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TECHNICAL REPORT E-82-5

FLUCTUATING WATER LEVELS IN RESERVOIRS; AN ANNOTATED BIBLIOGRAPHY ON ENVIRONMENTAL EFFECTS AND MANAGEMENT FOR FISHERIES

By G. R. Ploskey

U. S. Fish and Wildlife Service
U. S. Department of the Interior
Fayetteville, Ark. 72701

May 1982

Final Report

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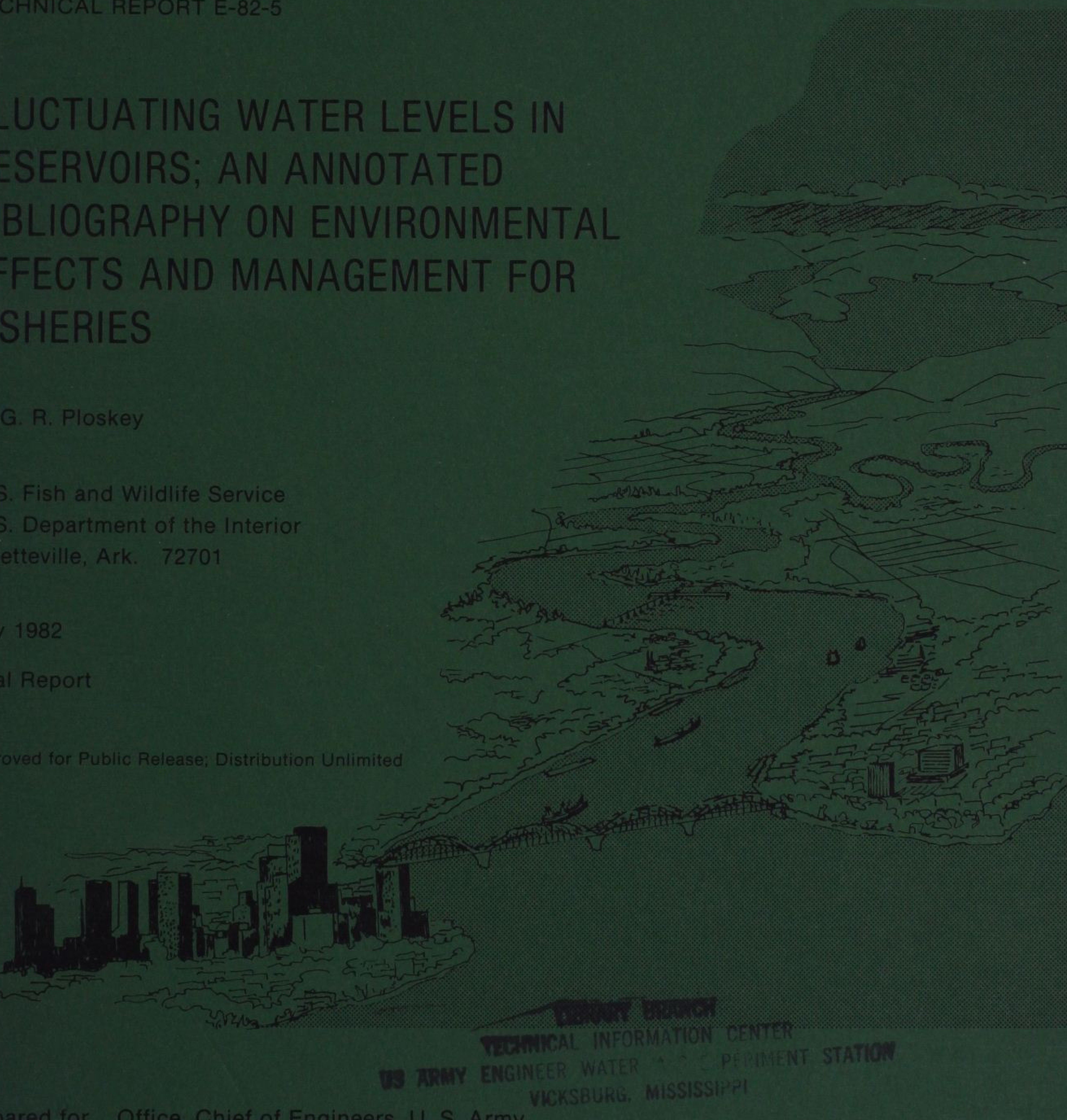

Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Under EWQOS TASK IIE

Monitored by Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
Technical Report E-82-5

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
FLUCTUATING WATER LEVELS IN RESERVOIRS; AN ANNOTATED BIBLIOGRAPHY ON ENVIRONMENTAL EFFECTS AND MANAGEMENT FOR FISHERIES

5. TYPE OF REPORT & PERIOD COVERED
Final report

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
G. R. Ploskey

8. CONTRACT OR GRANT NUMBER(s)
Intra-Army Order
WESRF-80-112

9. PERFORMING ORGANIZATION NAME AND ADDRESS
U. S. Department of the Interior
U. S. Fish and Wildlife Service
Fayetteville, Ark. 72701

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
EWQOS Task IIE

11. CONTROLLING OFFICE NAME AND ADDRESS
Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

12. REPORT DATE
May 1982

13. NUMBER OF PAGES
142

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)
U. S. Army Engineer Waterways Experiment Station
Environmental Laboratory
P. O. Box 631, Vicksburg, Miss. 39180

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22151.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Environmental impact analysis
Fisheries
Fishes
Reservoirs
Water quality

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
This report contains 367 annotations describing the effects of fluctuating reservoir water levels on fish. Citations on phytoplankton, zooplankton, and water quality that pertain to reservoir fisheries are also included. An index to facilitate location of references dealing with specific topic areas is included as an appendix.

PREFACE

This report was prepared by the U. S. Department of the Interior, U. S. Fish and Wildlife Service, National Reservoir Research Program (NRRP), for the U. S. Army Engineer Waterways Experiment Station (WES) under Intra-Army Order WESRF-80-112, dated 22 December 1980. The study forms part of the Environmental and Water Quality Operational Studies (EWQOS), Task IIE, "Environmental Effects of Fluctuating Reservoir Water Levels." The EWQOS Program is sponsored by the Office, Chief of Engineers, U. S. Army and is assigned to the WES under the management of the Environmental Laboratory (EL).

This annotated bibliography was prepared by Mr. G. R. Ploskey, Fishery Biologist (Research) for the NRRP. Mr. R. M. Jenkins is the Director of NRRP. The work was under the direct supervision of Dr. John Nestler and Mr. J. Norton, Chief, Water Quality Modeling Group, and the general supervision of Mr. D. L. Robey, Chief, Ecosystem Research and Simulation Division (ERSD); Dr. J. Mahloch, Program Manager, EWQOS; and Dr. J. Harrison, Chief, EL.

Commanders and Directors of WES were COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. The Technical Director was Mr. Fred R. Brown.

This report should be cited as follows:

> Ploskey, G. R. 1982. "Fluctuating Water Levels in Reservoirs; An Annotated Bibliography on Environmental Effects and Management for Fisheries," Technical Report E-82-5, prepared by the U. S. Fish and Wildlife Service, U. S. Department of the Interior, for the U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

CONTENTS

FLUCTUATING WATER LEVELS IN RESERVOIRS; AN ANNOTATED BIBLIOGRAPHY ON ENVIRONMENTAL EFFECTS AND MANAGEMENT FOR FISHERIES

PART I: INTRODUCTION

1. The U. S. Army Corps of Engineers regulates reservoir storage to provide for flood control, water supply, hydropower generation, irrigation, navigation, and recreation. Reservoir regulation to meet authorized purposes results in water level fluctuation and often necessitates trade-offs between conflicting reservoir purposes. Effective decisions to resolve conflicts between purposes can be made only by understanding the possible consequences of reservoir regulation. This report supplies information on the effects of different operational regimes on reservoir fisheries. The information can be applied to enhance reservoir fisheries and reconcile the needs of sport fishes with other project purposes.

2. Demand for quality fishing on reservoirs is rapidly increasing, as is the recognition that fishing represents a major use of impounded waters. The National Reservoir Research Program (NRRP) has estimated that fishing pressure on U. S. reservoirs increased from 105 million to about 200 million angler-days per year between 1974 and 1980. Projections for the year 2000 are for 400 million angler-days per year on an estimated 4.5 million hectares of reservoirs, an increase from 8.2 (1980) to 14.7 (2000) angler-days $hectare^{-1}$ $year^{-1}$ in 20 years.

3. To keep pace with increasing angling pressure on reservoirs, managers must use successful techniques to increase sport-fish production. Controlled manipulation of water levels has been recognized as one of the most valuable, practical, and successful techniques available to fishery managers for enhancing reservoir fisheries (Stroud 1948, Wood and Pfitzer 1960, Jenkins 1970, Keith 1975, Groen and Schroeder 1978); however, results are not always predictable because of other interacting variables (Hassler 1970). Uncontrolled fluctuations of water level can be detrimental (Ellis 1937, Benson 1968, June 1970), especially when fish are spawning.

4. This annotated bibliography summarizes results of published and unpublished research up through 1980 concerning fluctuating water levels and their effects on reservoir fisheries. Impacts of water-level fluctuations on physicochemical variables, algae, aquatic invertebrates, fish, and fishing are emphasized in annotations. Topics indirectly related to reservoir fisheries, such as the effects of fluctuations on erosion and reservoir aesthetics are also discussed. To facilitate use, a subject index is presented in Appendix A. Although this bibliography addresses water levels in reservoirs, research conducted on natural lakes, ponds, marshes, and floodplains is included when results provide insight into mechanisms by which changing water levels affect aquatic systems in general.

5. Units of measure are consistent with those in the original papers or abstracts, and consequently vary among annotations. Scientific names are used only when common names might be ambiguous (e.g., bream may refer to Lepomis sp. in North America or Abramis sp. in Europe) or of limited usage. Where applicable, common names are those recommended by the American Fisheries Society ("A List of Common and Scientific Names of Fishes from the United States and Canada," 4th edition, American Fisheries Society Special Publication No. 12, 1980).

Aass, P. 1960. The effects of impoundment on inland fisheries. Seventh Tech. Meeting, Internat. Union for Cons. of Nature and Natural Resour., Greece, 1958. 4: 69-76.

6. Factors that significantly affect the aquatic biota of Norwegian impoundments are discussed. The extent of water-level fluctuation is the only factor that affects changes in the fish-food fauna. The abundance of species with poor ability to follow receding waters is greatly reduced, or eliminated. Aquatic plants and benthos without a diapause or resting mechanism die from over-winter exposure and freezing. Gastropods and Gammarus usually are severely reduced by fluctuating water levels, and destruction of aquatic vegetation reduces populations of benthos by eliminating refuge and food. Initially, high water levels flood terrestrial areas and temporarily increase the food supply of fish by making terrestrial animals and nutrients available. Erosion induced by water-level fluctuations and wave action creates rocky shorelines that support a poor benthic fish-food fauna. Fish growth usually declines, because many species must supplement their diet with plankton. Although rapidly receding water apparently does not affect tipulids, oligochaetes, or plecopterans; ephemeropterans and trichopterans are eliminated. Occasionally, growth and yields of fish increase for several years after filling, but ultimately production declines even below the original level. Flooding may enhance the reproduction of fishes such as perches and pikes which spawn over flooded areas in the spring. Fry of these species prosper with increased cover and food. Reduced water levels may cause atresia or increase mortality of fry by stranding or predation. Because of water-level fluctuations and resulting variations in year-class strength, a single year class is apt to dominate the harvest for a number of years. Although trout catches invariably decline in fluctuating impoundments, probably because of low benthos populations, the harvest of chars frequently increases as a result of improved zooplankton production. The overall decline in harvest may be due to physical problems encountered in fishing areas in flooded timber or drifting vegetation.

Aass, P. 1964. Regulations and recruitment of char. Nor. Jeger-og Fiskerforb. Tidsskr. 93: 378-381. (In Norwegian)

7. This paper deals with the effects of winter drainage on the recruitment of char in lakes Pålsbufjord and Tunhovdfjord. In both lakes, winter draining of spawning sites destroys ova and alevins. Pålsbufjord Lake is drained early in winter, and about three-fourths of the bottom area is exposed. Mortality of ova and alevins is great, and optimal recruitment is not attained. In winters when the reservoir is emptied slowly or not fully exhausted, strong year classes of char are produced. The fishery is sustained mainly by a few strong year classes. Neighboring Tunhovdfjord Lake is drawn down in late winter

and although spawning areas are drained, most ova have hatched and alevins are capable of following the receding water. Consequently, fluctuations between weak and strong year classes are not as conspicuous in Tunhovdfjord as in Pålsbufjord. (Abstract adapted from K. W. Jensen, Vollebeck, Norway, as cited by Fraser 1972.)

Aass, P. 1969. Crustacea, especially Lepidurus arcticus Pallas, as brown trout food in Norwegian mountain reservoirs. Rep. Inst. Freshwater Res. Drottningholm 49: 183-201.

8. Studies of food of brown trout in 38 reservoirs in southern Norway showed that crustaceans were the principal food in August and September. In arctic impoundments, trout ate primarily Lepidurus arcticus, a tadpole shrimp that can survive water-level fluctuations of at least 35 m. Impoundments apparently are favorable environments for Lepidurus, as populations already present in subarctic lakes flourished after impoundment. Beginning in 1967, Lepidurus has been introduced into some impoundments to increase the production of brown trout.

Aass, P. 1970. The winter migrations of char, Salvelinus alpinus L., in the hydroelectric reservoirs Tunhovdfjord and Paalsbufjord, Norway. Rep. Inst. Freshwater Res. Drottningholm 50: 5-44.

9. Movements of tagged char were traced and correlated with changes in reservoir elevation. Post-spawning and early-winter migrations were toward shore for feeding. Water levels apparently affected the dispersion of char. When water levels were lowered, char moved toward deeper water until they came into contact with deep-flowing water. Because food in these currents was negligible, further winter migrations in a downstream direction probably resulted from passive displacement by currents. The affinity of char for currents may be exploited to improve fishing.

Aggus, L. R. 1971. Summer benthos in newly flooded areas of Beaver Reservoir during the second and third years of filling 1965-1966. Pages 139-152 in G. E. Hall, ed. Reservoir Fisheries and Limnology. Am. Fish. Soc. Spec. Publ. No. 8.

10. Multiple plate samplers showed that areas of recently flooded herbaceous vegetation contained greater numbers and biomass of benthos than did cleared areas or those with woody vegetation. Recently inundated herbaceous plants presumably provide space for attachment, food, and refuge from predators. Cleared areas were less productive than areas with vegetation and were subjected to greater and more rapid erosion. The typical summer decline in the number of organisms was more rapid after the breakup or decomposition of herbaceous vegetation, and decreases in chironomid abundance coincided with conspicuous increase in the rate of shoreline erosion and sediment redeposition.

Aggus, L. R. 1979. Effects of weather on freshwater fish predator-prey dynamics. Pages 47-56 in H. Clepper, ed. Predator-prey Systems in Fisheries Management. Sport Fishing Inst., Washington, D. C.

11. Impacts of environmental changes are difficult to understand because of the heterogeneous nature of reservoir habitats that modify the effects of meteorological events and because of difficulties in assigning cause-effect relations. In reservoirs, flow-related factors that result from changes in precipitation or water release may affect fish more than temperature, which exerts its greatest effect in physically stable environments such as natural lakes. Seasonal and annual variations in rainfall affect the fish community by altering water levels, rates of nutrient input, and runoff volumes. Literature on water levels indicates that spawning success of many species is influenced by the timing and duration of flooding and the type of substrate covered. Some studies suggest that high water levels have little positive effect on reproduction when terrestrial plants are not inundated. Changes in water levels alter the ratio of prey to predatory fish and the carrying capacity of the environment. Data suggest that populations of closely related species (e.g., largemouth, spotted, and smallmouth bass) may respond differently to changes in water level. As a result of receding waters, prey availability may increase rapidly for existing predators, thereby improving predator growth and use of prey.

Aggus, L. R. and G. V. Elliott. 1975. Effects of cover and food on year-class strength of largemouth bass. Pages 317-322 in H. Clepper, ed. Black Bass Biology and Management. Sport Fishing Inst., Washington, D. C.

12. Strong year classes of largemouth bass occurred only in years of high inflow and high water. The number of bass surviving their first summer was significantly correlated with the amount and duration of flooding of shoreline vegetation. Predation probably was a major cause of mortality in young-of-year bass. Growth of young largemouth bass accelerated when high inflows resulted in extensive flooding of terrestrial vegetation or when bass converted from a diet of invertebrates to one of fish. Over-winter survival was higher for large individuals.

Aggus, L. R. and S. A. Lewis. 1976. Environmental conditions and standing crops of fishes in predator-stocking-evaluation reservoirs. Proc. Annu. Conf. Southeast. Assoc. Fish Wildl. Agencies 30: 131-140.

13. Of eleven environmental variables tested (from 23 reservoirs) by multiple regression analysis, only storage ratio (i.e., reservoir volume divided by the annual outflow volume), outflow volume, growing

season, and total dissolved solids were consistently related to the standing crop of fish. Total standing crops and crops of sunfishes, clupeids, and small fishes were larger in impoundments with rapid rates of water exchange (storage ratio < 0.165, as in mainstream reservoirs) than in storage reservoirs with slow rates of water exchange. During periods of high inflow, storage reservoirs may become similar to mainstream reservoirs in terms of hydrology, fish standing crops, and fish community structure. Standing crops of all fishes increased more in storage reservoirs than in mainstream reservoirs after the high inflows of 1973. During 1973, flooded shoreline vegetation in the 23 fluctuating reservoirs added a new source of detritus, but the effects of water-level fluctuation (in vertical feet) were not significant, although relations were generally positive. Combinations of environmental variables explained 41 - 67% of the variation in the standing crops of selected taxa.

Alhonen, P. 1970. On the significance of the planktonic/littoral ratio in the Cladoceran stratigraphy of lake sediments. Comment. Biol. 35: 1-9.

14. Evidence is presented that relates water-level oscillations (as caused by rainfall) to variations in the abundance of major cladoceran taxa in pelagic and littoral zones. Water-level oscillations were associated with the index ILL = Bosminidae + Daphnidae / Chydoridae.

Allan, R. C. and J. Romero. 1975. Underwater observations of largemouth bass spawning and survival in Lake Mead. Pages 104-112 *in* H. Clepper, ed. *Black Bass Biology and Management*. Sport Fishing Inst., Washington, D. C.

15. Major factors affecting the reproduction and survival of largemouth bass in Lake Mead are evaluated (i.e., water-level fluctuation, wind and wave action, water quality, cover, temperature, predation, and human activities). Before impoundment of Lake Powell upstream, occasional floods in Lake Mead pushed water levels to new heights during the spawning season and resulted in good recruitment and several years of good fishing. After 1964, while Lake Powell was filling, water levels in Lake Mead declined. In the spawning season of 1974, receding water levels and strong winds caused excessive erosion, which buried or suffocated some nests. Nesting success was not positively correlated with the availability and quality of cover. The species and amount of zooplankton produced in coves and available for fry may be related to the inundation of green cover by rising waters. Poor survival of fry and fingerling bass may be related to a limited food supply.

Allen, G. W. 1969. Pool fluctuation in Corps impoundments in relation to fish spawning. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 23: 553-558.

16. Efforts of conservation agencies and the U. S. Army Corps of Engineers to provide suitable water levels during the spawning season of sport fishes is discussed. In spite of coordinated efforts, manipulation of water levels in reservoirs has never been proven to benefit or harm fisheries resources consistently, but because of the complex nature of the relation between fish populations and fluctuating water levels, coordinated manipulations will be continued until it is proved that they have no beneficial effect. Biologists apparently do not know enough about fish dynamics in reservoirs to predict future conditions in fisheries or to pinpoint exactly what is right or wrong with existing conditions.

Al Rawi, T. R. 1971. Investigating the validity of the scale method in determining the growth of two species of fish in Oklahoma and its relation to temperature and water level. Ph.D. Thesis, Oklahoma State Univ., Stillwater, Oklahoma. 152 pp.

17. Studies of gizzard shad and white crappie in Keystone Reservoir indicated that growth was independent of water-level fluctuation. However, fluctuations in water level were small during most of the sampling period except for one month (mid-June through mid-July). Growth appeared to be more closely related to temperature than to water level.

Antipova, O. P. 1961. Some basic information about reservoirs of the U.S.S.R. which are already built, or are planned. Izv. Gos. Nauchn. - Issled, Inst. Ozern. Rechn. Rybn. Khoz. 50: 261-269. (In Russian)

18. Information on 119 reservoirs is presented. Data include the river or lake source, year filled, area, volume, maximum and mean depths, maximum length, average long-term water turnover, decrease in water level for an average year, and anticipated catch of fish. (Abstract adapted from Referat. Zhur. Biol., 1963, No. 5I58; Biol Abstr. 45: 2718.)

Applegate, R. L. and J. W. Mullan. 1966. Food of the black bullhead (Ictalurus melas) in a new reservoir. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 20: 288-292.

19. Diets of black bullheads collected during periods of relatively stable water level differed significantly from those of fish sampled during periods of rapidly rising water. When water levels were stable, young-of-year bullheads fed mainly on entomostracans (72% of the stomach volume), and diets of bullheads 4.0 to 11.3 inches long consisted mostly

of filamentous algae and detritus (94% by volume). By contrast, when water levels rose rapidly during winter and spring and flooded terrestrial soils for the first time, terrestrial animals such as earthworms and insects were eaten preferentially (56% by volume).

Applegate, R. L. and J. W. Mullan. 1967. Food of young largemouth bass, Micropterus salmoides, in a new and old reservoir. Trans. Am. Fish. Soc. 96: 74-77.

20. Foods of young largemouth bass during the early development of a new reservoir and in a 14-year-old reservoir are described. Growth was substantially faster in the new than in the old reservoir. Average daily growth during early summer was 0.52 mm in Bull Shoals Lake and 1.17 mm in Beaver Lake. Large food items such as chironomid larvae, which "bridged the gap" from an entomostracan diet to a diet of fish in Beaver Lake, were almost completely lacking in the older reservoir. In Beaver Lake, chironomids were the dominant food (superseding entomostraca) for bass about 36 mm long. At 40 mm, bass preferentially selected gizzard shad over chironomid larvae. In Bull Shoals Lake, 40 mm bass switched from a diet dominated by entomostraca to one dominated by fish.

Applegate, R. L., J. W. Mullan, and D. I. Morais. 1966. Food and growth of six centrarchids from shoreline areas of Bull Shoals Reservoir. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 20: 469-482.

21. Stomach contents of longear sunfish, green sunfish, bluegills, largemouth bass, smallmouth bass, and spotted bass from Bull Shoals Lake were analyzed and compared. Fish were collected from nearshore areas of the fluctuating reservoir throughout the growing season of 1964, and seasonal changes in diets were documented. Data refute the hypothesis that fluctuations of water level (averaging 16 feet yearly) limit benthos production in littoral areas and thereby decrease the value of these areas as nurseries for young fish. The littoral benthos of Bull Shoals Reservoir contributed substantially to the diets of all centrarchids less than 4 inches long.

Arner, D. H., W. J. Lorio, B. M. Teels, and E. D. Norwood. 1971. The effects of age and water fluctuations on the limnological factors of impounded waters. Mississippi Water Resour. Res. Inst., Miss. State Univ. Completion Rep. A-047-Miss. 49 pp.

22. Effects of reservoir age and drawdown were studied by comparing the plankton, chlorophyll levels, benthos, fish, and water chemistry of Bluff Lake, Mississippi (an old lake subjected to drawdown), to that of Oktibbeha County Lake, Mississippi (a new lake with stable water levels). Drawdown had no obvious effect on the populations of phytoplankton and

zooplankton, which reached peak abundance in the fall in both lakes. Bluff Lake did exhibit a strong spring algal bloom that was lacking in the new non-fluctuating lake. Chlorophyll concentrations were significantly higher in Bluff Lake than in Oktibbeha Co. Lake during the fall drawdown period. Indications are that Bluff Lake is more productive than the other lake. Because no significant difference was noted in the numbers or weights of benthic taxa in the two lakes, the authors concluded that the 5- to 6-foot drawdown of Bluff Lake had no effect on benthos. However, all of the sampling stations in Bluff Lake were below the drawdown limit. Largemouth bass and bluegills collected from Bluff Lake had better condition factors than those from Oktibbeha Co. Lake. Rotenone sampling indicated that the sport-fish populations were low in both lakes but that there were more harvestable-sized fish in the drawdown lake. Drawdown apparently increased the amount of prey fish available to piscivores.

Aronin, E. S. and P. V. Mikheev. 1963. Rehabilitation of the fishery in the shallows of large reservoirs. In Materials of the first scientific technical conference for the study of the Kuibyshev Reservoir. Kuibyshev 3: 3-12. (In Russian)

23. Fluctuation of water levels in reservoir shallows destroyed conditions for the reproduction of fish and reduced the area of their summer feeding grounds. In winter, power generation at the hydroelectric station caused shallows to dry, resulting in mass mortality of young fish, particularly common carp (Cyprinus carpio). Construction of large fish hatcheries in the shallows would ensure an increase in the reservoir's fish production. (Abstract adapted from Referat. Zhur. Biol., 1964, No. 5I58; Biol. Abstr. 46:14374.)

Asch, R. L. and P. J. Kingsbury. 1972. Copepoda and Cladocera population of Red Rock Reservoir, Iowa, from April to November, 1970. Proc. Iowa Acad. Sci. 78: 73-75.

24. Effects of nutrient renewal, water level, and average weekly discharge of water on the species composition, relative abundance, and population fluctuations of the Copepoda and Cladocera in Red Rock Reservoir are examined. Three distinct seasonal peaks in populations were correlated with temperature, transparency, discharge rate, and nutrient levels. Abundance was not related to water level.

Axelson, J. 1961. Zooplankton and impoundment of two lakes in Northern Sweden (Ransaren and Kultsjoen). Rep. Inst. Freshwater Res. Drottningholm 42: 84-168.

25. Regulation and resulting water-level fluctuations affect zooplankton abundance. Data from Kultsjoen Lake was used as a control to

account for natural variation in zooplankton abundance. Regulation of Ransaren Lake created environmental conditions favorable to zooplankters, and densities increased greatly when water levels reached the upper limit. Increased abundance of zooplankton was attributed to reduced losses in summers when water discharge was low. Apparently large releases of water during the growing season impoverish the plankton and may result in deteriorated food conditions for fish.

Bailey, R. M. and H. M. Harrison, Jr. 1945. The fishes of Clear Lake, Iowa. Iowa State Coll. J. Sci. 20: 57-77.

26. A description of Clear Lake, its history and fish community are presented and compared with Spirit Lake, Iowa. The authors mention that small fishes were abundant in shallow areas a year after water levels rose rapidly in Spirit Lake in 1943. Additional sampling indicated improved sport-fish populations. Poor angling was attributed to an abundance of minnows which presumably increased food availability and thereby decreased the susceptibility of sport fish to harvest by fishermen.

Ball, J., C. Weldon, and B. Crocker. 1975. Effects of original vegetation on reservoir water quality. Water Resour. Inst., Texas A&M Univ., Tech. Rep. No. 64. 54 pp.

27. A series of leaching studies were conducted on grasses, herbaceous plants, and trees representative of those in basins of new reservoirs to determine the relative rates of nutrient release (nitrogen and phosphorus) and the effects of released nutrients on overlying waters. The quantity and rate of nutrient release varies greatly with the type of vegetation flooded. Nutrients from grasses and herbaceous plants were released at a greater rate and quantity per unit of vegetation weight than were nutrients from trees. Also, nutrients from herbaceous plants were more available in greater quantities per unit of area than were nutrients from trees. The rate at which nutrients are released and the amounts released are functions of the surface area to biomass ratio for vegetation. Productive or eutrophic waters leach nitrogen faster than less productive waters. Leaching apparently is rapid on the first day, but after the initial period (which may last 2 weeks) the rate slows. Herbaceous terrestrial plants usually are completely degraded and assimilated within 1 year.

Baranov, I. V. 1966. Biohydrochemical classification of the reservoirs in the European U.S.S.R. Pages 139-183 in P. V. Tyurin, ed. The Storage Lakes of the U.S.S.R. and Their Importance for Fishery. (Transl. from Russian) Israel Program Sci. Transl. Cat. No. 1638-50. U.S. Dep. Commerce.

28. An elaborate scheme for classifying reservoirs is presented. It is based primarily on the nature of humus in the water, anion concentrations, and the trophic phase of the reservoir. The "evolution" of most reservoirs can be divided into three arbitrary phases based on productivity. The initial phase (trophic upsurge) which lasts 2 to 3 years is characterized by high productivity of bacteria, which release nutrients to algae and thereby heighten algal production. Secondary production by all trophic levels is increased. In shallow reservoirs, slight increases in water level inundate vast areas of terrestrial vegetation, and the trophic upsurge is usually prolonged and intense. Trophic upsurges seldom occur in deep reservoirs, which usually pass into a second phase or "trophic depression." In this phase, the rate of decay of submerged terrestrial vegetation decreases, and nonproductive silts eroded from shorelines cover organic materials. Zooplankton and benthos biomasses decrease gradually during this 25- to 30-year period. The third phase is identified by a gradual increase in productivity because of the deposition of planktogenic detritus. The three stages vary in duration and detail, and not all reservoirs exhibit all three phases.

Barman, E. H., Jr. and D. G. Baarda. 1978. An evaluation of the effect of drawdown on the trophic status of a small reservoir. Environ. Resour. Cent., Georgia Tech. Univ. ERC 01-78. 73 pp.

29. Water levels of 5.4-ha Lake Laurel, Georgia, were drawn down to the original creek bed for 178 days (October 1975-April 1976). Pre- and post-drawdown estimates of dissolved oxygen, biological oxygen demand, turbidity, sulfide, nitrogen, phosphorus, and iron were compared. The distribution and abundance of benthos, phytoplankton biomass, and periphyton accrual were quantified before and after drawdown. Total phosphorus, total soluble phosphorus, and orthophosphate were significantly lower after drawdown. Phytoplankton biomass and periphyton production were reduced during the summer of 1976 after drawdown, but the effect lasted less than one year. Organic compounds and iron concentrations near the sediments increased after drawdown. No changes were apparent in dissolved oxygen, biological oxygen demand, turbidity, sulfides, or nitrogen, nor in the qualitative composition of the benthos. The abundance of benthic organisms was reduced. The lake pH was low (5.0-6.4).

Beard, T. D. 1971. Impact of an overwinter drawdown on feeding activities of northern pike. Wisconsin Dep. Nat. Resour., Res. Rep. No. 4. 6 pp.

30. Feeding activity, based on food studies of northern pike in Murphy Flowage, increased during the over-winter drawdowns of 1967, 1968, and 1969.

Beard, T. D. 1973. Overwinter drawdown. Impact on the aquatic vegetation in Murphy Flowage, Wisconsin. Wisconsin Dep. Nat. Resour., Tech. Bull. No. 61. 18 pp.

31. A lowering of water levels on 180-acre Murphy Flowage during the winters of 1967-68 and 1968-69 significantly reduced the relative abundance and acreage of aquatic vegetation. Before the drawdown, about 75 acres (42% of the flowage) were covered by plants, to the extent that fishing was almost impossible from June through the summer. After two over-winter drawdowns, 60 of the 75 acres were open to fishing. Five of the six plant species that dominated the flowage before drawdown were most affected, and densities of these five species were reduced greatly after two drawdowns. Management implications involving the use of an over-winter drawdown to control aquatic vegetation are discussed.

