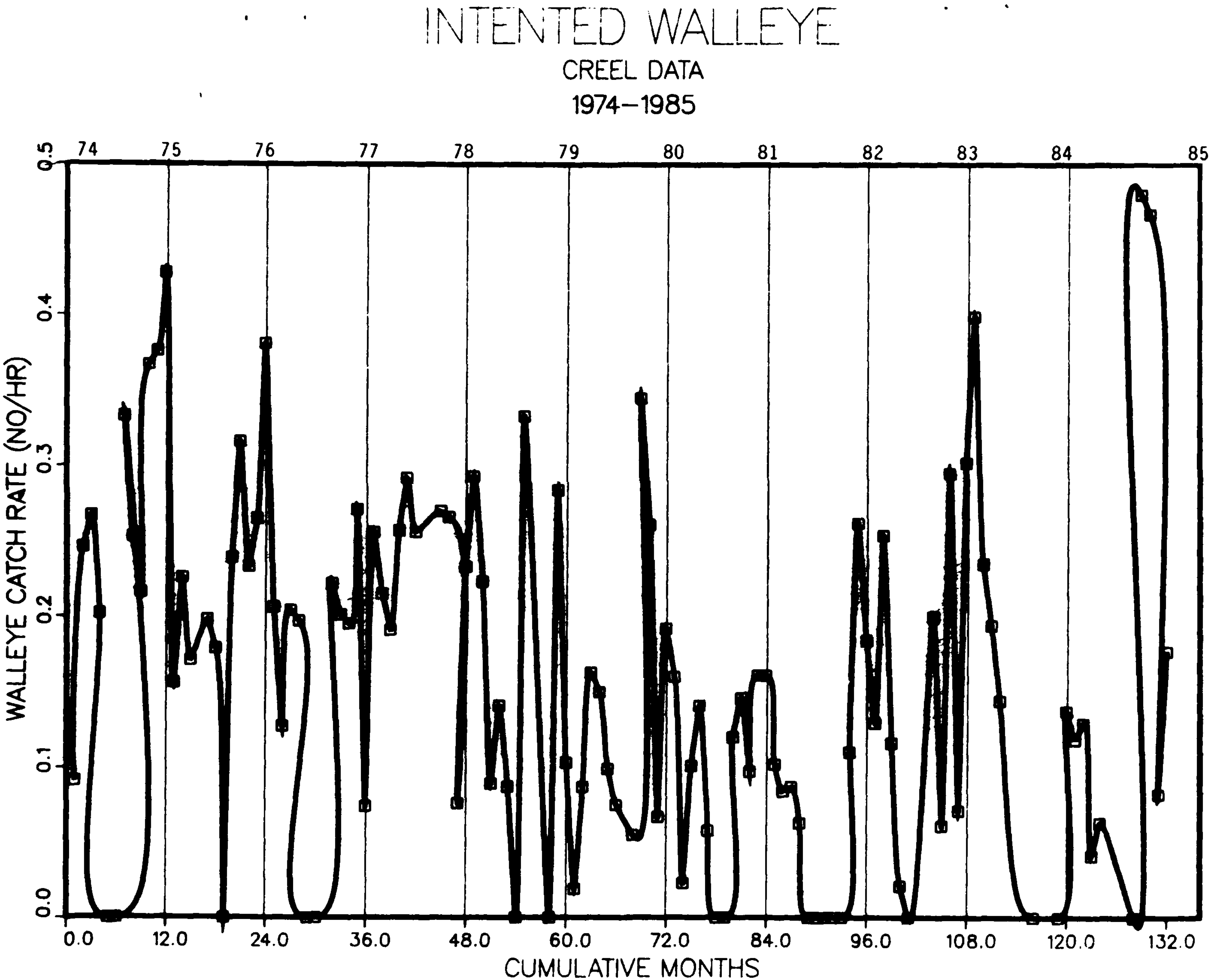


Figure 14. Intented Walleye Creel Trends

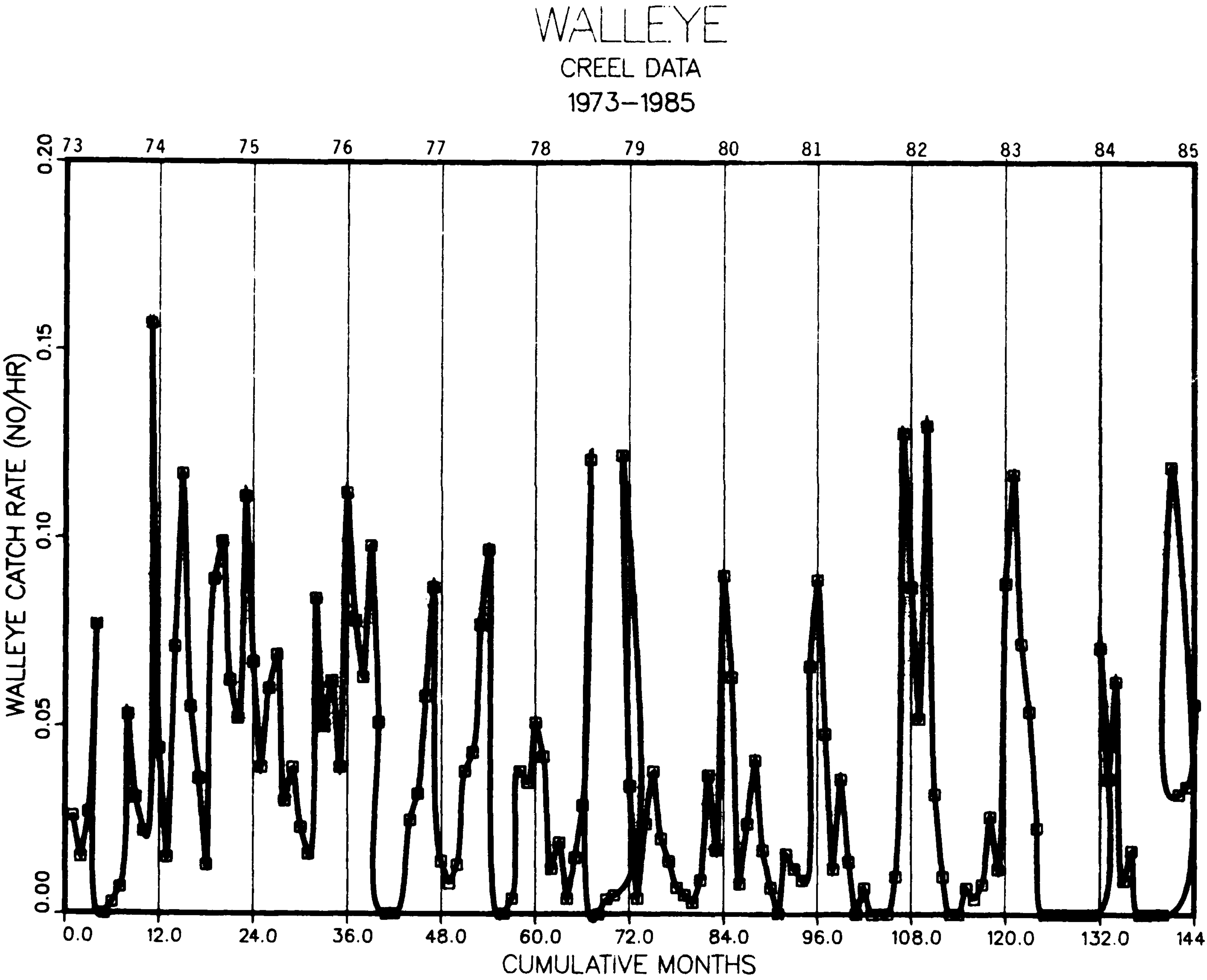


Figure 15. Walleye Creel Trends

CENTER HILL LAKE

INTENTED CRAPPIE
CREEL DATA
1974–1985

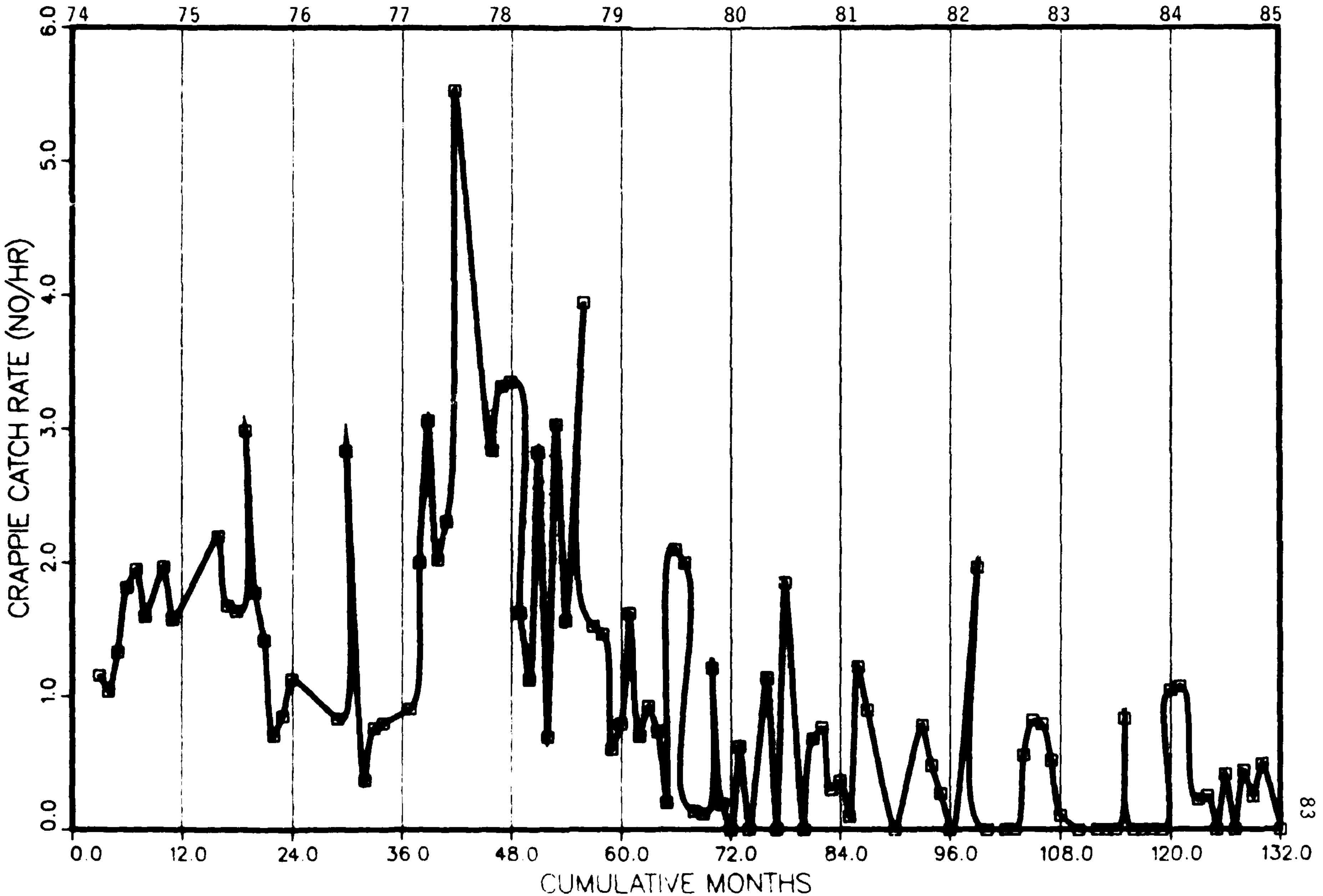
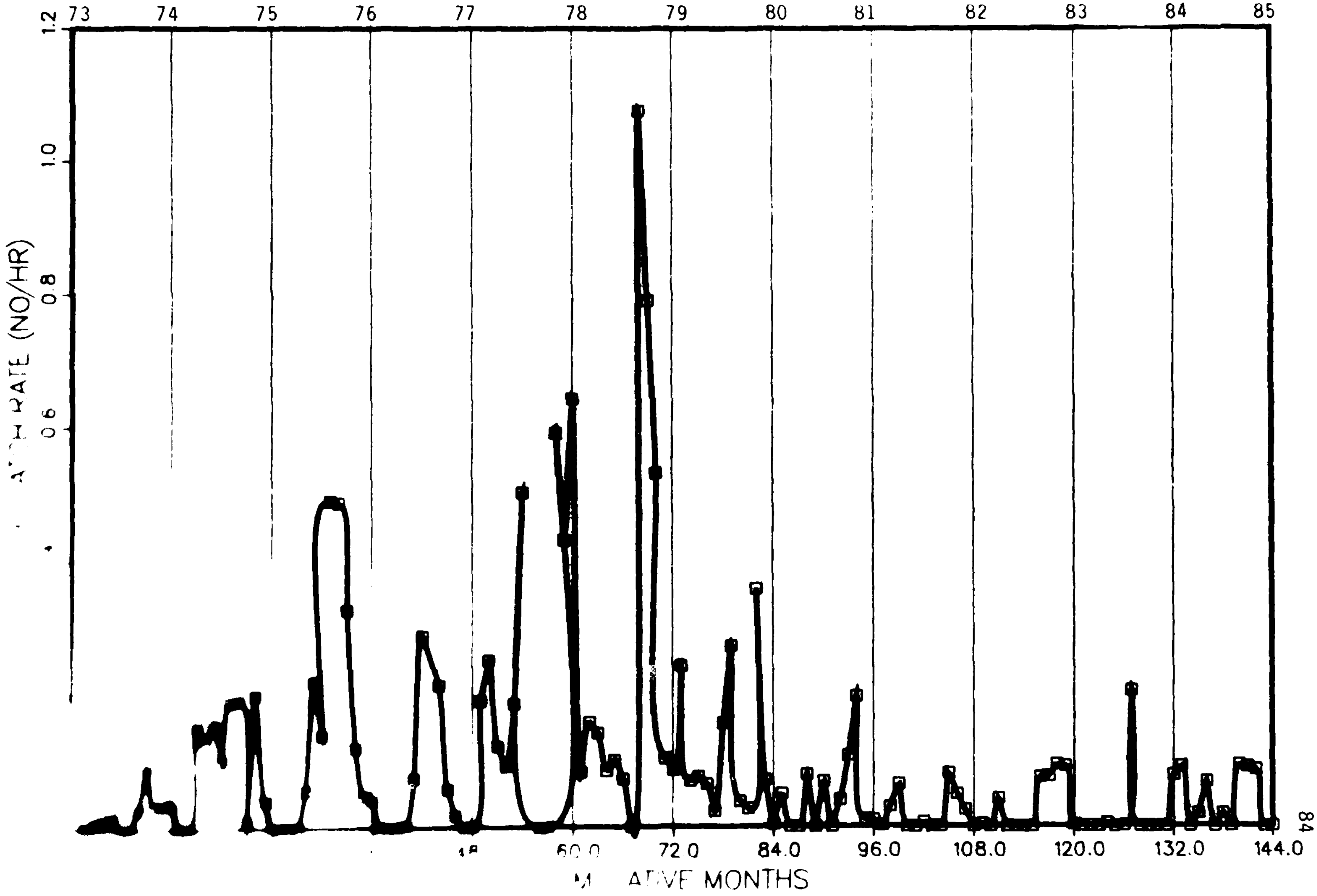