Beard, T. D. and H. E. Snow. 1970. Impact of winter drawdown on a slow-growing panfish population and associated species. Wisconsin Dep. Nat. Resour., Bur. Res. Rep. 18 pp.

32. Two consecutive winter drawdowns of Murphy Flowage to improve the growth of panfish populations reduced the abundance of all species except yellow perch and white suckers. Numbers of bluegills less than 5 inches long were greatly reduced. Feeding activity of northern pike increased after drawdowns, and largemouth bass ate more fish and fewer crayfishes.

Beckman, L. G. and J. H. Elrod. 1971. Apparent abundance and distribution of young-of-year fishes in Lake Oahe, 1965-69. Pages 333-347 <u>in</u> G. E. Hall, ed. <u>Reservoir Fisheries and Limnology</u>. Am. Fish. Soc. Spec. Publ. No. 8.

33. A 100- by 8-foot seine and an otter trawl were used to estimate the abundance and distribution of young-of-year fishes in Lake Oahe, North and South Dakota, during the last 5 years of filling. Young-of-year fishes were most abundant in waters at the upper ends of embayments. Large year classes of northern pike, common carp, smallmouth buffalo, and bigmouth buffalo were associated with rising water levels that covered terrestrial grasses and remained stable throughout the spawning period. Small year classes occurred in years when no vegetation was flooded. Inasmuch as future water levels will normally fluctuate over mud bottoms, prospects for strong year classes are poor unless terrestrial vegetation recovers and is flooded in the spring, or some aquatic plants become established. Yellow perch used inundated brush for egg deposition, and year classes were good when more brushy areas were flooded. After 1967, much of the brush had deteriorated and was sparse at higher elevations. As a result, the abundance of perch began to decline thereafter.

Bennett, D. H. 1975. Effects of pumped storage project operations on the spawning success of centrarchid fishes in Leesville Lake, Virginia. Ph.D. Thesis, Virginia Polytech. Inst. Blacksburg, Virginia. 141 pp.

34. Bluegills, redbreast sunfish, and largemouth bass spawned successfully during pumped storage operations, where maximum weekly fluctuations in water levels were 4 m during the spawning season. Apparently some individuals increase their spawning depth in response to regular widely fluctuating water levels. Fluctuating water levels and low water temperatures combine to cause about 81% mortality of eggs and fry of bluegills in the upper lake. Eggs and fry develop slowly at low temperatures and therefore are vulnerable to dewatering and desiccation for a greater period of time than eggs and fry in warmer water. Because the lower lake was warmer than the upper lake, eggs and fry developed more rapidly and their survival was about double that of fry in the upper lake. Spawning success of bluegills was about 31%. Exposure to air for 24 or more hours caused 100% mortality of eggs.

Bennett, G. W. 1954. Largemouth bass in Ridge Lake, Coles County, Illinois. Illinois Nat. Hist. Surv. 26: 217-276.

35. A management technique for culling out small fishes to improve populations of largemouth bass for anglers from 1941 to 1951 is evaluated. There was no relation between the number of bass fry produced and the number of bass of spawning age, but the production of fry was greater in years following draining when the number of small fish (particularly bluegills) was low. The largest catches (number and weight) of bass were made in the year after draining and culling operations. From 40 to 69% of the bass standing crop was harvested in these years, compared with 27 to 34% in years when the lake was not drained before the fishing season.

Bennett, G. W. 1954. The effects of a late summer drawdown on the fish population of Ridge Lake, Coles County, Illinois. Trans. N. Am. Wildl. Conf. 19: 259-270.

36. At two-year intervals for 10 years, Ridge Lake was drained in March to facilitate census of fish populations. In 1951 and 1952, the area of the lake was reduced by drawdown from 17 acres in early September to 5 acres in December, when runoff began to refill it. Fishery data collected during and after the drawdown were compared with data collected in the preceding 10 years (primarily 1947, 1949, and 1951), when water levels were relatively stable. From the standpoint of individual fish, no loss of bass resulted from drawdown. In years when the lake was drained in March and small fish were culled, production of bass fry was relatively heavy--suggesting that survival of young bass was largely controlled by predation. Drawdowns probably greatly reduced the benthos of Ridge Lake, because some invertebrates

were trapped in macrophytes or depressions as waters receded. The concentration of aquatic animals in a reduced volume of water exposed them to predators, which probably accounted for the greatly reduced number of fish-food animals. Numbers of bluegills, especially the smaller ones, were severely reduced by drawdown. The extent of drawdown probably was too severe (especially with respect to its effect on bluegills). A more nearly optimum amount of drawdown probably could be determined by further study.

Bennett, G. W. 1962. Theories and techniques of management. Chapter 6 in G. W. Bennett. Management of Artificial Lakes and Ponds. Reinhold Publ. Co., New York. 283 pp.

37. Techniques for fish sampling, removal (draining and poisoning), and population adjustment, as well as lake fertilization, vegetation control, and water-level manipulation are discussed in this chapter. Drawdown is viewed as a means of changing the relative abundance of fishes to favor the species important to man. Apparently, receding waters crowd fish, and over a period of months or years of low water, the smaller populations best equipped to deal with severe competition dominate previously abundant species. Upon reflooding, habitat is expanded and food becomes abundant. Predators frequently can take advantage of the large broods produced by nearly all fish during the first year of inundation. Exposure of sediments to the atmosphere during drawdown increases decomposition and soil pH. Under these conditions greater quantities of potassium and phosphorus are available. Exposure of bottom sediments to the air is considered more important to fish production than is the growth of terrestrial vegetation after drawdown. Drawdown does not greatly affect most macrophytes and is not considered to be an effective method of control. In fact, Potamogeton crispus expanded its habitat lakeward as drawdown occurred. On reflooding, it was established at greater depths. Drawdown strands and kills invertebrates or exposes them to new environmental conditions that decrease their chances for survival. Many small fishes also become stranded and perish. Those that migrate must leave the protection of vegetation and are exposed to increased predation. The net result is a selective culling action, which reduces the number of small sunfishes and thereby improves the chances for a successful bass spawn in the spring after the basin is reflooded. Drawdown to cull fish must reduce the surface area by 50% and force small fish from beds of aquatic plants. Predation will be significant only as long as prey is concentrated and temperatures are above 55° F. Annual cycles of water-level fluctuation have a great impact on fish populations, but even droughts that cause water levels to slowly recede can have an effect. Timing of annual drawdowns to benefit fish and waterfowl often conflict.

Bennett, G. W. 1974. Ecology and management of largemouth bass, *Micropterus salmoides*. Pages 10-17 *in* J. L. Funk, ed. *Symposium on Overharvest and Management of Largemouth Bass in Small Impoundments*. North Central Div., Am. Fish. Soc. Spec. Publ. No. 3.

38. On the basis of 30 years of data from Ridge Lake, Illinois, and the experience of many researchers, a discussion is presented on how bass production and harvest can be improved. Bass in a pond demonstrated their ability to replace their numbers and weights by producing a single successful year class, after surviving 1400 and 1600 man-hours of fishing pressure over two consecutive seasons. A fall drawdown is one of the simplest ways to reduce populations of sunfishes (predators of eggs and fry) and thereby produce a strong year class of bass the next spring. A fall drawdown every second or third year, or once in three years, should help bass maintain their numbers. During drawdown, fish are supposedly crowded, and excessive populations of crappies, sunfishes, and rough fishes are reduced. As the lake slowly refills in winter, most fish assemblages are composed of larger individuals, and contain fewer egg and fry predators than before drawdown.

Bennett, G. W., H. W. Adkins, and W. F. Childers. 1969. Largemouth bass and other fishes in Ridge Lake, Illinois, 1941-1963. Ill. Nat. Hist. Surv. Bull. 30: 1-67.

39. Fish populations of Ridge Lake were studied intensively by creel survey and biennial draining. Expansion of bluegills was directly related to time and inversely related to drawdowns and to the abundance of bass. The bass population controlled the numbers of bluegills only when drawdown was employed.

Bennett, G. W., H. W. Adkins, and W. F. Childers. 1973. The effects of supplemental feeding and fall drawdowns on the largemouth bass and bluegills at Ridge Lake, Illinois. Ill. Nat. Hist. Surv. Bull. 31: 1-30.

40. From 1965 to 1969, fish in Ridge Lake were fed supplementally with a commercial pelleted food during the summer. In September, lake levels were reduced until temperatures reached 55° F in October, and then the lake was refilled. This management program was successful in improving the bluegill fishery; twice as many large bluegills ($\geq$ 152 mm) were creeled during 1965-1969 than during earlier years. Without a fall drawdown, supplemental feeding probably would be wasteful, inasmuch as the bluegill population would increase in numbers rather than in mean weight per fish.

Benson, N. G. 1968. Review of fishery studies on Missouri River main stem impoundments. U. S. Fish Wildl. Serv., Bur. Sport Fish. Wildl. Res. Rep. No. 71. 61 pp.

41. Six mainstem Missouri River reservoirs are described, and information on plankton, water chemistry, fish populations, and watershed management is discussed. A number of findings were related to changes in water levels. Rising water levels in Garrison and Oahe reservoirs probably were responsible for an increased abundance of phytoplankton and rotifers from 1953 to 1961. Reproduction of bottom-spawning fishes (e.g., northern pike, white crappie, black crappie, largemouth bass, sauger, walleye, and yellow perch) was limited by wind action, suitability of substrate, and fluctuating water levels. Lowering of water levels to reduce the spawning success of common carp was of questionable value, as their success was largely independent of fluctuation patterns. Raising water levels in Lake Oahe to flood terrestrial vegetation was successful in improving the spawning success of northern pike, but this technique was not evaluated in an old reservoir where vegetation was sparse or absent.

Benson, N. G. 1973. Evaluating the effects of discharge rates, water levels, and peaking on fish populations in Missouri River mainstem impoundments. Pages 683-689 in W. C. Ackermann, G. F. White, and E. B. Worthington, eds. Man-Made Lakes: Their Problems and Environmental Effects. Geophysical Monograph 17, Am. Geophysical Union, William Byrd Press, Richmond, Virginia.

42. Biological changes that can be attributed to water management operations are discussed. Effects of water-level fluctuation, discharge rates, and peaking (diurnal variation in water level below dams) on reservoir biota are described. Reproduction of fishes that spawn during high water in the spring in rivers was successful during filling and during early years of impoundment but was irregular under normal operations. The reproduction of common carp, river carpsucker, smallmouth buffalo, and bigmouth buffalo is keyed to rising or stable water levels over suitable substrates. Northern pike depend on the inundation of herbaceous vegetation for spawning; however, rising water levels (which are usually beneficial) have no value if the proper substrate is lacking. Northern pike reproduction also can be disrupted by rapidly receding water levels before the spawning season. A succession of spawning periods exists for fish that deposit adhesive eggs on the bottom or on submerged material at depths less than 1.5 m. Although the exact time varies among years and reservoirs, any decline in water level between April 1 and July 1 reduces the spawning success of some species. Species like walleye, freshwater drum, and goldeyes are less affected by changes in water levels. Freshwater drum and goldeyes have buoyant or semi-buoyant eggs, and walleyes usually spawn at a depth below the limits of most drawdowns. Benthos biomass on submerged trees and on the bottom is reduced by late summer or fall drawdowns. Many littoral forms that are important as fish foods are rare in lakes with widely fluctuating water levels. Submerged trees in some Missouri River reservoirs support enormous growths of periphyton, which in turn support large populations of benthos. Drawdowns kill the periphyton and thereby severely limit

the production of benthos. A tentative model is presented that graphically describes interactions between abiotic and biotic components of Missouri River reservoirs.

Benson, N. G. 1976. Water management and fish production in Missouri River main stem reservoirs. Pages 141-147 *in* J. F. Osborn and C. H. Allman, eds. *Instream Flow Needs, Volume II*. Am. Fish. Soc., Bethesda, Maryland.

43. Although most reservoirs on the Missouri River are managed primarily for flood control, power generation, and navigation, conditions in some years permit changes in water levels or peaking schedules to benefit fish. Because growth and survival reflect the net reproductive success after predation and because knowledge of habitat requirements for spawning and nurseries are important (as is information about the time of spawning), most recommendations are directed toward altering water levels to enhance fish reproduction. Spawning and nursery requirements of 16 species of fish are presented. Time of spawning may vary annually but is directly related to water temperature, and each fish species initiates spawning activity when temperatures reach some species-specific level ($\pm$ 2-5° C). Water-level management is the most promising technique for increasing fish production. Most fishes in the reservoirs evolved in rivers or glacial lakes and developed reproductive cycles keyed to spring floods which inundated suitable substrates. High and constant water levels from April 1 to July 1 benefit reproduction of northern pike, yellow perch, walleye, white crappie, common carp, river carpsucker, smallmouth buffalo, and bigmouth buffalo. Water levels that are lowered after July 1 permit terrestrial vegetation to develop on the exposed bottoms and thereby provide good spawning habitat the following year. Growth of terrestrial vegetation also is important for aesthetic purposes and erosion control.

Benson, N. G. 1980. Effects of post-impoundment shore modifications on fish populations in Missouri River Reservoirs. U. S. Fish Wildl. Serv. Res. Rep. 80. 32 pp.

44. The configuration and lengths of shorelines in main-stem Missouri River reservoirs have changed as a result of hydro-dynamic processes (i.e., erosion and redeposition caused by wave action and water-level fluctuations) during the first 20 - 25 years of impoundment. Physical changes probably most influenced fish abundance and species composition by altering the quality and quantity of spawning and nursery habitats. As a result, the fish community sampled before reservoir shorelines reached some degree of stability was not indicative of the ultimate species composition. Water-level fluctuations retarded the development of relatively stable shores. Species of fish that spawned in tributaries or along rocky shores (sauger, channel catfish, white bass, goldeye, and river carpsucker) were seemingly unaffected by shoreline

changes. Other species requiring vegetation or suitable substrates for spawning (white crappie, black crappie, yellow perch, northern pike, bigmouth buffalo, smallmouth buffalo, and common carp) were adversely affected. Walleyes benefited from shoreline changes.

Benson, N. G. and B. C. Cowell. 1967. The environment and plankton density in Missouri River reservoirs. Pages 358-373 in Reservoir Committee of the Southern Division. Reservoir Fishery Resources Symposium. Am. Fish. Soc., Washington, D. C.

45. A limnological description of six main-stem reservoirs on the Missouri River is presented. Elements of the environment such as morphometry, chemistry, water exchange rate, temperature, and turbidity form the background for an evaluation of changes in phytoplankton and zooplankton abundance and biomass. Submerged trees are important substrates for periphyton development in Missouri River reservoirs; dense growths developed on submerged trees in Lewis and Clark Lake (6×10^6 cells cm^{-2}) in May. The maximum standing crop of periphyton on trees in Lake Francis Case was only 6.6×10^3 cells cm^{-2}, about 0.11% of that in Lewis and Clark Lake because Lake Francis Case fluctuated 9-11 m each year, and its periphyton communities died from exposure.

Benson, N. G. and P. L. Hudson. 1975. Effects of a reduced fall drawdown on benthos abundance in Lake Francis Case. Trans. Am. Fish. Soc., 104: 526-528.

46. Water levels of Lake Francis Case, which are normally drawn down 10-12 m in the fall to make room for inflowing water in the winter, were lowered only 6-7 m in 1971-73. Benthos samples collected in May from 1966 to 1973 showed more than a threefold increase in the density of bottom organisms during the period of reduced drawdown. Increased abundance was most evident in five burrowing taxa (chironomids, *Hexagenia*, *Caenis*, oligochaetes, and ceratopogonids). The abundance of benthos in September was similar under both drawdown regimes, except that *Hexagenia* was very abundant in September 1973. Reduced drawdown in the fall apparently allowed silt deposits to form at higher elevations and increased the amount of habitat for organisms requiring soft substrates.

Birch, H. F. 1960. Soil drying and soil fertility. Trop. Agric. (Trinidad) 37: 3-10.

47. A brief review of the literature illustrates the beneficial effect of soil drying on soil fertility. Drying increases the availability of several elements, among which soil nitrogen appears to be affected most consistently. Improved physical conditions after drying may also be involved, but this is less well established. Recent work on the effect of drying on humus decomposition and nitrification is discussed. The

effect of soil drying on the amount of mineral nitrogen produced by moistening is largely a function of the humus content of the soil and the logarithm of the time the soil is in an air-dry state before it is moistened. Amounts of mineral nitrogen produced in this way are sufficiently large, even with soils poor in humus, to exert a considerable influence on soil fertility. A possible explanation for the drying effect is presented, along with recorded observations.

Bondurant, D. C. and R. H. Livesey. 1967. Operational problems associated with a basin reservoir system. Pages 47-55 in Reservoir Committee of the Southern Division. Reservoir Fishery Resources Symposium. Am. Fish. Soc., Washington, D. C.

48. The operation of the Missouri River reservoir system is described, as well as problems encountered in fulfilling primary needs (flood control, hydroelectric power, navigation, and irrigation) and supplemental benefits to fish and wildlife or other concerns such as public health. When operational modifications required to benefit fish and wildlife are reasonable and well defined, primary operations frequently can be changed to provide supplemental benefits. Three essential elements are required for support and success in accomplishing fishery programs that require modification of reservoir operations: (1) an understanding and appreciation of the operational requirements of the overall system, (2) an effort to educate project management about needs, and (3) cooperative planning to most benefit all concerned groups.

Brasch, J. G. 1953. Drawdowns: fish management tool. Wisconsin Conserv. Bull. 23: 25-28.

49. Possible benefits of reservoir drawdowns as observed in impoundments of the Tennessee Valley and the States of Wisconsin and Illinois are outlined. After winter drawdown of water levels in Castle Rock Flowage, Pentenwell Flowage, and Lake Eau Claire, populations of common carp were reduced and sport-fish populations appeared to increase. Reduction of water levels 20 inches in Lake Eau Galle in the spring, exposed common carp eggs and limited the production of young carp, but the reproduction of bass and crappies was successful. Severe winter drawdown to induce winter-kill of undesirable fishes is discussed.

Bross, M. G. 1969. Fish samples and year-class strength (1965-1967) from Canton Reservoir, Oklahoma. Proc. Okla. Acad. Sci. 48: 194-199.

50. August abundance of young-of-year fishes based on rotenone samples forms the basis for evaluating the effects of a number of physicochemical variables on year-class strength in Canton Reservoir, Oklahoma. Except for temperature and water levels, measured variables (dissolved oxygen concentration, pH, alkalinity, conductivity, and turbidity) remained

relatively constant over the 3-year period; whereas, the number of young-of-year fishes was much higher in 1965 and 1967 than in 1966. Water temperatures rose earlier in 1966 than in 1965 or 1967, but the rise was not smooth; frequent cool periods kept temperatures below 60°F most of April. In 1965 and 1967, temperatures probably favored spawning and egg survival more than in 1966, as they exceeded 60° F through most of April. Water levels were high but stable during spawning and early growth periods in 1966, but rose 15 feet in 1965 and 6 feet in 1967. Rising water levels presumably stimulated spawning, provided spawning sites, and enhanced the food base and survival by inundating vegetation and increasing the biomass of plankton and benthos. Wind was not considered a primary factor affecting year-class strength because both pelagic-spawning and vulnerable nest-building species produced strong year classes in the same years.

Brouha, P. and C. E. von Geldern, Jr. 1979. Habitat manipulation for centrarchid production in western reservoirs. Pages 11-17 *in* D. L. Johnson and R. A. Stein, eds. *Response of Fish to Habitat Structure in Standing Water*. North Central Div. Am. Fish. Soc. Spec. Publ. No. 6.

51. Water fluctuation regimes and a general lack of cover for fish in western reservoirs pose severe problems for management of cover-dependent centrarchids. Floating artificial reefs, mid-water reefs, artificial seaweed, and revegetation of drawdown zones have all proved effective in providing habitat for centrarchids. Living vegetation, established in much of the drawdown zone, coupled with the addition of structure below the normal low-water zone, can provide cover for centrarchids at all water levels. Reefs increase cover and firm substrate, thus improving primary and invertebrate productivity and ultimately the condition, growth, and survival of fish. Plants such as *Salix alba tristis*, *Taxodium distichum*, and *Eucalyptus camaldulenus* have shown considerable tolerance to flooding, and test plots of these and other plant species have been successfully established in fluctuation zones. Guidelines to implement revegetation programs are described.

Bryant, H. E. and A. Houser. 1971. Population estimates and growth of largemouth bass in Beaver and Bull Shoals Reservoirs. Pages 349-357 *in* G. E. Hall, ed. *Reservoir Fisheries and Limnology*. Am. Fish. Soc. Spec. Publ. No. 8.

52. Shoreline estimates of largemouth bass populations were made in large coves on Beaver and Bull Shoals reservoirs, Arkansas, during April in 1969 and 1970. Scale readings and length-weight relations were used to estimate growth of bass. There were 55 more bass ≥ 250 mm long and 195 fewer bass < 250 mm long (per km of shoreline) in 1970 than in 1969. Differences were due to the strong year class of 1968 which was associated with rising water levels, inundated terrestrial vegetation, and large populations of young-of-year gizzard and threadfin shad.

Buck, H. and F. Cross. 1951. Early limnological and fish population conditions of Canton Reservoir, Oklahoma, and fishery management recommendations. Rep. to Oklahoma Fish Game Council Res. Foundation, Oklahoma A and M College. 174 pp.

53. Limnological features and characteristics of the fish populations of Canton Reservoir were studied during the first 2.5 years of impoundment (1948-50), and standard physicochemical variables were recorded. The largest year classes and the greatest annual growth by each age group of most fishes occurred in 1948, during the first year of impoundment. Growth of carpsuckers was most rapid in 1949. High rates of survival and growth presumably resulted from the inundation of over 4,000 acres of heavily vegetated bottomland. Reproduction and growth of most fishes were poor in 1949, due to receding water levels during the spawning and growing seasons. Angling was best when water levels were rising or high.

Bulkley, R. V. 1975. Chemical and physical effects on the centrarchid basses. Pages 286-294 *in* H. Clepper, ed. *Black Bass Biology and Management*. Sport Fishing Inst., Washington, D. C.

54. Effects of several physicochemical factors (turbidity, water-level fluctuations, oxygen concentration, acidity, salinity, and pesticides) on the biology of black basses are discussed. Water-level changes or manipulation affect growth, food supply, reproduction, and movement. High water levels at appropriate times are associated with improved growth and reproduction. Drawdowns in midsummer or fall may also improve growth the following year. Fluctuations in water depth in the form of wave action may hinder spawning success.

Burris, W. E. 1952. The bottom fauna development of a newly constructed pond in central Oklahoma. Proc. Oklahoma Acad. Sci. 33: 129-136.

55. Bottom samples were collected with a Peterson dredge from a 1/3-acre pond being filled for the first time. Quantitative and qualitative development of benthos was documented for 1 year. A rapid rise in water level may have caused the apparent decline in the volume of benthos in July. It seems unlikely that bottom organisms migrate into newly inundated areas, as no organisms were found along the 1- and 2-foot bottom contours after water had covered these areas for 2 weeks.

Busch, W.-D. N., R. L. Scholl, and W. L. Hartman. 1975. Environmental factors affecting the strength of walleye (*Stizostedion vitreum vitreum*) year-classes in western Lake Erie, 1960-70. J. Fish. Res. Board Can. 32: 1733-1743.

56. Under present conditions, success of year-classes of walleyes in western Lake Erie depends largely on favorable spawning conditions, especially rapidly warming water and a lack of strong winds. Year-class strength was not correlated with the size of the brood stock or with fluctuations of water level, but water levels fluctuated only 0.7 m in the spring of each year (1960-1970).

Butler, R. L. 1965. Freshwater drum, *Aplodinotus grunniens*, in the navigational impoundments of the upper Mississippi River. Trans. Am. Fish. Soc. 94: 339-349.

57. The freshwater drum fishery was evaluated on the basis of a study of scale samples and estimates of total and fishing mortality. Year-class strength was related to air and water temperatures but not to water levels during the spawning season.

Cantrell, M. A. and A. J. McLachlan. 1977. Competition and chironomid distribution patterns in a newly flooded lake. Oikos 29: 429-433.

58. In the early colonization of a new lake, interaction (competition) between colonizing midges is important in determining their distribution in new areas. *Chironomus plumosis* is frequently the first species to successfully colonize new habitats made available by rising waters. Its large size and tolerance of low oxygen tensions enables it to out-compete most other species--including *Tanytarsus gregarius*, which moves toward lake margins where encounters with *C. plumosis* are less frequent.

Carroll, B. B. and G. E. Hall. 1964. Growth of catfishes in Norris Reservoir, Tennessee. J. Tennessee Acad. Sci. 39: 86-91.

59. Growth rates of 87 channel and 254 flathead catfishes in Norris Reservoir were determined by examining annuli of pectoral spines. Growth of 3- to 5-year-old flathead catfish accelerated after an extreme drawdown of water levels in 1955-56. Growth acceleration did not occur in younger flatheads and was not evident in channel catfish, although the channel catfish of the 1956 year class were longer at all ages than those of the 1954 and 1955 year classes. A strong year class of channel catfish was produced in 1957, one year after drawdown.

Carroll, B. B., G. E. Hall, and R. D. Bishop. 1963. Three seasons of rough fish removal at Norris Reservoir, Tennessee. Trans. Am. Fish. Soc. 92: 356-364.

60. The composition and value of the commercial catch, the effectiveness of different types of commercial gear in fishing, the effects of

these gears on game fish, and the possibility for a sustainable commercial fishery in Norris Reservoir were examined. The harvest of rough fishes which progressively declined over 3 years, apparently was more closely related to annual variations in abundance and the size composition of individuals than to the effects of water-level fluctuations. Although commercial fishermen blamed high water levels for reduced catches in the second season, the catch continued to decline in the third season, when water levels were comparable to those in the first season. The fishermen preferred declining water levels because fish movement apparently increased.

Carter, J. P. 1963. Experimental crappie removal. Kentucky Dep. Fish Wildl. Resour. Fed. Aid Proj. F-21-R. Job No. I-13. 18 pp.

61. Crappies and rough fishes were removed from Dewey Lake, Kentucky, during the planned winter drawdown of 1962-63. Effects of their removal on fish populations of Dewey Lake were obscured by the effects of drawdown. Increased predation through crowding and loss of fish through the dam probably reduced the population of gizzard shad. Exposure and weathering of large areas of lake bottom probably are important in increasing lake fertility.

Charles, J. R. 1967. The Buckhorn Reservoir fishery during the fourth, fifth, and sixth years of development. Kentucky Dep. Fish. Wildl. Resour., Fish. Bull. No. 46: 40 pp.

62. The standing crop and harvest of fishes from Buckhorn Reservoir were evaluated by rotenone sampling and a non-uniform probability creel census, respectively. Although a tremendous spawn of threadfin shad occurred in 1964, threadfin shad were absent from the reservoir by 1965. Presumably they migrated from the reservoir during the winter drawdown, and were not killed by cold water. The maximum carrying capacity (89 pounds per acre) of the reservoir apparently was reached in 1962, the second year after the lake was filled. Fish standing crops declined after 1962, but harvest increased slightly from 18 to 23 pounds per acre from 1964 to 1966.

Chevalier, J. R. 1977. Changes in walleye (Stizostedion vitreum vitreum) population in Rainy Lake and factors in abundance, 1924-75. J. Fish. Res. Board Can. 34: 1696-1702.

63. Yearly commercial harvests of walleyes steadily decreased from 150,000 kg in the 1920's to 19,000 kg in the early 1970's. Observed increases in growth probably were a compensatory mechanism in response to decreased abundance of walleyes and related decreases in intraspecific competition for prey. Abundance of brood stock and spring water levels were positively related to abundance 5 years later.

Coefficients for correlations (r) of commercial catch per unit effort and water levels 4, 5, and 6 years earlier were 0.48, 0.71, and 0.47, respectively. The regression equation for the 5 years combined was $Y = -93.26 + 16.81 X$, where Y is the annual commercial catch per unit effort, and X is the average spring water level five years earlier. The coefficient of determination (r^2) was 0.50. Low water levels force walleyes to spawn in less desirable habitat than the clean shoal areas that are normally available.

Claflin, T. O. 1968. Reservoir aufwuchs on inundated trees. Trans. Am. Microsc. Soc. 87: 97-104.

64. Periphyton and associated benthic invertebrates on inundated trees were studied from April 1964 to January 1966 in Lewis and Clark Lake and in Lake Francis Case. Because fluctuating water levels in Lake Francis Case exposed most of the suitable tree substrates for 4 or 5 months of the year, the standing crop of periphyton was much lower there than in Lewis and Clark Lake. Periphyton growth was slower in deep than in shallow water; the heaviest standing crop occurred between 3 and 7 m. There was a significant positive correlation between the density of midge larvae and the standing crop of periphyton. In 1964, abundance of midges in Lewis and Clark Lake increased from a seasonal low on 15 April to about 10,500 m^{-2} by 24 May; density of pupae increased from 0 to 4,800 m^{-2}. Peak densities of midges in Lake Francis Case were in June and August but never exceeded 300 m^{-2}. Periphyton and benthos populations inhabiting shallow-water areas of Lake Francis Case are severely reduced annually by fluctuating water levels.

Cooke, C. R., Jr. 1971. Stabilization study of Falcon Reservoir. Texas Parks Wildl. Dep., Fed. Aid Proj. F-20-R-3. 18 pp.

65. Gill netting, seining, and trawling data showed no significant change in the percent of rough or game fish in the reservoir fish community after 1 year of stabilized water levels. Water chemistry changed little, and no thermocline was established. Fishing quality decreased: the catch rate decreased from 1.4 to 1.2 fish per man-hour (14%) and from 1.3 to 0.8 pounds per man-hour (38%).

Cooper, B. D. 1957. A study of the game fish species in Sheldon Reservoir. Texas Parks Wildl. Dep. Fed. Aid Proj. F-012-R-02. Job 04. 11 pp.

66. Diets of young largemouth bass stocked in Sheldon Reservoir, Texas, in 1956 were studied from April to December, and weight gain or loss of tagged bass was monitored after July. As bass grew and water levels were reduced 1.5 feet in the fall, food apparently became limiting, though it had initially been abundant when terrestrial vegetation was

first flooded. Many bass lost weight, and others grew at slower rates. The reservoir was filled to only one-fifth its total capacity during the study.

Cooper, C. M. 1980. Effects of abnormal thermal stratification on a reservoir benthic macroinvertebrate community. Am. Midl. Nat. 103: 149-154.

67. Increased water levels in Grenada Reservoir, Mississippi, during 1973-76 prolonged hypolimnial stagnation because the reservoir was not drawn down sufficiently to disrupt thermal stratification. Massive kills of immature Hexagenia bilineata and Oecetis inconspicua occurred in 1973. Recurring stagnation in 1974 prevented recolonization, and over the 1973-76 period, the benthic community was altered from one dominated by Hexagenia, Oecetis, Chaoborus, and chironomids to one dominated by Limnodrilus, Chaoborus, and chironomids--forms that are more tolerant of low oxygen than are Hexagenia and Oecetis. Standing crops initially decreased but later recovered.

Cooper, G. P. 1967. Fish production in impoundments. Michigan Dep. Cons., Res. Dev. Rep. No. 104. 16 pp.

68. The production of sport fishes in U. S. impoundments is reviewed, with emphasis on fisheries in the northeast. Nutrients that precipitate or are bound to sediments after organisms die may be released if basins are drained and left fallow for several months. Retention of nutrients by sediments probably is a major reason for the decline in productivity as impoundments age. Some large impoundments remain highly productive for 10 to 30 years; whereas, smaller ponds may be productive for only 5 to 10 years. The concept of declining productivity is most often associated with sport fish, and two hypotheses have been developed to explain decreasing production. One hypothesis is related to losses of nutrients and the other to a change in the species composition of fishes. Evidence supporting both hypotheses has been published.

Cowell, B. C. and P. L. Hudson. 1967. Some environmental factors influencing benthic invertebrates in two Missouri River reservoirs. Pages 541-555 in Reservoir Committee of the Southern Division, Reservoir Fishery Resources Symposium. Am. Fish. Soc., Washington, D. C.

69. Variations in water levels and water discharge interact with environmental factors (e.g., temperature, bottom type, depth, dissolved oxygen concentration, wave action, and the presence or absence of inundated vegetation) to strongly influence the abundance, distribution, migration, and survival of benthic invertebrates. Water-level fluctuations of 13.7 m annually (often 0.3 m per day) and wave action probably were responsible for the relative scarcity of Hexagenia in

Lake Francis Case. Despite exposure of the littoral area in Lake Francis Case, chironomids are three times more abundant there than in Lewis and Clark Lake, which fluctuated little. Although Hexagenia migrates in response to temperature and population density, chironomid larvae migrate with water levels. Water discharge can result in significant losses (44 metric tons in Lewis and Clark Lake in 1964) of invertebrates through the turbines. The distribution of invertebrates is strongly influenced by substrate type, and in Lake Francis Case, wave action at different water levels has mechanically sorted populations into horizontal bands of different size groups. Stranding of invertebrates by rapidly receding waters was observed on all sampling dates, and survival of stranded individuals was negligible. In one instance, 6,146 chironomids m^{-2} were stranded 4 m above the shoreline in Lake Francis Case. Inundated trees serve as substrates for periphyton communities which are eventually colonized by benthos. Densities of most invertebrates were higher--11 times greater in Lewis and Clark Lake--on the tree-based periphyton than on adjacent bottom substrates. In Lake Francis Case, the density of benthos on the periphyton-tree substrate was only 4 times greater than on adjacent bottom areas. Winter drawdown apparently destroyed the full development of periphyton communities in Lake Francis Case. Invertebrates were two times more abundant in smartweed than in barren areas.

Crawford, B. 1957. Report on the second fall and winter drawdown of Nimrod Lake - 1956-1957. Arkansas Game Fish Comm., Little Rock, Arkansas. 8 pp.

70. Nimrod Lake was drawn down for several reasons: to aerate bottom soils, to facilitate removal of commercial and rough fishes, to improve the availability of prey fish for predators by concentrating them, to permit the construction of fish attractors, and to permit seeding of rye grass in the drained zone. After the first drawdown, Secchi disc readings increased 2 to 3 feet, and boat dock owners reported improved fishing in the spring. Also, sport fishes in the catch of commercial fishermen increased 28% by number and 15% by weight in one year.

Crowder, L. B. and W. E. Cooper. 1979. Structural complexity and fish-prey interactions in ponds: a point of view. Pages 2-10 in D. L. Johnson and R. A. Stein, eds. Response of Fish to Habitat Structure in Standing Water. North Central Division Am. Fish. Soc. Spec. Publ. 6.

71. A conceptual model of fish-prey interactions as influenced by structure was developed from a review of current literature. The model predicts that the feeding efficiency and growth of fish peaks at intermediate levels of structural complexity. As a test of this hypothesis, macrophytes (primarily Ceratophyllum demersum) were manipulated by hand in three 0.1-ha experimental ponds at the Kellogg Biological

Station, Michigan, to form ponds with high, medium, and low densities. Bluegills, 8.6 cm long, grew fastest at intermediate macrophyte densities. Alterations of structural complexity, whether by addition of artificial structures or removal of macrophytes, may alter feeding efficiency and production of fishes in the littoral zone.

Culver, D. A., J. R. Triplett, and G. B. Waterfield. 1980. The evaluation of reservoir water-level manipulation as a fisheries management tool in Ohio. Ohio Dep. Natural Resour., Div. Wildl., Fed. Aid Proj. F-57-R. Study No. 8.

72. Dual problems of high fishing pressure and declining fishing success associated with reservoir aging confront fishery managers in Ohio. Water-level fluctuation (drawdowns and reflooding) can do much to restore high productivity to fisheries of older lakes. In the application of this management technique an attempt is made to revert older lakes to an earlier sere of succession, when fish populations were expanding into new habitat. This study attempts to delineate potential applications of existing techniques of water-level management to enhance sport fisheries of Ohio impoundments. To identify existing techniques, the authors conducted an exhaustive literature survey and interviewed fishery administrators throughout the northeastern United States to ascertain current use of water-level manipulation in the region. Potential reservoir sites were selected for field studies. Available data on Ohio reservoirs were surveyed, and a list of studies that might be performed in Ohio to assess the utility of water-level manipulation was developed. (Abstract adapted from Triplett et al. 1980.)

Currier, J. P. 1954. The history of Lake Minnewanka with reference to the reaction of lake trout to artificial changes in environment. Can. Fish. Cult. 15: 1-9.

73. The population of lake trout was dominated by small fish less than 15 inches long after successive increases in lake level for development of hydroelectric power. Mortality of eggs and fry decreased after construction of the dam in 1941, but mortality seemed to be very high when fish reached a length of 12 or 13 inches. After impoundment, newly flooded areas that had been dewatered for the previous 5 months were not productive. Food studies showed that fish shorter than 15 inches were not piscivorous. Apparently young lake trout were inhabiting much deeper water than their prey (ciscoes and mountain whitefish). The two prey fishes were still present in moderate numbers after impoundment but were not well adapted to the environment that was inhabited by young lake trout and created by increased water levels. Many young lake trout could not survive the critical transition period from a diet of plankton and benthos to one of fish.

Dahl, K. 1933. The influence of river regulations on fisheries in lakes. Oslo, J. W. Cappelens Forlag. 120 pp. (In Norwegian)

74. A thorough discussion is presented of the influence of water storage on fisheries, fish, and fish-food animals in Norwegian hydroelectric reservoirs. In 1932, the standing crop of the cladoceran Eurycercus lamellatus increased greatly after water storage. The reduction or disappearance of such important fish-food animals as Gammarus lacustris, snails, and insect larvae was more than compensated for by the increased density of Cladocera after regulation. (Abstract from K. W. Jensen, Vollebekk, Norway, as adapted from Fraser 1972.)

Dale, E. E., Jr. and J. R. Sullivan, Jr. 1978. The composition and abundance of vegetation inhabiting the water fluctuation zone of Beaver and Bull Shoals Lakes. Final Rep. to the U. S. Fish and Wildlife Service. Arkansas Water Resour. Cent., Fayetteville, Arkansas. 78 pp.

75. This paper documents relations between microenvironmental factors and the composition and abundance of plants and organic mulch in the fluctuation zone of two Arkansas reservoirs. Information was collected from the literature and the field to determine which species of plants would be suitable for planting in fluctuation zones and which would provide increased cover and food for fish. In general, woody plants provide more cover than herbaceous plants, but herbaceous plants provide more food (directly or indirectly). Black willow and button bush are woody plants highly tolerant of flooding. Smartweed, bermuda grass, rushes, and sedges are herbaceous plants that survived up to 90 days of flooding. Assemblages of plants after 1, 2, 3, and 4 years of flooding are described.

Davies, W. D., W. L. Shelton, D. R. Bayne, and L. M. Lawrence. 1980. Fisheries and limnological studies on West Point Reservoir, Alabama-Georgia. Contract No. DACW 01-78-C-0082. U. S. Army Eng. Dist., Mobile, Alabama. 238 pp.

76. Changes in the fisheries and limnology of West Point Reservoir (impounded in 1974) are described, with emphasis on identifying the factors contributing to an expected decline in sport-fishing quality. Post-spawning abundance of largemouth bass fingerlings in 1978 was twice that in 1977. Improved production of fry was associated with high water levels that were maintained throughout the growing season in 1978. Unfortunately, mortality in summer 1978 also was high and by fall, the density of young-of-year bass was essentially the same as it was in 1977. A bimodal length-frequency distribution in the 1975 year class was attributed to food availability and not to disrupted spawning. A water management plan was proposed that would encourage terrestrial plant development in the fluctuation zone. Flooding these areas should improve the chances of producing a strong year class of bass by providing cover during their first year of life.

Davis, J. T. 1967. Water fluctuation. Louisiana Conservationist (Jan. - Feb. 1967): 5-7.

77. Manipulation of water level for fish management is not a new procedure but one that has occurred in nature for many years and results in balanced fish populations, weed control, and nutrient addition. However, water-level fluctuations are not always popular for a variety of reasons: mud flats and decaying vegetation are not aesthetically appealing; access for boaters is difficult; boating and water skiing become hazardous due to exposed stumps, logs, or treetops; some aquatic weeds proliferate; and drought may prolong the drawdown for one or more years. Nevertheless, benefits of properly planned and implemented water-level programs usually outweigh the bad features. Drawdowns effectively control aquatic weeds; whereas, chemical control is prohibitively expensive or harmful to fish. High spring water levels improve spawning of sport fishes, and low winter levels reduce numbers of bluegills and shad by crowding them and exposing them to increased predation. The fishery improves because sport fish grow rapidly and nutrient levels of lakes are increased.

Davis, J. T. and J. S. Hughes. 1965. Effects of impoundment on the benthic population of Bayou D'Arbonne, Louisiana. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 19: 364-374.

78. An investigation was conducted to determine the effects of impoundment on stream benthos and the effects of water-level fluctuations on benthic invertebrates in reservoirs. Many species rapidly colonized newly inundated areas; whereas, others remained in the old creek channel. Impoundment greatly reduced the number of benthic families, and except for chironomids, reduced the density of individuals. The benthos was established within one year. The abundance of all benthic families increased during drawdown. Assuming a high degree of mobility of organisms and a lack of significant predation, crowding of individuals as waters receded may explain increases in abundance. Organisms either rapidly recolonized newly flooded areas or managed to survive desiccation during the 3-month drawdown, because densities were high even in recently inundated areas. Drawdown did not depress benthos populations, and may have enhanced them.

Davis, J. T. and J. S. Hughes. 1970. Investigations of fish management practices in Bussy Lake. Louisiana Wildl. Fish. Comm., Fed. Aid Proj. F-7-R8.

79. An 8-foot drawdown was begun in October 1962 to control vegetation. Refilling of the lake started in 1963. The lake was drawn down again in late October of 1965 to manipulate the fish community. Water-level fluctuation effectively controlled aquatic vegetation and forage fishes.

Densities of benthic invertebrates increased sharply during and immediately after drawdown, as did populations of game fish. Fishing pressure and harvest on the lake also increased after the drawdown, because fishing improved and interest in the lake project increased.

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

80. Stomach contents of nine species of fish from Norris Reservoir were examined: largemouth bass, spotted bass, smallmouth bass, walleye, sauger, freshwater drum, black crappie, channel catfish, and gizzard shad. Aquatic insects and crayfish were scarce in Norris Reservoir, presumably because of large water-level fluctuations (60-80 ft.). Small shad and black crappies provided most of the food for game fish; consequently the most important food chain was plankton-shad-piscivores.

Denisova, A. I. 1977. Factors governing the biological productivity, regime, and content of biogenic and organic substances in the sequence of Dnepr reservoirs. Vodnye Resury 6: 106-119. (Transl. from Russian, 1978, Plenum Publ. Corp.)

81. Two decades of study of Dnepr River reservoirs revealed the primary factors and processes that determine the content, dynamics, and transformation of biogenic (P, N, Si, Fe) and organic elements in reservoirs and how these elements affect productivity. A number of nutrient sources are discussed such as runoff and inflow from drainage basins, leaching from newly flooded areas, wastewater (industrial, municipal, or agricultural), precipitation, shoreline erosion, bottom deposits, and in situ production. The amount of nutrients and organic matter from newly flooded areas in the first year of impoundment ranged from one to two times the amount inflowing from the drainage basin in several reservoirs and greatly enhanced productivity. Organic materials in newly flooded areas are derived from soils, higher aquatic plants, and herbaceous and woody terrestrial vegetation, especially during the first years of impoundment. The quantity and rate of nutrient leaching during decomposition of vegetation depends on the type, age, and amount of flooded material. The quantity of nutrients, per unit of plant material, is greatest in higher aquatic plants, followed by meadow vegetation, and then woody vegetation. Decomposition of different plants is important in forming bottom deposits. Most biogenic substances enter the reservoirs in the spring (50-60%) and winter (22-30%). In the spring, inflows carry most of the annual load of organic nitrogen (47-72%) and organic phosphorus (56-61%).

Derksen, A. J. 1967. Variations in abundance of walleyes, Stizostedion vitreum vitreum (Mitchill) in Cedar and Moose Lakes, Manitoba. M. S. Thesis, Univ. of Manitoba, Manitoba, Canada. 98 pp.

82. By gill-netting walleyes and examining the age composition of walleyes in catches of commercial fishermen, year-class strength was estimated in two ways. Estimates of year-class strength based on catches in 9.5- and 10-cm mesh gill nets were significantly correlated with estimates based on commercial catches, and with discharge of water from the Saskatchewan River during the year in which a year class was produced. Water levels affected spawning success by determining the amount of spawning area available. Water levels may affect the sustained production of zooplankton, the principal food of young-of-year walleyes and thereby influence the survival of young walleyes by increasing or decreasing competition for food.

Doan, K. H. 1945. Catch of Stizostedion vitreum in relation to changes in lake level in western Lake Erie during the winter of 1943. Am. Midl. Nat. 33: 455-459.

83. The winter catch of walleyes (y), in pounds per man-hour, was significantly correlated ($p < 0.01$) with the total change in water level (x) between 0800 and 2000 hours as follows: $y = 0.15 + 2.08 \log x$, where x is expressed in hundredths of feet. Currents under the ice are closely related to water levels in Lake Erie, and currents probably affect movements of walleyes and hence their chance of being caught by anglers.

Domermuth, B. and L. Dowlin. 1975. Fisheries management report for Tuttle Creek Reservoir, status 1975. Kansas Forestry Fish Game Comm. Pratt, Kansas. 59 pp.

84. Water-level manipulation is the only management technique readily applicable to entire reservoirs. Weak year classes of largemouth bass in 1969 and 1970 were associated with high turbidity caused by peak inflows in early February to mid-April and high rates of water discharge from mid-April through June. Crappie year classes did not seem to depend on water-level patterns but more on some intrinsic control such as intraspecific predation. The strong 1974 year class of walleyes resulted from stable to slowly rising water levels from March to April and outflows less than 1,000 cfs. In other years, walleye year classes were poor due to unfavorable water-level patterns. The purposes of water-level management are two-fold in this turbid reservoir: Water-level fluctuations must be favorable for spawning and survival, and discharge must be controlled to lessen turbidity. In 1974, a multiple spawn of gizzard shad insured the presence of shad of a forage size throughout the growing season. Because gizzard shad often exceed forage size by the end of their first season, reservoir operations that result in slightly

increased water levels in late June are desirable because they may produce multiple spawns of gizzard shad. Decreased abundance of river carpsuckers in 1975 may have resulted from a midsummer drawdown that increased predation.

Dorris, T. C. and B. J. Copeland. 1962. Limnology of the middle Mississippi River. III. Mayfly populations in relation to navigation water-level control. Limnol. Oceanogr. 7: 240-247.

85. Naiads of Hexagenia rigida in Navigation Pool 21 of the Mississippi River were most abundant at the upstream end of the channel during the summer. Densities of naiads were reduced at all stations, especially at near-shore sites, after a 6-week drawdown of about 4 feet.

Driver, E. A. 1977. Chironomid communities in small prairie ponds: some characteristics and controls. Freshw. Biol. 7: 121-134.

86. In small prairie ponds in central Saskatchewan, chironomid diversity depends on the stage of development of the plant community within a moisture gradient. Rapid or complete water-level reduction in a pond maintains a very simple chironomid community of 3 to 10 species and a simple plant community of two to three species. Increased water levels eliminate emergent and submergent plants and associated chironomids.

Dumont, P. and R. Fortin. 1977. Effects of spring water levels on the reproduction of upper Richelieu and Missisquoi Bay: northern pike (Esox lucius L.). Int. Joint Comm., Int. Champlain-Richelieu Board, Univ. of Massachusetts. 105 pp.

87. Upper Richelieu and Missisquoi Bay floodplain and wetland areas are classified in terms of their potential for northern pike spawning and early development. Four potential spawning areas begin to be inundated at a lake level of 98.5 feet and are productive at a level of 100 feet. Good fry production also seems to be related to relatively stable water levels for 30-40 days after the lake reaches elevation 98.5, and to a gradual drawdown from peak elevations. If regulation is implemented, a predictive model based on air temperature profiles, precipitation, etc., should be developed from historical data on Lake Champlain. Also, measures should be taken to protect all high-potential spawning areas from drainage and land fill. (Abstract adapted from Selected Water Resour. Abstr. 12(16): W79-07742.)

Dunst, R. C., S. M. Born, P. D. Uttormark, S. A. Smith, S. A. Nichols, J. O. Peterson, D. R. Knauer, S. L. Serns, D. R. Winter, and T. L. Wirth. 1974. Survey of lake rehabilitation techniques and experiences. Wisconsin Dep. Nat. Resour., Tech. Bull. No. 75. 179 pp.

88. A comprehensive survey of techniques for limiting fertility, controlling sedimentation, and managing eutrophication is presented. Results obtained in almost 600 accounts of management programs provide the basis for evaluating various techniques. Drawdown to consolidate sediments was successfully employed in a number of waters. In Beaver Lake, Wisconsin, for example, drawdown increased the lake depth by 11% after refilling and improved the fishery. Consolidation of flocculent sediments is largely irreversible and may increase nutrients in the lake when it is refilled. Many accounts of successful control of macrophytes by drawdown are cited. Aquatic macrophytes are reduced primarily as a result of desiccation, freezing, mechanical removal, or soil compaction. Drawdown can be effective in controlling populations of fish by exposing eggs, by stranding small individuals, or by concentrating fish and thereby increasing harvest and predation. When drawdown is implemented in a non-spawning period, timing is less critical, perhaps because predation is the main factor affecting the fish community. Although drawdown can be successful, cause-effect relations are not always clear.

Duthie, H. C. 1968. Ecology of phytoplankton in Lake Belwood, a storage reservoir in southern Ontario. J. Fish. Res. Board Can. 25: 1229-1245.

89. A 16-month investigation, conducted to determine what factors control the seasonal development of phytoplankton in an Ontario reservoir, revealed that populations of blue-green algae and flagellates were reduced in the upper end of the reservoir when water levels of the impoundment were lowered. Densities of phytoplankton below the dam increased at the same time.

Duthie, H. C. and M. L. Ostrofsky. 1975. Environmental impact of the Churchill Falls (Labrador) hydroelectric project: a preliminary assessment. J. Fish Res. Board Can. 32: 117-125.

90. Construction of the Churchill Falls hydroelectric project created two reservoirs totalling 6650 km^2. Inundation began in 1971 and full pool was expected in 1974. Researchers concentrated on cataloging fish and wildlife, determining the effects of impoundment on plants in the spray zone of the falls, and evaluating the impact of flooding on water quality and aquatic biota. Preliminary findings showed little humification or oxygen deficiency in newly flooded areas (perhaps as a result of the rapid rate of water exchange and the polymictic nature of these reservoirs). Conductivity and dissolved ion concentrations

increased. The immediate effect of impoundment was a decrease in primary production per unit of surface area due to increased turbidity and diluted standing crops. The long-term effect was a severalfold increase in primary production, increased nutrients, and increased standing crops of phytoplankton. Both phytoplankton and zooplankton populations generally increased and changed qualitatively with impoundment, especially in shallow water.

Eckblad, J. W. 1973. Population studies of three aquatic gastropods in an intermittent backwater. Hydrobiologia 41: 199-219.

91. Populations of three species of snails in an intermittent backwater were studied over a 20-month period. Population dynamics, mean biomass, net production, and survival were estimated. Although one snail (Lymnaea palustris) could reduce desiccation structurally, drought caused high mortality in the other two species. An extended dry period in the early summer of 1970 reduced total production 18 - 24% of that in 1969, although summer turnover ratios ($P/\overline{B}$) were relatively constant.

Elder, H. Y. 1964. Biological effects of water utilization by hydro-electric schemes in relation to fisheries, with special reference to Scotland. Proc. Royal Soc. Edinburgh 69: 246-271.

92. The creation of reservoirs and the effects of increased reservoir water levels on agriculture, rare plants or animals, benthos, production of plankton and fish, and reproduction of fish are discussed. Initially, biological production increases because of (1) nutrient leaching from soils and terrestrial vegetation, (2) increased production of Cladocera, (3) increased food sources for fish (terrestrial invertebrates), and (4) increased foraging area. Ultimately, however, fluctuating water levels result in the loss of valuable benthic fish-food organisms and in the increased survival of species that are less available to fish or of lower caloric values than other forms. Fish feeding may eventually be reduced.

Ellis, M. M. 1937. Some fishery problems in impounded waters. Trans. Am. Fish. Soc. 66: 63-71.

93. Major fishery problems in reservoirs are associated with basin configuration (and the creation of large areas of slack water), reservoir age, water inflow, and water removal. One of the most difficult problems is the decline of fish production as reservoirs age and favorable biological conditions (produced by the solution of nutrients from organic debris and vegetation) are lost. The problem apparently is one of nutrient loss, and fish restocking programs are not entirely successful in restoring productivity. Some nutrients may be provided from

plants that develop in areas dewatered during drawdowns, but effective operations for such drawdowns are difficult to schedule when other needs are considered first. Of all factors adversely affecting fisheries, drawdown is the easiest to recognize. Nesting areas are exposed in the spawning season, beds of submerged vegetation are left dry, and fish are often forced into waters that are unsuitable or lethal (anoxic). Some ways to ease the harmful effects of drawdown include the establishment of marginal pools with shallow stable water levels and the construction of floating nest areas that ride at anchor and maintain a constant spawning depth.

Ellis, M. M. 1942. Fresh-water impoundments. Trans. Am. Fish. Soc. 71: 80-93.

94. A number of conditions can limit the productivity of reservoirs: stagnation, flushing of nutrients and materials, limited littoral area, extensive fluctuation of water levels, and heavy siltation. Production can be increased to some extent by maintaining fairly constant water levels in the spring when desirable fishes are spawning. Other measures include stocking, enhancement of spawning and nursery habitat by building lateral pools with constant levels, construction of artificial structures or shelters, and chemical enrichment.

Elrod, J. H. and T. J. Hassler. 1971. Vital statistics of seven fish species in Lake Sharp, South Dakota 1964-69. Pages 27-40 in G. E. Hall, ed. Reservoir Fisheries and Limnology. Am. Fish. Soc. Spec. Publ. No. 8.

95. The abundance of seven species of fish (goldeye, common carp, river carpsucker, blue sucker, smallmouth buffalo, bigmouth buffalo, and shorthead redhorse) declined after impoundment. Data on the age composition, year-class strength, growth, and survival are presented for each species. Rapid growth of most species in 1964 may have resulted from an abundance of food in the newly flooded lake. When large areas of terrestrial vegetation were first flooded, strong year classes of common carp, bigmouth buffalo, and smallmouth buffalo were produced. Since 1964, no new areas were flooded and little aquatic vegetation developed. As a result, only weak year classes were produced.

Engelhardt, W. 1958. Limnological investigations in Lake Walchensee in the years 1950-58: II. Investigations of the littoral fauna of the Walchensee in upper Bavaria and the influence of regulation. Arch. Fischereiwiss. 9(3): 203-222.

96. Since 1924, the Walchensee has been used for generation of electricity, and, as a result, its water level has fluctuated up to 6.6 m. Although the total density of benthos is similar to that of benthos in

natural lakes, certain turbellarians, plecopterans, and trichopterans are noticeably scarce. Many littoral organisms descend with the receding waters and densities often increase markedly in sub-littoral and secondary littoral areas. Other species dig into the substrate to survive desiccation or freezing for over 3 months. Ample amounts of fish-food organisms are present for existing fish populations.

Erickson, J. and F. Stevenson. 1972. Evaluation of environmental factors of Ohio reservoirs in relation to the success of walleye stocking. Ohio Dep. Nat. Resour., Div. Fish. Res., Fed. Aid Rep. F-29-R-11.

97. Physical, chemical, and biological data are related to the success of walleye introductions in Ohio reservoirs. Fluctuations in water levels are important to walleye populations, especially if water levels fluctuate slowly and permit waves to clean gravel bars in river reservoirs or the rip-rap in man-made basins (up-ground reservoirs). Clean rocky areas are necessary for successful spawning and to improve the survival of stocked fish. Stocking is most successful in larger impoundments where water levels recede slowly, as in water supply and navigation reservoirs.

Eschmeyer, R. W. 1949. The fisheries picture -- with special reference to TVA impoundments. Prog. Fish-Cult. 11: 267-271.

98. Three significant components of the picture of fish conservation are (1) the importance of fishing for relaxation in a stressful world, (2) the decline in satisfactory angling due to increased fishing pressure, and (3) the realization that more large impoundments will have to support increasing angling pressure. In addition to a discussion of the many different conditions that exist in mainstream and storage impoundments and of general trends in fishing on TVA reservoirs, topics related to water-level changes, such as spawning success, winter drawdown, food-chain interactions, and vegetation are discussed. Slowly declining waters apparently do not decrease spawning success, and under normal operations water levels usually are constant (mainstream reservoirs) or rising slowly (storage reservoirs) at spawning time. Winter drawdown does not seem to hinder the reproduction of game fishes, although rough fishes (bottom feeders such as common carp, buffalo, and adult shad) may be hindered by food shortages. Rough fishes are much more abundant in mainstream reservoirs (where drawdowns are limited) than in storage reservoirs. Although drawdown helps control rough fishes, it may interfere with boating and degrade aesthetic qualities of shorelines. Aquatic macrophytes seldom become established in storage reservoirs where drawdown is common, but they are present in mainstream impoundments where drawdown is limited to a few feet.

Eschmeyer, R. W., R. H. Stroud, and A. M. Jones. 1944. Studies of the fish population on the shoal area of a TVA main-stream reservoir. J. Tennessee Acad. Sci. 19: 70-122.

99. The distribution and abundance of fish on the shoals of Chickamauga Reservoir, Tennessee, is described. Drawdown apparently would be the best mean of controlling the large rough-fish populations so typical of main-stream reservoirs. Commercial fishing may be useful, except that the average size of rough fishes is too small. Limited drawdowns can control spawning of buffaloes and common carp without affecting the reproduction of shad and some rough fishes.

Estes, R. D. 1971. The effects of the Smith Mountain pump storage project on the fishery of the lower reservoir, Leesville, Virginia. Ph.D. Thesis, Virginia Polytechnic Inst. and State Univ., Blacksburg, Virginia. 151 pp.

100. The effects of water-level fluctuation and temperature on the spawning, growth, and standing crop of fishes in a mainstream pump-storage reservoir were examined. Water levels frequently fluctuated 6 to 8 feet weekly and 1 to 4 feet daily in response to operations of the Smith Mountain power plant. Neither water-level fluctuation nor temperature reduced the numbers of young fish produced. Water-level fluctuation did not affect spawning or growth of bass or bluegills directly, but its effect on the reproduction of gizzard shad may have influenced bass growth, since the growth of bass was correlated with shad reproduction. Low water temperatures apparently delayed the normal spawning of bass, which spawned in mid-July instead of in May and June. Because there was no indication that bass or bluegill reproduction was more successful in one of the three years than in the others, there was no basis for correlating the degree of fluctuation with spawning success during the three years of the study. Fluctuations may sometimes have caused nest abandonment and fry mortality, but not the loss of an entire year class, although fluctuations may have been one factor influencing relative year-class strength. Evidently, largemouth bass and bluegills are more flexible in their spawning requirements than once thought, as they successfully spawned when water levels fluctuated widely. Perhaps water levels can be manipulated to control reproduction of forage and undesirable fishes without adversely affecting centrarchid spawning.

Ferguson, V. M. and R. C. Fox. 1978. A comparison of aquatic insects in natural inlets with those in the heated effluent from the Oconee Nuclear Station-littoral zone. J. Georgia Entomol. Soc. 13: 202-213.

101. Aquatic insects were sampled weekly from May 1975 to May 1976 at the discharge cove and in three natural inlets on Lake Keowee. Of the aquatic insects collected, 99% were dipterans. Abundance was influenced by the type of substrate, the amount of organic matter present, and

water levels.

Fillion, D. B. 1967. The abundance and distribution of benthic fauna of three mountain reservoirs on the Kananaskis River in Alberta. J. Appl. Ecol. 4: 1-11.

102. Three oligotrophic reservoirs (Barrier Reservoir and Upper and Lower Kananaskis Lakes) do not support high standing crops or diversity of benthos. Maximum abundance occurs in the vicinity of the drawdown limits rather than in the littoral zone. In Barrier Reservoir, the regions with the greatest standing crops of benthos are those not directly influenced by water-level fluctuations, and which receive input of allochthonous materials from the river. The fluctuation zone contains various benthic organisms, but is dominated by chironomids, which survived in areas dewatered up to 85 days. Although chironomids in Barrier Reservoir were most diverse in the 0- to 10-m zone, greater numbers occurred below the drawdown limit.

Fitzgerald, G. P. 1970. Aerobic lake muds for the removal of phosphorus from lake waters. Limnol. Oceanogr. 15: 550-555.

103. Experiments indicated that aerobic lake muds have a strong affinity for phosphate phosphorus and can absorb as much as 0.125 mg PO_4 -P per gram (dry weight) of sediment in 30 minutes. Although two phosphorus-limited algae (Selenastrum and Cladophora) increased growth in response to as little as 0.02 mg PO_4-P in solution, growth did not increase after 1 or 2 weeks of exposure to 2 mg phosphorus in lake muds, under aerobic conditions. Findings suggest that under aerobic conditions lake muds can be used to remove phosphorus from lake water.

Fourt, R. A. 1978. The effects of a two year water-level management plan on the production of sport fish in Beaver Reservoir. Arkansas Game Fish Comm. 15 pp.

104. In 1977, water levels of Beaver Lake were reduced to permit the growth of terrestrial vegetation around the barren shoreline. In spring 1978, abundant rainfall enabled an inundation of terrestrial vegetation on about 6,880 acres of the fluctuation zone, without severely reducing generation of electric power. Favorable environmental conditions during spawning produced the highest density of young bass since the reservoir was impounded. Cove sampling with rotenone indicated a density of 733 young black bass per acre; the average number in August for the preceding 10 years was 281 per acre, and the highest density previously recorded was 491 per acre. Young-of-year crappies also were abundant (78 per acre). The abundance of prey fishes (sunfishes, minnows, and shad) was low -- an unfortunate occurrence, since the overwinter survival of young-of-year bass depends greatly on high sunfish production, especially

when other forage is scarce. Although low survival may result from cannibalism by larger young-of-year and yearling bass, improved growth of surviving young-of-year bass should benefit the fishery.

Fox, J. L., P. L. Brezonik, and M. A. Keirn. 1977. Lake drawdown as a method of improving water quality. U. S. Environ. Protection Agency, Environ. Res. Lab., Corvallis, Oregon. EPA-600/3-77-005. 94 pp.