Figure 16. Intented Crappie Creel Trends

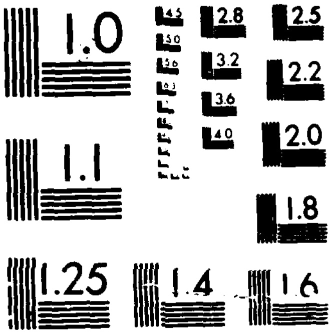
CENTER HILL LAKE

CRAPPIE
CREEL DATA
1973–1985



Crappie Creel Trends

AD-A180 359 CENTER HILL RESERVOIR FISHERY STUDY--WATER LEVEL 2/2
EFFECTS(U) TENNESSEE TECHNOLOGICAL UNIV COOKEVILLE
WATER RESOURCES CENTER J A GORDON ET AL AUG 86
UNCLASSIFIED DACW62-84-C-0057 F/G 6/6 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

beginning in 1978, the catch rate decreased to virtually nothing. (The numbers plotted are the sum of white and black crappie in the creel.)

Intented White Bass

155. Intented white bass catches are shown by Figure 18. The catch of white bass has obviously dropped off since the mid-1970's. Catches remain low and there are fewer white bass fishermen.

White Bass

156. The regular white bass creel is shown by Figure 19. White bass catches have steadily declined since 1974 and were virtually non-existent from 1979 to 1985. During 1983-1985 almost no white bass were included in the creel.

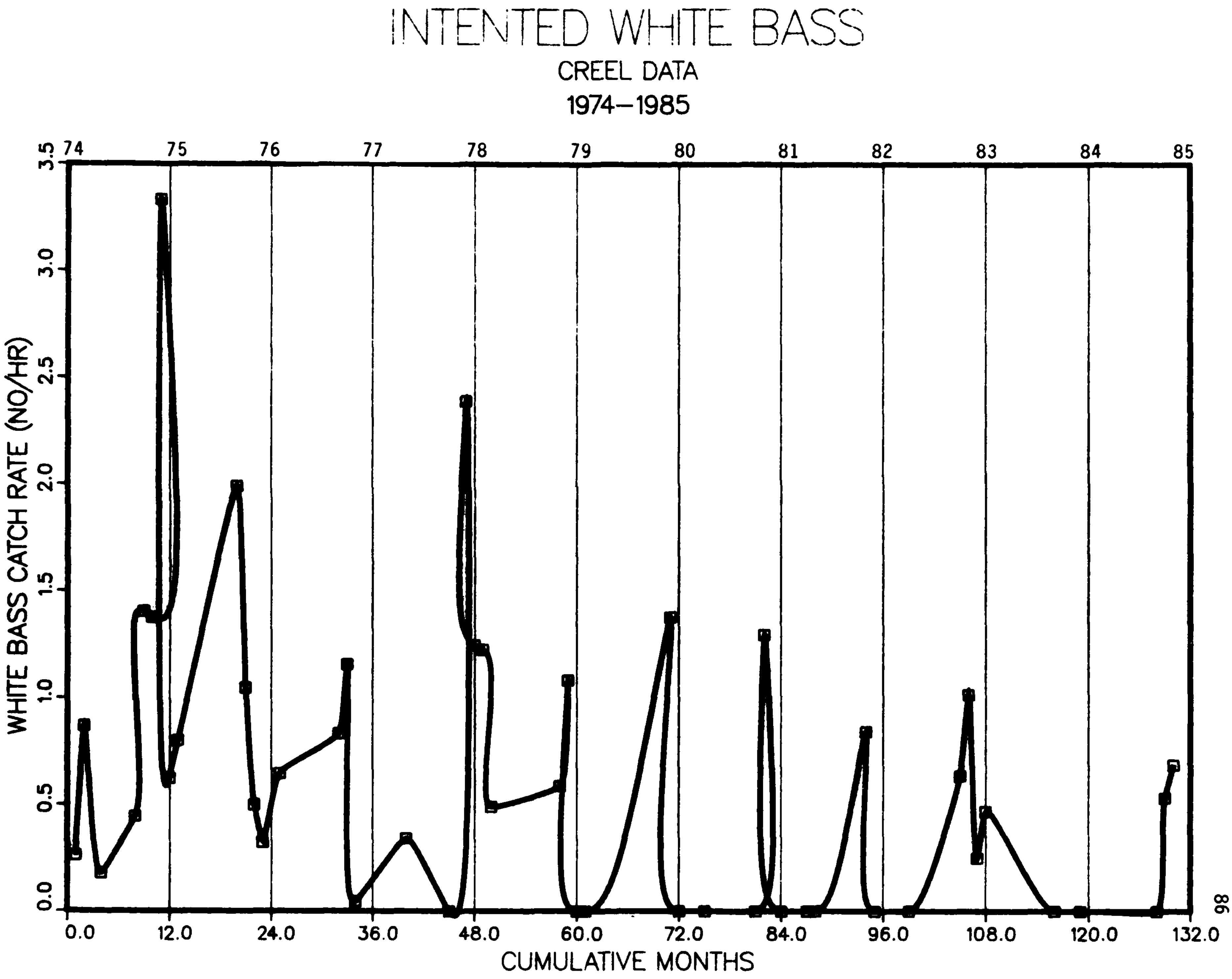
Conclusions

157. 1) Crappie and white bass are not being caught and creeled by fishermen on Center Hill Reservoir. The crappie decline began in 1978 and the white bass decline began in 1979.

158. 2) Smallmouth bass catches have declined since 1973 with only a few good catch years.

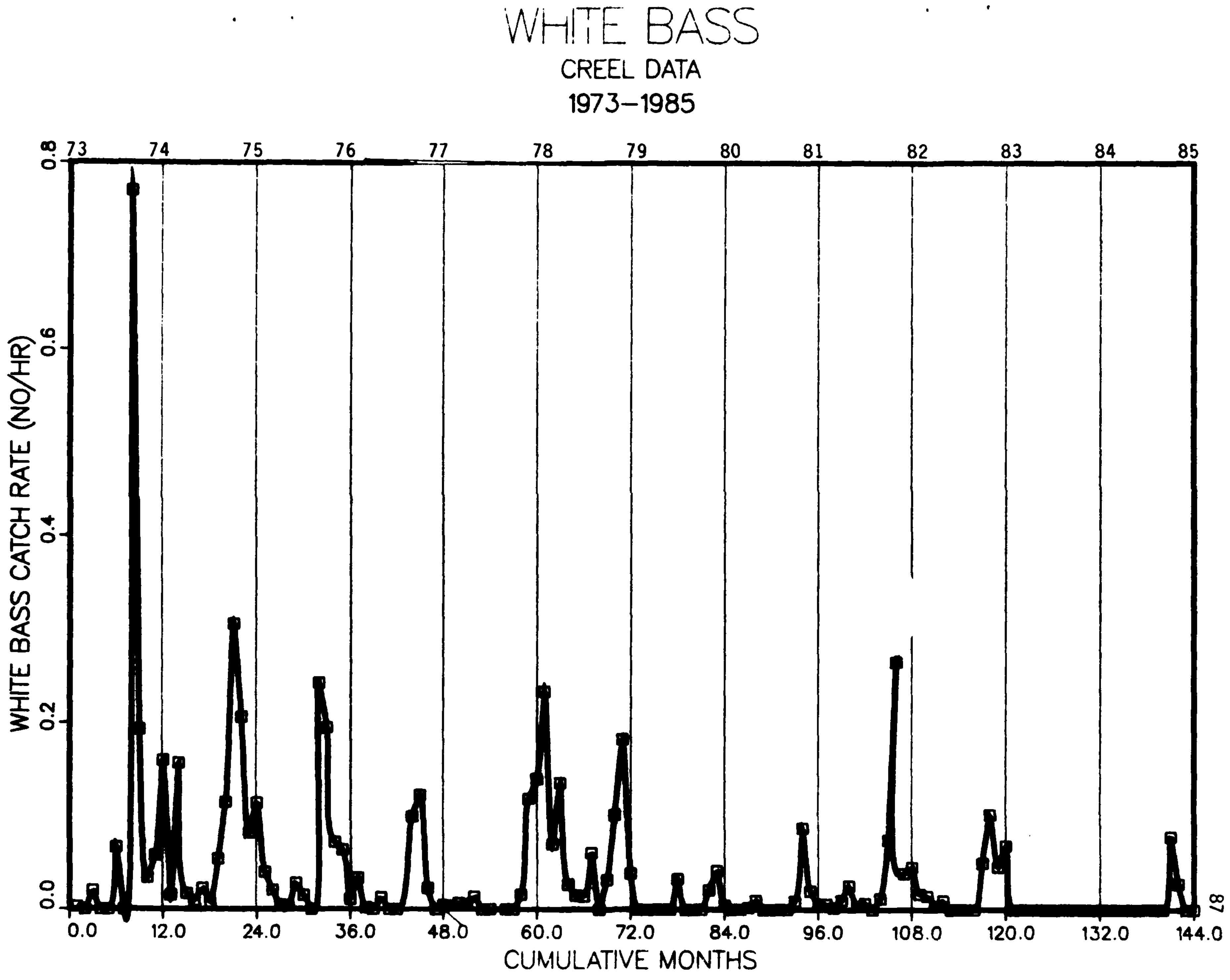
159. 3) Kentucky bass catch rates have increased dramatically beginning 1982. This has helped offset the decrease in the catch of smallmouth bass

160. 4) No specific trends were noted for any other species in the sport fish creel which included largemouth bass, walleye, and bluegill.



CENTER HILL LAKE

Figure 18. Intented White Bass Creel Trends



CENTER HILL LAKE

Figure 19. White Bass Creel Trends

PART VII: LONG-TERM TRENDS IN WATER QUALITY

Introduction

161. Since Part VI had shown that there were long-term trends in the creel data for Center Hill Reservoir, the obvious next step was to see if there were long-term changes in the fishery-related water quality parameters. The following five water quality parameters were studied to enable the identification of any positive or negative changes in the reservoir water quality with the passage of time: temperature, dissolved oxygen, pH, nitrogen, and phosphorus. The CalComp plotter was used to plot data points of the five parameters at depths 0, 10, 20, 30, 50, 100, and 150 feet from the surface of the reservoir at the deepest point (at the dam). To accomplish the identification of trend changes, data were recorded in a file corresponding to similar times of the month for different years. Thus, for example, if there were data for the early part of January on at least three years, these data points were recorded, then plotted to observe any changes. In order to document changes of any consequence, a statistical procedure was used to show points that differed significantly from the mean.

162. Data used for this phase were comprised mainly of Corps of Engineers data and any other data which could be found pertaining to water quality in Center Hill Reservoir. These data were arranged in a file, a sample of which is shown below.

10.9	12.2	16.0	12.0	9.0
10.5	12.2	13.9	11.5	8.8
10.3	12.1	13.0	11.0	8.7
10.2	12.0	12.5	10.5	8.5
7.9	9.9	7.1	6.5	8.0
7.9	99.0	6.9	99.0	7.8

This sample data file is one which lists temperatures for late March and early April of five different years. The number 99 was inserted for missing data. The rows signify temperatures at depths of 0, 10, 20, 30, 50, 100, and 150 feet from the surface at the dam. Files for dissolved oxygen, pH, nitrogen, and phosphorus were arranged in the same manner. Then, a statistical analysis was performed and plots generated.

163. The tables which follow provide results from a statistical analysis referred to as the Duncan's Multiple Range Test which allows the distinction of significantly different data from a group of data. Under the Duncan Grouping column, two letters (A and B) will be found, each of which corresponds to the mean of data recorded on similar days of different years ranging from 1971 through 1983. Means with same letter are not significantly different. The N column denotes the number of observations per year. The significance of this test will be described later. The plots were generated using "TECHPLOT; Graphics Production Software." The software and documentation were developed and written by Charlotte Middlebrooks (1985). Techplot is a menu-driven program for development and display of some features of the DISSPLA software by ISSCO, the Integrated Software System Corporation.

164. The plots enable the identification of any positive or negative changes in the reservoir water quality (specifically temperature, dissolved oxygen, pH, nitrogen, and phosphorus) with the passage of time. Each plot contains a variety of symbols which will be defined on each page of plots. The purpose of this effort was to determine any long-term trend changes. This was first attempted using the Duncan's Multiple

Range Test on the variables of temperature, dissolved oxygen, pH, nitrogen, and phosphorus. The values of each parameter from the surface through 150 feet of depth were averaged for at least three different years. The Duncan grouping in the Duncan's Multiple Range Test showed which group(s) of data was/were significantly different from the average of all data in the time period of concern.

165. The discussion which folows is a summary of all information provided by the results of the Duncan's Multiple Range Test.