105. The feasibility of using rapid drawdown to improve water quality of Lake Apopka, Florida (a hypereutrophic lake with continual algae blooms, abundant macrophytes, and nutrient-rich sediments), was examined. Laboratory studies indicated that dewatering compacts sediments but produces only minor changes in their chemistry. Two algae colonized the sediments, and respiration by algae and bacteria created anoxic conditions that caused a large fish kill. The standing crop of fish decreased from 146.2 pounds per acre in 1954 to 19.1 pounds per acre after drawdown in 1958.

Franklin, D. R. and L. L. Smith, Jr. 1963. Early life history of the northern pike, *Esox lucius L.*, with special reference to the factors influencing the numerical strength of year classes. Trans. Am. Fish. Soc. 92: 91-110.

106. Abundance of adults and year-class strength of northern pike were not directly related. Growth, and concentrations of oxygen, ammonia, and sulfide did not appear to affect young-of-year survival. Mortality was increased by rapid changes in temperature and toxic concentrations of iron compounds during two critical periods. Survival of fingerlings was greatest when water levels in nursery areas were stable for 3 months after the spawning season.

Fraser, J. C. 1972. Water levels, fluctuation, and minimum pools in reservoirs for fish and other aquatic resources - an annotated bibliography. FAO Fish. Tech. Pap. No. 113. 42 pp.

107. A collection of references, abstracts, and notes is presented of much of the literature concerning the effects of water-level fluctuations and minimum pools on fish and other aquatic resources.

Frey, D. G. 1967. Reservoir research -- objectives and practices with an example from the Soviet Union. Pages 26-36 *in* Reservoir Committee of the Southern Division. *Reservoir Fishery Resources Symposium*. Am. Fish. Soc., Washington, D. C.

108. Differences in approach and goals of reservoir research in the Soviet Union and United States are examined, and some limnological

perspectives are presented on how reservoirs differ from natural lakes. A distinct difference between lakes and reservoirs is water-level fluctuation, a common phenomenon in many Soviet and U. S. impoundments. Some Soviet reservoirs are very large and shallow, consequently even a relatively small drop in water level exposes large areas of the bottom (as much as 75% in the Rybinsk Reservoir) and severely stresses benthos and fishes. As a result, Soviet biologists have extensively studied the drained zone of reservoirs. Invertebrates associated with gravel or well-drained soils are killed by drawdown, but many organisms on silt or clay soils often are able to burrow into the substrate and survive. In reservoirs where the drained substrate retains water and where bottom animals can burrow, productivity of the drained zone may not be appreciably less than that on continually flooded bottoms. In reservoirs where drawdown lasts long enough for a dense growth of terrestrial vegetation to develop, reflooding usually increases production of algae and benthos.

Frost, W. E. 1956. The growth of brown trout (Salmo trutta L.) in Haweswater before and after the raising of the level of the lake. Salmon Trout Mag. 148: 266-275.

109. Growth of trout in the lake increased after the lake water level was raised 38 feet. Growth was fastest during the first year of flooding and was accounted for by the many terrestrial organisms that were consumed (53% of stomach contents). The decrease in size and growth several years after impoundment indicated that the increased fish production was only temporary.

Fuerst, M. 1970. Experiments on the transplantation of new fish-food organisms into Swedish impounded lakes. Fauna Flora 3: 94-105. (In Swedish)

110. The abundance of bottom-dwelling fish-food organisms decreases greatly as a result of artificial water-level fluctuations in impounded lakes. Plankton does not provide enough food to maintain sufficient growth and quality of char, brown trout, or whitefish. Three species of Crustacea (Mysis relicta, Pallasea quadrispinosa, and Gammaracanthus lacustris) are being introduced to replace the original bottom-fauna. They live near the bottom and are not influenced by water-level fluctuations because of their mobility. Char, brown trout, burbot, and grayling fed heavily on dense Mysis populations. The quality of the fish flesh improved greatly, and the flesh coloration of char and trout became more reddish than before the introductions. The impact of the new diet on fish growth and density is not yet evident. (Abstract adapted from Fraser 1972.)

Gabel, J. A. 1974. Species and age composition of trap net catches in Lake Oahe, South Dakota, 1963-67. U. S. Fish Wildl. Serv., Tech. Pap. No. 75, 21 pp.

111. Twenty-seven species of fish were sampled with trap nets in Lake Oahe. Because catch per unit effort did not accurately reflect the abundance of some species (due to variations in water level and other environmental conditions), the ability of species to adapt to reservoir conditions was based on the frequency and strength of post-impoundment year classes. As the reservoir filled and waters inundated terrestrial vegetation for the first time, strong year classes of bigmouth buffalo, common carp, smallmouth buffalo, and northern pike were produced. Due to the strong 1962 year class, freshwater drum, common carp, and bigmouth and smallmouth buffalos remained abundant through 1967. After 1962, year classes of some species that do not require flooded vegetation for spawning were more consistent than those of species that require vegetation. The exceptional year classes of 1962 can be attributed to a marked rise in water level that continued during and after the spawning season of most species. Rising water levels in the spring may be required for successful reproduction of the bigmouth buffalo. Because the growth of aquatic vegetation was hindered by water-level fluctuations in Lake Oahe and the inundation of vegetation was not timely, reproduction of common carp was poor. Because freshwater drum are pelagic spawners, their reproductive success was relatively independent of water-level fluctuations.

Gasaway, C. R. 1970. Changes in the fish population in Lake Francis Case in South Dakota in the first 16 years of impoundment. U. S. Fish. Wildl. Serv., Tech. Pap. No. 56. 30 pp.

112. The abundance of adult fish in Lake Francis Case declined after impoundment in 1952 and the catch by fishermen decreased from 1.37 to 0.27 fish per hour after 1954. Growth of 13 species increased after impoundment but later declined. The species composition in the lake and in the harvest changed somewhat since impoundment; some species became rare and others abundant. Reproduction was unusually high for many species in 1967, a year of high water levels. Strong year classes of northern pike were produced in 1954, 1964, and probably 1965. The 1964 year class of northern pike and common carp may have come from Lake Sharpe (upstream), as water levels in Francis Case were not conducive to good spawning that year (i.e., they were drawn down 3 feet to control common carp spawning). Attempts to destroy the spawn of common carp in 1956 were unsuccessful; this year class made up 78% of the catch in 1959. Scarcity of submerged terrestrial vegetation probably was as important as water-level drawdown in limiting carp reproduction. Because common carp spawn over an extended period, short-term manipulation of water levels may be of only limited value as a control measure.

Geagan, D. W. 1961. A report of a fish kill in Chicot Lake, Louisiana during a water level drawdown. Louisiana Acad. Sci. 23: 39-44.

113. After water levels were reduced in Lake Chicot to control aquatic plants (especially Elodea, which covered 50% of the lake), large numbers of fish died due to near-anoxic conditions (oxygen concentrations were less than 0.1 mg l^{-1} near the main boat landing). This kill reduced the fish standing crop from 146.2 to 19.1 pounds per acre. This kill might have been avoided if the lake had been drawn down annually to control plants (it was not drawn down in 1956-57; consequently plants became over-abundant).

Geiger, W., H. J. Meng, and C. Ruhle. 1975. Effects of simulated pumped storage operation on northern pike fry. Schweiz. Z. Hydrol. 37: 225-232. (In German)

114. Effects of periodic simulated water-level fluctuations on northern pike fry, as produced by pumped-storage operations, were examined. Daily fluctuations of 10 cm caused a significant increase in mortality of fry. Waves reduced the detrimental effect of water-level fluctuations, at least during the adhesive phase of development.

Ginzburg, Ya. I. 1958. Biology and abundance of young fish in the Tsimlyansk Reservoir (according to observations of 1953-1955). Izvest. Vses. Nauchn.-Issled Inst. Ozernogo i Rechnogo Rybn. Khoz. 45: 111-141. (In Russian)

115. Variations in the reproduction of fish in different years resulted from the following factors: (1) changes in the water regime, (2) the absence of permanent spawning grounds and the sharp fluctuations in their dimensions and condition, (3) the number of spawners, and (4) biological conditions in the reservoir. Spawning of phytophilic fish was successful in 1952, the first year the reservoir was filled; 1953 and 1954 were poor years for most species, but 1955 was a better one. The decrease in common carp reproduction in 1953 and 1954 was due to the sparse distribution of spawners in the reservoir, together with a sharp reduction in the size of the spawning area (due to reduced water levels, common carp spawned in a narrow coastal strip of meadow and aquatic vegetation). Replenishment of pike-perch (Stizostedion sp.) reserves after they shift to a fish diet depends on prey availability and production. The reproduction of bream (Abramis ballerus) was more successful than pike-perch (Stizostedion) and common carp and its stocks were more abundant. Favorable spawning conditions in 1955 improved the reproduction of bream, common carp, pike-perch, and predatory fishes. (From Referat. Zhur. Biol., 1959, No. 88778; Biol. Abstr. 48: 79056.)

Goddard, J. A. and L. C. Redmond. 1978. Northern pike, tiger muskellunge, and walleye populations in Stockton Lake, Missouri: a management evaluation. Pages 313-319 in R. L. Kendall, ed. Selected Coolwater Fishes of North America. Am. Fish. Soc. Spec. Publ. No. 11.

116. In addition to describing the fishery of Stockton Lake and the effects of stage filling, the authors evaluated the effectiveness of length limits and stocking. Survival and growth of walleye and northern pike fry were excellent during the first year of impoundment and continued to be good for several years thereafter. High survival and rapid growth were attributed to the abundance of flooded terrestrial vegetation in three successive springs of stage filling. Filling in three stages provided a fertile environment as flooded plants decayed, and zooplankton and small forage fishes were abundant. The continual rise of water into terrestrial vegetation also provided protection and an important feeding area for young fishes.

Goodson, L. F., Jr. 1965. Diets of four warmwater game fishes in a fluctuating, steep-sided, California reservoir. Calif. Fish Game 51: 259-269.

117. Food studies of largemouth bass, black crappies, white catfish, and bluegills collected from Pine Flat Lake in 1963 and 1964 revealed that stomachs contained a seasonal abundance of cladocerans, terrestrial arthropods, and threadfin shad. White catfish ate terrestrial plants when water levels were rising in the winter. Terrestrial insects were the main food of bluegills from July to October. Chironomids apparently are well adapted to the lake's changing environment and may prove to be the most important invertebrate fish food in fluctuating steep-sided reservoirs.

Gophen, M. 1979. Population density, migration and food composition of Echinogammarus veneris in Lake Kinneret, Israel. Hydrobiologia 66: 99-104.

118. Migrations of Echinogammarus veneris (a small amphipod) were controlled by water levels and littoral currents.

Goryainova, L. I., O. V. Karpichova, L. N. Kopyteva, L. P. Kostyuchenko, L. D. Lysin, N. Yu. Milovidova, and A. N. Pangina. 1969. The Neberdzhai Reservoir during its first eight years. Hydrobiol. J. 5(6): 45-50.

119. Information is presented on the qualitative and quantitative composition of plankton, benthos, and fish in Neberdzhai Reservoir during the first and eighth years of impoundment. Declining water levels expose large portions of the reservoir bottom by late summer. The number of species of benthos decreased from 21 to 11, as species living in thick plant growths disappeared after the vegetation was eliminated. The

average biomass of benthos was highest in the first year (3.3 g m^{-2}), declined to 0.2 g m^{-2} in the second year, and gradually increased to 2.2 g m^{-2} by the eighth year. In 1959-60 the benthos was very diverse, but by 1967 only oligochaetes and chironomids remained.

Graham, T. R., and J. W. Jones. 1960. The biology of Llyn Tegid trout 1960. Proc. Zool. Soc. Lond. 139: 657-683.

120. After outflows were controlled in 1955, water levels and the range of fluctuations decreased. Fish sampled in 1959-60 exhibited a decrease in growth, condition, food ration, and caloric value of the diet. The standing crop of the bottom fauna in the littoral zone was reduced by decreased water levels, and this reduction was reflected by a decrease in the number and types of organisms eaten by trout. When water levels were high, plecopterans, tipulids, and molluscs composed most of the volume of trout diets. After water levels and fluctuations were decreased, stomachs contained mostly oligochaetes, chironomid pupae, and for the first time, zooplankton. Although the types of fish that trout ate differed under the two operational regimes, the volumes were similar.

Gras, R. and St. J. Lucien. 1978. Duration and characteristics of juvenile development of some Cladocera from Lake Chad. Cah. Orstrom Ser. Hydrobiol. 12: 119-136. (In French)

121. The relative duration of the juvenile period of Moina and Diaphanosoma, as estimated by two methods, was shortened by accelerated development and a decrease in the number of instars between 1968 (a high-water year) and 1973 (a low-water year). Improved nutritional conditions in the lake after the fall in water level apparently resulted in accelerated development. (From Biol. Abstr. 68: 74005.)

Grimås, U. 1961. The bottom fauna of natural and impounded lakes in northern Sweden (Ankarvattnet and Blåsjön). Rep. Inst. Freshwater Res. Drottningholm 42: 183-237.

122. The influence of lake regulation was studied by comparing the benthos of regulated Lake Blåsjön with that of unregulated Lake Ankarvattnet. The annual amplitude of water-level fluctuation in Lake Blåsjön was about 6 m, the drawdown occurring in winter. The littoral zone of the regulated lake consisted of a block bottom interspersed with gravel that was exposed by erosion. Erosion reduced transparency, and eroded materials were deposited on top of sediments in littoral regions below the drawdown limit, greatly altering their character. Water-level fluctuations significantly reduced the density of benthic animals (70% in the fluctuation zone; 25% in other areas). The abundance of benthos was greatest just below the limit of drawdown. Abundance of chironomids (midges) increased while densities of Crustacea

declined. Densities of Cladocera initially increased after regulation but decreased after continuous erosion and loss of nutrients. Populations of Gammarus and other benthic invertebrates (e.g., insect larvae) that depend on an intact littoral zone, also were greatly reduced.

Grimås, U. 1962. The effect of increased water level fluctuation upon the bottom fauna in Lake Blåsjön, northern Sweden. Rep. Inst. Freshwater Res. Drottningholm 44: 14-41.

123. Effects of increased annual water-level fluctuations (from 6 m to 13 m) on benthos was evaluated. Densities of benthos were reduced 50% during 10 years of 6-m fluctuation and another 40% during 2 years of 13-m fluctuations. Increased fluctuation affected all of the fauna in the fluctuation zone and altered the balance among major taxa. Littoral benthos such as amphipods, larger insect nymphs, and gastropods decreased in abundance, while oligochaetes, nematodes, and pisidians increased in abundance. There was a short-term increase in the density of littoral crustaceans, but long-term fluctuation increased the abundance of chironomids and other animals that are not normally available as food for fish. Fluctuation caused changes in chironomid patterns of emergence, and consequently they apparently were less available as fish food than before fluctuations were increased. Freezing and drying of the substrate in the fluctuation zone may have been responsible for qualitative changes in the bottom fauna. Losses of aquatic bottom vegetation and organic deposits from the littoral zone were important factors limiting benthos abundance.

Grimås, U. 1964. Studies on the bottom fauna of impounded lakes in southern Norway (Tunnhovdfjord, Paalsbufjord, and Rödungen). Rep. Inst. Freshwater Res. Drottningholm 45: 94-104.

124. Large insect larvae of the orders Plecoptera, Ephemeroptera, and Trichoptera were established in the littoral of the impounded lakes, in contrast to previous observations made in other regulated lakes. In exposed areas, insects were concentrated on old tree stumps. They also were abundant in the loose drift materials along shorelines. Quantitative benthos samples from Tunnhovdfjord were similar to those from other natural lakes in that the numerical abundance of benthos in the fluctuation zone was low. In unprotected areas, erosion and drawdown caused an inverted vertical distribution of animals, the maxima occurring just below the drawdown limit. In protected areas, the vertical distribution of benthos was similar to that observed in natural lakes (i.e., abundance was greater in the littoral zone than in deeper areas). Scattered areas of moss and submerged tree stumps supported more individuals than did eroded bottom deposits. The diverse shore fauna in Lake Rödungen was attributed to a slow rhythm of regulation and the restricted amplitude of the water-level fluctuations. Early years of regulation typically were unstable with erosion adversely affecting

benthos in the fluctuation zone and deeper regions. Over many years, however, leaching out of the fluctuation zone resulted in stabilization of conditions, and a more diverse fauna was established, although annual fluctuations still limited development. This study showed the importance of original forest vegetation in preserving the lake organisms that are important as fish food.

Grimås, U. 1965. Inlet impoundments. An attempt to preserve littoral animals in regulated subarctic lakes. Rep. Inst. Freshwater Res. Drottningholm 46: 22-30.

125. The benthos of inlet impoundments adjacent to impounded natural lakes was studied to determine the suitability of inlets for fish-feeding areas. Inlet impoundments with their stable water levels supplemented the fish-food fauna of the reservoir littoral, which often is degraded by erosion and water-level fluctuation. The development of benthic species that depend on migrations to deep water in the winter (e.g., Gammarus lacustris) seemed to be hampered in the shallow inlet impoundments. However, low winter temperatures and the rapid warming of shallow inlet impoundments in the spring seemed to benefit cladocerans. Littoral insects dominated the fauna of the inlet reservoirs and many of the large species were important as fish foods. Although the inlet impoundments did not counterbalance the loss of the original littoral, they did preserve some littoral vegetation.

Grimås, U. 1965. The short-term effect of artificial water-level fluctuations upon the littoral fauna of Lake Kultjön, northern Sweden. Rep. Inst. Freshwater Res. Drottningholm 46: 5-21.

126. Immediately after impoundment, the bottom fauna of Lake Kultsjön differed from that of older regulated lakes with a similar degree of fluctuation. Within the fluctuation zone there were no areas of refuge to harbor large densities of benthos. Short-term regulations had a negative effect on fish-food organisms. The original littoral fauna, which was composed primarily of chironomids, became dominated by oligochaetes. The most significant short-term effect of regulation on benthos resulted indirectly from structual changes in the surface of the substrate. Desiccation and freezing directly decimated benthos inhabiting surfaces of attached plants or sediments.

Grimås, U. 1967. Impounded lakes and river reservoirs: two new ecosystems for the Swedish nature. Sven. Naturvetensk 1967: 168-177.

127. Two types of storage basins are used to provide a continuous water supply during the year in northern Sweden (i.e., impounded lakes in the high mountains and river reservoirs in the immediate vicinity of power stations in the lower reaches of rivers). Impounded mountain lakes are

characterized by great fluctuations in water level and river reservoirs by a relatively steady water level and variable rate of water flow. Effects of impoundment on phytoplankton, zooplankton, bottom vegetation, bottom fauna, and the feeding habits and production of fish have been studied. Changes in the abiotic environment that affect various communities also have been described. Production in impounded lakes and river reservoirs seems to follow two different lines (production is not favored in impounded lakes as it is in river reservoirs). Several experiments have been started to establish new productive food chains in impounded lakes and to channel more biological production into desirable species of fish in river reservoirs. (Abstract adapted from Fraser 1972.)

Grimås, U. and N. A. Nilsson. 1965. On the food chain in some north Swedish river reservoirs. Rep. Inst. Freshwater Res. Drottningholm 46: 31-38.

128. The food chain in Swedish river reservoirs is discussed and compared with that in impounded natural lakes. River reservoirs differ from impounded natural lakes in having relatively smaller, though perhaps more rapid changes in water level. When water levels are stable, aquatic vegetation can develop throughout large portions of river reservoirs. The remains of original vegetation are important for production in inundated areas. The eurybathic distribution of littoral animals in river reservoirs diminishes the importance of the upper littoral zone as a feeding area for fish.

Grizzell, R. A., Jr. 1960. Fish and wildlife management on watershed projects. Trans. North Am. Wildl. Conf. 25: 186-192.

129. Strategies are discussed for managing fish, waterfowl, and upland game resources on small watershed projects. A slot or gate release for flood-retarding structures increases flexibility in effecting drawdown on watershed impoundments of 4 to 100 acres in surface area. Advantages of such a release structure and drawdown include control of mosquitos, manipulation of fish populations, and control of water supply to downstream areas.

Groen, C. L. 1977. Effects of water level management on Milford Reservoir. Paper presented at The Kansas Chapter, Am. Fish. Soc., Feb. 26, 1977. 11 pp.

130. Water-level management on Milford Reservoir, Kansas, plays an important role in increasing numbers of forage fish, sport fish, and harvest. After overwinter drawdown increased the reservoir's flood capacity, refilling in the spring lessened shoreline erosion and increased populations of red shiners, emerald shiners, and white bass as well as the standing crops of young-of-year fishes. Multiple

spawns of gizzard shad were observed. More walleyes, white crappies, and bluegills were creeled during the year after drawdown, and growth of sport fish probably improved.

Groen, C. L. and T. A. Schroeder. 1978. Effects of water level management on walleye and other coolwater fishes in Kansas reservoirs. Pages 278-283 in R. L. Kendall, ed. Selected Coolwater Fishes of North America. Am. Fish. Soc. Spec. Publ. No. 11.

131. Most Kansas reservoirs can be managed to sustain productive fisheries by recreating, to some extent, conditions in newly impounded lakes. This plan involves raising water levels in the spring to improve spawning and nursery conditions by providing submerged herbaceous vegetation (which provides substrate, refuge, turbidity control, and nutrients). A midsummer drawdown follows to permit regrowth of vegetation in the fluctuation zone, to improve the availability of forage for piscivores, and to control populations of rough fish. Due to uncontrollable weather that may negate the benefits of water-level manipulation, plans may have to be implemented for several years to achieve desired results. Success depends greatly on the type and amount of vegetation that can be grown in the fluctuation zone. For early drawdowns, the seeding of Japanese millet and hybrid sudan-sorghum produces lush stands of vegetation valuable for fish habitat, turbidity control, and waterfowl food. Annual wheat or rye seeded in September or October provides good growth for late drawdowns. Water-level management has increased growth, recruitment, and harvest of walleyes and improved the forage base and survival of stocked walleye fry and northern pike fingerlings. Improved structure of fish populations and water quality also are attributed to water-level management. In Council Grove Reservoir, the proportion of harvestable sized sport fish increased from 15.5 to 52.9% of the total number and from 30.3 to 44.1% of the total weight 2 years after water levels were manipulated. In Milford Reservoir, catch per unit of effort by fyke netting nearly doubled in 3 years. The relative abundance of walleyes, white crappies, river carpsuckers, and gizzard shad has increased in Milford Reservoir since water levels were first managed.

Gulyaeva, A. M. 1964. Biology and fishery of lake smelt in Vodlozero. In Fisheries of Karelia. Petrozavodsk 8: 144-148. (In Russian)

132. From 1934 to 1940, the catch of lake smelt decreased by about 97%, probably as a result of increased water levels that displaced spawning grounds. A change in water conditions when the lake was converted into a temporary reservoir may have limited fish production. (From Referat. Zhur. Biol., 1964, No. 24I95; Biol. Abstr. 47: 10690.)

Gulyaeva, A. M. 1964. Present day state of the reservoir fisheries in southern and central Karelia and prospects of their growth. In Fisheries of Karelia. Petrozavodsk 8: 111-117. (In Russian)

133. In the period 1950-60, the annual catch of fish in lake reservoirs was 18% of the average catch in Karelian inland waters. Species composition of catches before and after regulation of the lakes Vodlozero, Vedlozero, Sandal, Vygozero and Segozero is described. Poor catches are attributed to adverse effects of water-level fluctuation, humification, pollution, and unregulated fishing. Productivity of lake reservoirs probably can be raised considerably by ameliorative conservation and acclimatization measures. (From Referat. Zhur. Biol., 1965, No. 1I89; Biol. Abstr. 47: 30646.)

Guseva, K. A. 1958. The influence of water level regime of the Rybinsk Reservoir on the development of phytoplankton. Tr. Biol. Sta. Borok. Akad. Nauk. SSR. 3: 112-124. (In Russian)

134. The greatest development and abundance of phytoplankton was associated with high water levels that filled the reservoir completely and flooded large areas of terrestrial litter and detritus. Littoral areas contained the greatest biomass of phytoplankton (monthly mean, 7 mg l^{-1}). The development of plankton in the central portion of the reservoir was independent of water levels, and the biomass (2.2 mg l^{-1}) was lower than in the littoral zone. (From Referat. Zhur. Biol., 1959, No. 38614; Biol. Abstr. 47: 65732.)

Hassler, T. J. 1969. Biology of northern pike in Oahe Reservoir, 1959 through 1965. U. S. Fish Wildl. Serv., Tech. Pap. No. 29. 13 pp.

135. Fish collected over a 7-year period were examined for variations in length, weight, growth, maturity, sex ratios, and year classes. After impoundment, strong year classes (1959, 1962, and 1965) were associated with high spring water levels that exceeded previous high levels and remained high throughout the summer.

Hassler, T. J. 1970. Environmental influences on early development and year-class strength of northern pike in Lakes Oahe and Sharpe, South Dakota. Trans. Am. Fish. Soc. 99: 369-380.

136. Factors affecting early development and year-class strength were delineated by monitoring environmental variables and the survival of artificially fertilized ova and larvae of northern pike. Large year classes were associated with stable to rising water level and temperature, recently flooded vegetation, and calm weather during the spawning season; whereas, small year classes were related to abrupt decreases in water level. However, availability of suitable water level and substrate

does not guarantee a strong year class, inasmuch as low water temperature, rapid fluctuation in temperature, high siltation (due to wind-induced turbulence), or a lack of suitable food may separately or in combination result in weak year classes.

Hassler, W. W. 1955. The influence of certain environmental factors on the growth of Norris Reservoir sauger, Stizostedion canadense canadense (Smith). Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 9: 111-119.

137. A number of environmental variables (i.e., agricultural growing season, number of days between the first and last 60° F (15.6° C) day, precipitation, solar radiation, air temperature, and water-level fluctuation) were examined in relation to the first-year growth of saugers. No significant correlation was found between changes in water level and first year growth of saugers, but the data suggest that a relation does exist between first-year growth and a cycle of water-level changes. Because other factors (like population density) influence the relation, further evidence of the association between a cycle of water-level fluctuation and changes in first-year growth is needed.

Heisey, P. G., D. Mathur, and N. C. Magnusson. 1980. Accelerated growth of smallmouth bass in a pumped storage system. Trans. Am. Fish. Soc. 109: 371-377.

138. In a 12-year study of smallmouth bass in Muddy Run Reservoir, a pumped storage impoundment in Pennsylvania, accelerated growth was related to the abundance of gizzard shad after their introduction in 1972. Drawdowns of 9 m day^{-1} or 15.6 m $week^{-1}$ (volume reduced 45%) increased the vulnerability of shad by concentrating both shad and bass. In the lower reservoir (Conowingo Pond), where water levels fluctuated $\leq$ 1 m each day, growth of smallmouth bass was not greatly improved after shad were introduced. Water-level fluctuations inhibited successful spawning of most fishes in all years except 1967, when water levels were constant in spring and early summer. In 1967, large numbers of forage fish were produced.

Heman, M. L. 1965. Manipulation of fish populations through reservoir drawdown, with emphasis on Micropterus salmoides (Lacepède). M. A. Thesis, Univ. of Missouri. 65 pp.

139. Water levels on Little Dixie Lake were lowered 8 feet in July 1964 in an effort to enhance the population of largemouth bass. Surface area was reduced 42% and volume 58%. Because water was released from the hypolimnion, the lake mixed at 86° F (30.0° C) and 7.2 mg l^{-1} of oxygen. Drawdown reduced the density of small and intermediate sized bluegills by leaving them stranded, by exposing them to increased

predation, and by destroying nests. Largemouth bass fed more when less vegetation was present than when vegetative cover was abundant. Increased growth of all age classes of bass except young-of-year indicates that predation increased during and after drawdown. Harvest of bluegills increased greatly immediately after drawdown; whereas, that of largemouth bass decreased. However, the harvest of bass was higher in the fall after drawdown than in the fall of the previous year. Growth of yearling and older bass accelerated in the year after drawdown; whereas, the length attained by young-of-year bass by the end of the year decreased slightly (from 5.0 to 4.6 inches).

Heman, M. L., R. S. Campbell, and L. C. Redmond. 1969. Manipulation of fish populations through reservoir drawdown. Trans. Am. Fish. Soc. 98: 293-304.

140. Effects of a mid-summer drawdown (July 19-29) on growth of largemouth bass, total harvest, and the size composition of bluegills were examined in Little Dixie Lake, Missouri. In 10 days, water levels were lowered 2.4 m by releasing hypolimnial water. Surface area was reduced by 42%, volume by 58%, and the lake became isothermal at 30° C. The relative weight of food in stomachs of largemouth bass increased by a factor of 2.7, and the percent of empty stomachs decreased. Growth of largemouth bass, as indicated by scale reading, also increased after the drawdown. Harvest of bluegills increased immediately after drawdown and then decreased over the next 2 months. Harvest of largemouth bass was reduced in August but increased significantly in September and October. Drawdown presumably reduced the densities of fry and intermediate-sized bluegills by stranding them, increasing predation, and exposing nests.

Henson, E. B. and M. Potash. 1977. Biological production and nutrient studies of Lake Champlain. Int. Joint Comm., Int. Champlain-Richelieu Board, Univ. of Massachusetts. 58 pp.

141. An evaluation is made of the ecological significance of the distribution and abundance of higher plants, algae, zooplankton, and large invertebrates in a Lake Champlain wetland. The nutrient budget and cycle are examined. For the best growing conditions, water levels should be maintained at elevation 98.4 feet from late May through June and should not go below 97.4 feet. From July through the rest of the growing season, the water level should not be reduced below 95.1 feet. This level permits lateral movement of water through the emergent zone, thus providing needed nutrients, and also maintains an ample submergent-floating zone within the wetland. The submergent zone supports the greatest densities of macroinvertebrates that are used for food by fish. Lake levels maintained below elevation 95.1 during the winter will kill off much of the aquatic vegetation and increase decomposition in spring and summer. As a result, more nutrients will be released into the lake. (From Selected Water Resour. Abstr. 12(16): W79-07741.)

Hildebrand, S. G., editor. 1980. Analysis of environmental issues related to small-scale hydroelectric development. III: Water-level fluctuation. ORNL/TM-7453. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 132 pp.

142. Effects of water-level fluctuations on the limnology of small-scale hydropower reservoirs (25 MW or less) that operate in a store and release mode (peaking) are examined. Physicochemical impacts include resuspension and redistribution of bank and bed sediment, leaching of soluble organic matter from littoral areas, and changes in water quality due to changes in thermal stratification or "trap efficiency" -- i.e., the percentage of total inflowing sediment (or nutrients) retained in the basin. Water-level fluctuations potentially can reduce standing crops, production, and diversity of aquatic animals by destroying habitat or altering its quality. Impacts of changing water level in tailwaters of reservoirs also are discussed.

Hoffman, D. A. and A. R. Jones. 1973. Lake Mead, a case history. Pages 220-233 in W. C. Ackermann, G. F. White, and E. B. Worthington, eds. Man Made Lakes: Their Problems and Environmental Effects. Geophysical Monograph 17, Am. Geophysical Union, William Byrd Press, Richmond, Virginia.

143. All aspects of the history of Lake Mead are discussed, including geology, climate, physical limnology, chemical limnology, ecology of the surrounding terrestrial area and the reservoir, hunting, fishing, and the relation of the reservoir to man. The general pattern of water-level fluctuation involves rising waters in spring and early summer and receding waters in fall and winter. Fishing was fair to excellent during the early years of impoundment, but declined after 1941. Investigations showed poor development of plankton and benthos. Historically, peak fishing success was noted following the years of 1952, 1957, 1958, and 1962 -- all years of high runoff and greatly increased lake levels. Spawning success was phenomenal when exceptionally high water levels covered wide expanses of brushy shoreline. After construction of Glen Canyon Dam upstream, some control of water levels was gained and recommendations were made to maximize benefits to fish. A recommended management program called for steady water levels during spring spawning (April, May, and June) and then for rising water levels from July through September to enhance the overwinter survival of young-of-year game fishes by providing refuge in inundated plants.

Holčík, J. and I. Bastl. 1976. Ecological effects of water level fluctuation upon the fish populations in the Danube River floodplain in Czechoslovakia. Acta Sci. Nat. Acad. Sci. Bohemoslov Brno (10)9: 1-46.

144. Species composition, abundance, and biomass of fish in the Danube River arm of Zofin were determined twice a year in 1969 and 1973. Results demonstrated the extreme importance of floodplains to fish communities. During periods of high water, fish invaded the floodplain, which operates as a spawning ground, a food source, a refuge (for resident main-stream fish), and as a source for repopulating areas where spates have destroyed fish populations. Fish stocks and harvest are higher in streams with a floodplain than in those without.

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

145. After dewatering, littoral vegetation moved lakeward and expanded its coverage from 9,000 to 10,500 acres in Lake Tohopekaliga, Florida. The distribution of vegetation was determined largely by the prevailing water levels within the basin, and the lakeward limit of perennial emergents was related to historically low water elevations. Many of the plants that increased after drawdown produced food for major sport fish and fish-food organisms, as indicated by the high standing crops of fish-food organisms present. Densities of water hyacinth (which was considered detrimental to the fishery) and other plants declined markedly after dewatering.

Houser, A. and W. C. Rainwater. 1975. Production of largemouth bass in Beaver and Bull Shoals Lakes. Pages 310-316 in H. Clepper, ed. Black Bass Biology and Management. Sport Fishing Inst., Washington, D. C.

146. Growth of largemouth bass in Beaver (1968-73) and Bull Shoals (1969-73) lakes was estimated from scale samples of bass collected by shoreline electrofishing along shore. Production was greater in Beaver Lake (the newer reservoir) than in Bull Shoals Lake. Bass populations responded favorably to flooding and high inflow, but year classes were poor when water elevations and inflow were low. Production also decreased drastically when water levels were low. In Beaver Lake, production of the 1966 year class from age II through V was 20.4 lbs acre^{-1}, as compared with the 13.7 lbs acre^{-1} for bass in the 1967 year class (at ages I through V). The difference between the total production of the two year classes was attributed to differences in water level during their first year of life. In 1966, water levels dropped 10 feet by spawning time. The 1968 year classes in Beaver and Bull Shoals lakes contributed more production than any others during the study period. In 1968, extreme flooding occurred in both lakes, and spawning and survival of young bass was excellent.

Hubbs, C. L. and R. W. Eschmeyer. 1938. The impoundment of lakes for fishing. Michigan Dep. Cons., Bull. Inst. Fish. Res. No. 2. 233 pp.

147. Management techniques designed to increase the crops of valuable fishes in lakes are discussed. Major topics include the adjustment of environmental factors to enhance fisheries by control of water levels, weeds, and pollution, or by stocking, fertilizing or building artificial shelters. In general, stable water levels are preferred over fluctuating levels, which may limit spawning success. Biological effects of increasing or decreasing shoal areas are discussed.

Hubert, W. A. and R. T. Lackey. 1980. Habitat of adult smallmouth bass in a Tennessee River Reservoir. Trans. Am. Fish Soc. 109: 364-370.

148. The movement and distribution of radio-tagged smallmouth bass was evaluated for 4 years relative to water temperature, current velocity, turbidity, surface light intensity, reservoir elevation, bottom contours, substrate, and cover. Fluctuations in current velocity and reservoir levels influenced the depth distribution and movement of individuals. In Pickwick Reservoir, smallmouth bass moved to deeper water as current velocities increased. Bottom relief and cover were major variables affecting distribution and movement.

Huitfeldt-Kaas, H. 1935. Der Einfluss der Gewässerregelungen auf den Fischbestand in Binnenseen. Oslo, National - trykkeriet. 105 pp.

149. Effects of impoundment on fish populations, fish-food animals, and inland fisheries of 15 hydropower reservoirs are discussed. In the first years after impoundment, total standing crop of fish-food animals increased and the fish, especially brown trout, showed improved growth and quality. This is a short-term effect, and experience from old hydroelectric reservoirs has shown that yields of brown trout decline in the long run, but that chars are influenced less. (Abstract by K. W. Jensen, Vollebekk, Norway, as adapted from Fraser 1972.)

Hulsey, A. H. 1956. Effects of a fall and winter drawdown on a flood control lake. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 10: 285-289.

150. Drawdown of Lake Nimrod, Arkansas, in 1955-56 reduced the surface area by about 81%. Over 200,000 pounds of rough fish (mostly smallmouth buffalo) were removed by commercial fishermen. A comparison of cove-rotenone samples before and after drawdown showed increased abundance of young-of-year black and white basses after drawdown as well as a threefold increase in the standing crop of nonedible prey fishes (e.g.,

shads and minnows), and a 50% reduction in the biomass of edible forage species (buffalo and drum). The number of young catfish, common carp, and drum was reduced, but the abundance of young sunfishes and minnows increased. Sport fishing apparently improved after drawdown (especially for white crappie), as indicated by boat dock owners. Because the primary purpose of Lake Nimrod was flood control, lowering water levels did not hinder any other beneficial use of the reservoir, and drawdown enhanced the reservoir fishery by improving water clarity and sport-fish survival and harvest.

Hulsey, A. H. 1958. A proposal for the management of reservoirs for fisheries. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 12: 132-143.

151. A management plan to incorporate a fish-management pool (or harvesting basin) into the basic design of reservoirs is proposed. A timber-free, smooth, fish-management pool in the deepest part of a basin facilitates manipulation of fish populations by seining or use of rotenone after the water levels have been reduced. A management pool need not exceed 20% of the area at normal pool and can be much less. Drawdowns in late summer or winter on many Arkansas reservoirs have controlled aquatic weeds such as coontail, fanwort, waterweed, parrot feather, water hyacinths, and water shield. In the early fall, rye grass and water fowl foods are planted in the drained zone. Rye grasses help to reduce clay turbidity upon reflooding. Aeration of soils frees nutrients that are later available to microorganisms after the reservoir is refilled. By beginning drawdowns on about 15 September, when waters are relatively warm (as opposed to winter drawdown), predators consume more forage, and fall destratification is close at hand making oxygen depletion unlikely. Refilling of reservoirs should begin on about 1 January or 1 February. A number of successes in reducing forage-fish populations (e.g., shad, minnows, sunfishes) by drawdown are cited. Improved reproduction in the spring after a drawdown has been observed for black basses, crappies, walleyes, white bass, and flathead catfish. The desired frequency of drawdowns depends on the type of reservoir. Drawdown in alternate years may be best for relatively shallow turbid reservoirs where fish stocks are dominated by sunfishes, buffaloes, and other food fishes. Clear, deep reservoirs may require a drawdown once every 5 or 6 years to produce a dominant year class of sport fishes.

Humphries, R. L. 1964. Small lake studies. North Carolina Wildl. Resour. Comm., Fed. Aid Proj. No. F-13-R. 32 pp.

152. Studies were conducted on many small infertile lakes to determine the best type of regulations for angling and harvest, as well as the best procedures for stocking, manipulation of water levels, and associated operations. Low production in the small lakes -- not unbalanced or overcrowded fish populations -- was the factor most limiting fishing

success. Winter drawdown was tested on Crappie Lake, but unfortunately the lake received fish from a washed-out pond, and results obtained must be viewed with caution. Fishermen on Crappie Lake caught more bluegills (per unit of effort) than fishermen on a control lake, but fewer than fishermen on another lake. Biennial draining of two lakes showed that the bass population could control the chubsucker population with the help of fish removal, but because chubsuckers supplied most of the food to bass, draining was believed to be detrimental.

Hunt, P. C. and J. W. Jones. 1972. The effect of water level fluctuations on a littoral fauna. J. Fish Biol. 4: 385-394.

153. This study compares the abundance and species composition of littoral benthos in 1968-69 with that recorded by other authors in 1951-52 and in 1957 and 1959. Water levels fluctuated 2 m before 1955, 4.3 m between 1955 and 1967, and about 2 m after 1967. In 1967-69, fluctuations were similar to those before 1955, except that lake levels were 3 m lower. Nevertheless, all major groups of animals recorded before fluctuations increased in 1955 were found in 1968-69, when fluctuations were reduced, and most were fully reestablished. Long-term effects of regulation included an increase in the total number and a decrease in diversity of animals in the littoral zone. Numbers ranged from 1504 to 6488 organisms m^{-2} in 1951-52 and from 2239 to 9224 organisms m^{-2} in 1968-69. The 42% increase in numbers was accounted for by chironomids and oligochaetes, exclusively. Gradual removal of silt by wave action and reestablishment of macrovegetation, after fluctuations in water level are reduced, should return the littoral zone to its original status, though it may take years. The reestablishment of <u>Gammarus pulex</u> and <u>Asellus meridianus</u> (perhaps the invertebrates most sensitive to water-level fluctuations) is indicative of decreased fluctuations in recent years. Comments on other major taxa are presented.

Hunt, P. C. and J. W. Jones. 1972. The littoral fauna of Llyn Celyn, North Wales. J. Fish Biol. 4: 321-331.

154. Water-level fluctuations of up to 5.5 m and erosion caused by wave action created a uniformly barren littoral zone in which Lumbriculidae, Sphaeriidae, and Chironomidae were the only benthos present in significant numbers. As a result of the mortality of other benthic forms (mayflies, stoneflies, caddisflies, crustaceans), food and growth of trout were reduced.

Hunt, P. C. and J. W. Jones. 1972. The profundal fauna of Llyn Tegid, North Wales. J. Zool. 168: 9-49.

155. The seasonal distribution, abundance, and life cycles of benthic

invertebrates of Llyn Tegid in 1968-69 are discussed, and the benthos and limnology of the lake are compared with that present in 1951-52, as documented by another biologist, before regulation reduced lake levels. Before regulation, the littoral zone of Llyn Tegid consisted of a gradually shelving rocky area. Lower mean lake levels after 1955 eliminated most of the littoral zone, leaving behind a steep-sided basin with a mud bottom. The profundal fauna increased significantly after 1951-52, primarily because of the increased abundance of oligochaetes and chironomids. Steep shorelines accelerated the fallout of organic matter to greater depths, and this acceleration may have accounted for the apparent increase in the production of profundal benthos. Terrestrial materials inundated during periods of high water were rapidly transported to the profundal zone.

Huston, J. E. 1965. Investigation of two Clark Fork River hydroelectric impoundments. Proc. Montana Acad. Sci. 25: 20-40.

156. Ten years of fishery investigations conducted on Noxon Rapids and Cabinet George reservoirs, Montana, are discussed. Cabinet George is a reregulating impoundment for Noxon Rapids and fluctuates little; whereas, Noxon Rapids is a storage reservoir that fluctuated 5 feet weekly and 10 to 15 feet annually between 1958 and 1960. After 1961, Noxon Rapids was drawn down 35 to 40 feet in the spring. Drawdowns reduced the surface area from 8,600 to about 5,500 acres. Before 1961, and a 33-foot drawdown, rooted and floating aquatic plants were abundant in littoral areas; after 1961 they were scarce. Aquatic vegetation always was present in Cabinet George Reservoir at depths of 5 to 20 feet and became more abundant after water levels were stabilized in 1961. Before 1961, rainbow trout were important to the fishery of Noxon Rapids, but after 1961, populations decreased, as indicated by catches of anglers and biologists. Fall-spawning species such as Dolly Varden, brown trout, and lake whitefish adapted to the altered environment, but few rainbow trout spawned successfully in Noxon Rapids.

Hynes, H. B. N. 1961. The effect of water-level fluctuations on littoral fauna. Verh. Internat. Verein. Limnol. 14: 652-656.

157. In 1955, a dam was installed in the outlet of Llyn Tegid (Lake Bala), Great Britain, and annual water-level fluctuations increased from about 2 m (before 1955) to about 5 m thereafter. Typical fluctuations involved a winter minimum and summer maximum. The first dewatering stranded and killed enormous numbers of animals, including small fish -- as did subsequent fluctuations. Although water-level fluctuations greatly altered the species composition of the community and completely or almost completely eliminated sponges, flatworms, leeches, gastropods, amphipods, mites, stoneflies, mayflies, some bugs, and caddisflies, the density of bottom animals was not reduced but increased along shorelines with sparse cover because of a great abundance of oligochaetes. Two new species of worms appeared and became abundant.

Low water levels altered the littoral substrate significantly. Lower portions of stony shores were more silty, and sheltered stone-covered shores gave way to gritty mud at about 1 m and to soft mud at greater depths.

Il´ina, L. K. 1962. Effect of the 1960 water level on the spawning of fishes in Rybinsk Reservoir. Byul. Inst. Biol. Vodokhran. Akad. Nauk. SSR. 13: 26-30. (In Russian)

158. Because water levels were 2 m lower in 1960 than in 1959, the spawn of many fishes deteriorated. Spawning success, as estimated from the proportion of fish with uncast spawn, agreed well with estimates based on the abundance of young-of-year fish. Loss of spawning areas had the greatest detrimental effect on the spawning of Blicca Bjoerkna, Abramis brama, Leuciscus idus, and Esox lucius; spawning of Rutilus rutilus and Perca fluviatilus were largely unaffected. (From Referat. Zhur. Biol., No. 17I13; Biol. Abstr. 46: 550).

Il´ina, L. K. and A. G. Poddubnyi. 1963. Water levels of the upper Volga Reservoirs and their control in the interest of hatcheries. Pages 47-56 in Fisheries of the Inland Waters of the U.S.S.R. Akad. Nauk. SSR, Moscow. (In Russian)

159. Water levels in reservoirs of the upper Volga affected fish during the spawning and over-wintering seasons and had a definite impact on young-of-year abundance and on the harvest of adult fish by fishermen. Yields of fish from the Rybinsk Reservoir were high when water levels exceeded those of the preceding year by 1.5 to 2.5 m and average in years when water levels were relatively low. Declining water levels in the fall and winter increased mortality by stranding fish in shallows or by suffocating them in anoxic waters under the ice. Abundance was low in years of low water levels that followed high-water years.

Il´ina, L. K. and N. A. Gordeyev. 1972. Water-level regime and the spawning of fish stocks in reservoirs. J. Ichthyology 12: 373-381.

160. A review of information on spawning conditions required by phytophilous fishes forms the basis for reconciling interests of the fishing industry and those of other water users. Water levels are controlled primarily to generate power or to provide water for navigation and irrigation. Interests of the fishing industry typically oppose these "normal" operations, and no consideration is given to the needs of fish. Water-level fluctuations that destroy littoral vegetation important to fish spawning or that cause mass mortality of eggs have been documented. Winter kill caused by drawdown after ice formation has also been observed. Optimum spawning conditions, as outlined by many biologists, require high stable water levels in the spring, throughout the spawning season, followed by reductions of 1 m in the summer and another meter

just before reservoirs freeze over. Such a regime is not practical for all reservoirs in a chain because lowering of levels in one reservoir merely raises them in the next reservoir downstream. Volume released without benefit to other users therefore must be progressively increased for downstream reservoirs. As reservoirs age, the "optimum" regime of water-level fluctuations required to benefit fish spawning may change. In the Rybinsk reservoir, for example, terrestrial vegetation will not grow on sands that remain after years of erosion of the banks and bottom. Optimum water-level regimes vary among reservoirs, and plans should be tailored for local conditions. Some aspects of the general outline for regulating water levels to benefit fish spawning have merit and should be considered. These include (1) elimination of short-term reductions of water levels during fish spawning, (2) autumn discharge of some water to prevent winter kill under ice, (3) establishment of minimum pools, and (4) drawdown to uncover shallows of new reservoirs and lessen erosion. More emphasis must be placed on artificial propagation of fish.

Ioffe, Ts. I. 1966. Formation and classification of the bottom fauna in U.S.S.R. reservoirs. Pages 184-224 in P. V. Tyurin, ed. The Storage Lakes of the U.S.S.R. and Their Importance for Fishery. (Transl. from Russian) Israel Program Sci. Transl. Cat. No. 1638-50. U.S. Dep. Commerce.

161. The development of benthic invertebrate faunas in Soviet reservoirs is discussed. Topics include the origins, composition, quantitative development, seasonal changes, and enrichment of benthos. Water level fluctuations in some reservoirs cause deposition of silt upon which herbaceous vegetation may develop. Periodic flooding of this type of vegetation improves the food resource for benthos, benthos production, and the productivity of the entire reservoir. For example, in Tsimlyanshoe Reservoir, shrub land flooded for 2 months contained 18,000 benthic organisms m^{-2}, with a wet weight of more than 315 grams. A benthic biomass of 123 g m^{-2} was observed on tree surfaces in Rybinsk Reservoir. Decreased water levels exposed large areas of bottom and caused mass mortality of benthic invertebrates, especially when ice formed after winter drawdown.

Irwin, W. H. 1956. The management of large impoundments for fish production. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 10: 271-275.

162. Reservoir fertility is limited by the fertility of the watershed after impoundment, but initially bottom lands usually contain a large supply of detritus and living vegetation that decay and increase production at all trophic levels. Because the supply of fish food in established reservoirs seldom keeps pace with demand, much attention is given to techniques of increasing harvest. Techniques discussed here include advertisement, fishermen education, fish concentration

(with brush shelters), commercial fishing, stocking predatory fishes, water-level fluctuation, rotenone treatment, and draining and filling. Drawdown can serve to concentrate fish for increased predation or to disrupt spawning of some species. Draining is a last resort but can increase fish production on refilling if terrestrial plants such as sorghum, oats, smartweed, and millet are established on exposed areas. Maintenance of a slow rate of water exchange after filling of the basin is important so that nutrients are retained as long as possible.

Isom, B. G. 1971. Effects of storage and mainstream reservoirs on benthic macroinvertebrates in the Tennessee Valley. Pages 179-191 in G. E. Hall, ed. Reservoir Fisheries and Limnology. Am. Fish. Soc. Spec. Publ. No. 8.

163. Various studies have demonstrated that stream benthos in new reservoirs may be limited or eliminated by increased siltation, decreased water flow, water-level fluctuation, low oxygen concentrations, increased hydrostatic pressure, or reduced light. Although typical stream faunas are virtually eliminated by impoundment, fishing in TVA impoundments improved 50-fold over that in the original rivers, due to short food chains linking plankton to fish.

Jackson, S. W., Jr. 1957. Comparison of the age and growth of four fishes from Lower and Upper Spavinaw Lakes, Oklahoma. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 11: 232-249.

164. Growth rates of gizzard shad, spotted sucker, largemouth bass, and white crappie from a new reservoir (Upper Spavinaw) and from an old reservoir (Lower Spavinaw) were compared. Prolonged drawdown and refilling of Lower Spavinaw Lake increased the growth rates of all species in a manner similar to that observed in the new Upper Spavinaw Lake after initial impoundment. Largemouth bass spawned very successfully in the new lake after impoundment, at least during the first 2 years. A similar successful spawn was observed in the older lake after a 2-year drawdown and subsequent refilling. Apparently lowering water level in the fall and gradually raising it after largemouth bass spawn greatly enhances reproductive success of bass. Large predators dominated the fish community in Upper Spavinaw Lake during early impoundment and in Lower Spavinaw Lake after drawdown. Seasonal changes in water level may simulate the impoundment of new reservoirs by providing conditions that favor more opportunistic species.

Janisch, J. L. 1976. Fish management at Starve Hollow Lake 1970-1975. Indiana Dep. Nat. Resour. 10 pp.

165. Fall drawdowns of Starve Hollow Lake decreased surface area by 50% for 4 months. The creel survey revealed an increase in the average size

of bluegills harvested, though the total numbers caught decreased. Fishing pressure and fishing success decreased. After 5 years of management, growth and condition factors of largemouth bass, bluegills, and channel catfish were better than average growth and condition factors for fish of southern Indiana. Desirable changes in the fish population were attributed to fall drawdowns and a 14-inch length limit for bass. Other management practices included the addition of structure and stocking of channel catfish and northern pike.

Jearld, A., Jr. 1970. Fecundity, food habits, age and growth, length-weight relationships and condition of channel catfish, *Ictalurus punctatus* (Rafinesque), in a 3300-acre turbid Oklahoma reservoir. M. S. Thesis, Oklahoma State Univ., Stillwater, Oklahoma. 78 pp.

166. Various aspects of the life history of the channel catfish in Lake Carl Blackwell, Oklahoma, are discussed. Data are presented on fecundity, food, age and growth, length-weight relation, and condition. Decreased growth during the study coincided with decreasing water levels.

Jenkins, R. M. 1967. The influence of some environmental factors on standing crop and harvest of fishes in U. S. reservoirs. Pages 298-321 *in* Reservoir Committee of the Southern Division. *Reservoir Fishery Resources Symposium*. Am. Fish. Soc., Washington, D. C.

167. Effects of nine environmental factors on standing crop and harvest of sport and commercial fishes in reservoirs were examined by regression. Factors considered were water-level fluctuation, shoreline development, storage ratio, area, mean depth, total dissolved solids, reservoir age, outlet depth, and growing season. As a single variable, water-level fluctuation had no significant effect on standing crop or harvest except in 70, carbonate and bicarbonate chemical-type reservoirs, where water-level fluctuation was negatively correlated with standing crop ($r = -0.225$; Prob $> F = 0.0047$). A multiple regression of commercial harvest on mean depth, water-level fluctuations (vertical), storage ratio (reservoir volume divided by average annual discharge), and growing season (average number of days between the first and last frosts of the year) was significant ($R^2 = 0.48$; Prob $> F = 9 \times 10^{-5}$) and was one of the four most useful equations developed. Sport-fish harvest was directly related to storage ratio, which in turn was inversely related to clupeid standing crop and commercial harvest.

Jenkins, R. M. 1969. Large reservoirs - management possibilities. Proc. Midwest Assoc. Game Fish Comm. 36: 82-89.

168. A number of fishery management practices for reservoirs are discussed, including fishing regulations, stocking, fertilization, optimum timber clearing, draining or population removal, aquatic weed control,

brush shelters, artificial destratification, drawdown, and water-level manipulation. Drawdowns to aerate mud bottoms, to facilitate seeding of herbaceous vegetation and removal of rough fishes, and to concentrate forage should become increasingly useful to managers. Although uncontrolled water-level fluctuation may be harmful to sport fishes, soundly conceived and implemented schemes can be effective. Spring drawdowns are not compatible with spawning requirements of black basses and crappies and have not been consistently successful in controlling spawning of rough fishes. In suitable reservoirs, extreme drawdown followed by planting of herbaceous plants on exposed mud bottoms, refilling, and stocking of desired species is one of the important management tools available to fishery managers today.

Jenkins, R. M. 1970. The influence of engineering design and operation and other environmental factors on reservoir fishery resources. Water Resour. Bull. 6: 110-119.

169. The apparent effect of reservoir environmental variables (i.e., water-level fluctuation, mean depth, outlet depth, thermocline depth, surface area, storage ratio, shoreline development, total dissolved solids, growing season, and reservoir age) on the standing crop of fish in 140 large reservoirs was examined by partial correlation and multiple-regression analyses. Water-level fluctuation had a positive influence on the biomass of spotted gar, flathead catfish, black basses, and white crappies. It had a negative influence on the standing crops of gizzard shad, northern pike, pickerels, carpsuckers, and sunfishes. In reservoirs with a stable thermocline, fluctuation of water levels had a significant positive influence ($P < 0.05$) on the standing crops of largemouth bass and white crappies.

Jenkins, R. M. 1970. Reservoir fish management. Pages 173-182 in N. G. Benson, ed. A Century of Fisheries in North America. Am. Fish. Soc., Spec. Publ. No. 7.

170. Efforts of fishery managers to meet increasing demands for angling on reservoirs are recounted. Drawdowns that reduce surface area by 10 to 80% in the late summer or fall can be effective, especially when combined with fishery improvement techniques such as planting of grasses and removal of rough fishes. Ideally, forage fishes are concentrated for predatory sport fishes as waters recede, and large portions of bottom areas are aereated. Although drawdown to control spawning of common carp and other rough fishes has produced erratic results, drawdown and refilling of reservoirs improves water clarity and fishing success for 1 to 4 years. Pronounced rises in water levels in the spring have been directly correlated with strong year classes of largemouth bass, white bass, and green sunfish and inversely correlated with strong year classes of bluegills and longear sunfish. Winter drawdowns have been effective in reducing populations of shad and small sunfishes.

Short-term (2-3 months) drawdowns seldom produce measurable results. Although uncontrolled water-level fluctuation can be harmful to fish populations, carefully controlled changes in water level can be the most effective management tool available. Heavy growths of aquatic vegetation have been successfully controlled by increased fluctuation of water levels in shallow impoundments in which water levels were stable.

Jenkins, R. M. 1973. Reservoir management prognosis: migraines or miracles. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 27: 374-385.

171. Problems and progress in the management of fisheries in reservoirs of the southern United States are reviewed. Trends in data on the standing crop of fishes in 172 reservoirs are discussed with reference to potential production of sport fishes and to physicochemical variables. Certain management techniques that involve manipulation of controllable environmental factors deserve more emphasis. Deliberate, long-term management of the fluctuation zone of reservoirs is a critical need, and quantitative measurements of natural vegetation in this zone should be made to determine which species of plants provide optimum spawning habitat and cover for desirable sport fishes. Cultivation of seasonally exposed portions of reservoirs should enhance production of sport fish, other factors being equal. Fish attractors and standing timber have helped increase harvest but drawbacks exist (e.g., structures that have deteriorated due to exposure during drawdown must be refurbished).

Jenkins, R. M. and D. I. Morais. 1971. Reservoir sport fishing effort and harvest in relation to environmental variables. Pages 371-384 *in* G. E. Hall, ed. *Reservoir Fisheries and Limnology*. Am. Fish. Soc. Spec. Publ. No. 8.

172. The effect of 10 environmental variables on sport-fish harvest and angler effort were examined by logarithmic partial correlation and multiple-regression analyses. Independent variables included area, mean depth, outlet depth, thermocline depth, water-level fluctuation, storage ratio, shoreline development, total dissolved solids, growing season, and reservoir age. Harvests of black basses and sunfishes were inversely correlated with reservoir age, but the relation was not always obvious in single reservoirs because of occasional strong year classes. Vertical fluctuation of water levels was negatively related to the harvest of bullheads ($P < 0.20$) and white bass ($P < 0.05$).

Jensen, K. W. and P. Aass. 1958. Bottom conditions in regulated lakes. Jeger Fisker (2): 44-45. (In Swedish)

173. Bottom conditions in 11 lakes, impounded for hydroelectric purposes, were studied for many years. Fishing, especially with seines

and bottom nets, was difficult, expensive, and often impossible in impounded lakes, but the effect was modified by time. In Lake Møsvatn, which was impounded in 1906, the dead birch forest first disappeared in the late 1940's, but among bushes and trees, the birch is one of the species that seem to decompose quickest after impoundment. Fir and juniper decompose slowly, in spite of being covered every winter and lying dry every summer. In sheltered areas of Lake Møsvatn, juniper and even heather (Calluna vulgaris) that were killed in 1906 were still a nuisance to the gillnet fishery for trout and char in 1957. (Abstract adapted from Fraser 1972.)

Jeppson, P. 1957. The control of squawfish by use of dynamite, spot treatment, and reduction of lake levels. Prog. Fish-Cult. 19: 168-171.

174. Adequate control of squawfish populations required an understanding of their ecology in each body of water and the successful destruction of adult fish and their young during spawning. Spawning in Hayden Lake occurred on wave-washed rubble from mid-June to mid-July, at depths less than 1 foot. Incubation lasted 7 to 8 days at water temperatures of 60 to 68° F. A slight reduction in lake levels caused mortality by desiccation, and a drawdown of 2 inches per day, for about a month after water temperatures reached 60° F, destroyed nearly all of the squawfish spawn in northern Idaho lakes.

Jester, D. B. 1971. Effects of commercial fishing, species introductions, and drawdown control of fish populations in Elephant Butte Reservoir, New Mexico. Pages 265-285 in G. E. Hall, ed. Reservoir Fisheries and Limnology. Am. Fish. Soc., Spec. Publ. No. 8.

175. From 1963 to 1970, managers implemented programs to harvest rough fish (smallmouth buffalo, common carp, and carpsuckers) commercially, to introduce white bass and walleyes, and to stabilize water levels during the spawning seasons of largemouth bass, white crappies, and black crappies. Larger populations of crappies or largemouth bass did not result from stabilized water levels, perhaps because of predation by flathead catfish. Crappie populations varied with large changes in the volume of water stored, apparently responding to crowding and relief from crowding.

Jester, D. B. and B. L. Jensen. 1972. Life history and ecology of gizzard shad, Dorosoma cepedianum (Le Sueur), with reference to Elephant Butte Lake. New Mexico State Univ. Agr. Exp. Sta. Res. Rep. 218. 56 pp.

176. All aspects of the life history of gizzard shad were examined, and growth was calculated. In 1964, 1968, and 1971, enormous numbers of gizzard shad died after the volume of the reservoir was greatly reduced (from 150,000 to 50,000 acre-feet) in July and August. Shad and many

other fishes apparently died from nitrogen bubbles in their blood, which resulted from the activity of coliform bacteria. The bacterium Aerobacter aerogenes apparently causes gas bubble disease only when fish are subjected to severe environmental stress such as crowding. Mortality was wavelike, proceeding down the reservoir from the upper reaches to the dam.

Johnson, D. L. and R. A. Stein, editors. 1979. Response of fish to habitat structure in standing water. North Central Div., Am. Fish. Soc., Washington, D. C. Spec. Publ. No. 6. 77 pp.

177. Papers in this symposium deal with the effects and importance of structure -- defined as any material or condition which affords fish protection, food, security, or reference points by reducing light or providing a discontinuous substrate -- to fishes in lentic systems. Structure may improve reproduction (by affording more spawning sites), accelerate growth (by increasing fish-food production and decreasing activity of fish), decrease mortality (by providing refuge for small fishes), and increase harvest (by concentrating sport fishes). Changes in the amount and complexity of cover and how these changes influence predator-prey and other important relations that affect sport-fish production and harvest are discussed in several papers. Because changes in the amount and complexity of structure can be controlled to some extent by manipulating water levels in reservoirs, papers in this symposium help to identify some of the ways in which water-level fluctuations influence fish communities.

Johnson, F. H. 1957. Northern pike year-class strength and spring water levels. Trans. Am. Fish. Soc. 86: 285-293.

178. Relations between spring water levels and the year-class strength of northern pike in Ball Lake, Minnesota, were studied from 1945 through 1952. Water conditions were quantified by the height of water during spawning and the amount of fluctuation during egg incubation. Year-class strength was estimated by the number of pike speared during the winter dark-house spearing season. Over the 7-year period, year classes of pike were significantly correlated with water levels that were high in the spring during spawning and that declined only slightly during egg incubation.

Johnson, F. H. 1961. Walleye egg survival during incubation on several types of bottom in Lake Winnibigoshish, Minnesota, and connecting waters. Trans. Am. Fish. Soc. 90: 312-322.

179. Studies of the effects of substrate on the survival of walleye eggs revealed that survival to the eyed stage was greatest on gravel-rubble bottoms (survival averaged 25%). Survival on a muck bottom

was as low as 0.6% percent. Walleyes selected gravel bottoms when available, and most eggs were deposited at depths of 12 to 30 inches. The weak year class of 1958 may have resulted from low spring water levels that eliminated much of the preferred spawning area.