Temperature

166. In Table 18, 1973, 1976, 1979, and 1972 were significantly different from 1983. An alternative interpretation showed 1979, 1972, and 1983 to be significantly different from 1973 and 1976. In other words, the mean late March and early April average temperatures were the same for 1972, 1973, 1976 and 1979, but the 1983 mean of 8.5°C was lower than those for previous years. Alternatively, the means for 1972, 1979 and 1983 are similar to each other, but the means for

Table 18

Duncan Grouping for Temperature in Late March and Early April for the Years Shown

Duncan Grouping		Mean	N	Year
	A	11.650	6	1973
	A	11.343	7	1976
B	A	10.000	6	1979
B	A	9.529	7	1972
B		8.500	7	1983

1983 and 1986 are different, being slightly higher. Winter temperatures are functions of meteorological conditions and are not really expected to be different unless the weather changes dramatically; 1983 was evidently a colder winter.

167. The graphical analysis of temperature is shown by Figures 20, 21 and 22. These figures show that the lake is slightly stratified in late March and early April (21-A) and then is more stratified during mid-May, early June, late June, mid and late July, August and September. Fall overturn is in progress by late October (22-B). A careful study of the plots shows that temperature remained similar throughout the 1971-1984 period.

pH

168. Table 19 showed 1979 and 1973 to be significantly different from 1972 and 1983 during late March and early April. Table 20 indicated 1981, 1979, and 1973 as differing from 1971 in late May and early June. Alternatively, 1981 and 1979 differed from 1973 and 1971 in late May and early June. Table 21 suggested that 1975 differed significantly from 1971 and 1979 during mid-to-late June, although 1971 may have differed significantly from 1979 and 1975. The results also indicated that 1981 may have differed from 1979 and 1974 for the same part of the year. These results suggested that there were no trends for the period of study. Obviously the previous description is confusing but some simplication is possible. In early April, the mean pH was 7.9 in 1973 and 1979, which was slightly different from the mean pH of 7.5 in 1972 and 1983. In early June the mean pH was between 7.7 and 8.1 during 1973, 1979, and 1981, and this was different from the 7.0

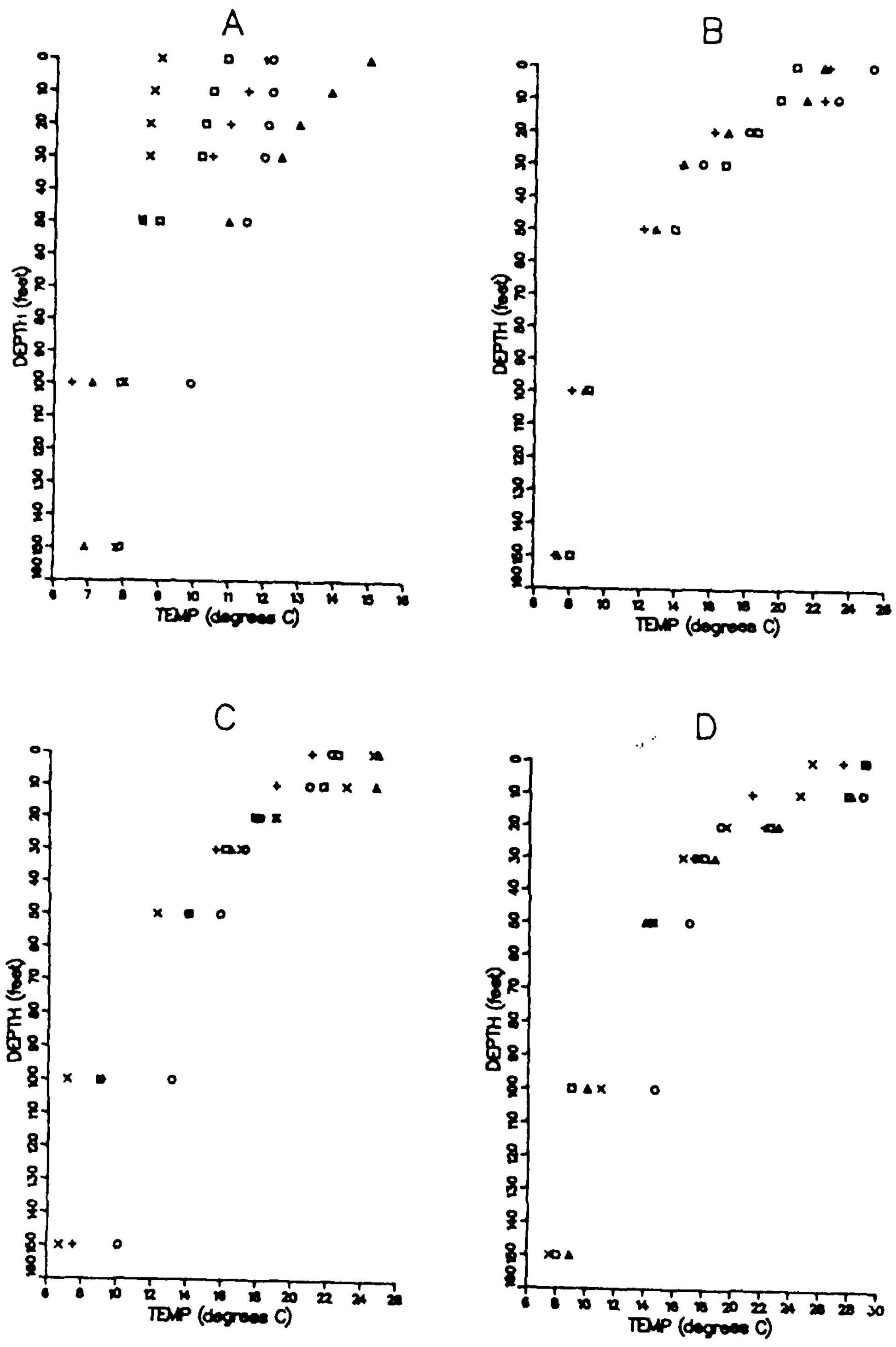


Figure 20. Temperatures of Same Days, Different Years. A: Late March and Early April of 1972 (□), 1973 (○), 1976 (△), 1979 (+), and 1983 (×). B: Mid May of 1972 (□), 1977 (○), 1979 (△), and 1982 (+). C: Late May and Early June of 1971 (□), 1973 (○), 1977 (△), 1979 (+), and 1981 (×). D: Mid-To-Late June of 1971 (□), 1973 (○), 1975 (△), 1977 (+), and 1979 (×)

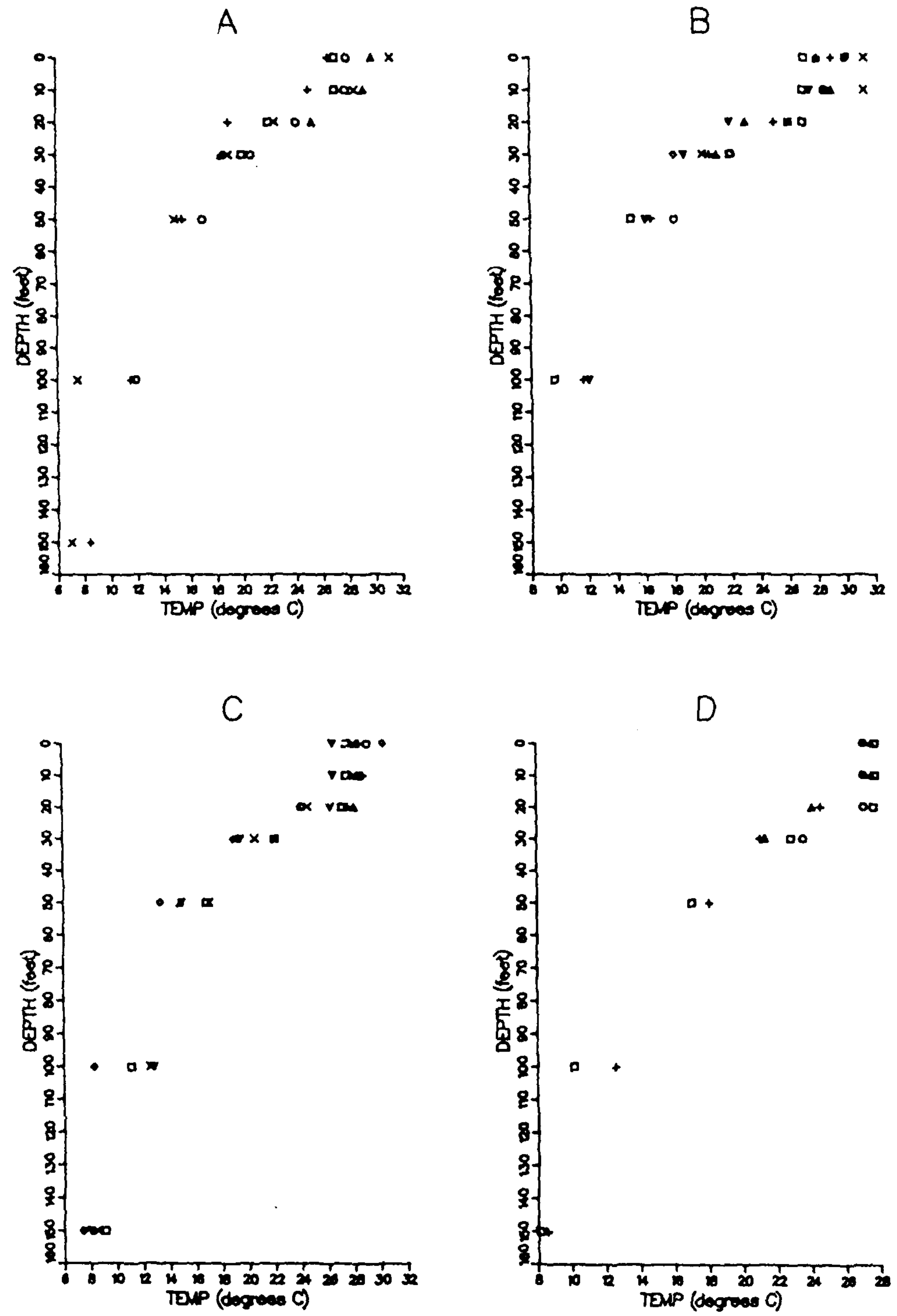


Figure 21. Temperatures of Same Days, Different Year
A: Mid July of 1973 (▫), 1974 (○), 1977 (▵), 1979 (+
and 1981 (×). B: Late July of 1971 (▫), 1972 (○), 1973 (▵), 1974 (+), 1977 (×), 1982 (◇), and 1983 (▿). C: Early August of 1972 (▫), 1973 (○), 1975 (▵), 1977 (+), 1979 (×), 1982 (◇), and 1984 (▿). D: Mid August of 1971 (▫), 1973 (○), 1976 (▵), and 1979 (+)

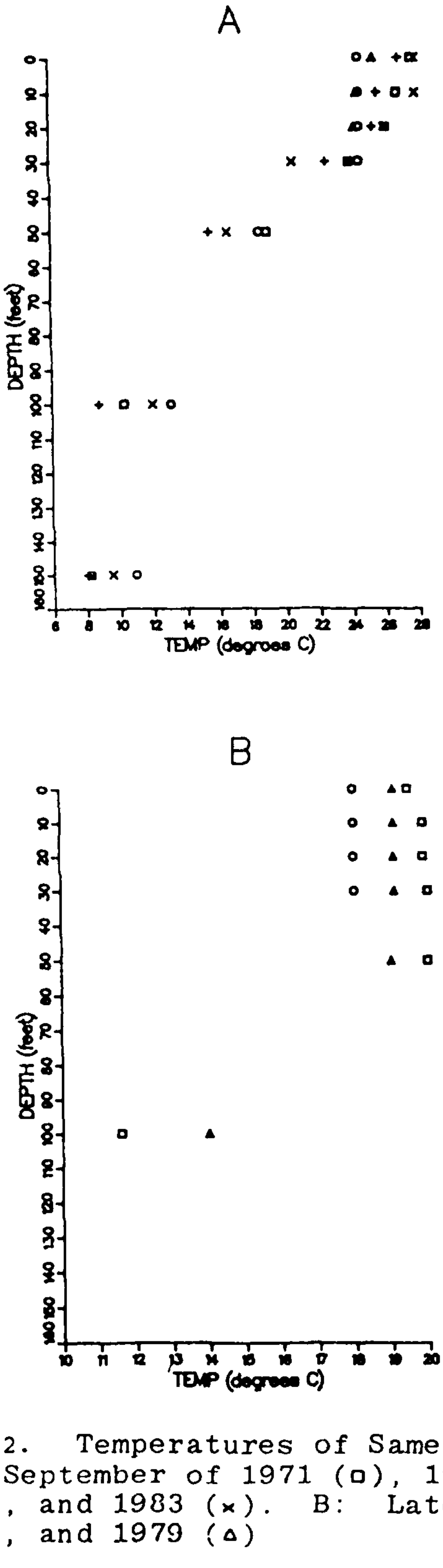


Figure 22. Temperatures of Same Days, Different Years. A: Mid September of 1971 (□), 1974 (○), 1976 (△), 1982 (+), and 1983 (×). B: Late October of 1970 (□), 1976 (○), and 1979 (△)

Table 19

Duncan Grouping pH in Late March and Early April for the Years Shown

Duncan Grouping	Mean	N	Year
A	7.95000	6	1979
A	7.86667	6	1973
B	7.47143	6	1972
B	7.45174	7	1983

Table 20

Duncan Grouping for pH in Late May and Early June for the Years Shown

Duncan Grouping		Mean	N	Year
	A	8.1143	7	1981
	A	7.9857	7	1979
B	A	7.7000	7	1973
B		7.0173	7	1971

Table 21

Duncan Grouping for pH in Mid-June for the Years Shown

Duncan Grouping		Mean	N	Year
	A	8.0000	7	1981
B	A	7.8714	7	1979
B		7.1000	7	1974

pH average for 1971. By mid June, the average pH ranged from 7.9 to 8.0 for 1979 and 1981 and this was above the 7.1 value recorded for 1974.