Johnson, F. H., R.D. Thomasson, and B. Caldwell. 1966. Status of the Rainey Lake walleye fishery, 1965. Minnesota Dep. Cons., Div. Game Fish, Res. Planning Invest. Rep. No. 292. 22 pp.

180. The walleye population of Rainey Lake was considerably lower in 1965 than in 1959, and the commercial catch (per 1000 feet of net) was directly correlated with mean water levels during walleye spawning 4, 5, and 6 years earlier. A decrease in walleye stock followed three consecutive years of low spring water levels and poor reproduction. Spring water levels sufficient to inundate the best spawning shoals should be maintained every year.

Johnson, J. N. 1974. The effects of water level fluctuations on the growth, relative abundance, mortality, and standing crop of fishes in Lake Carl Blackwell, Oklahoma. M. S. Thesis, Oklahoma State Univ., Stillwater, Oklahoma. 72 pp.

181. Decreased water levels from 1962 to 1967 were related to reduced growth of white crappies (age I), channel catfish (I, II, VI), and common carp (I and III). Increased growth of yearling and older white crappie probably resulted from increased availability of prey immediately after drawdown. Production of the littoral zone apparently was poor after drawdown, and this may have contributed to slow growth of young common carp. Improved growth of most yearling and older channel catfish and common carp was attributed to drawdown which supposedly concentrated prey and thereby made them more accessible to predators. Decreased abundance of channel catfish, river carpsucker, and largemouth bass probably resulted from poor reproductive success due to fluctuation of water level during spawning seasons. Reduced populations of gizzard shad suggested that receding water levels increased vulnerability of shad to predators.

Johnson, J. N. and A. K. Andrews. 1973. Growth of white crappie and channel catfish in relation to variations in mean annual water level of Lake Carl Blackwell, Oklahoma. Proc. Annu. Conf. Southeast. Assoc. Fish Game Comm. 27: 767-776.

182. A causal relation between water levels and the growth of crappies from 1962 to 1971 is documented. Decreased growth of yearling crappies between 1966 and 1971 may have resulted from reduced production of benthos in the littoral zone as water levels receded. Increased growth of yearling and adult crappies in the 1960's may have resulted from

increased availability of prey fishes during and immediately after decreases in water level. Growth of channel catfish was not significantly correlated with mean water levels, but significant negative correlations were found between growth increments and mean water levels for 2-, 3-, and 6-year-old flathead catfish. Declining water levels reduced intra- and interspecific competition among young fishes by increasing predatory mortality of young catfish, and by decreasing spawning success.

Johnson, W. L. 1944. Limnological studies of a new artificial lake in southwestern Indiana. Ph.D. Thesis, Univ. of Indiana, Indianapolis, Indiana. 48 pp.

183. Draining of Greenwood Lake, Indiana, to a very low level in 1940 directly or indirectly caused the failure of the 1940 year class of black crappies and white crappies. The period of refilling in 1941 and 1942 was not favorable for growth. In fact, the drawdown period of 1940 probably was better for growth than the refilling period. Growth of crappies was greatly retarded after July 1940 through the fall due to crowding and perhaps accumulations of metabolic wastes. Poor growing conditions during reflooding of the reservoir probably resulted from poor production of fish-food organisms in Greenwood Lake.

Jones, W. E. and J. H. Selgeby. 1974. Invertebrate macrobenthos of Lake Oahe, 1968-69. U. S. Fish Wildl. Serv., Tech. Pap. No. 73, 11 pp.

184. The early faunal composition of benthos in Lake Oahe is described on the basis of 450 samples. Chironomids and oligochaetes predominated, numerically and gravimetrically. Greater abundance and biomass in certain areas (Moreau River Embayment) were attributed to large amounts of terrestrial vegetation that had recently been inundated.

Judd, J. B. and S. H. Taub. 1973. The effects of ecological changes on Buckeye Lake, Ohio, with emphasis on largemouth bass and aquatic vascular plants. Ohio Biol. Surv., Biol. Notes No. 6. 50 pp.

185. Buckeye Lake, Ohio, had fewer but larger largemouth bass in 1970 than it did in previous years, and the growth of bass was improved. Changes in the bass population resulted from ecological changes in the artificial lake after 1947. Clearing of the bottom and a decrease in the extent and number of aquatic macrophytes reduced the carrying capacity of the lake for largemouth bass. Before 1926, macrophytes expanded their range in the lake from late summer through November each year as the lake level was reduced. This annual expansion of vegetation ceased after 1926, because water levels were maintained at stable levels through November. Turbidity was increased as a result of decreased aquatic vegetation, clearing of the bottom, increased wave action, and increased plankton abundance.

June, F. C. 1970. Atresia and year-class abundance of northern pike, Esox lucius, in two Missouri River impoundments. J. Fish. Res. Board Can. 27: 587-591.

186. Atresia or intraovarian degeneration of eggs in northern pike was associated with low abundance of young-of-year and yearling pike in 1966-68. The high incidence of atresia in ovaries probably resulted from spawning interruptions that were associated with fluctuations in water level or temperature. Sudden lowering of water levels occasionally reduced the number of gravid females in spawning areas or prevented them from returning to spawning sites. A 1-m drop in water level in 6 hours apparently reduced the percentage of females with normal ovaries from 94 to 28.

June, F. C. 1974. Ecological changes during the transitional years of final filling and full impoundment (1966-70) of Lake Oahe, an upper Missouri River storage reservoir. U. S. Fish Wildl. Serv., Tech. Pap. No. 71. 57 pp.

187. Baseline data on the physicochemical limnology and plankton dynamics of Lake Oahe during filling of the reservoir is presented. Waters reached operational levels by 1967 and fluctuated an average of 3.9 m annually. Multivariate analyses indicated that zooplankton abundance at lower reservoir stations was inversely related to summer discharge of water. The inverse relation may have resulted from loss of zooplankton or food of zooplankton through the dam. Water temperature and turbidity also were important factors affecting zooplankton abundance, and both water temperature and turbidity may be controlled occasionally by rates of water release.

June, F. C. 1976. Changes of young-of-the-year fish stocks during and after filling of Lake Oahe, an upper Missouri River storage reservoir, 1966-74. U. S. Fish Wildl. Serv., Tech. Pap. No. 87. 25 pp.

188. Trawling samples of young-of-year fishes in Lake Oahe showed that the abundance of most species increased while the reservoir was filling (yellow perch and emerald shiners were most abundant) but later declined. Abundance was especially high when water covered vegetation in spring and was maintained at stable levels through May or longer. After the reservoir was filled, littoral spawning and nursery habitats were degraded and reduced. As a result, the abundance of young-of-year fish decreased. Large populations of species favored by inundation are not likely to be produced under the regime of water-level fluctuation of the mid 1970's, but favorable spawning and nursery conditions (such as freshly flooded grass areas) will probably lead to the formation of occasional strong year classes.

Kadlec, J. A. 1960. The effect of a drawdown on the ecology of a waterfowl impoundment. Michigan Dep. Conserv., Game Div. Rep. No. 2276. 181 pp.

189. Ecological effects of drawdown on Backus Lake were studied in three phases -- pre-drawdown in the summers of 1956 and 1957, drawdown (4 feet) during the summer of 1958, and post-drawdown in 1959. Effects of drawdown on soil, water, vegetation, invertebrates, and waterfowl were evaluated. Soil and water studies showed a definite increase in nutrient concentrations in the water during drawdown. Soil nitrates also increased during drawdown due to aerobic nitrification, and high concentrations persisted until the spring of the first year of reflooding. Although the response of other nutrients was less obvious, solubility and plant growth did increase. Most nutrient changes diminished after reflooding for 1 year. Invertebrate populations were considerably reduced by reflooding. Many submerged and floating-leaf plants were reduced in number during the first year of reflooding, except for waterlilies, smartweed, and bushy pondweed. Emergent vegetation spread and increased in abundance as a result of drawdown. Populations of breeding waterfowl did not change greatly during the study. Use of drawdown and its effectiveness as a management technique for marshes is discussed.

Kaster, J. L. and G. Z. Jacobi. 1978. Benthic macroinvertebrates of a fluctuating reservoir. Freshwater Biol. 8: 283-290.

190. Benthic macroinvertebrate distribution, abundance, and composition were studied in a fluctuating (7.7 m) central Wisconsin reservoir during 1973-74. Chironomids and oligochaetes made up 98% of the total fauna by number. Mean annual biomass (g m^{-2}) in areas exposed to air, exposed to ice cover, and remaining inundated were 1.8, 4.5, and 16.0, respectively. A substantial portion of the benthic fauna was stranded and died rapidly in drying and frozen substrates exposed to air. Total benthic numbers and biomass were greatest immediately below the drawdown limit.

Keith, W. E. 1967. Turbidity control and fish population renovation on Blue Mountain Lake, Arkansas. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 21: 495-505.

191. Blue Mountain Reservoir, which was plagued with high turbidity and an over-abundance of rough fishes 4-5 years after impoundment, was treated by fall-winter drawdowns, shad kills, removal of commercial fishes, and planting of rye grasses. Although these measures reduced the turbidity and improved fish populations, the benefits were short-lived. In 1965, treatments included drawdown; seeding of sorghum, sudan, and a sudan-sorghum hybrid; a rotenone kill of 95% of the fish; and restocking with selected game fishes. After the lake was refilled in 1966, waters remained relatively clear (12-14 inches visibility) except

during floods. During early 1967, sport fishing was excellent. Population sampling of a cove with rotenone indicated larger numbers of crappies, channel catfish, freshwater drum, and shad. Crappies, white bass, buffaloes, common carp, freshwater drum, and shad exhibited increased rates of growth.

Keith, W. E. 1974. Management by water level manipulation. Arkansas Game Fish Comm. 25 pp.

192. Fish populations respond to water-level changes in a predictable way, whether fluctuations are natural (due to variation in runoff) or artificial (created by dams, diversions, or some other structure). Effects are most pronounced in impounded waters or low-water streams where vast flat areas (flood plains) are inundated during high water. Simulating natural seasonal and annual cycles of increasing and decreasing water levels is an effective way to optimize black bass production and manage fisheries in general. Water-level controls are most feasible on impounded waters. In the southern United States, the largemouth bass is the principal bass affected by this technique. Increased water levels just before, during, and for a short time after spawning increase the amount of desirable habitat for nearshore fishes and improve the productivity of impoundments. High water levels enhance spawning success, survival, growth, and recruitment. Controlled drawdowns can restrain the spread of nuisance aquatic vegetation, increase predator use of prey fishes, and accelerate nutrient recycling from bottom muds. Severe manipulation of water levels often conflicts with primary uses such as power generation or flood control. For many impoundments, the needs for different interests should be reevaluated periodically.

Keith, W. E. 1975. Management by water level manipulation. Pages 489-497 *in* H. Clepper, ed. *Black Bass Biology and Management*. Sport Fishing Inst., Washington, D. C.

193. Significant increases in water level above normal elevations (1) flood terrestrial vegetation, which decays and releases nutrients that heighten overall productivity, (2) increase the availability of terrestrial fish-food organisms (e.g., insects and earthworms), (3) create excellent cover and desirable habitat for shoreline dwelling fishes, and (4) stimulate the natural reproduction and growth of fishes, ultimately leading to the production of a strong year-class. Flooding of herbaceous vegetation also precipitates colloidal particles and reduces turbidity. In Bull Shoals Lake, Arkansas, strong year classes of largemouth bass, as indicated by abundance of young-of-year collected in August (1954-74), were highly correlated with high water levels in the spring of the same year. Spawning and survival of forage fishes were also enhanced in years when water was high during the spring. As a result, young bass grew rapidly. Decreased water levels hinder or disrupt spawning and decrease the abundance of fish-food organisms.

Nevertheless, planned and controlled drawdowns can help managers regulate aquatic vegetation and the number and spawning of rough fishes. Forage fish are forced from protective cover, thereby increasing their availability to predators. Numbers of stunted sunfish are reduced, and growth of harvestable-sized predators is improved. Aerated soils release nutrients upon reflooding, and bottom muds are usually consolidated. Refilling of a lake in the spring after a drawdown usually results in excellent reproduction by black basses.

Kimsey, J. B. 1958. Fisheries problems in impounded waters of California and the lower Colorado River. Trans. Am. Fish.Soc. 87: 319-332.

194. Problems in and management of reservoirs in the western U. S. are discussed. In general, fish-food production in the littoral zone of impoundments is poor due to water-level fluctuations. Water-diversion or irrigation reservoirs like Lake Havasu usually have severe drawdowns during the growing season, which greatly limit fish production and reduce or eliminate aquatic plants. Large irrigation impoundments, such as Millerton Lake, usually fill in the spring (at least until June), lose water through July or August, and reach their lowest elevations in the fall. These annual fluctuations of up to 140 feet create a very unstable and sterile littoral zone after a few years. Although most reservoirs have poor benthos development and sunfish are stunted, plankton development is good in open water. The decline in fisheries after an initial productive period of 2 to 5 years probably results from a loss of fertility (nutrients, vegetation, and detritus) inherent to new basins. After the initial phase, fish production depends mainly on the fertility of the watershed and basin. Most management practices are based on attempts to modify the decline of the fishery and maintain its quality as close as possible to that present during early impoundment. One technique suggested involves the establishment of a ground cover that perpetuates itself in the fluctuation zone, even though it may be submerged for considerable periods. Mats made of Bermuda or similar grasses provide a good substrate for benthos and release nutrients into the water.

Kirkland, L. 1963. Results of a tagging study on the spotted bass, Micropterus punctulatus. Proc. Annu. Conf. Southeast. Assoc. Game Fish. Comm. 17: 242-255.

195. The spotted bass fishery of Allatoona Reservoir, Georgia, is described on the basis of tag returns and a creel census. Factors affecting the capture rate of bass included season, surface temperature, water level, turbidity, and fishing pressure. Effects of turbidity and water levels were difficult to separate, because turbidity was closely related to water level. A flood in mid-April greatly reduced the catch of spotted bass and fewer tags were returned in this period. The fact that small or slow changes in water level did not appear to affect the

catch rate suggests that increased turbidity was more important than water level.

Kononov, V. A., N. S. Menyuh, and A. M. Paradnikov. 1966. The Dnieper Reservoir. Pages 42-55 in P. V. Tyurin, ed. The Storage Lakes of the U.S.S.R. and Their Importance for Fishery. (Transl. from Russian) Israel Program Sci. Transl. Cat. No. 1638-50. U. S. Dep. Commerce.

196. Aspects of the hydrology, morphometry, chemistry, and biology of the Dnieper Reservoir are discussed. Water levels fluctuate sharply during spring floods in some sections of the reservoir, depending on the floodplain altitude, flood volumes, and daily rates of water discharge. For example, in the upper reaches, the water level fell 70 cm in 9 days and the spawning grounds and eggs of many fishes were left exposed to the air. The constantly changing shoreline in this reservoir prevents the formation of natural spawning grounds. Sharp daily fluctuations of water level, combined with the dense growth of hard vegetation, make the shallow Samara branch unsuitable for spawning. Control of water levels on a daily basis is one of the measures needed to increase the yield of fish.

Koshov, M. M., and N. V. Tyumentsev. 1961. The biological consequences of fluctuations in the level of lake Baikal. Biull. Moskov OBshcestva Ispyt. Spytatelei Prirody Otdel Biol. 66: 32-39. (In Russian)

197. After the Irkutsk hydroelectric station was constructed on the Angara River, Lake Baikal became a reservoir. High water levels increased the shallow littoral area and enhanced the reproduction of fish that spawn in tributary streams. Reproduction of fish was impaired in years of low water levels, and the fishing economy was severely damaged when water levels were decreased from 0.6 to 1.0 m for several years. A 0.6- to 1.0-m reduction in water level decreased littoral area by more than 20,000 ha. The best fishing was obtained when the amplitude of fluctuations did not exceed 2 m for a long time. Periodic flooding and drying of soils resulting from 3- to 5-m fluctuations will seriously damage industrial fishing.

Kushlan, J. A. 1976. Environmental stability and species diversity. Ecology 57: 821-825.

198. On marshes of the Everglades, drastic seasonal fluctuation of water level is the most important factor affecting fish. By May, water levels often recede to the extent that most surface water disappears and only localized pools remain. Although the density of fish decreased during 27 months of high stable water level, the biomass, average size, and diversity of fish increased. Populations of small omnivorous fishes were reduced, and populations of larger piscivores (especially centrarchids) increased because of immigration of piscivores from other areas.

Under stable water levels, predation assumes the major role in restructuring the fish community. Fish communities of Everglades' marshes are dominated by small omnivores during low water, when habitat is limiting, and by large predators during periods of high water.

Kuznetsov, V. A. 1971. The effects of regulated Volga flow on the reproduction of asp, blue bream, white bream, and bleak in the Sviyazh Bay of the Kuibyshev Reservoir. Vopr. ikhtiol. 11: 232-239. (In Russian)

199. Construction of the Kuibyshev Reservoir led to significant changes in the hydrology of the middle Volga. To determine the effects of the reservoir on fish, the reproduction of several species was studied during a 7-year period (1963-69) at Sviyazh Bay. The best adaptability in terms of reproduction was shown by asp and bleak which began to deposit eggs on rocky regions, plants, and submerged roots. In addition, bleak began to spawn at greater depths. Populations of asp and bleak remained relatively high. Blue bream adapted fairly well to the new habitat conditions and started to deposit eggs in river-bank regions that were rich in plant life and well protected from winds. However, in years of low water, many eggs died, and the abundance of blue bream dropped sharply. White bream began to deposit eggs close to banks when waters began to rise (end of May to beginning of June) and thereby exhibited greater adaptability to changing water levels than did the blue bream. (From Biol. Abstr. 54: 36435.)

Kuznetsov, V. A. and N. I. Fadeev. 1979. Some characteristics of fish reproduction in parts of the Volga, U.S.S.R., before and after current regulation. Vopr. ikhtiol. 19: 93-102. (In Russian)

200. Condition of Kuibyshev Reservoir was studied in relation to water volume. In years when the reservoir was full and water levels relatively stable, reproduction was more successful in the reservoir than in the river. In years when spring water levels in the river were high, but levels in the reservoir varied, reproduction was more successful in the river than in the reservoir. (From Biol. Abstr. 69: 63561.)

Lambou, V. W. 1959. Fish populations of backwater lakes in Louisiana. Trans. Am. Fish. Soc. 88: 7-15.

201. Standing crops, predator-prey relations, and the effects of overflow are discussed. Alternate flooding and exposure of land has important effects on fish populations. Floods during the spawning season induce the production of large numbers of young-of-year fishes such as largemouth bass. Flooding presumably reduces competition for food, space, and spawning territory within and among species. The whole fish community expands in numbers and weight. Conversely, when waters are lowered, available food and habitat become limiting, although backwater lakes usually support large standing crops even during periods of low water.

Fish in these lakes usually are in good condition and sport fishing remains of high quality even during low water. Fish of backwater lakes are considered fluctuating populations that are regulated by flooding and dewatering.

Lantz, K. E. 1974. Natural and controlled water level fluctuations in a backwater lake and three Louisiana impoundments. Louisiana Wildl. Fish. Comm., Fish. Bull. No. 11. 36 pp.

202. Changes in fish populations, aquatic vegetation, fish-food organisms, and physiocochemical variables were assessed to evaluate the effectiveness of water-level manipulation as a management tool in shallow bodies of water. Control of aquatic macrophytes usually required drawdown each year for 2 or 3 years, but the responses of plants varied among species. Water-level fluctations in the three reservoirs resulted in a gradual increase in total standing crop per acre and rapid increases in the numbers of harvestable sized sport fish and in sport-fish reproduction during the first 2 or 3 years of management. However, increases in standing crop (total and sport fish) and reproduction diminished after 4 or 5 consecutive years of treatment.

Lantz, K. E. 1978. Largemouth bass studies in Toledo Bend Reservoir. Louisiana Dep. Wildl. Fish., Fed. Aid Proj. F-28-R. 15 pp.

203. Spawning success and survival of young-of-year largemouth bass was evaluated for three years on Toledo Bend Reservoir, Louisiana and Texas. Rapid lowering of water levels in March and April of 1975 and 1976 reduced spawning success, and poor year classes developed subsequently. In 1977, waters rose gradually throughout the spring, creating ideal spawning conditions for largemouth bass. A strong year class developed in 1977.

Lantz, K. E., J. T. Davis, J. S. Hughes, and H. E. Schafer, Jr. 1964. Water level fluctuation - its effect on vegetation control and fish population management. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 18: 483-494.

204. Three Louisiana Lakes (Anacoco, Bussey, and Lafourche) are used as examples of water-level manipulation as a management practice. The effects of drawdown were evaluated by comparing pre- and post-drawdown standing crops of fish as estimated by rotenone sampling of enclosed 1-acre areas. A creel census also was conducted on two of the lakes (Bussey and Lafourche). Drawdowns in all three lakes were extremely effective in controlling aquatic vegetation. For example, the drawdown of Lake Anacoco reduced the surface area covered by aquatic macrophytes from 40 to 5%; in Bussey Lake, the reduction was from 32.0 to 1.4% in 1 year. Drawdown increased the standing crop and numbers of fish of

harvestable size, while reducing the biomass of intermediate sized fish (especially sunfishes) in Anacoco Lake. Similar results were observed in Bussey Lake, but the fish population changed somewhat (i.e., intermediate sized shad were severely reduced and in the following year were replaced by an enormous abundance of fingerlings). The slow refilling of Bussey Lake hindered the spawning of the black basses and crappies that year. In Lafourche Lake, drawdown rapidly increased the numbers of harvestable sized predatory and nonpredatory game fish and decreased the number of intermediate sized fish. However, because the water levels did not return to normal pool, spawning of predatory game fish failed for 2 consecutive years. The total harvest of fish from Bussey Lake increased in 1 year, though the catch in pounds per hour decreased. In Lafourche Lake, the harvest of fish decreased slightly after drawdown, perhaps due to the slow rate of refilling.

Lapitskii, I. I. 1966. The Tsimlyanskoe Reservoir. Pages 13-29 in P. V. Tyurin, ed. The Storage Lakes of the U.S.S.R. and Their Importance for Fishery. (Transl. from Russian) Israel Program Sci. Transl. Cat. No. 1638-50. U. S. Dep. Commerce.

205. Fluctuation of water level and its effect on reservoir biota are among the many physical, chemical, and biological features of the reservoir that are discussed. Annual fluctuations in water level (up to 6.1 m) inhibit the development of aquatic vegetation which in turn hinders the spawning of phytophilous fishes. When the water level declines below elevation 31.0 m, a winter kill of fish (primarily common carp) normally occurs in the upper portion of the reservoir, and the standing crop of benthos is severely reduced. During the first year after the reservoir was filled, fish of all species grew rapidly and attained sexual maturity at a younger age than usual. Growth decreased in the following years except for that of blue bream.

Lewis, G. and D. Robinson. 1967. Drawdowns for species control. West Virginia Dep. Nat. Resour., Div. Game Fish., Fed. Aid Proj. F-10-R-8/9. Job III - 3. 6 pp.

206. Baker Lake (4 acres) and Warden Lake (36 acres) were drawn down in the fall of 1964 and 1965. Population estimates from rotenone samples in 1965 showed that the number of fingerling and intermediate sized fish increased after the first drawdown in both lakes. Numbers and weight of harvestable fish increased in Baker Lake, but no fish of harvestable size were taken from Warden Lake. In 1966, the number and weight of all sizes of fish in both lakes decreased. The second drawdown (fall 1965) may not have been effective in enhancing fish populations; however, the accuracy of the estimates based on the rotenone samples of 1966 was questionable.

Lewis, W. M. 1967. Predation as a factor in fish populations. Pages 386-390 in Reservoir Committee of the Southern Division. Reservoir Fishery Resources Symposium, Am. Fish Soc., Washington, D. C.

207. Findings concerning the vulnerability of different prey species to predation and the implications of their vulnerability to the management and production of sport fishes are discussed. Food consumption by sport fishes is believed to be limited to a maintenance level by the availability of highly vulnerable foods. As a result, the production of important sport fishes potentially can be improved by increasing the amount of highly vulnerable prey. New reservoirs presumably contain many species of forage that are exceptionally vulnerable, but which are eliminated or reduced to low levels by predation. Less vulnerable forage species such as bluegills become abundant as reservoirs age, and consequently, bass production declines. The success of drawdowns is probably related to increased vulnerability of forage fish.

Lindstroem, T. 1962. Life history of whitefish young (Coregonus) in two lake reservoirs, Rep. Inst. Freshwater Res. Drottningholm 44: 113-144.

208. Primary topics of this paper include life history events of young whitefish in reservoirs, but some discussion of lake regulation and water-level fluctuation is mentioned. With the exception of slightly accelerated growth of young in Lake Storavan after raised water levels in 1968, little evidence was obtained to indicate any effect of altered water levels on growth. Findings of other researchers who have worked on impounded natural lakes are discussed in relation to life history events of young whitefish and to the effects of water levels.

Lötmarker, T. 1964. Studies on planktonic crustacea in thirteen lakes in northern Sweden. Rep. Inst. Freshwater Res. Drottningholm 45: 113-189.

209. Zooplankton densities in six regulated and seven unregulated natural lakes in Sweden were not significantly different, but there was a trend toward reduced abundance of zooplankters in lakes with whitefish (a planktivore). Regulation did seem to reduce numbers of Daphnia longispina hyalina and Bosmina coregoni. In newly impounded lakes, zooplankton production may be increased because of increased phytoplankton production and the addition of nutrients from flooded areas. In older regulated lakes, as in this study, zooplankton densities return to pre-impoundment levels.

Lukin, A. V. and K. M. Kurbangalieva. 1965. The Sviyaga inlet of the Kuibyshev Reservoir and its role in fish production. Pages 3-30 in Results of Large Scale Observations on the Sviyaga Bay Fauna of the Kuibyshev Reservoir During the Period of Its Formation. Kazan, Kazansk Univ. (In Russian)

210. Before regulation of the Volga flow, the estuarine section of the Sviyaga River was very important to sturgeon, sterlet, asp, and "undermouth" (Chondrostroma nasus) and was distinguished by an abundant food supply. By 1965, the Sviyaga inlet was a shallow body of water with a depth of up to 3 m. Water level, which had been falling since 1957-58, was very low in spring, dewatering and drying a large area each year and adversely affecting the natural productivity of fish that spawn in shallow water. Spawning success of bream (Abramis) and yellow perch was largely conditioned by the presence of a high concentration of young of different sizes, which led to cannibalism. Lower water levels also severely reduced the production of roach (Rutilus) and stint (Osmerus). Roach and yellow perch have acclimated to open parts of the reservoir. (From Referat. Zhur. Biol., 1966, No. 2I186; Biol. Abstr. 48: 52909.)

Makhoton, Yu. M. 1977. Effectiveness of fish spawning in Kuibyshev Reservoir and factors determining it. Vopr. ikhtiol. 17: 27-38. (In Russian)

211. Studies were conducted from 1960 to 1972 on the success of fish reproduction in the Kuibyshev Reservoir. The principal cause of lower-than-projected fish catches for the Reservoir was the absence of necessary conditions for reproduction of most of the commercial fishes. The effect of different environmental factors varied, but water level was a major determinant of fish productivity. Special measures were considered necessary to increase commercial fish catches in the Reservoir. (From Biol. Abstr. 65: 45143.)

Markosyan, A. K. 1969. Benthic productivity of Lake Sevan. Pages 146-152 in B. Golek, ed. Trans. 6th Conf. Biol. Inland Waters (10-19 June 1957). (Transl. from Russian) Israel Program Sci. Transl., Cat. No. 5136. U. S. Dep. Commerce.

212. Lowering of water levels of Lake Sevan by more than 10 m exposed more than 85 km^2 of bottom area and greatly altered the hydrochemical regime and biology of the largest mountain lake in the U.S.S.R. Before water levels were lowered, the lake bottom consisted of a stony gravel littoral zone (to 2 or 3 m); a zone of sand, moss, and Chara; and a deeper zone of mud. Benthos of the littoral zone was most diverse and supported a good trout fishery before water levels were reduced. Reduced water levels exposed most of the stony littoral zone, and, because mud sediment then extended to the water's edge, sediments were suspended by wave action, and turbidity increased greatly. The oxygen

content of the water was reduced 10-20%; certain bacteria and phytoplankton populations increased exponentially; and zooplankton biomass in July increased from 0.77 g/m^3 in 1947 to 1.36 g/m^3 in 1956. The solid belt of moss and Chara at depths between 7 and 15 m was reduced to isolated patches. Total benthic biomass (metric tons) increased from 6150, before water levels were lowered, to 40,500 afterwards. Increases in the 10- to 40-m zone were due to increased abundance of chironomids and oligochaetes. The biomass in the 0- to 10-m zone decreased somewhat because the biomass of gammarids was reduced 23%. Because gammarids composed 90% of the trout food, the increase in benthic biomass (mostly inaccessable chironomids and oligochaetes) probably did not result in a more productive fishery.

Martin, N. V. 1955. The effect of drawdowns on lake trout reproduction and the use of artificial spawning beds. Trans. North Am. Wildl. Conf. 20: 263-271.

213. Studies of the effects of drawdowns on lake trout reproduction in three Ontario lakes showed that reduced water levels during spawning in October stranded eggs and larval fish. Reduced water levels before spawning were unfavorable, because fewer spawning sites were available and trout were forced to spawn in less desirable areas, where egg mortality was high (due to predation by bullheads and natural causes). Artificial spawning beds, installed to help alleviate problems associated with water-level fluctuation, were only marginally successful. Only one of three artificial beds constructed on Lake Shirley was used by lake trout for spawning. This bed was positioned near a previous spawning ground -- which suggests that lake trout may require some kind of stimulus to initiate spawning, such as familiarity with the area or an odor.

Martin, N. V. 1957. Reproduction of lake trout in Algonquin Park, Ontario. Trans. Am. Fish. Soc. 86: 231-244.

214. The spawning grounds and reproduction of lake trout (e.g., behavior, sex ratios, egg distribution, incubation, and hatching) are described and major causes of egg loss such as fungus infection, predation, and water-level fluctuation, are identified. Some loss of eggs was observed because of drawdown in the late fall and winter when spawning occurs. In lakes Shirley and Hays, drawdowns exposed considerable areas (up to 200 square yards in Lake Shirley) of potential spawning ground before the spawning season.

Martin, R. G. and R. S. Campbell. 1953. The small fishes of the Black River and Clearwater Lake, Missouri. Pages 45-66 in The Black River Studies. Univ. of Missouri Studies, Columbia, Missouri.

215. Small fishes of the Black River were sampled by seining before the formation of Clearwater Lake. Effects of impoundment on the fish fauna were studied in detail. Environmental conditions in the new reservoir were judged to be highly favorable for successful spawning and high survival of fry. Food in the form of drowned terrestrial invertebrates and benthos was abundant, cover and space were plentiful, and predation was low. Water-level fluctuations affected the abundance of different fish species during the spawning period. Largemouth bass, white crappies, and gizzard shad increased in abundance after the spring of 1950, when water levels were high but relatively stable. In June and most of July, water levels dropped almost 1 foot per day and may have reduced the overall abundance of bluegills and longear sunfish, and bluntnose minnows.

Martin, R. G., N. S. Prosser, and R. H. Stroud. 1978. Evaluation of planning for fish and wildlife: Carlyle Lake Project. U. S. Army Corps of Engineers, Washington, D. C. 103 pp.