169. The graphical analysis of pH is shown by Figures 23, 24 and 25. The pH is fairly constant in the winter, but becomes stratified during the summer due to photosynthesis at the surface and CO_2 additions at the bottom. Cloudy days reduce the pH in the photic zone and lead to variations from 7.0 to 8.5 dependent upon the amount of sunlight. The 8.5 value represents the point where all free CO_2 has been captured by photosynthesis. Careful study of the pH plots shows that the pH varies from year to year but no long-term trend persists from month to month or year to year. Figure 23-A shows no sign of acidification as the 1972 and 1983 lines are almost identical.

Dissolved Oxygen

170. In late May and early June of 1981, 1971, 1973 and 1979, the dissolved oxygen was significantly different from 1977 as shown in Table 22. The years 1971, 1973, 1979, and 1977 could also be catagorized as similar with 1981 being sigificantly different. Table 23 showed 1979 to differ from 1976 and 1971 during mid August. 1976 also differed from a grouping of 1971 and 1979. These results offered no evidence of long-term trends for the period of study.

171. The graphical analysis of D.O. is shown by Figures 26, 27, and 28. The D.O. in Center Hill Lake is known to be variable with depth with supersaturation of D.O. at the bottom of the epilimnion, strong depletion in the metalimnion and some depletion at the bottom of the hypolimnion just above the benthic deposits. The D.O. mechanisms

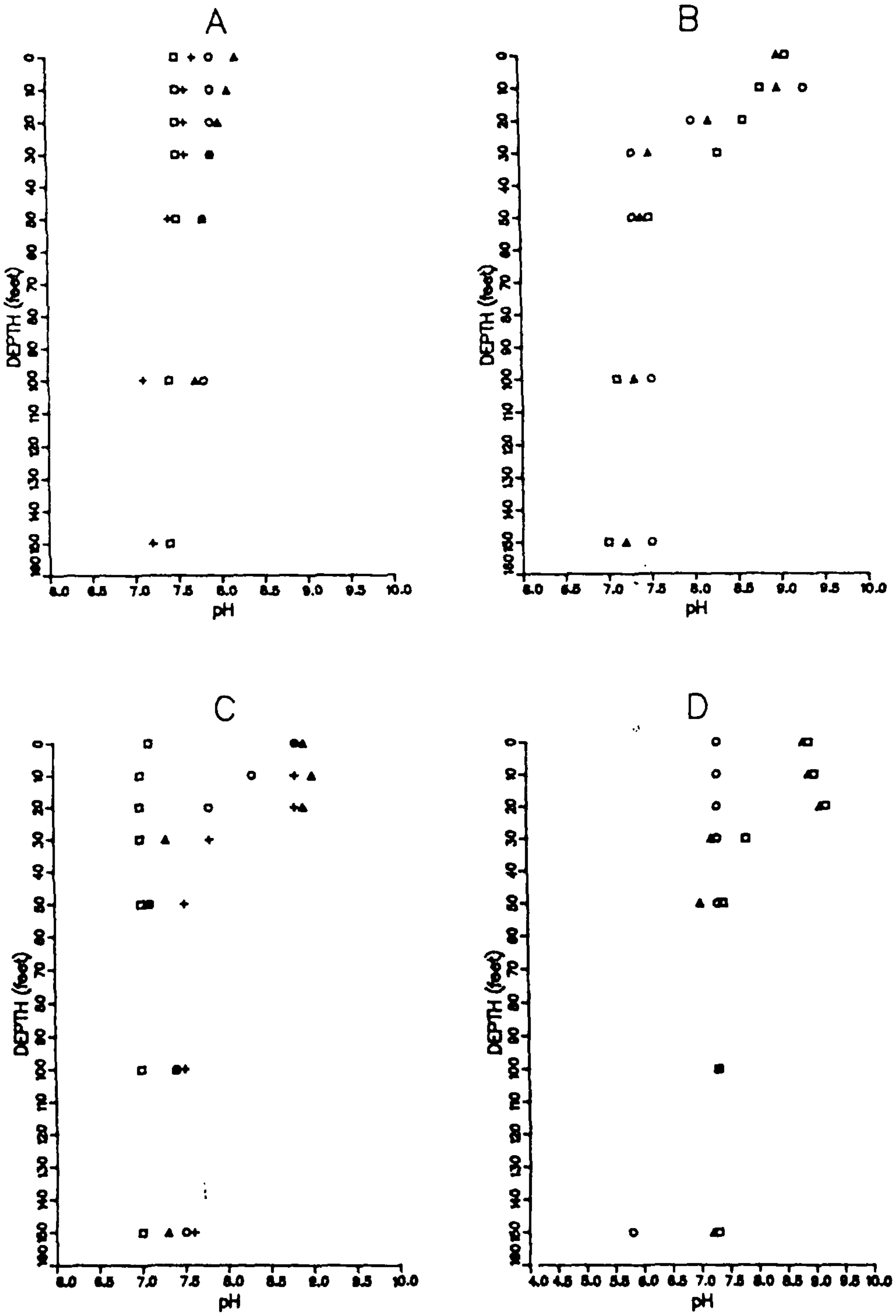


Figure 23. pH of Same Days, Different Years. A: Late March and Early April of 1972 (□), 1973 (○), 1979 (△), and 1983 (+). B: Mid May of 1972 (□), 1979 (○), and 1982 (△). C: Late May and Early June of 1971 (□), 1973 (○), 1979 (△), and 1981 (+). D: Mid-To-Late June of 1971 (□), 1975 (○), and 1979 (△)'

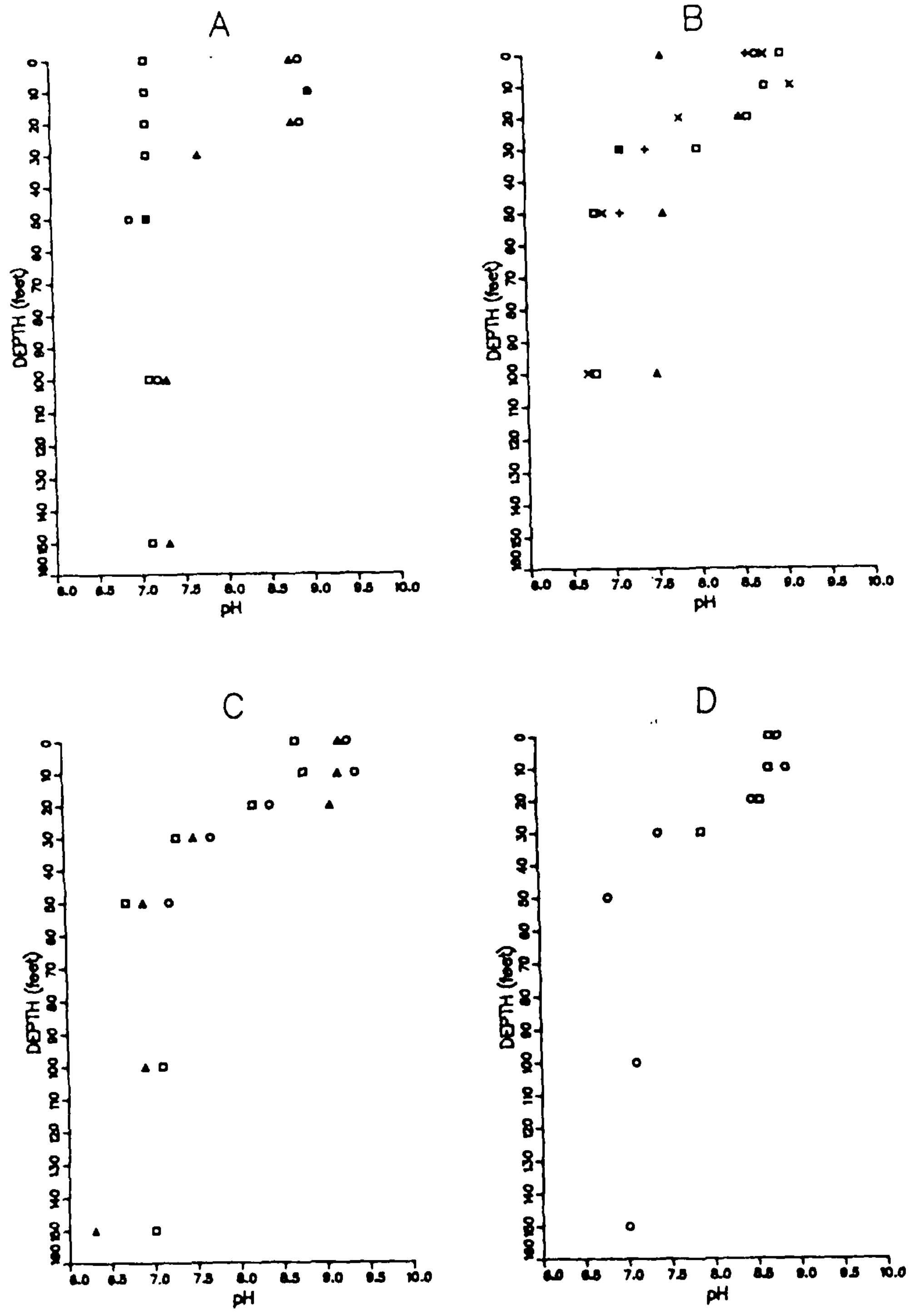


Figure 24. pH of Same Days, Different Years. A: Mid July of 1974 (□), 1979 (○), and 1981 (△). B: Late July of 1971 (□), 1972 (○), 1974 (△), 1982 (+), and 1983(×) C: Early August of 1979 (□), 1982 (○), and 1984 (△). D: Mid August of 1971 (□) and 1979 (○)

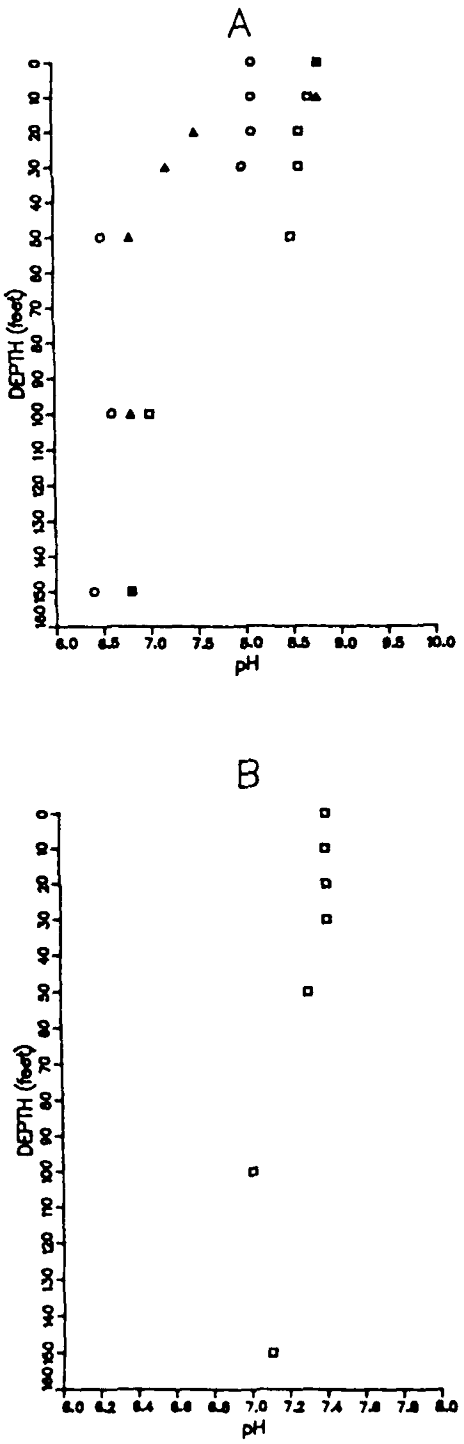


Figure 25. pH of Same Days, Different Years. A: Mid September of 1971 (□), 1974 (○), and 1983 (△). B: Late October of 1979 (□)

Table 22

Duncan Grouping for DO in Late May and Early June for the Years Shown

Duncan Grouping		Mean	N	Year
	A	9.6429	7	1981
B	A	9.0833	6	1971
B	A	9.4000	7	1973
B	A	8.0571	7	1979
B		7.6250	4	1977

Table 23

Duncan Grouping for DO in Mid-August for the Years Shown

Duncan Grouping		Mean	N	Year
	A	9.325	4	1976
B	A	6.929	7	1971
B		4.586	7	1979

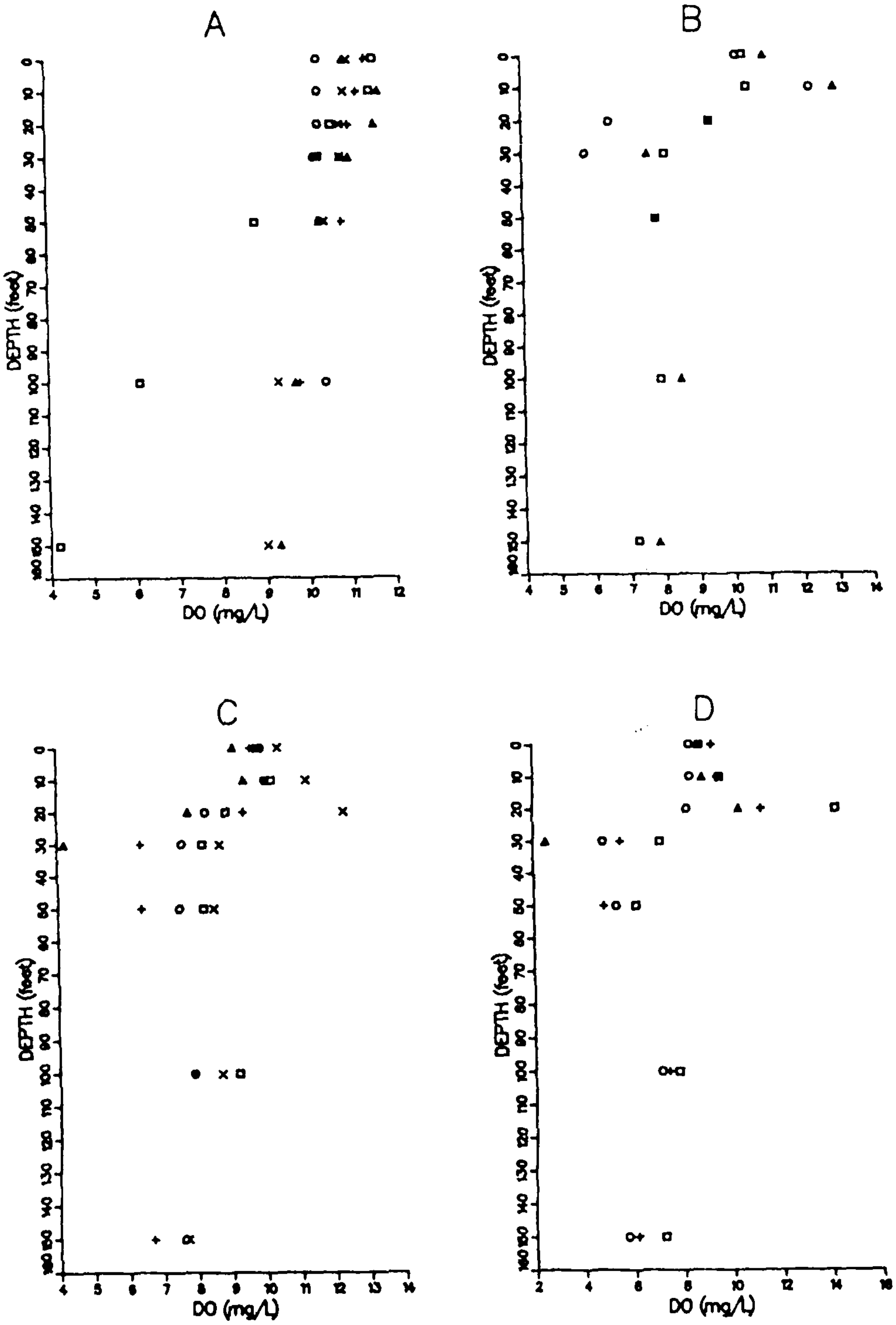


Figure 26. Dissolved Oxygen of Same Days, Different Years. A: Late March and Early April of 1972 (□), 1973 (○), 1976 (△), 1979 (+), and 1983 (×). B: Mid May of 1972 (□), 1977 (○), and 1979 (△). C: Late May and Early June of 1971 (□), 1973 (○), 1977 (△), 1979 (+), and 1981 (×). D: Mid-To-Late June of 1971 (□), 1975 (○), 1977 (△), and 1979 (+)

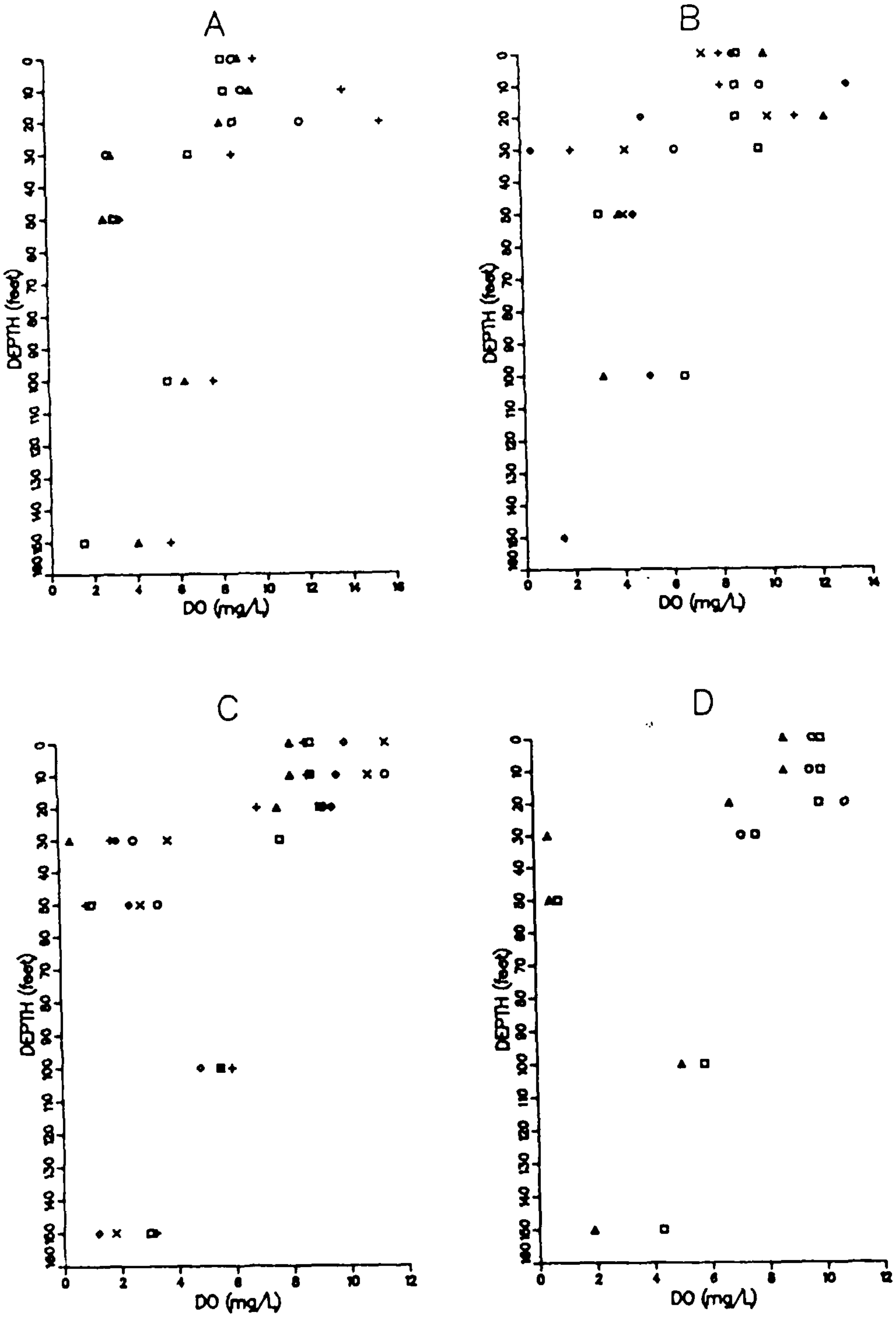


Figure 27. Dissolved Oxygen of Same Days, Different Years. A: Mid July of 1974 (□), 1977 (○), 1979 (△), and 1981 (+). B: Late July of 1971 (□), 1972 (○), 1974 (△), 1977 (+), 1982 (×), and 1983 (◇). C: Early August of 1972 (□), 1975 (○), 1977 (△), 1979 (+), 1982 (×), and 1984 (◇). D: Mid August of 1971 (□), 1976 (○), and 1979 (△)

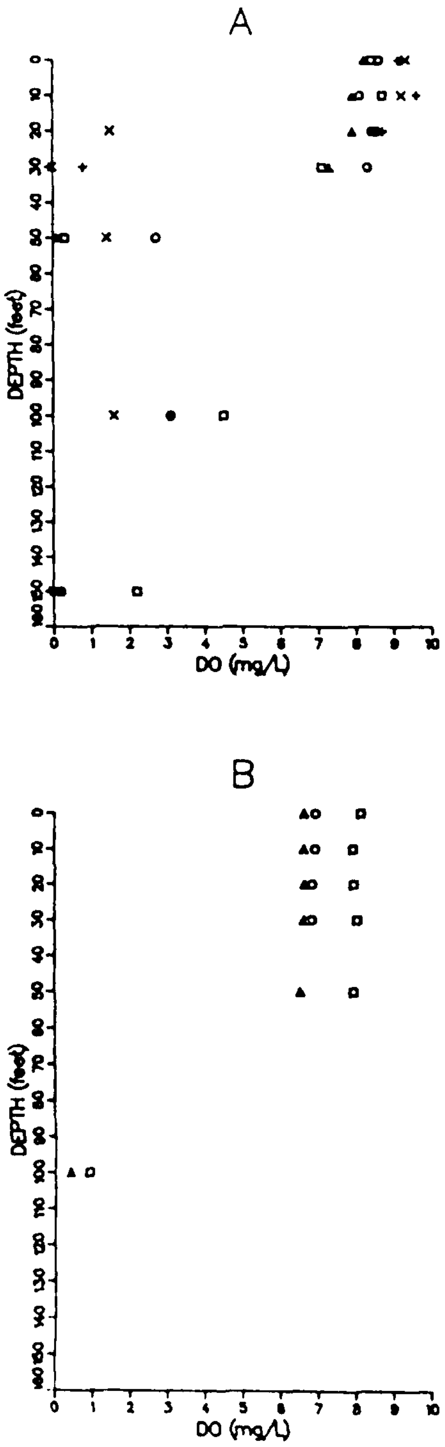


Figure 28. Dissolved Oxygen of Same Days, Different Years. A: Mid September of 1971 (□), 1974 (○), 1976 (△), 1982 (+), and 1983 (×). B: Late October of 1970 (□), 1976 (○), and 1979 (△)

are complex and vary with hydrodynamics, light penetration, meteorology, nutrients and phytoplankton dynamics as described by Gordon and Skelton, 1977, and Gordon and Morris, 1978. A careful study of the plots showed that there were no long-term trends in the dissolved oxygen levels of Center Hill Reservoir.

Inorganic Nitrogen

172. The only suitable data for inorganic nitrogen suitable for Duncan's Multiple Range test are shown by Table 24.

Table 24

Duncan Grouping for Nitrogen in Late July for the Years Shown

Duncan Grouping	Mean (mg/L)	N	Year
A	0.4000	3	1982
B	0.2000	2	1983

Of course, the nitrogen values for 1982 and 1983 are different with 1983 being lower. The graphical analysis of the nitrogen data are shown by Figures 29 and 30. Figure 29-A shows that the total inorganic nitrogen levels in late March and early April have steadily declined since 1972 from 0.7 mg/l to 0.3 mg/l. This trend holds through mid-May (Figure 18-B). During the summer period, data are sparse and become more complicated due to biological interactions. Surface levels in the fall also follow a long-term decline as shown by Figures 30-C and 30-D.

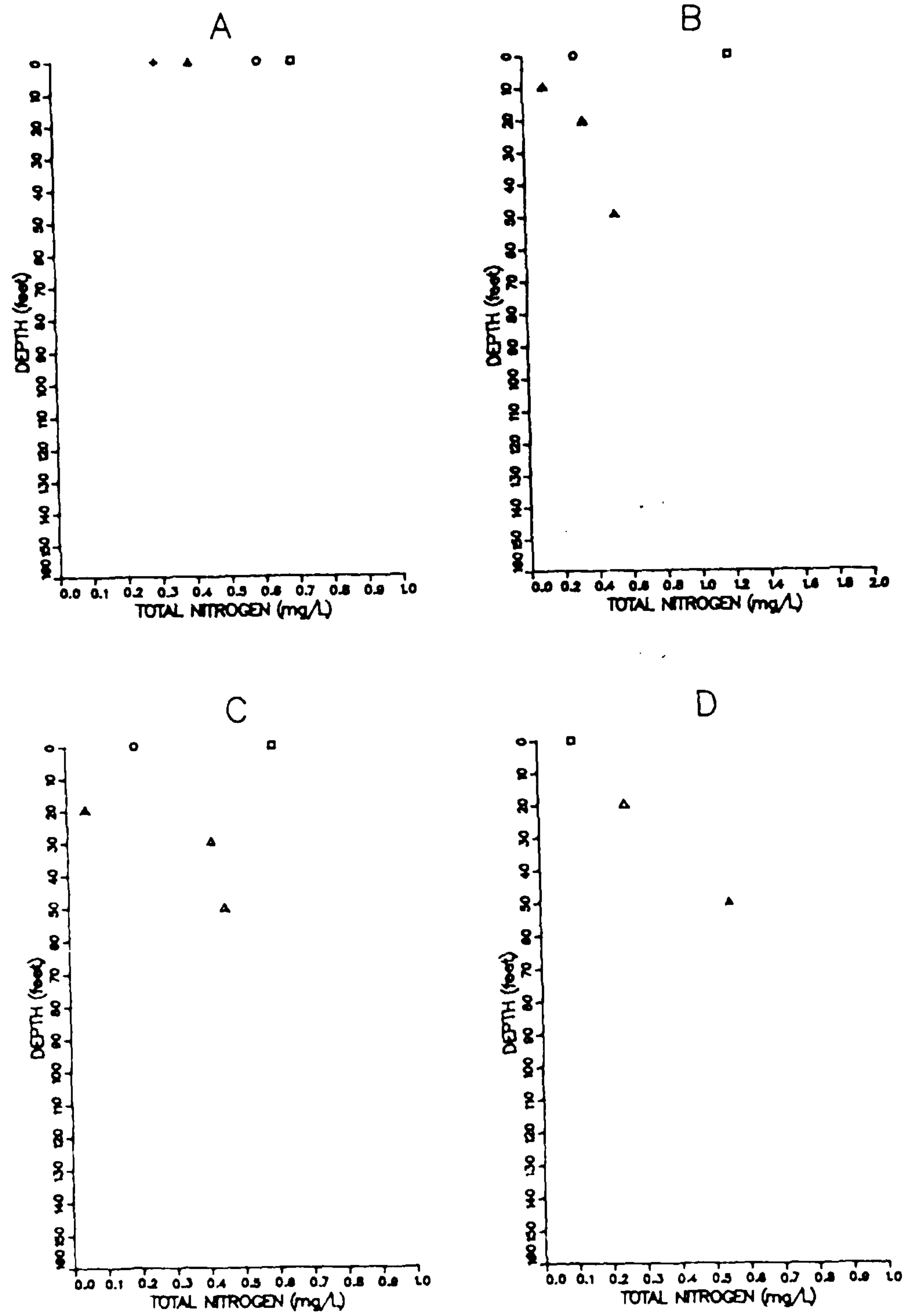


Figure 29. Total Nitrogen of Same Days, Different Years. A: Late March and Early April of 1972 (□), 1973 (○), 1976 (△), and 1983 (+). B: Mid May of 1972 (□), 1977 (△), and 1982 (○). C: Late May and Early June of 1973 (□), 1977 (△), and 1981 (○). D: Mid-To-Late June of 1975 (□) and 1977 (△)