216. Predicted value of the post-impoundment sport fishery was extremely low, partly because of expected fluctuations of water level. By 1977, pool fluctuation during the spring spawning period was identified by the Corps of Engineers as the primary factor limiting fish populations, particularly those of black bass and sunfish.

Martin, R. G., N. S. Prosser, and R. H. Stroud. 1979. Evaluation of planning for fish and wildlife: Keystone Lake Project. U. S. Army Corps of Engineers, Washington, D. C. 107 pp.

217. Recommendations pertinent to wildlife resources made in 1961 by the U. S. Fish and Wildlife Service are evaluated. Reservoir water-level fluctuations substantially reduced waterfowl foods such as smartweed and millet, and prolonged floods 9 years after impoundment eliminated green trees at the margin of the reservoir. Pool fluctuations adversely affected largemouth bass. Bass production was greatest in seasons when water levels were relatively stable.

Mathur, D. and T. W. Robbins. 1979. Food of the white crappie, Pomoxis annularis Rafinesque, in two new impoundments. Proc. Pennsylvania Acad. Sci. 53: 34/36.

218. Diets of white crappies in two new impoundments (Muddy Run Lake and an adjacent pumped-storage pond) differed significantly. Large white crappies ate more fish than plankton in the lake, but in the pond the

plankton feeding phase of crappies was prolonged and few fish were eaten. Because water levels of Muddy Run Lake remained stable, forage fish reproduced adequately and were abundant and available to crappies. In contrast, water levels of the pumped-storage pond fluctuated widely and limited forage-fish reproduction. Apparently white crappies are opportunistic feeders, eating the most abundant and available foods.

Mauck, P. E. 1970. Food habits, length-weight relationships, age and growth, gonadal-body weight relationships, and condition of carp, Cyprinus carpio (Linnaeus), in Lake Carl Blackwell, Oklahoma. M. S. Thesis, Oklahoma State Univ., Stillwater, Oklahoma. 73 pp.

219. Life-history and growth information on common carp is presented and discussed to provide fishery managers with knowledge pertinent to managing a reservoir with a large population of common carp. Growth of yearling common carp was not affected by prolonged drought, but growth increased significantly over previous years when lake levels increased.

Mayhew, J. 1977. The effects of flood management regimes on larval fish and fish food organisms at Lake Rathbun. Iowa Cons. Comm., Fish. Sect., Tech. Ser. 77-2. 46 pp.

220. Regression analyses revealed three significant relations as follows: (1) flushing rate explained 77% of the variability in the density of young-of-year gizzard shad; (2) flushing rate explained 94% of the variation in copepod density; and (3) water temperature explained 74% of the variation in copepod density. Flushing rate and temperature were significantly correlated, but the effect of flushing rate on copepod density probably was greater than that of temperature, inasmuch as water temperature was affected by flushing rate. Data strongly suggest that the relation between flushing rate and gizzard shad abundance controls the most important path of energy flow and that zooplankton density is influenced by shad abundance. Growth of shad is density dependent. Thus, by manipulating flushing rates to increase shad density it may be possible to increase the length of the period when young-of-year shad are vulnerable to predators. The ideal water-retension time is about one year for Lake Rathbun.

McAfee, M. 1977. Effects of water drawdown on the fauna in small coldwater reservoirs. J. Colorado-Wyoming Acad. Sci. 9: 9-10. (Abstr.)

221. Effects of drawdown on primary production, invertebrate abundance, and fish abundance and condition was examined by comparing two coldwater reservoirs with stable water levels with two other coldwater reservoirs where water levels were drawn down. Primary production was low in all impoundments and varied only slightly among them. Densities of invertebrates were relatively high in one stable and one drawdown

reservoir, as were fish densities and condition factors. Drawdown either had no demonstrable effects on reservoir biota or the effects were small in relation to differences in reservoir productivity, as determined by other variables (e.g., drainage area or water chemistry).

McCammon, G. W. and C. von Geldern, Jr. 1979. Predator-prey systems in large reservoirs. Pages 431-442 in H. Clepper, ed. Predator-Prey Systems in Fisheries Management. Sport Fishing Inst., Washington, D.C.

222. Although the potential for increasing yields of fish from cold-water reservoirs is low, possibilities are good for improving fisheries in existing warmwater reservoirs by developing techniques for manipulating relations between predator and prey fishes. The authors review findings about some of the most promising techniques for managing predator-prey relations of reservoir fishes. Literature is cited to establish the importance of high and stable water levels for improving spawning success of sport fishes and increasing survival of young-of-year bass. Planting vegetation in the fluctuation zone can also enhance reproductive success of largemouth bass by providing cover when vegetation is flooded. Juvenile bass were six times more abundant in flooded beds of ladysthumb than in unvegetated areas of Millerton Lake. "Wattling" experiments (burying cigar-shaped bundles of willows in rows parallel to shorelines) were successful in protecting bass from adverse wave action and soil erosion. After inundation, willow slips sprout and create a shield. Drastic drawdowns during late summer, fall, and winter at intervals of 5 to 10 years should increase predator use of available prey.

McCarraher, D. B. 1959. The northern pike-bluegill combination in north central Nebraska farm ponds. Prog. Fish-Cult. 21: 188-189.

223. Quality pike fishing was produced in two farm ponds by stocking northern pike and bluegills. Summer drawdown of 4 to 8 feet impaired neither the recruitment of bluegills nor the food habits or growth of pike.

McClendon, E. W. 1976. Conflicts and capabilities associated with regulating the Missouri River main stem reservoir system to enchance the fishery resource. Pages 148-157 in J. F. Osborn and C. H. Allman, eds. Instream Flow Needs, Volume II. Western Div., Am. Fish. Soc., Bethesda, Maryland.

224. Six major reservoirs on the Missouri River have been operated for over 20 years for flood control, power generation, navigation, irrigation, water supply, water quality control, recreation, and fish and wildlife. During the filling of most of the reservoirs, operations were of little consequence to the fishery, as new areas of vegetation

were being inundated each year, and reproduction and survival were excellent for most important fish species. After 1967, however, when all impoundments reached capacity, special operations required to enhance fisheries often conflicted with primary uses (e.g., power, flood control, or irrigation). Special operations that relate to water levels include scheduling releases to (1) raise water levels and inundate vegetated areas in the spring, (2) dewater areas to permit the growth of vegetation for future inundation, and (3) maintain steady or rising waters from early spring to early summer to enhance fish reproduction. By scheduling releases of the larger upstream storage reservoirs, normal fluctuations in water level in lower impoundments were successfully altered in many years to inundate terrestrial vegetation in the early spring (instead of mid-summer) to provide suitable spawning habitat for northern pike. Because this technique requires two years (one to allow vegetation to develop and one year for spawning) and sometimes fails to produce successful year classes of pike, emphasis has been shifted toward management to enhance spawning of forage fishes. Successful spawning of forage fishes results when water levels rise from early spring through early summer.

McLachlan, A. J. 1970. Some effects of annual fluctuations in water level on the larval chironomid communities of Lake Kariba. J. Anim. Ecol. 39: 79-90.

225. The influence of water-level fluctuation on the larval chironomid community of Lake Kariba, Africa, was studied on gradually sloping shorelines. During periods of stable water levels, densities peaked in the shallows and diminished rapidly with increasing depth. Rising water levels reduced the number of species present near the shoreline, but increased the biomass of chironomids and altered their distribution. The numbers and weights of chironomids increased markedly in the 20-cm zone as water levels rose, primarily because of the presence of one large species (Chironomus transvaalensis). Despite a recession of the water line by as much as 1.5 km in 4 months and the stranding of many larvae (up to 2825 larvae m^{-2}), no significant quantitative changes in species composition or density were found. As water levels rise, oxygen tensions decrease and nutrients may be "injected" into the system. Results suggest that invasion of new areas is primarily by oviposition, perhaps supplemented by some migration of larvae. Fluctuations of water levels are expected to be important to the lake's ecology.

McLachlan, A. J. 1974. Development of some lake ecosystems in tropical Africa, with special reference to the invertebrates. Biol. Rev. 49: 365-397.

226. Ecological changes in new lakes in tropical Africa are discussed. Two large man-made lakes (Volta and Kariba) provide most of the

material for this review. Two phases of development are recognized: "filling," characterized by sudden appearances of organisms and rapid growth of plant and animal populations; and "post-filling," characterized by the development and exploitation of existing habitats (e.g., beaches and mud flats). The role of water-level fluctuation in post-filling phases of development also is considered. Water levels result in an interaction between the terrestrial and aquatic ecosystems, providing new habitat such as flooded trees (at least in shallow areas). Water-level changes impede the establishment of rooted aquatic plants and the development of shorelines (formation of beach areas and mud habitat). Effects of fluctuations are more pronounced in gradually sloping or shelving areas. Drawdown on Lake Kariba, where water levels over gradually shelving areas receded as much as 2 km, stranded chironomid larvae (up to 200 mg m^{-2}). Because losses were rapidly made up by oviposition at the receding water line, the benthos was relatively unaffected by drawdown. During periods of low water, dense growths of grass developed on mudflats and feces of large game animals accumulated. Upon reflooding, dissolved oxygen decreased, and concentrations of potassium, nitrate, and phosphate increased in shallow water. The biomass of chironomids (especially one species) increased greatly. The annual interaction between the terrestrial and aquatic system, brought about by water-level fluctuations, may be of considerable importance to the nutrient economy of lakes. Inundated grasses that develop during low water release large quantities of organic materials and nutrients into the water.

McLachlan, A. J. 1977. The changing role of terrestrial and autochthonous organic matter in newly flooded lakes. Hydrobiologia 54: 215-217.

227. Newly flooded lakes pass through two phases (flooding and post-flooding). During flooding of lakes, mud-dwelling organisms depend on terrestrial organic matter for food. After inundation is complete, diets immediately shift to include more autochthonous-based foods. Gut contents of 500 insects (primarily chironomids) -- collected from lakes Kariba and Chilwa, Africa, and from Ladyburn Lough in England, during filling and post-filling phases -- were examined. Reduced biomass of benthos after filling of lakes was associated with a change in diet from terrestrial detritus to algae. The percent of allochthonous organic matter in diets decreased from 93% to 64% in Lake Chilwa and from 89% to 52% in Ladyburn Lough. Biomass (mg dry weight m^{-2}) declined from 2967 to 1051 in Lake Chilwa, from 1558 to 708 in Ladyburn Lough, and from 2911 to 215 in Lake Kariba.

McLachlan, S. M. 1970. The influence of lake level fluctuation and the thermocline on water chemistry in two gradually shelving areas in Lake Kariba, Central Africa. Arch. Hydrobiol. 66: 499-510.

228. When flat areas covered with grasses and animal dung were flooded to a depth less than 20 cm, alkalinity, conductivity, carbon dioxide, and potassium increased considerably, while pH and dissolved oxygen concentration decreased. By contrast, no significant changes in these variables were observed when water levels decreased. Decomposition of grass and dung apparently used oxygen and released nutrients and was largely responsible for chemical changes. The extent of observed changes depended partly on the amount of grass and dung inundated. Chemical changes were more pronounced over gently sloping shorelines than they were over steep rocky shorelines, because more area was inundated by fluctuations, and the growth of plants was far more extensive.

Merna, J. W. 1964. The effect of raising the water level on the productivity of a marl lake. Proc. Michigan Acad. Sci. 49: 217-227.

229. In 1957, a dam installed on Big Portage Lake raised the water level three feet and increased the area from 335 to 435 acres. Aquatic vegetation in the lake in 1959 consisted of *Scirpus* sp. and scattered beds of *Nymphaea odorata*; few plants were at depths exceeding 5 m. Before 1946, 20 species of plants were present, and 10 were common. The range of total phosphorus increased for a year after water levels were raised (from 6 - 25 mg ℓ^{-1} to 23 - 40 mg ℓ^{-1}), and alkalinity decreased, though not significantly. The numerical abundance of benthos decreased significantly ($P < 0.01$) after lake levels were raised (from an average of 100 organisms ft^{-2} to 40 organisms ft^{-2}). Qualitatively, benthos samples were similar before and after the water-level change. Growth of bluegills, largemouth bass, and black crappies increased, perhaps because of greater zooplankton production. The average length attained by all ages of bluegills, largemouth bass, and black crappies was longer in 1959 than in 1953-54.

Mikulski, J. St. 1978. Value of some biological indices in case histories of lakes. Verh. Int. Verein. Limnol. 20: 992-996.

230. Biological indices based on remains of fossilized zooplankton and benthos are developed to permit an evaluation of historical changes in lake basins. Lake-level oscillations influence relations between pelagic and littoral zones. The index, ILL = Bosminidae minus Daphnidae ÷ Chydoridae, closely reflects water-level oscillations caused by rainfall, as established on the basis of geological and geomorphological investigations. This index may also be useful in recounting oscillations in water level caused by flow variations or activities of man.

Miller, K. D. and R. H. Kramer. 1971. Spawning and early life history of largemouth bass (*Micropterus salmoides*) in Lake Powell. Pages 73-83 *in* G. E. Hall, ed. *Reservoir Fisheries and Limnology*. Am. Fish. Soc. Spec. Publ. No. 8.

231. The spawning time, habitat, and early life history of largemouth bass is described, with emphasis on embryo survival, growth, and feeding by fingerlings. An index to year-class strength based on shore-line seining was developed, but its value is questionable until validated by estimates of year-class strength based on a creel census. The mean depth of nests at time of construction increased from 1.6 to 4.5 m in 1968 and from 1.5 to 2.9 m in 1969, as water levels rose continuously. Strong winds and wave action destroyed nests in water less than 1.5 m deep, but nests in deeper water or protected from waves by boulders or ledges were unaffected. Cover was limited to certain depth strata and was more limiting to successful nesting than was water depth over the nests.

Miller, R. B. and M. J. Paetz. 1959. The effects of power, irrigation, and stock water developments on the fisheries of the south Saskatchewan River. Can. Fish Cult. 25: 13-26.

232. Power projects on high-altitude lakes and rivers that have large-scale water-level fluctuations (e.g., 35 feet in Lakes Minnewanka and Spray; 43 feet in Lower Kananaskis Lake) do not support good sport fisheries. Although physical and chemical conditions and plankton are affected little, the bottom fauna is greatly reduced. Trout growth typically is arrested at a weight of about 1 pound, the weight at which the fish normally convert from a diet of plankton to one of benthos. Power projects on rivers and streams of Saskatchewan have not increased sport-fish production over that existing before impoundment. Fluctuating water levels rule out any useful management scheme. Irrigation impoundments and diversions at altitudes lower than those of power projects are more fertile (due to rich soils) and warmer, and are subjected to smaller drawdowns. As a result, irrigation, stock-water, and diversion reservoirs often develop valuable commercial fisheries for northern pike and whitefish and sport fisheries for pike. Small reservoirs of these types with coarse fish provide good pike angling and those without coarse fish often have good trout fisheries. Winter kills created by drawdown of small trout reservoirs may provide a better population balance among trout of different sizes.

Mitchell, S. F. 1975. Some effects of agricultural development and fluctuations in water level on the phytoplankton productivity and zooplankton of a New Zealand reservoir. Freshwater Biol. 5: 547-562.

233. Daily phytoplankton productivity in Lake Mahinerangi increased from 76 mg carbon m^{-2} in 1964-66 to 210 mg m^{-2} in 1968-70. Although none of the three dominant zooplankters increased in abundance, densities of two less abundant taxa increased substantially. About 78% of the variation in hourly primary productivity during 1964-66 was explained by the equation $Y = 3.3326\ x_1 + 0.1635\ x_2 + 0.1381\ x_3 - 13.6933$, where Y = hourly production (mg carbon m^{-3}), x_1 is water level at the dam (ft.),

x_2 is temperature (°C), and x_3 is day length (h). Estimates of productivity for two dates in 1969 were about three times as high as rates for corresponding dates in 1965--as was expected from differences in water level and temperature. When compared with actual measurements of production in 1968-70, predicted values agreed well with observed values, but not all of the variation was explained. Undoubtedly the effects of changes in water level are complex, and it is not surprising that a multiple-linear-regression model did not explain more of the variability. Rates determined experimentally in November 1968 and on all but one date after 2 April 1969 were typically twice as high as calculated rates. The response of phytoplankton productivity to changes in water level may take one of several forms. A linear response (i.e., increased production depends on water level only) would be produced if nutrients were released from newly inundated areas at a nearly constant rate and were mineralized and reused completely or not at all. If nutrients were released rapidly in relation to the rate of fluctuations, the response would not be to water level but to changes in water level (increasing levels would increase productivity, but decreasing levels would have no effect). Another possibility is that nutrient releases may be delayed for a long period--even months--because of the time required for breakdown of inundated terrestrial vegetation. In this case, the response may depend on average annual water levels. Whatever the response, it probably is modified by the ratio between volume of reservoir and the area inundated, over a range of water levels.

Moen, T. E. 1974. Population trends, growth, and movement of bigmouth buffalo, Ictiobus cyprinellus, in Lake Oahe, 1963-70. U. S. Fish Wildl. Serv., Tech. Pap. No. 78. 19 pp.

234. Bigmouth buffalo populations, which declined irregularly from 1964 to 1970 in Lake Oahe, were dominated by three strong year classes (1959, 1960, and 1962). Successful reproduction was associated with inundation of shoreline vegetation during spring and early summer. Growth of fish was rapid in the first few years of impoundment, but later declined. Because Lake Oahe reached normal pool in late 1967, future flooding of terrestrial vegetation probably will be infrequent, and populations of bigmouth buffaloes are expected to decline further. Commercial harvest of bigmouth buffaloes depleted the 1962 year class.

Moffett, J. W. 1943. A preliminary report on the fishery of Lake Mead. Trans. North Am. Wildl. Conf. 8: 179-186.

235. The environment of Lake Mead during the early years of impoundment is described as well as the fishery in 1940 and 1941. No aquatic macrophytes were expected to develop in the lake because of poor soil fertility and anticipated water-level fluctuations of 65 feet. In spring 1941, the game fish of Lake Mead were in poor condition for the first time since impoundment. It is likely that the spawn of 1940 was

interrupted by some environmental factor, and young bass and bluegills provided most of the food for predators. High water levels in spring 1941 resulted in an excellent spawn of bass and bluegills and the condition of large bass improved rapidly. A recommendation was made to stabilize water levels during April, May, and June and prevent drops of 5 to 10 feet, which would undoubtedly destroy many bass and bluegill nests.

Moon, H. P. 1935. Flood movements of the littoral fauna of Windermere. J. Anim. Ecol. 4: 216-228.

236. The littoral fauna in Lake Windermere was continually moving and rapidly recolonized artificially depopulated areas, especially during floods. Mobile species of benthos (Ecdyonurus sp., Isopteryz sp., and Gammarus pulex) moved into newly flooded areas quickly (within 8 hours). The benthic fauna was extremely sensitive to changes in lake level; a rise of only 2.5 cm was sufficient to initiate movement. Only after algae developed in newly flooded areas did the main mass of benthos move in. The character of the substrate (i.e., with stones, grass, or mud) was a factor determining the extent of possible colonization. Flood movements were considered a special manifestation of normal random movements characteristic of the entire benthic fauna.

Mullan, J. W. and R. L. Applegate. 1965. The physical-chemical limnology of a new reservoir (Beaver) and a fourteen-year-old reservoir (Bull Shoals) located on the White River, Arkansas and Missouri. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 19: 413-421.

237. Limnology of two impoundments was compared to determine whether differences in fertility were associated with reservoir age. No significant differences were detected in commonly measured chemical variables, but differences may not be detectable if nutrients are assimilated as soon as they become available. Slightly higher concentrations of N, P, dissolved organic matter, and some trace elements in the new reservoir (Beaver Lake) may indicate greater availability of nutrients than in the 14-year-old reservoir (Bull Shoals).

Mullan, J. W. and R. L. Applegate. 1967. Centrarchid food habits in a new and old reservoir during and following bass spawning. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 21: 332-342.

238. Stomach contents of selected species of centrarchids (longear and green sunfish, bluegills, and largemouth and spotted basses) in Beaver (a new reservoir) and Bull Shoals (an old reservoir) indicated that food was abundant only in the new impoundment. Sunfishes in both reservoirs ate substantial quantities of terrestrial foods, but sunfish in Beaver Lake ate more than those in Bull Shoals Lake. In Beaver Lake rising waters flooded new areas and greatly increased the supply of

terrestrial animals, such as earthworms. Percent of food volume composed of terrestrial invertebrates from May to June 1965 in Beaver Lake was as follows for 4- to 8-inch fish: 67.9% (bluegills), 61.1% (green sunfish), 76.2% (longear sunfish), 58.4% (largemouth bass), and 39.9% (spotted bass). In Bull Shoals Lake, these percentages were 18.4% (bluegills), 23.6% (green sunfish), 18.6% (longear sunfish), 0.6% (largemouth bass), and 0.8% (spotted bass).

Mullan, J. W. and R. L. Applegate. 1970. Food habits of five centrarchids during filling of Beaver Reservoir, 1965-66. U. S. Fish Wildl. Serv., Tech. Pap. No. 50. 16 pp.

239. Stomach contents of largemouth bass, spotted bass, bluegills, green sunfish, and longear sunfish were examined during the first two years of filling of Beaver Lake, Arkansas. The greatest volumes of food were observed in fish collected during the winter and spring months when water levels rose and flooded terrestrial areas for the first time. Terrestrial organisms were major foods (by volume) during these seasons, especially for basses 101-200 mm long (26-76%) and sunfishes longer than 100 mm--bluegills (70-98%), green sunfish (ca. 50%), and longear sunfish (ca. 84%). The volumes of food were smallest in the late fall (except in large bass), following a decline in food volume that began when water levels stabilized in June. Earthworms composed 78.3% and insects 15.7% of the total volume of terrestrial foods in stomachs of centrarchids from January through June.

Munro, D. A. and P. A. Larkin. 1950. The effects of changes to natural water levels and water courses on wildlife. Trans. British Columbia Nat. Resour. Conf. 3: 267-272.

240. The effect of an increase in lake level depends on the basin configuration; in general, area and depth are inversely correlated with productivity. Waters less than 30 feet deep are the most productive of fish-food organisms, and, therefore a serious loss of productivity occurs when water levels rise more than 30 feet and gently sloping usually productive areas are confined to deep water. By contrast, when extensive shoal areas are flooded, productivity may increase. The type of substrate flooded greatly influences the development of aquatic plants that provide essential cover and areas productive of food organisms for fish and waterfowl. Decaying vegetation also is productive of such food organisms but may degrade aesthetic qualities and accessibility for hunters and fishermen. Seasonal lowering of lake levels may eliminate nearshore plants and animals or strand eggs of valuable fishes such as sockeye salmon and kokanee (autumn). Extensive, rapid increases of levels in the spring (April, May, and June) may result in losses of eggs of nesting waterfowl or fish.

Neal, R. A. 1963. Black and white crappies of Clear Lake, 1950-1961. Iowa State J. Sci. 37: 425-445.

241. Water levels may have directly or indirectly altered the balance between white crappies and black crappies in Clear Lake by influencing the amount of turbidity and vegetation present. Black crappies were the more abundant species in the lake from 1948 to 1956, but by 1961, white crappies, which supposedly are more tolerant of turbidity, predominated. Condition factors of white crappies remained fairly constant; whereas, those of black crappies declined. Mean water levels, which declined after 1956, were correlated with black crappie abundance (α = 0.01). Water levels and Secchi disk readings also were correlated. At low water levels, wave action apparently increased turbidity, and little vegetation (preferred by black crappie for spawning) was inundated. Crowding caused by decreased water levels between 1955 and 1959 may also have had an effect.

Nebol'sina, T. K., N. S. Elizarova, O. V. Roenko, and L. P. Abramova. 1971. Number of commercial fish in the Volgograd Reservoir and measures for increasing their productivity. Tr. Sarat. Otd. Gos. Nauchno-Issled Inst. Rechn. Ozern. Rybn. Khoz. 10: 129-175. (In Russian)

242. The population of commercial fishes in the Volgograd Reservoir reached a maximum in 1956, nine times greater than that in 1959. The reproductive efficiency of most species remained low as a result of constant unfavorable variation in water level. Some species such as bream (Abramis) and pike-perch (Stizostedion), which are adapted to spawning at great depths in the open part of the reservoir, preserved their numbers at a relatively high level. After construction of the Saratov Hydroelectric Power Station in 1968-69, reproductive conditions deteriorated sharply, particularly in the upper portion of the reservoir. As a means of increasing fish reproduction in the middle and lower portions of the reservoir, shallow-water artificial spawning grounds like those used in Dniepr River reservoirs are proposed. (From Referat. Zhur. Biol., 1971, No. 9I211; Biol. Abstr. 54: 18930.)

Neel, J. K. 1963. Impact of reservoirs. Chapter 21 in D. G. Frey, ed. Limnology in North America. Univ. of Wisconsin Press, Madison, Wisconsin.

243. A general discussion is presented on reservoirs and their limnology. Operations may be modified to alter water levels and thereby benefit fish and waterfowl. Examples include seasonal discharge regulations that may allow flooding of desirable waterfowl areas or cause sudden drops of water levels that will discourage spawning of undesirable fishes. A chain of reservoirs offers numerous advantages over a single impoundment, in part by enabling greater control of releases (and therefore water levels) in selected reservoirs. Drawdowns may dry large areas of bottom for various periods of time and expose silt deposits to bed and bank erosion.

Neeves, R. J. 1975. Factors affecting fry production of smallmouth bass (<u>Micropterus dolomieui</u>) in South Branch Lake, Maine. Trans. Am. Fish. Soc. 104: 83-87.

244. A study of the early life history of smallmouth bass during the summers of 1971 and 1972 was directed toward determining what factors affect the production of smallmouth bass fry. A drop in water level was considered to be the primary cause for lower nesting success in 1971 than in 1972. Three of 15 nests were abandoned after 3 days of windy weather and a water-level decline of 23 cm. A 9-cm increase in water level in 1972 had no apparent effect on spawning success. Nest attendance by an adult male, to prevent high egg predation by other species of fish, was mandatory for successful fry production.

Nelson, J. S. 1965. Effects of fish introductions and hydroelectric development on fishes in the Kananaskis River System, Alberta. J. Fish. Res. Board Can. 22: 721-753.

245. Data from surveys (1936 to 1961) indicated changes in the abundance and distribution of fishes after hydroelectric development on the Kananaskis River and the introduction of new fish species. Changes in the physicochemical environment and invertebrate fauna in the reservoirs seemed to be of secondary importance to interactions among fishes in causing changes in species distributions and abundance. Contrary to findings in Swedish reservoirs (e.g., that fluctuating water levels increase the abundance of fish that eat plankton and decrease the abundance of benthos feeders), densities of benthophagous fish did not decrease, probably because of the high densities of chironomids that inhabited flooded areas.

Nelson, R. W., G. C. Horak, and J. E. Olson. 1978. Western reservoir and stream habitat improvements handbook. U. S. Fish Wildl. Serv., Office Biol. Serv. - 78/56. 250 pp.

246. Guidelines are provided for selecting effective habitat improvement measures that may be considered by administrators, biologists of fish and game agencies, and engineers of construction agencies. Some 286 individual improvement measures that historically have been successful are discussed, and potentially effective measures are presented. Topics of potential relevance to the effects of water level on reservoir fishes include the following: selective clearing, exposed area planting, stage filling, fluctuation control, seasonal manipulation, minimum pools, and dam discharge systems. Fluctuation control often severely limits other uses, such as power generation, irrigation, or flood control. Recommendations for fluctuation control were general and actual costs in terms of water lost to other users could not be evaluated. A scheme for seasonal manipulation of water levels is presented. The regime was originally proposed by biologists of the Kansas Fish and Game Commission (see Groen and Schroeder 1978).

Nelson, W. R. 1968. Reproduction and early life history of sauger, Stizostedion canadense, in Lewis and Clark Lake. Trans. Am. Fish. Soc. 97: 159-166.

247. Of the environmental variables monitored, water-level fluctuations in the Missouri River between Fort Randall Dam and Lewis and Clark Lake greatly influenced the reproductive success of saugers. Maximum egg survival occurred at depths 4 feet below the minimum water level in the river. Year classes were above average when mean daily fluctuations were less than 3 feet and below average when fluctuations exceeded 3 feet. Year-class strength was significantly correlated with water-level fluctuation ($r = -0.72$; $P < 0.02$) and apparently was determined before young of year entered Lewis and Clark Lake. Abundance of larvae was 15 times greater in 1965, when water-level fluctuation over spawning grounds was 2.67 ft/day, than in 1963 when the fluctuation was 4.44 ft/day.

Nelson, W. R. 1974. Age, growth, and maturity of thirteen species of fish from Lake Oahe during the early years of impoundment, 1963-68. U. S. Fish Wildl. Serv., Tech. Pap. No. 77. 29 pp.

248. Growth, as determined from scales, is described for 13 species of fish: goldeye, northern pike, common carp, river carpsucker, smallmouth buffalo, bigmouth buffalo, white bass, white crappie, black crappie, yellow perch, sauger, walleye, and freshwater drum. Inundation of terrestrial areas was associated with the rapid growth of fishes, and increased reservoir depth, which reduced the extent of the littoral, was associated with reduced growth. Water-level fluctuations during the growing season had no discernible effect on growth rates. Decreased growth rates of sport fishes may be related to reduced forage (primarily yellow perch).

Nelson, W. R. 1978. Implications of water management in Lake Oahe for the spawning success of coolwater fishes. Pages 154-158 in R. L. Kendall, ed. Selected Coolwater Fishes of North America. Am. Fish. Soc. Spec. Publ. No. 11.

249. After the filling of Lake Oahe in 1958, newly flooded prairie grasses provided ideal spawning and nursery habitat for northern pike and yellow perch. Large populations of these two species developed until 1967, when the operational level of the impoundment was reached. Because spawning substrates consisting of prairie grasses were destroyed by water-level fluctuations and wave action, populations of both species declined after 1967. Future diversions of water that are expected to reduce inflows will hinder spawning of saugers and decrease the average lake level. Reduced lake levels will adversely affect spawning habitat

in the reservoir. If sport-fish populations are to be maintained, reservoir spawning areas must be protected and enhanced artificially, and minimum stream flows in the spring must be maintained.

Nelson, W. R. and C. H. Walburg. 1977. Population dynamics of yellow perch (*Perca flavescens*), sauger (*Stizostedion canadense*), and walleye (*S. vitreum vitreum*) in four main stem Missouri River reservoirs. J. Fish. Res. Board Can. 34: 1748-1763.

250. The development of three percid populations in the four lower main stem Missouri River reservoirs is described. Saugers were the most abundant percid initially, but their populations declined because spawning habitat in rivers decreased and water clarity increased. Year-class strength of saugers was primarily determined by fluctuations in water levels over spawning areas in tailwaters. Growth of yellow perch and saugers was most rapid during the first few years of impoundment. Two primary factors affecting the year-class strength of yellow perch in Lakes Oahe and Francis Case were spring water levels and the amount of terrestrial vegetation inundated during the spawning season; combined, these two factors accounted for 79% of the variation in year-class strength of the species. Abundance of young walleyes was correlated with water levels ($r = 0.62$; $P < 0.1$). Future abundance of all three species apparently will depend on reproductive success as influenced by precipitation, water levels, water-exchange rate, and siltation.

New York State Department of Environmental Conservation. 1977. Lake Champlain Fisheries Investigations: United States Waters. Int. Joint Comm., Int. Champlain-Richelieu Board, Univ. of Massachusetts. 229 pp.