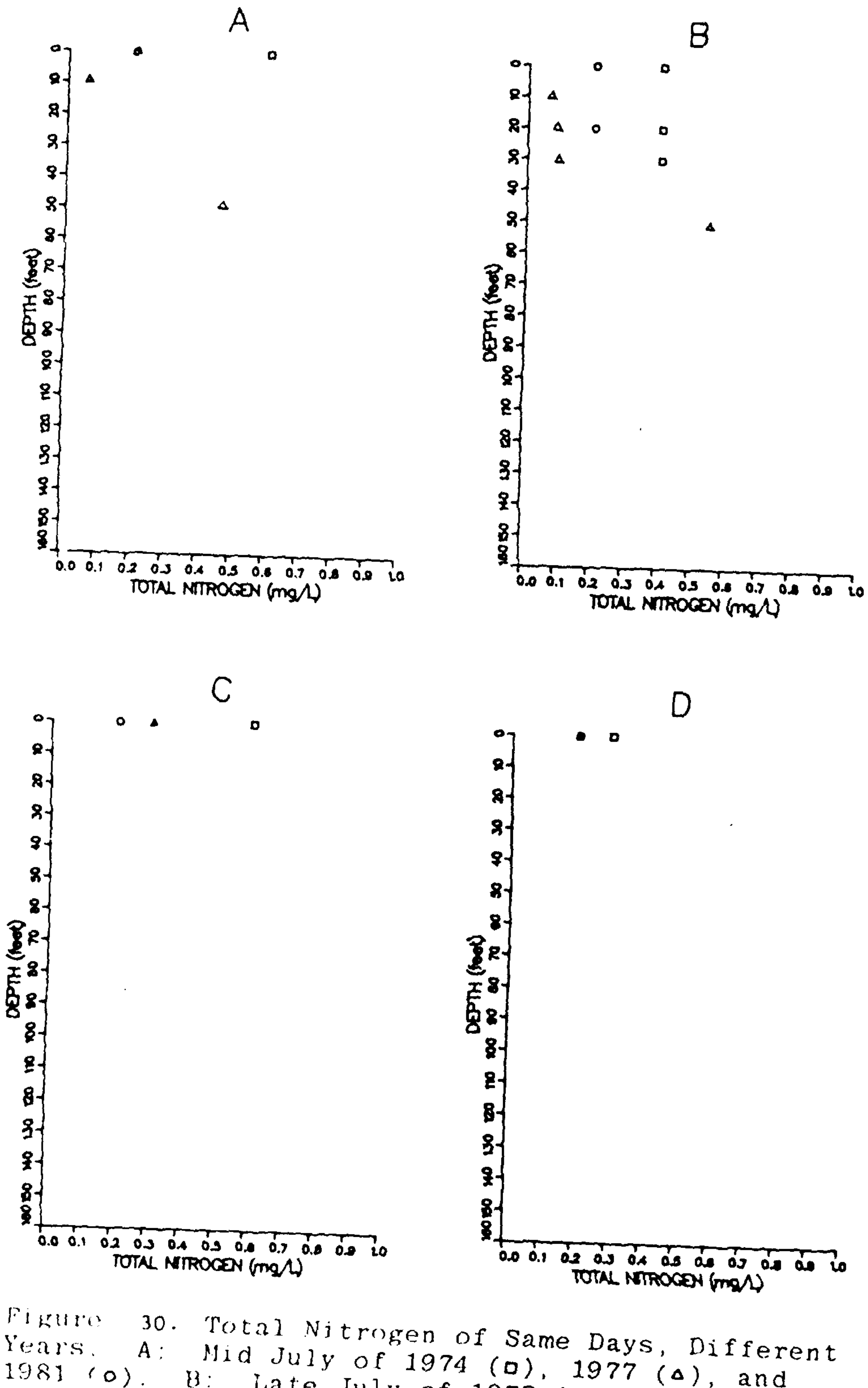


Figure 30. Total Nitrogen of Same Days, Different Years. A: Mid July of 1974 (□), 1977 (△), and 1981 (○). B: Late July of 1977 (△), 1982 (□), and 1983 (○). C: Early August of 1972 (□), 1982 (○), and 1984 (△). D: Mid September of 1974 (□), 1982 (○), and 1983 (△)

173. Thus there appears to have been a long-term decline in total inorganic nitrogen in Center Hill Lake during the period of 1972-1983.

Inorganic Phosphorus

174. The graphical analysis of total inorganic phosphorus are shown by Figures 31 and 32. Figure 31-A shows that the total inorganic phosphorus levels declined from the 1972-73 period to the 1976-83 period from levels of 60 μgm/L to less than 10 μgm/L. Figure 31-B shows a decrease between 1972-77 and 1983 during mid-May. Again, phosphorus levels during the summer are complicated by biological production but the late summer and fall trends substantiate the long-term decline in total phosphorus concentrations.

Summary of Long-Term Water Quality in Center Hill Lake

175. This analysis of the long-term trends in water quality in Center Hill Reservoir showed no changes in temperature, pH, nor dissolved oxygen. There were long-term reductions in total inorganic nitrogen and total phosphorus which are probably significant in regard to the levels of sport fish production. Vollenweider (1970) indicated that springtime concentrations of assimilable phosphorus and inorganic nitrogen should be kept below 10 μgm/L and 0.3 mg/L to insure oligiotrophic conditions. Mackenthun (1965) listed limiting concentrations of phosphorus ranging from 5 to 17 μgm/L. Sawyer (1947) recommended that soluble phosphorus should be below 10 μgm/L and inorganic nitrogen should be below 0.3 mg/l during the spring season to prevent algal growth.

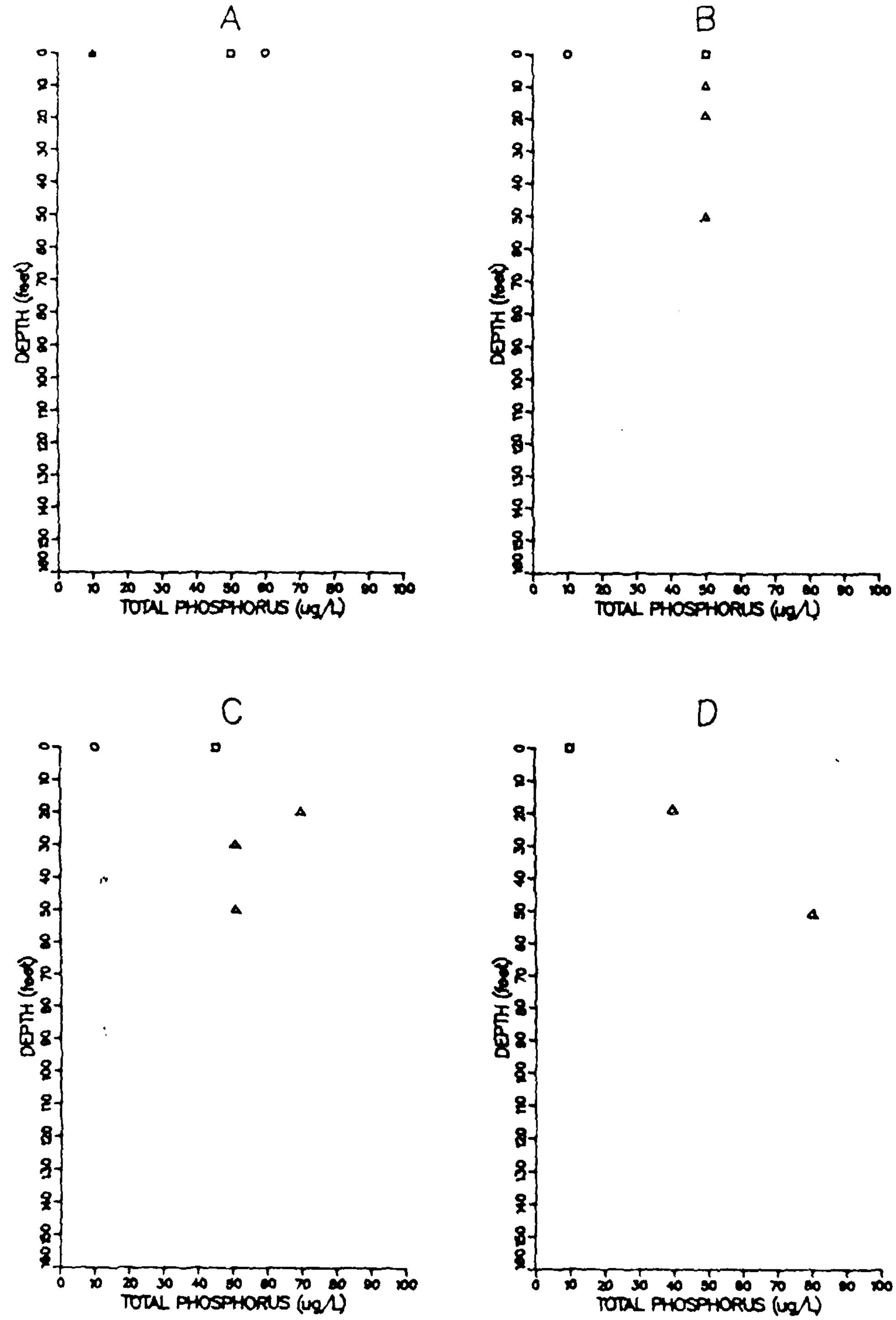


Figure 31. Total Phosphorus of Same Days, Different Years. A: Late March and Early April of 1972 (◻), 1973 (○), 1976 (△), and 1983 (+). B: Mid May of 1972 (◻), 1977 (△), and 1982 (○). C: Late May and Early June of 1973 (◻), 1977 (△), and 1981 (○). D: Mid-To-Late June of 1975 (◻) and 1977 (△)

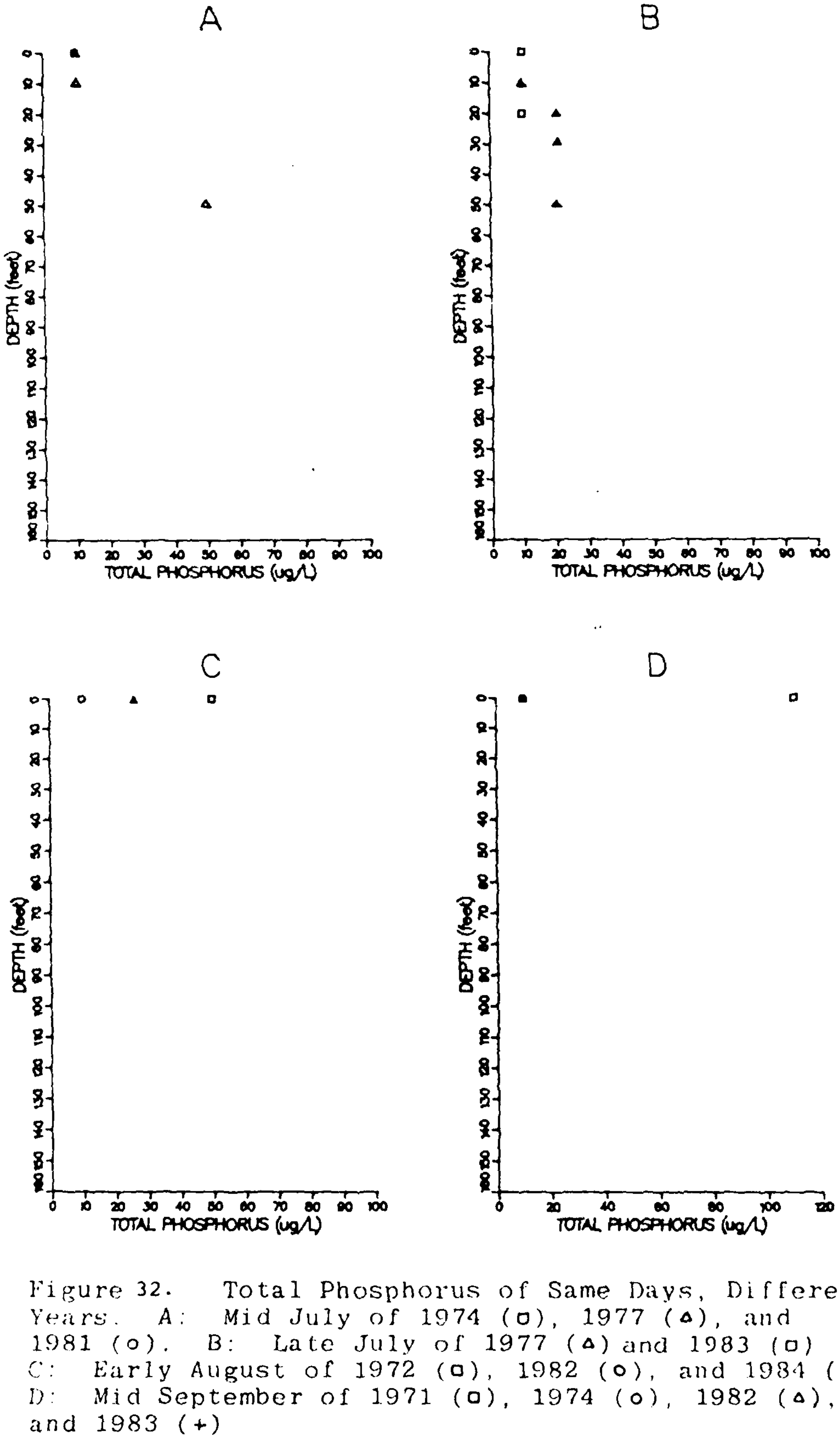


Figure 32. Total Phosphorus of Same Days, Different Years. A: Mid July of 1974 (□), 1977 (△), and 1981 (○). B: Late July of 1977 (△) and 1983 (□) C: Early August of 1972 (□), 1982 (○), and 1984 (△). D: Mid September of 1971 (□), 1974 (○), 1982 (△), and 1983 (+)

176. Since Center Hill nutrient levels at the surface during late March and early April of 1982-83 were less than 10 µgm/L of total phosphorus and 0.3 mg/l of total inorganic nitrogen, it is very likely that low nutrient levels are decreasing the primary productivity of the lake. This effect would be expected to be evident in the food chain and might limit the numbers of certain game fish in the lake.

177. The reasons for a decrease in nutrients include improved sewage treatment at Smithville and Cookeville, better erosion and fertilizer control by local farmers, greatly improved erosion and strip mining reclamation due to the new regulations and improved forestry management. Gordon (1976) noted that total phosphorus concentrations in Center Hill Lake increased in mean value and range over the Great Falls releases between CFRM 60 and 90. There were agricultural, mining and municipal inputs into this zone at that time and the runoff of phosphatic soils above the Sligo Bridge was felt to be a contributing factor. At the onset of stratification, nitrate concentrations were high possibly due to the agricultural runoff and municipal sewage inputs. These spring nitrate concentrations were evenly distributed with length and depth but were slightly higher in the upstream reaches. Thus, better point and non-point management of runoff to Center Hill Reservoir would be expected to contribute to improved (lowered) nutrient levels in Center Hill.

178. The writers have observed the land use changes in the drainage basin of Center Hill lake since about 1972. In the 1970's, strip mining, hillside farming and clearcut forestry practices were common in the basin. Center Hill lake received turbid inflows in the spring from

runoff and these turbid waters were rich in essential nutrients. During the 1980's, the drainage area is now thickly forested in pines and hardwoods, strip mines are being reclaimed, hillside farms are less in evidence, and better agricultural practices are in vogue. A runoff event in May, 1984, filled the lake to its highest level on record and the writers noted that the water was quite clear -- no evidence of sediment runoff was apparent.

179. Thus, we may conclude that there have been long-term changes in land use in the Center Hill drainage area and that these changes have lowered the levels of nitrogen and phosphorus to the limiting levels.

PART VIII: WATER LEVEL FLUCTUATIONS AND WATER QUALITY

Introduction

180. Water quality data were obtained from the U.S. Corps of Engineers from years 1970-1984. Data were recorded for many different water quality parameters throughout the depth of the reservoir at various river miles upstream of Center Hill Dam. The data utilized for this sub-study consisted of stage, temperature, specific conductivity, dissolved oxygen, pH, alkalinity, dissolved solids, nitrogen, and phosphorus at the surface and 10, 20, and 30 feet below the surface. A data file was constructed with the aforementioned data at eight points along the reservoir. Those points were as follows: Caney Fork River Mile 27.2 (near dam), Caney Fork River Mile 31.9, Caney Fork River Mile 39.4, Caney Fork River Mile 48.8, Caney Fork River Mile 61.1, Caney Fork River Mile 67.0, Caney Fork River Mile 75.4, and Falling Water River Mile 5.1.

Results

181. Correlations were executed between stage and the eight water quality parameters and in addition, correlations were executed one-to-one between the eight parameters using a SAS program on a VAX 11/785 which is made by the Digital Equipment Corporation. Valid correlations at an alpha level of 0.05 were tabulated and then plotted. In the analysis, each of the parameters are defined as follows: V1 = temperature, V2 = specific conductivity, V3 = dissolved oxygen, V4 = pH, V5 = alkalinity, V6 = dissolved solids, V7 = nitrogen, and V8 = phosphorus. ELEV represents the stage or water surface elevation. The Tables 25-32 are listed in order of ascending river miles (RMs) beginning at a station close to Center Hill Dam (RM 27.2), proceeding through a station much further upstream at RM 75.4, and ending with a station at Falling Water RM 5.1 which is a portion of Center Hill Reservoir. Each table consists of four parts which are previously defined correlations at depths 0, 10, 20, and 30 feet.

181. The numbers shown in Tables 25-32 are actual values of correlations from -1 to +1 with a corresponding value which aids in evaluating the validity of the correlation. The corresponding value which is found beneath each correlation value represents the sample size from which the correlation was derived. Thus, for example, if 50 temperatures at 30 feet from the surface at Caney Fork River Mile 27.2 were present in the data file to be correlated with stage, then the sample size would be 50. With the knowledge of the correlation value and its corresponding sample size, Table 33 was used to determine if the correlation

Table 25

Correlation Table of Parameters at RM 27.2

	V1	V2	V3	V4	V5	V6	V7	V8
Depth = 0								
Elevation	--	-0.42809 46	0.46731 57	--	--	--	0.47147 20	0.45044 20
V1	--	-0.33187 46	-0.33912 57	0.53098 41	--	--	--	--
V2	--	--	--	--	--	--	--	-0.59320 20
V7	--	--	--	--	--	--	--	-0.69016 20
Depth = 10								
Elevation	--	-0.45027 46	0.42988 57	--	--	--	--	--
V1	--	-0.39842 46	--	0.49187 41	--	--	--	--
V3	--	--	--	0.38878 40	--	--	--	--
Depth = 20								
Elevation	-0.28801 59	-0.46211 46	-0.33736 57	--	--	--	--	--
V1	--	--	--	0.32149 41	--	--	--	--
V2	--	--	--	-0.32577 41	--	--	--	--
V3	--	--	--	0.49029 40	--	--	--	--

Table 25 (continued)

	V1	V2	V3	V4	V5	V6	V7	V8
Depth = 30								
Elevation	-0.34889 59	-0.45377 46	0.26414 47	--	-0.94660 3	--	--	--
V1	--	--	-0.50343 57	--	--	--	--	--
V2	--	--	-0.40031 45	-0.32504 41	0.98189 3	--	--	--
V3	--	--	--	0.40392 40	--	-0.88654 4	--	--

Table 26

Correlation Table of Parameters at RM 31.9

	V1	V2	V3	V4	V5	V6	V7	V8
Depth = 0								
Elevation	--	-0.46674 31	0.41184 33	--	--	--	--	--
V1	--	--	--	0.65288 28	--	--	--	--
V2	--	--	--	--	--	0.81637 7	--	--
V3	--	--	--	0.42035 28	--	--	--	--
Depth = 10								
Elevation	--	-0.44675 31	0.48306 32	--	--	--	--	--
V1	--	--	--	0.53985 28	--	--	--	--
V3	--	--	--	0.52119 28	--	--	--	--
Depth = 20								
Elevation	--	0.40012 32	0.45855 31	--	--	--	--	--
V1	--	--	-0.41748 31	0.37397 28	--	--	--	--
Depth = 30								
Elevation	-0.47820 32	-0.39547 31	--	--	--	--	--	--
V1	--	0.40304 30	-0.58622 31	--	--	--	--	--
V2	--	--	-0.71891 30	--	--	--	--	--

Table 27

Correlation Table of Parameters at RM 39.4

	V1	V2	V3	V4	V5	V6	V7	V8
Depth = 0								
Elevation	--	-0.60327 15	0.81391 15	0.75160 15	--	--	--	--
V1	--	-0.55742 15	--	0.61743 15	--	--	--	--
V2	--	--	--	0.78370 15	--	--	--	--
V3	--	--	--	0.61716 15	--	--	--	--
Depth = 15								
Elevation	--	-0.66840 15	0.86366 15	0.79275 15	--	--	--	--
V2	--	--	-0.51436 15	-0.79266 15	--	--	--	--
V3	--	--	--	0.74278	-- 15	--	--	--
Depth = 20								
Elevation	--	-0.66269 15	--	--	--	--	--	--
V1	--	--	-0.51059 15	--	--	--	--	--
V2	--	--	-0.58012 15	--	--	--	--	--

Table 27 (continued)

	V1	V2	V3	V4	V5	V6	V7	V8
Depth = 30								
V1	--	0.77787 15	-0.80911 15	--	--	--	--	--
V2	--	--	-0.71044 15	--	--	--	--	--
V3	--	--	--	0.79913 15	--	--	--	--

Table 28

Correlation Table of Parameters at 48.8

	V1	V2	V3	V4	V5	V6	V7	V8
Depth = 0								
Elevation	-0.27749 60	-0.58014 45	0.45258 56	--	--	--	0.83674 20	--
V1	--	--	-0.55033 56	0.52701 42	--	--	0.57314 20	--
V2	--	--	--	--	--	0.56888 18	--	--
V4	--	--	--	--	--	--	-0.55964 16	--
Depth = 10								
Elevation	-0.38818 58	-0.58587 43	--	--	--	--	--	--
V1	--	--	-0.26755 57	0.47325 40	--	-0.99050 3	--	--
V3	--	--	--	0.37605 39	--	--	--	--
Depth = 20								
Elevation	-0.44008 59	-0.48527 44	--	--	--	--	--	--
V1	--	--	-0.33863 57	--	--	--	--	--
V2	--	--	-0.48767 43	--	--	--	--	--
V3	--	--	--	0.39537 39	--	-0.8800 6	--	--

Table 28 (continued)

	V1	V2	V3	V4	V5	V6	V7	V8
Depth = 30								
Elevation	-0.38603 59	-0.60066 44	0.45020 58	--	--	--	--	--
V1	--	--	-0.65540 58	--	--	--	--	--
V2	--	--	-0.58458 43	-0.32077 40	--	--	--	--
V3	--	--	--	0.54182 40	--	--	--	--

Table 29

Correlation Table of Parameters at RM 61.1

	V1	V2	V3	V4	V5	V6	V7	V8
Depth = 0								
Elevation	--	-0.71193 40	0.41842 50	--	-0.50871 18	--	0.79114 18	0.81300 18
V1	--	--	-0.38615 50	0.72955 36	--	--	--	--
V2	--	--	--	--	0.46551 18	--	-0.71546 18	-0.78755 18
V4	--	--	--	--	--	--	-0.57758 15	--
V7	--	--	--	--	--	--	--	0.88752 18
Depth = 10								
Elevation	-0.32279 62	-0.76134 39	0.38419 50	--	--	--	--	--
V1	--	--	--	0.69643 35	--	--	--	--
V2	--	--	--	0.35662 35	--	--	--	--
Depth = 20								
Elevation	-0.41197 62	-0.64991 39	0.39850 50	--	--	--	--	--
V1	--	0.43800 39	-0.59611 50	0.38322 35	--	--	--	--
V2	--	--	-0.60605 38	--	--	--	--	--

Table 29 (continued)

	V1	V2	V3	V4	V5	V6	V7	V8
Depth = 30								
Elevation	-0.36179 61	-0.68870 39	0.53520 49	--	--	-0.98753 3	--	--
V1	--	0.47227 39	-0.71235 49	--	--	--	--	--
V2	--	--	-0.62034 38	--	--	--	--	--
V3	--	--	--	0.43861 34	--	--	--	--

Table 30

Correlation Table of Parameters at RM 67.0

	V1	V2	V3	V4	V5	V6	V7	V8
Depth = 0								
Elevation	--	-0.92526 13	0.70910 15	--	-0.78612 7	--	0.99189 6	0.98317 6
V1	--	--	--	0.77828 12	--	--	-0.94111 6	-0.89081 6
V2	--	--	-0.66766 13	--	0.77763 7	--	-0.93828 6	-0.92937 6
V4	--	--	--	--	--	0.95301 4	-0.86464 5	-0.91689 5
V7	--	--	--	--	--	--	--	0.97980 6
Depth = 10								
Elevation	-0.74455 14	-0.94808 12	--	-0.61771 11	--	--	--	--
V1	--	0.78120 12	--	0.59654 11	--	--	--	--
Depth = 20								
Elevation	-0.81656 14	-0.79936 12	--	--	--	--	--	--
V1	--	0.61940 12	--	--	--	--	--	--
V2	--	--	-0.80796 12	--	--	--	--	--

Table 30 (continued)

	V1	V2	V3	V4	V5	V6	V7	V8
Depth = 30								
Elevation	-0.71950 14	-0.86606 12	0.81098 14	--	--	--	--	--
V1	--	0.62815 12	-0.62846 14	--	--	--	--	--
V2	--	--	-0.77463 12	--	--	--	--	--

Table 31

Correlation Table of Parameters at RM 75.4

	V1	V2	V3	V4	V5	V6	V7	V8
<u>Depth = 0</u>								
Elevation	--	-0.89452 28	0.50576 28	--	-0.64329 18	-	0.75287 18	0.77433 18
V1	--	--	--	0.70631 24	0.51316 18	--	-0.50343 18	--
V2	--	--	-0.43858 28	--	0.75685 18	--	-0.71281 18	-0.81128 18
V4	--	--	--	--	--	--	-0.73357 15	--
V5	--	--	--	--	--	--	-0.55261 17	-0.60813 17
V6	--	--	--	--	--	--	-0.49329 17	--
V7	--	--	--	--	--	--	--	0.85972 19
<u>Depth = 10</u>								
Elevation	-0.38504 32	-0.85435 27	--	-0.44533 23	--	--	--	--
V1	--	0.46774 27	--	0.69105 23	--	--	--	--
V2	--	--	--	0.53327 23	--	--	--	--

Table 31 (continued)

	V1	V2	V3	V4	V5	V6	V7	V8
Depth = 20								
Elevation	-0.43752	-0.70578	0.49655	--	0.99844	--	--	--
	32	27	27		3			
V1	--	0.46625	-0.70609	0.45145	--	--	--	--
		27	27	23				
V2	--	--	-0.74195	--	--	--	--	--
			27					
Depth = 30								
Elevation	-0.39188	-0.79575	0.55139	--	--	--	--	--
	32	27	27					
V1	--	0.43408	-0.73535	--	--	--	--	--
		27	27					
V2	--	--	-0.70542	--	--	--	--	--
			27					

Table 32

Correlation of Parameters at Falling Water RM 5.1

	V1	V2	V3	V4	V5	V6	V7	V8
Depth = 0								
Elevation	--	-0.56006 27	--	--	--	--	0.79775 18	0.52934 18
V1	--	--	--	0.37650 29	--	0.56531 17	-0.57280 18	--
V2	--	--	--	--	0.54201 18	--	--	-0.58186 17
V4	--	--	--	--	--	--	-0.55002 13	--
V5	--	--	--	--	--	--	--	-0.46546 18
Depth = 10								
Elevation	--	-0.48160 27	-	--	--	--	--	--
V1	--	--	-0.38993 27	--	--	--	--	--
Depth = 20								
Elevation	-0.34154 45	-0.44187 27	--	--	--	--	--	--
V1	--	--	-0.42406 27	--	--	--	--	--
V2	--	--	-0.67472 26	-0.60120 23	00	0.99634 3	--	--
V3	--	--	--	0.69729 22	-0.95190 3	--	09.99954 3	
V5	--	--	--	--	--	--	-0.96077	--

Table 32 (continued)

	V1	V2	V3	V4	V5	V6	V7	V8
Depth = 30								
Elevation	-0.32448 45	-0.56153 27	--	--	--	--	0.96260 3	--
V1	--	--	-0.64909 27	00	00	9.96941 3	--	--
V2	--	--	-0.43438 26	0.51558 23	--	--	--	--
V3	--	--	--	0.59589	--	0.98691	--	--

Table 33

Values of the Correlation Coefficient for Different Levels of Significance

n	P = .05	.02	.01
1	.996917	.9995066	.9998766
2	.95000	.98000	.990000
3	.8783	.93433	.95873
4	.8114	.8822	.91720
5	.7545	.8329	.8745
6	.7067	.7887	.8343
8	.6319	.7155	.7646
9	.6021	.6851	.7348
10	.5760	.6581	.7079
11	.5529	.6339	.6835
12	.5324	.6120	.6614
13	.5139	.5923	.6411
14	.4973	.5742	.6226
15	.4821	.5577	.6055
16	.4683	.5425	.5897
17	.4555	.5285	.5751
18	.438	.5155	.5614
19	.4329	.5034	.5487
20	.4227	.4921	.5368
25	.3809	.4451	.4869
30	.3494	.4093	.4487
35	.3246	.3810	.4182
40	.3044	.3578	.3932
45	.2875	.3384	.3721
50	.2732	.3218	.3541
60	.2500	.2948	.3248
70	.2319	.2737	.3017
80	.2172	.2565	.2830
90	.2050	.2422	.2673
100	.1946	.3201	.2540

Source: Table V-A of R.A. Fisher, <u>Statistical Methods for Research Workers</u>, Edinburgh: Oliver and Boyd, Ltd.

was valid. If a correlation proved to invalid, a dash was inserted in its place. In Table 33, n is the sample size, and P is the level of significance.

182. For example, a valid correlation between stage and temperature would have a value equal to or greater than .2732 for a sample size of 50 and a level of significance of 0.05. A level of significance of 0.05 was used for all correlations. The tables should be read by focusing on the first column begining with ELEV and locating the valid correlation to the right (on the same row) which is beneath the variable to which ELEV is correlated. Follow in this manner with the remaining variables beneath ELEV in the first column.

183. A positive correlation is one where the sign is common (positive or negative) to both variables. A negative correlation is one where the sign of one variable is the opposite of the other. In other words, with a positive correlation, as one variable increases or decreases, the other variable increases or decreases correspondingly. With a negative correlation, as one variable increases or decreases, the other variable behaves inversly.

184. Tables 34-39 were prepared to summarize the information from the previous Tables 25-32. Table 34 indicated that temperature, specific conductivity, and, in one case, alkalinity were negatively correlated to the water surface elevation, while dissolved oxygen, nitrogen, and phosphorus were positively correlated to the water surface elevation. In the subsequent tables, 35-39, results of positive and negative correlations between the eight water quality parameters were found. A significant number of correlations were found to be negative between

Table 34

Valid Correlations Between Eight Water Quality Parameters and State

	Temperature V1/EL	Conductivity V2/EL	DO V3/EL	pH V4/EL	Alkalinity V5/EL	Solids V6/EL	Nitrogen V7/EL	Phosphorus V8/EL
Table 1								
0		-X	X				X	X
10		-X	X					
20	-X	-X	X					
30	-X	-X	X		-X			
Table 2								
0		-X	X					
10		-X	X					
20		-X	X					
30	-X	-X						
Table 3								
0		-X	X	X				
10		-X	X	X				
20		-X						
30								
Table 4								
0	-X	-X	X				X	
10	-X	-X						
20	-X	-X						
30	-X	-X	X					
Table 5								
0		-X	X		-X		X	X
10	-X	-X	X					
20	-X	-X	X					
30	-X	-X	X			-X		
Table 6								
0		-X	X		-X		X	X
10	-X	-X		X				
20	-X	-X						
30	-X	-X	X					

Table 34 (continued)

	Temperature V1/EL	Conductivity V2/EL	DO V3/EL	pH V4/EL	Alkalinity V5/EL	Solids V6/EL	Nitrogen V7/EL	Phosporus V8/EL
Table 7								
0		-X	X		-X		X	X
10	-X	-X		-X				
20	-X	-X	X		-X			
30	-X	-X	X					
Table 8								
0		-X					X	X
10		-X						
20	-X	-X						
30	-X	-X					X	

Table 35

Valid Correlations Between Temperature and the Remaining Seven Water Quality Parameters

	V2/V1	V3/V1	V4/V1	V5/V1	V6/V1	V7/V1	V8/V1
Table 1							
0	-X	-X	X				
10	-X		X				
20			X				
30		-X					
Table 2							
0			X				
10			X				
20		-X	X				
30	X	-X					
Table 3							
0	-X		X				
10							
20		-X					
30	X	-X					
Table 4							
0		-X	X			-X	
10		-X	X		-X		
20		-X					
30		-X					
Table 5							
0		-X	X				
10			X				
20	X	-X	X				
30	X	-X					
Table 6							
0			X			-X	-X
10	X		X				
20	X						
30	X	-X					

Table 35 (continued)

	V2/V1	V3/V1	V4/V1	V5/V1	V6/V1	V7/V1	V8/V1
Table 7							
0			X	X		-X	
10	X		X				
20	X	-X	X				
30	X	-X					
Table 8							
0			X		-X	-X	
10		-X					
20		-X					
30		-X			X		

temperature and dissolved oxygen and positive between temperature and pH in Table 35. In Table 36, many negative correlations between specific conductivity and dissolved oxygen and a few negative correlations between specific conductivity and phosphorus were found. It appeared that there may have been some positive correlation between specific conductivity and alkalinity although the data for alkalinity were limited. In Table 37, there were a significant number of positive correlations between dissolved oxygen and pH. In Table 38, there were a few negative correlations between pH and nitrogen. Although data for nitrogen and phosphorus were sparse, indications from Table 39 were that the two nutrients were positively correlated.

185. In some cases where nitrogen and phosphorus were correlated with other parameters, valid correlations were normally identified at depth zero. This is due to the paucity of data for these two parameters, and because most nutrient data were recorded only at the surface.

Discussion of Results

186. The intent of this section is to discuss several of the significant correlations described in the previous section in the context of several physical, chemical and biological phenomena known to occur in stratified reservoirs.

Stage Versus Temperature and Conductivity

187. The correlations showed that temperature was inversely related to reservoir elevation. That is, as the water level rises, the upper 30-feet of water becomes cooler. Most of the data for the correlations

Table 36

Valid Correlations Between Specific Conductivity and the Six Remaining Water Quality Parameters

	V3/V2	V4/V2	V5/V2	V6/V2	V7/V2	V8/V2
Table 1						
0						-X
10						
20		-X				
30	-X	-X	X			
Table 2						
0				X		
10						
20						
30	-X					
Table 3						
0		-X				
10	-X	-X				
20	-X					
30	-X					
Table 4						
0				X		
10						
20	-X					
30	-X	-X				
Table 5						
0			X		-X	-X
10		X				
20	-X					
30	-X					
Table 6						
0	-X		X		-X	-X
10						
20	-X					
30	-X					

Table 36 (continued)

	V3/V2	V4/V2	V5/V2	V6/V2	V7/V2	V8/V2
Table 7						
0	-X		X		-X	-X
10		X				
20	-X					
30	-X					
Table 8						
0			X			-X
10						
20	-X	-X		X		
30	-X	-X				

Table 37

Valid Correlations Between Dissolved Oxygen and the Remaining Five Water Quality Parameters

	V4/V3	V5/V3	V6/V3	V7/V3	V8/V3
<u>Table 1</u>					
0	X				
10	X				
20	X		-X		
30	X				
<u>Table 2</u>					
0	X				
10	X				
20					
30					
<u>Table 3</u>					
0	X				
10	X				
20					
30	X				
<u>Table 4</u>					
0					
10	X				
20	X		-X		
30	X				
<u>Table 5</u>					
0					
10					
20					
30	X				
<u>Table 6</u>					
0					
10					
20					
30					

Table 37 (continued)

	V4/V3	V5/V3	V6/V3	V7/V3	V8/V3
Table 7					
0					
10					
20					
30					
Table 8					
0					
10					
20	X	-X		-X	
30	X		-X		

Table 38

Valid Correlations Between pH and the Remaining Four Water Quality Parameters and Between Alkalinity and the Remaining Three Water Quality Parameters

	V5/V4	V6/V4	V7/V4	V8/V4	V6/V5	V7/V5	V8/V5
Table 1							
0							
10							
20							
30						-X	
Table 2							
0							
10							
20							
30							
Table 3							
0							
10							
20							
30							
Table 4							
0			-X				
10							
20							
30							
Table 5							
0			-X				
10							
20							
30							
Table 6							
0		X	-X	-X			
10							
20							
30							

Table 38 (continued)

	V5/V4	V6/V4	V7/V4	V8/V4	V6/V5	V7/V5	V8/V5
Table 7							
0			-X			-X	-X
10							
20							
30							
Table 8							
0			-X				-X
10							
20						-X	
30							

Table 39

Valid Correlations Between Dissolved Solids and the Remaining Two Water Quality Parameters and Between Nitrogen and Phosphorus

	V/7/V6	V8/V6	V8/V7
Table 1			
0			X
10			
20			
30		-X	
Table 2			
0			
10			
20			
30			
Table 3			
0			
10			
20			
30			
Table 4			
0			
10			
20			
30			
Table 5			
0			X
10			
20			
30			
Table 6			
0			X
10			
20			
30			

Table 39 (continued)

	V7/V6	V8/V6	V8/V7
Table 7			
0	X		X
10			
20			
30			
Table 8			
0			
10			
20			
30			

were taken during the spring and summer months when rainfall produces the high elevations and the cooler temperatures. High water levels also are an indication of shorter retention times which result in less heating of the surface waters.

188. Likewise, rainfall has a dilution effect in Center Hill Lake which reduces the specific conductivity. (This may not be true for all lakes). This is the result of the watershed being largely forested and rural according to Uttormark et al., 1974. This is a significant finding which relates to the management of the project.

Stage Versus DO, Nitrogen, and Phosphorus

189. The surface elevation is positively related to D.O., nitrogen and phosphorus. Again, runoff produces flow, increased elevation, mixing, and cooler temperatures which yield higher D.O. values. In Center Hill, the only sources of nutrients are external and these are brought in by runoff. Increased nutrients mean increased phytoplankton which contribute to the D.O. levels in the upper 30-foot layer. Thus it is seen that stage is not exactly a management tool, but one should understand its effects. For instance, even though elevation is positively related to nutrients, it is not really possible to increase the nutrient regime of the lake by halting outflows. Only high inflows will bring in nutrients and these inflows are not under the power of the reservoir manager.

Stage Versus pH, Alkalinity, and Dissolved Solids

190. It is important to note that water surface elevation was not correlated with pH nor dissolved solids. This means that Center Hill

is not impacted by acid rain and that the runoff does not contain significant quantities of ionized materials.

Cross-Correlations Among Parameters

191. While there were many interesting and important cross-correlations developed, they do not relate to the objective of water level fluctuations and were included to help document the validity of the other correlations.

PART IX: STUDY CONCLUSIONS

192. The following conclusions were developed from the studies discussed in the preceeding sections.

1. Water level fluctuations in a deep, steep-sided reservoir like Center Hill are not correlated with sport fish biomass, nor with monthly average creel success. Water levels should be held constant during spawning periods.

2. The daily creel averages showed that the catch of sport fish is poorer whenever the water rises or falls more than one-half foot per day.

3. Long-term trends in the creel data are apparent in that crappie and white bass catches have declined to negligible levels. Smallmouth bass catches have declined while Kentucky bass catches have dramatically increased.

4. Long-term trends in water quality reflect a marked decline in total phosphorus and inorganic nitrogen. These nutrient decreases may be related to the decline in certain species in the creel.

5. Water quality parameters are related to the water surface elevation in some cases. Temperature, dissolved oxygen, specific conductivity, nitrogen and phosphorus were correlated with surface elevation. There were cross-correlations between temperature and dissolved oxygen, pH and specific conductivity.

PART X: A PROGRAM TO MONITOR THE EFFECTS OF WATER LEVEL CHANGES ON SPORT FISHING

193. One of the objectives of this study was to determine, based upon historical data, what a monitoring program should include to clearly show the effects of water level changes on sport fish biomass and creel success. Therefore, the previous studies were examined to see what data needs to be available in the categories of biomass, creel results and water quality.

Biomass

194. The biomass should be recorded on an annual basis for at least five years. Fall cove-rotenone studies would provide biomass estimates, year-class recruitment, predator-prey relationships and long-term trends which could be correlated with the important variables of water level fluctuations. Biomass detail is the most important aspect of the monitoring program.

Creel Results

195. Good long-term creel data are important for establishing trends and evaluating the effects of water level changes on the catch or harvest of the standing crop of sport fish. The Tennessee creel survey is

a good design for this purpose and would meet the needs for future analyses.

Water Quality Data

196. A good long-term water quality data base becomes essential if any trends in creel or biomass are developed. The most important features of a water quality data set are spring levels of nutrients, oxygen regime during the stratification period and some measure of phytoplankton biomass. Sampling intervals will depend upon the water quality dynamics of the particular reservoir.

PART XI: ACKNOWLEDGMENTS

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