251. Healthy northern pike populations exist throughout Lake Champlain wetlands, but tend to be more dominant in the low-gradient wetlands located near the northern portions of the lake. Flooded terrestrial vegetation such as grasses and grass-brush-tree combinations and emergent aquatic plants were preferred substrates for spawning. Water levels above elevation 30.0 m during the spawning period were required for access to, and flooding of, preferred substrates for egg deposition. If lake-level regulation is implemented, inundation of this habitat for 40-50 days at least once every 3 years should insure egg and fry survival. Dropping water levels during the critical egg and spawning period would have an adverse effect on northern pike production. Reduction of lake elevations from 31.0 to 29.5 m would eliminate about 42% of the 37,500 mapped wetlands now existing. (From Selected Water Resour. Abstr. 12(16): W79-07743.)

Nilsson, N.-A. 1961. The effect of water-level fluctuations on the feeding habits of trout and char in the Lakes Blåsjön and Jormsjön, Northern Sweden. Rep. Inst. Freshwater Res. Drottningholm 42: 238-261.

252. Effects of water-level fluctuation were examined by comparing pre-regulation information on benthos and fish with post-regulation data on feeding by trout and char and by comparing the food habits of fish in regulated and unregulated natural lakes. After regulation in both lakes, trout ate more terrestrial insects and fish, perhaps because the abundance of native benthos was reduced and the littoral areas had deteriorated. Char, which feed to a large extent on plankton and forage over wider areas than trout, were less affected by fluctuating water levels. In comparing a regulated and unregulated lake, the following differences were noted: (1) Limnaea and Trichoptera were eaten more frequently in the unregulated than in the regulated lake; (2) Gammarus, which was very important to trout and char in the unregulated lake, was entirely lacking in the regulated lake; (3) Eurycercus lamellatus (Plecoptera) and terrestrial insects were eaten more frequently in the regulated than in the unregulated lake; and (4) young char were more important as food for trout in the regulated than in the unregulated lake.

Nilsson, N.-A. 1964. Effects of impoundment on the feeding habits of brown trout and char in Lake Ransaren (Swedish Lappland). Int. Verh. Verein. Limnol. 15: 444-452.

253. Effects of regulation were examined by using previously published information concerning the effects of regulation on allochthonous organisms, zooplankton, prey fishes, and benthos and by comparing the food of brown trout and char, before and after regulation. Regulation initially floods new areas, provides a temporary surplus of terrestrial invertebrates as fish food, and increases zooplankton production. Some prey fishes have strong year classes during the early years of impoundment. Littoral benthos usually declines drastically after impoundment. Damming results in increased fish predation on allochthonous organisms and zooplankton. Drawdown increases consumption of zooplankton and prey fish by trout. Fish predation on benthos decreases after drawdown, and different taxa of benthos are eaten.

Nilsson, N.-A. 1966. The effect of hydro-electric power utilization on Swedish fishery. Pages 10-22 in Limnologisymposion, Limnologiska Föreningen i Finland, Helsinki.

254. Research mainly by the Salmon Research Institute and the Institute of Freshwater Research, Drottningholm, indicates that the loss of salmon reproduction after dam construction has been successfully compensated for by stocking of hatchery-reared smolt. In impounded lakes, water-level fluctuations damage food resources of fish, and thus exert adverse effects on growth and possibly on survival. In the lower courses of rivers, where water-level fluctuations are less extensive, a relatively large amount of food is present. Adverse effects primarily alter the fish fauna (from salmonids to coarse fish). Experiments are being made to

compensate for damage by introducing glacial relicts and exotic fish species. The most promising results have been reached with the introduction of the North American lake trout. (Abstract adapted from Fraser 1972.)

Nursall, J. R. 1953. The early development of a bottom fauna in a new power reservoir in the Rocky Mountains of Alberta. Can. J. Zool. 30: 387-409.

255. The benthos of Barrier Reservoir, Alberta, was sampled for 2 years years shortly after impoundment began. The bottom fauna was greatly affected by the rapid replacement of water, periodic fluctuations of water level, and a marked deposition of sediment. Typical annual fluctuations of water level began with a drawdown in late March or early April and continued to the seasonal low in May. Spring runoff then refilled the reservoir. Many benthic animals (e.g., the midge larvae *Chironomus* and *Tanytarsus*) preferred certain depths, and fluctuating water levels frequently altered the depth of water over bathymetric bands of organisms. Fluctuations were slow enough so that distinct bathymetric bands of certain organisms remained evident during most of the year.

Orth, D. J. 1978. Computer simulation models for predicting population trends of largemouth bass (*Micropterus salmoides*) in large reservoirs. Proc. Oklahoma Acad. Sci. 58: 35-43.

256. Two computer simulation models of population dynamics of largemouth bass are described. Model I simulates population trends on the basis of an equilibrium population exhibiting constant fecundity and age-specific survival. Analysis of this model indicates that the density of bass is most sensitive to variations in survival of age 0, age I, and age II bass, in that order. Multiple regression equations, with mean water level during May spawning and water-level fluctuation since the end of the previous growing season as predictor variables, resolved 88.2% of the observed variation in year-class strength -- estimated as young-of-year (YOY) abundance on 13 August -- and 86.7% of the observed variation in bass mortality from egg to age I in Lake Carl Blackwell. Equations were $Y = -7601.4 + 62.5 (X_1) + 27.0 (X_2)$ and $Z_0 = 230.8 - 1.0 (X_1) - 0.8 (X_2)$, where Y = YOY abundance; X_1 = water level change since the end of the previous growing season in October; X_2 = mean water level in May; and Z_0 = annual instantaneous mortality. Model II also simulates population dynamics of bass but accounts for the effects of reservoir water level and water-level fluctuation on survival of the YOY. Predictions of the number of yearling recruits from Model II closely agree with population estimates for Lake Carl Blackwell.

Orth, D. J. 1980. Changes in the fish community of Lake Carl Blackwell, Oklahoma, (1967-1977) and a test of the reproductive guild concept. Proc. Okla. Acad. Sci. 60: 10-17.

257. Changes in numerical density, areal biomass, and diversity of fishes in coves of Lake Carl Blackwell were estimated over a 10-year period. The hypothesis that fishes using similar reproductive strategies to exploit the same resources exhibit similar trends in abundance was not substantiated every year. Some fishes within the same reproductive guild had similar trends in abundance during the 7 years they were examined, as did some species from different guilds. However, other species within the same reproductive guild had different trends in abundance. Dramatic changes in density may have been related to changes in water level, habitat, and biota.

Osipova, V. B. 1979. Ecology of wild carp, Cyprinus carpio, of the Cheremshansk arm of the Kuibyshev Reservoir, Russian SFSR, U.S.S.R. Vopr. ikhtiol. 19: 936-939. (In Russian)

258. A discussion is presented of the dynamics of winter and spring migrations of wild carp as a function of the condition of brood stock in the low-water years of 1971 and 1976, and the high-water years of 1972 and 1974. Statistical differences in condition factors of fish during low- and high-water years are evaluated. The best-fed specimens spawned at lower water temperatures (15-16°C) than did specimens in poorer condition (19-20°C), when water levels fluctuated between 4 and 5 cm per day. (From Biol. Abstr. 70: 63602.)

Paragamian, V. L. 1977. Fish population development in two Iowa flood control reservoirs and the impact of fish stocking and floodwater management. Iowa Fish. Res. Tech. Ser. No. 77-1. 59 pp.

259. The abundance, age and size distribution, reproduction, and growth of major species of fish were monitored in Lake Red Rock and Lake Rathbun, Iowa, after impoundment. Species composition and stocking also were evaluated, as were the effects of reservoir operations. In 1973, high water levels in the spring resulted in the production of strong year classes of bass and bullheads in Lake Red Rock and of bluegills, crappies, and largemouth bass in Lake Rathbun. Increased populations of white bass, crappies, and bigmouth buffaloes in Lake Red Rock were related to high water levels in 1974. Increased storage volume accelerated the growth of fish in Lake Rathbun more than in Lake Red Rock, because Rathbun has more littoral area at higher elevations.

Parsons, J. W. 1957. Fishery management problems and possibilities on large southeastern reservoirs. Trans. Am. Fish. Soc. 87: 333-355.

260. Four types of southeastern reservoirs (flood control, power, storage, and mainstream) are described, as are their typical water-level regimes and problems associated with inefficient and selective harvest of fish. Damages to fisheries in tailwaters and tributary streams also are discussed. Water levels in multi-purpose reservoirs are controlled largely by needs for power, navigation, and flood control. Therefore the manipulation of levels for fishery management must be weighed against other uses, especially when the regime requested conflicts with normal operations. Many fishermen and dock operators on southeastern reservoirs believe that receding water levels in the spring reduce the success of fishermen. Because fish caught in the spring constitute nearly half of the total annual harvest, severe drawdown during this season may reduce the annual harvest. Stable levels in the spring may improve fishing. Rapid spring drawdowns also are detrimental because they may expose bass nests or leave them in shallow water, where nest desertion increases. Rapid drawdown in late spring or early summer may be used to control overly abundant sunfish populations, but stable water levels should be maintained during this period if production of young sunfish limits the bluegill fishery. In one reservoir in Tennessee, fluctuations in water level offered a reliable method to control common carp spawning. Before drawdowns are used for this purpose, however, biologists should verify that populations of common carp are hindering sport-fish production. Water-level fluctuations exceeding 2 feet per month in storage reservoirs during the spring and early summer should be avoided whenever possible. The greatest opportunity for developing fisheries in flood-control impoundments is to establish a large seasonal conservation pool to provide additional capacity. Water levels can then be lowered in the fall to provide space for flood water.

Parsons, J. W. and C. C. Crossman. 1955. An example of state and federal cooperation in establishing water control for fisheries management purposes. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 9: 108-110.

261. A description is presented of the benefits that accrued to fisheries in two Tennessee Valley reservoirs (Dale Hollow and Center Hill) and their associated tailwaters as a result of manipulation of operational regimes, as agreed upon by the Tennessee Game and Fish Commission and the U. S. Army Corps of Engineers. A 3-year study indicated that water-level stabilization, or at least the elimination of drawdowns exceeding 2 feet during the spawning period, would decrease the mortality of largemouth bass eggs caused by stranding nests. Previously, many nest sites were stranded by rapid drawdowns in June.

Paterson, C. G. and C. H. Fernando. 1969. The effect of winter drainage on reservoir benthic fauna. Can. J. Zool. 47: 589-595.

262. Winter draining of Laurel Creek Reservoir, southern Ontario, exposed benthos for 168 to 176 days. Sediments were frozen to depths

greater than 20 cm for 100 days. This exposure destroyed much of the benthic fauna, but freezing of the substrate also eliminated oligochaetes, nematodes, and oribatoid mites, and reduced the chironomid fauna. Small numbers of one caddisfly, two molluscs, and one chironomid survived freezing. Glyptotendipes barbipes survived better than other organisms; its numbers were reduced 54-88% by exposure. Survival probably was greater for organisms located in deeper layers of sediment than for those located within 20 cm of the surface. Three species (one caddisfly and two chironomids) pupated and emerged from exposed substrates.

Paterson, C. G. and C. H. Fernando. 1969. The macro-invertebrate colonization of a small reservoir in eastern Canada. Verh. Int. Verein. Limnol. 17: 126-136.

263. Information is presented on the colonization of benthos in Laurel Creek Reservoir, a 64.8-ha impoundment in Ontario, and the effects of depth, substrate, and reservoir aging on colonization are discussed. Sources for and mechanisms of colonization also are described. The biomass of benthos in this shallow reservoir decreased with increasing mean depth as the reservoir filled. Areas of grassland supported greater densities of benthos than areas of woodland at similar depths. Stripping of organic debris greatly reduced the initial populations of benthos.

Paterson, C. G. and C. H. Fernando. 1969. Macroinvertebrate colonization of the marginal zone of a small impoundment in eastern Canada. Can. J. Zool. 47: 1229-1238.

264. Colonization of the macroinvertebrate fauna along the margin of Laurel Creek Reservoir was studied from first filling in the spring of 1967 until the reservoir was drained in mid-October of the same year. Of the species collected, 62% were facultative, having populations in the lotic environment before impoundment. Colonization was an active process which accelerated as water temperature increased. During spring 1968, the marginal fauna was very similar to that of the previous year, although colonization was more rapid as a result of overwintering of many limnophilic species. Overwintering of several marginal macroinvertebrates resulted in a larger number of taxa and greater standing crop in April.

Paterson, C. G. and C. H. Fernando. 1970. Benthic fauna colonization of a new reservoir with particular reference to the Chironomidae. J. Fish. Res. Board Can. 27: 213-232.

265. Laurel Creek Reservoir was filled in March 1967 and drained between mid-September and October. Examination of the benthos 2 weeks after the dam was closed revealed that it was composed of submerged terrestrial organisms and creek-derived species. Although the density of terrestrial animals was small, their biomass was sufficient to maintain a fish fauna

immediately after the reservoir was filled and before the reservoir benthos became established. Drainage disrupted changes in populations. Many limnophilic species overwintered in the frozen substrate, remaining pools, or Laurel Creek. Upon refilling, terrestrial organisms were absent and the species that had successfully overwintered rapidly dominated the benthic community.

Patriarche, M. H. 1953. The fishery in Lake Wappapello, a flood-control reservoir on the St. Francis River, Missouri. Trans. Am. Fish. Soc. 82: 242-254.

266. Data are presented on the fish and fishery in Lake Wappapello after its impoundment in 1941 until 1951. Fish abundance, standing crop, growth (of eight species), and harvest were assessed. Water levels in the lake were fairly stable in April and May 1948, 1949, and 1951. In 1950, however, spring water levels dropped 10 feet in 24 days and another 10 feet in 10 days. The reproduction of white crappies and largemouth bass was better in 1951 than in 1950, but results for other species were not conclusive. The spawning of common carp, buffaloes, black basses, and crappies may have been curtailed as a result of the rapidly receding water levels in 1950.

Patriarche, M. H. and R. S. Campbell. 1958. The development of the fish population in a new flood-control reservoir in Missouri, 1948 to 1954. Trans. Am. Fish. Soc. 87: 240-257.

267. Changes in species composition, abundance, growth, reproductive success, and harvest of fishes in Clearwater Lake, Missouri, are described for the first 7 years of impoundment. Growth of most fishes (smallmouth bass excepted) was most rapid in the first year of impoundment and declined thereafter. In 1952, receding water levels had a detrimental effect on the spawning success of largemouth bass and on the survival of many species. The two years of most successful spawning were marked by stable or rising water levels during the spawning period. Small fluctuations in water level in 1954 apparently had no significant impact on the abundance of young bass, as estimated by shoreline seining.

Pazderin, V. P. 1966. The effect of water level on fish culture in the Kama Reservoir. Tr. Ural. Otd. Sib. Nauchno-Issled. Inst. Rybn. Khoz. 7: 225-231. (In Russian)

268. A winter drawdown of 7 m at Kama Reservoir reduced reservoir area by one-third and damaged fish populations. Drying of part of the bottom hindered the accumulation of biogenes; no productive biological processes occurred there. Also, oxygen-deficient water flowing from drying marshes killed fish, as ice forced fish into constricted depressions on the bottom. Despite reduced fish abundance, catches in sections with

favorable O_2 conditions increased for a time because fish congregated there. The reservoir level was unfavorable for most fishes except for bream (Abramis) and pike-perch (Stizostedion), and even they lacked spawning grounds. A 0.5-m drop in water level during the third 10-day period of June would ensure a higher yield of fish without hindering navigation or power production. (From Referat. Zhur. Biol., 1968, No. 1I174; Biol. Abstr. 49: 108944.)

Pelzman, R. J. 1980. Impact of Florida largemouth bass, Micropterus salmoides floridanus, introductions at selected northern California, U.S.A., waters with a discussion of the use of meristics for detecting introgression and for classifying individual fish of intergraded populations. Calif. Fish Game 66: 133-162.

269. Populations of largemouth bass in Folsom Lake, New Hogan Reservoir, Lake Amador, Lake Isabella, and Clear Lake, California, possessed a wider spectrum of performance capabilities (i.e., reduced susceptibility to angling, rapid growth, and larger mean size) after the inclusion of desirable genetic traits from Florida bass. This is advantageous in reservoirs where heavy angling pressure, water-level fluctuations, and competition between young bass and prey fishes hinder the maintenance of a bass production.

Perrin, C. 1976. Effects of water level manipulation of black bass spawn and survival - Greers Ferry Lake. Arkansas Game Fish Comm., Little Rock, Arkansas. 9 pp.

270. Since Greers Ferry Lake was impounded in 1962, the spawning success of black basses has fluctuated form year to year, and above average spawns have been associated with high water levels throughout the spawning season. High water levels also improved the reproduction of shad, which undoubtedly increased the survival of bass and permitted the development of strong year classes of bass. Data indicate that water levels that are higher than those of the previous year may often produce similar results. In 1976, a strong year class was produced when water was held 2 feet above power pool. Remarkably, this success was obtained in a year when some conditions for spawning were relatively poor (below-average temperature and frequent passage of frontal systems).

Petkevich, A. N. 1963. Biological bases for a rational fishery on Lakes Baraba and Kulunda. Pages 13-22 in The development of Siberian lake fisheries. Novosibirsk. (In Russian)

271. Feeding and reproductive conditions for fish worsened as a result of periodic fluctuations in water level that periodically obstructed the movement of fish to and from spawning inlets. Inlets become shallow and narrow as a result of declining water levels. (From Referat. Zhur. Biol., 1964, No. 7I59; Biol. Abstr. 46: 23414.)

Petr, T. 1975. On some factors associated with the initial high fish catches in new African man-made waters. Arch. Hydrobiol. 75: 32-49.

272. The time required to fill reservoirs varies greatly, and fish populations apparently respond more favorably to prolonged than to rapid filling. Inundation of several virgin floodplains during prolonged filling of lakes provides a tremendous supply of nutrients. Secondary production over gradually sloping shallow areas is greatly increased. Periphyton and associated invertebrates on submerged terrestrial plants are important foods for fish. Fish prefer submerged forests to open or cleared areas. Drawdown and reflooding kills terrestrial vegetation, and subsequent wave action causes erosion.

Pieczyn'ska, E. 1972. Production and decomposition in the eulittoral zone of lakes. Pages 271-285 *in* Z. Kajak and A. Hillbricht-Ilkowska, eds. *Productivity Problems of Freshwaters*. Polish Sci. Publ. Warszawa, Poland.

273. Primary sources of organic matter in the eulittoral (a transition zone between minimum and maximum water-level elevations) are described. The extent of the eulittoral, and therefore the influence of this highly productive zone on total lake productivity, depends on the configuration of the shoreline terrace, shoreline development, and water-level fluctuations. In Lake Mikolajskie, algal biomass was six times higher in the eulittoral than in the pelagic zone, and primary production was 11.6 times greater. Sources of organic matter in the eulittoral were primary production (2100 kcal m^{-2} $year^{-1}$), autochthonous organic matter (4860 kcal m^{-2} $year^{-1}$), and terrestrial organic matter (1940 kcal m^{-2} $year^{-1}$). Decomposition provides the most rapid supply of organic matter from the eulittoral to other parts of the lake, and the period and extent of the supply depends greatly on changes in water level. Water levels also affect decomposition.

Pierce, P. C., J. E. Frey, and H. M. Yawn. 1963. An evaluation of fishery management techniques utilizing winter drawdowns. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 17: 347-363.

274. Fifteen small impoundments (2 to 500 acres) were manipulated by several management techniques or combinations thereof and results were evaluated. Nine ponds, reduced to about 25% of their original size, exhibited no improvement in bluegill fishing, though the numbers of intermediate-sized bream were reduced. Bluegills were emaciated in the spring after winter drawdown in ponds with few bottom organisms. Recolonization of dried areas by benthos after reflooding was slow, but reflooding improved bass spawning. Seining and culling of intermediate-sized bluegills after drawdown in the winter decreased the growth and reproduction of the species and increased that of bass. Gill netting a pond after a winter drawdown was effective as a selective method of

reducing the numbers of golden shiners and thereby rebalancing the fish populations.

Pollock, C. W. 1965. A study of the young of the year largemouth and smallmouth bass in Dale Hollow Reservoir, Tennessee. M. S. Thesis, Tennessee Tech. Univ., Cookeville, Tennessee.

275. Populations of young largemouth and smallmouth bass were examined to evaluate growth, condition, and food habits. Diets of young largemouth and smallmouth bass consisted mainly of plankton at first but gradually were dominated by insects. Young largemouth bass converted from a diet dominated by insects to one dominated by fish by 5 August. Most forage fish were concentrated in dense growths of bushy pondweed (Najas sp.) located at the heads of coves. Young largemouth bass were unable to prey effectively on the forage fishes until a drawdown forced prey fishes out of the cover and into open water.

Posey, L. E., Jr. 1962. Changes occurring in the fish population of Black Bayou Lake following an increase in water level. Louisiana Acad. Sci. 25: 93-108.

276. During the winter of 1954-55, water levels of Black Bayou Lake were raised 4 feet (nearly doubling the surface area) to improve fishing and to control aquatic vegetation. Cutgrass and parrot's feather were reduced or killed by deeper water, but the effect on parrot's feather, fanwort, and bladderwort was only temporary. Initially, standing crop of fishes declined (from 59 to 26.7 pounds per acre) as a result of the greatly increased area. In 1956, however, the standing crop of fishes increased to 70.4 pounds per acre. Shad production increased from 7.1% of total fish production in 1954 to about 73.8% in 1959; production of largemouth bass decreased from 16.3% to 1% of the total. Raising lake levels apparently did not benefit the sport fishery and may have degraded it.

Priegel, G. R. 1970. Reproduction and early life history of the walleye in the Lake Winnebago region. Wisconsin Dep. Nat. Resour., Tech. Bull. 45. 105 pp.

277. The early life history of walleyes in Lake Winnebago and connecting waterways was examined to determine what factors affect spawning success, egg development, and fry survival. Egg development and fry survival were affected by water-level fluctuations, but because spawning areas were large and numerous, year-class strength was not limited by egg or fry mortality. Even when high mortality occurred in some areas, other areas made up the difference. Controlled burning is considered essential to curtail plant succession and retain desirable grasses needed for successful spawning. Eggs spawned in 1963 on Spoehr's marsh either

did not hatch or dried up after water receded, and in 1964, the water level was low and the marsh was not available as a spawning ground. From 1960 to 1967, no successful hatch developed from the marshes along the Fox River because water levels dropped greatly. Receding waters often resulted in the stranding and death of fry.

Prophet, C. W. 1970. Limnological features of Lyon County Lake after drainage and reflooding. Southwest. Nat. 14: 317-325.

278. Variations in physicochemical conditions, primary productivity, and the relative abundance and composition of zooplankton were studied from 1963 through 1967 to assess changes in these variables during and immediately after reflooding of Lyon County Lake, Kansas. No significant differences were found in dissolved oxygen or phosphate content in successive years, although mean oxygen concentrations were lower in the last year than in the first. Gross primary production recorded from April 1966 to April 1967 was lower than that of the two previous years. Gross production (mg O_2 ℓ^{-1}hour^{-1}) averaged 83 in the third year after refilling of the lake and 34 in the fourth year. Chlorophyll, organic seston, and phosphate also decreased during the fourth year. Cladocerans and copepods were nearly 10 times more abundant in the first two years following reflooding of the basin than they were in the last 2 years. In the 4-year study, average annual zooplankton biomass was high in the first and second years after filling of the lake (13.01 g dry weight m^{-3} and 13.63 g m^{-3}) and significantly lower in the next 2 years (1.29 g m^{-3} in 1965-66 and 1.44 g m^{-3} in 1966-67).

Prophet, C. W., N. Youngsteadt, and L. Schnittker. 1966. Limnology of Lyon County State Lake during reflooding, April, 1964 - March, 1966. Trans. Kansas Acad. Sci. 69: 214-225.

279. In March 1963, studies of the limnology of Lyon County Lake were initiated during a reflooding period that followed draining of the lake in 1962. Refilling of the lake was slow (32 months). There was no direct evidence of a surge in production or increase in the nutrient base due to decomposition of submerged vegetation, perhaps because of the slow filling process. Specific conductance and bicarbonate alkalinity increased only slightly. Mean gross primary production was low compared with that in other aquatic communities (however, 52.6% of all individual estimates exceeded 200 mg of oxygen m^{-2} hour^{-1}).

Prosser, N. S., R. G. Martin, and R. H. Stroud. 1978. Evaluation of planning for fish and wildlife, Council Grove Lake Project. U. S. Army Corps of Engineers, Washington, D. C. 69 pp.

280. Planning efforts and interagency cooperation are evaluated for the water resources development of Council Grove Reservoir, Kansas. Beginning

in 1970, water levels were manipulated to benefit fish and wildlife according to the following regime: (1) on July 1, the lake level is lowered up to 4 feet to permit the growth of vegetation in the drawdown zone; (2) in the fall, levels are raised 1 foot to attract waterfowl; (3) after the waterfowl season levels are lowered 1 foot, and (4) in the spring, levels are raised 4 feet to benefit fish spawning. Improved fish populations were documented by netting samples; successful reproduction of walleyes and several centrarchids occurred every year after 1972.

Rainwater, W. C. and A. Houser. 1975. Relation of physical and biological variables to black bass crops. Pages 306-309 in H. Clepper, ed. Black Bass Biology and Management. Sport Fishing Inst., Washington, D.C.

281. The standing crop of black basses in Beaver and Bull Shoals Reservoirs varied greatly over the time periods sampled (1966-73 in Bull Shoals; 1963-73 in Beaver). An exceptional increase in both standing crop and numbers of black basses in Beaver Lake in 1973 occurred when water levels were unusally high, but standing crop was not significantly correlated with water-level fluctuations, abundance of young-of-year shad, or rate of inflow from 1963 to 1973. By contrast, the biomass and numbers of black basses in Bull Shoals Lake were highly correlated with inflow, mean seasonal lake elevations, and the standing crops of young-of-year threadfin and gizzard shad. The reproductive success of black basses in Bull Shoals from 1966 to 1973 was significantly correlated ($P < 0.01$) with fluctuation of water levels during the 3-month spawning season. Strong year classes were produced in years when water levels rose or were already high. A higher rate of survival of young-of-year bass over other years was attributed to accelerated growth and to refuge provided by flooded shoreline vegetation.

Ramsey, D. L. and B. E. Pierce. 1979. Summersville Reservoir Study, West Virginia Reservoir Invest., West Virginia Dep. Nat. Resour., Fed. Aid Proj. F-11-R-17, Job I-2.

282. The fishes in Summersville Reservoir were monitored to determine the effects of forage and predatory fish introductions and to measure the influence of modified water levels on the fishery. An increased winter pool level (55 feet higher than normal) was implemented for five winters to reduce fish loss through the dam. Before initiation of higher winter levels, many fish (particularly walleyes) were found dead downstream from the dam. The sport fishery at Summersville Reservoir improved during the last 4 years, and a hypolimnial trout fishery was maintained in summers when cold waters were not depleted by normal drawdown.

Ramsey, D. L. and B. E. Pierce. 1979. Sutton Reservoir Study, West Virginia Reservoir Invest., West Virginia Dep. Nat. Resour., Fed. Aid Proj. F-11-R-17. Job. I-1.

283. Sutton Reservoir was sampled to determine the results of introductions of forage and predatory fish and to measure the influence of modified water levels on the fishery. Losses of fish through Sutton Dam during winter drawdown were substantial and, as a result, stocking of muskellunge, northern pike, walleyes, and trout were largely unsuccessful. The summer pool was held 3 feet lower than normal to reduce the magnitude and abruptness of downstream water releases. Although the reduced summer pool level reduced losses of fish through the dam, it reduced the surface area, productive littoral area, overhanging shoreline vegetation, and submerged shoreline cover; it also accelerated shoreline erosion and increased turbidity.

Rawson, D. S. 1958. Indices to lake productivity and their significance in predicting conditions in reservoirs and lakes with disturbed water levels. Pages 27-42 in P. A. Larkin, ed. The Investigation of Fish Power Problems. H. R. MacMillan Lectures in Fisheries, Univ. of British Columbia.

284. A review is presented of the limnology and management of fisheries in fluctuating reservoirs in British Columbia. Emphasis is placed on case histories of reservoirs in the Canadian Rockies. Because scientific data, methods, and understanding are limited, predictions of productivity from descriptive variables such as area, mean depth, shoreline development, and water levels are crude at best. Productivity among fluctuating reservoirs varies greatly. Therefore, more careful pre- and post-impoundment studies are needed.

Rideout, S. G., and P. H. Oatis. 1975. Population dynamics of smallmouth and largemouth bass in Quabbin Reservoir. Pages 216-221 in H. Clepper, ed. Black Bass Biology and Management. Sport Fishing Inst., Washington, D. C.

285. The catch of smallmouth bass and largemouth bass over 20 years is examined and related to boating effort, water-level fluctuations, legal restrictions, and to the catch of other warm-water fishes in Quabbin Lake, Massachusetts. Largemouth bass and pickerels were more affected by water-level fluctuation than other species, and white perch apparently were not influenced by water-level changes. Because the east arm of the reservoir was shallow, several thousand acres of largemouth bass habitat were eliminated, when water levels fell below the 20-foot mark. A sharp increase in water levels in 1972-73 may have been detrimental to fishing success, because inundated brush provided cover that reduced the effectiveness of anglers. Elimination of restrictions on bass angling during the spawning season has no discernible effect on angling quality.

Riel, A. D. 1965. The control of an overpopulation of yellow perch in Bow Lake, Strafford, New Hampshire. Prog. Fish-Cult. 27: 37-41.

286. After a dam was constructed on this 1,198-acre lake, the lake was drawn down in the fall. For years, fall drawdown to the original lake level forced perch into open water where they were subjected to increased predation. In later years, water levels were more constant, because less water stored behind the dam was used. After fall drawdowns were eliminated or reduced, yellow perch became overabundant, and other means of control had to be developed. Control by netting and destruction of eggs are discussed.

Robbins, T. W. and D. Mathur. 1976. The Muddy Run pumped storage project: a case history.

287. Effects of pumped-storage operations on fish populations in Conowingo Pond (the lower pond) and Muddy Run Pumped Storage Pond (the upper pond) are discussed. Water-level fluctuations in Muddy Run limit the effective reproduction of nest-building fishes. Recruitment to Muddy Run depends largely on a transfer of fishes from Conowingo Pond during pumping. Bluegills and pumpkinseeds spawn in one location of the fluctuating pond (a quarry 9 m below full pool) which retains water even after the level of Muddy Run falls below that elevation.

Rodhe, W. 1964. Effects of impoundment on water chemistry and plankton in Lake Ransaren (Swedish Lappland). Verh. Internat. Verein. Limnol. 15: 437-443.

288. The effects of rising water levels and initial impoundment were evaluated by comparing water chemistry, phytoplankton, and zooplankton in newly impounded lakes and natural lakes. Dam construction and burning of brush along the shore temporarily increased the level of phosphate and primary production. Though primary production increased in the first year, algal biomass remained the same. In the second and third years of impoundment, the standing crop and production of algae and zooplankton doubled or tripled. Increased productivity must have resulted from input of nutrients from flooded or eroded terrestrial areas. Observed changes in phosphate, total phosphorus, and total nitrogen were small, probably because the nutrients were rapidly assimilated. Increased phytoplankton and zooplankton production seemed to corroborate this hypothesis.

Roseberry, D. A. 1951. Fishery management of Claytor Lake, an impoundment on the New River in Virginia. Trans. Am. Fish. Soc. 80: 194-209.

289. The fish population, harvest, and fishery management of Claytor Lake, Virginia, in 1948 and 1949 are described. The shore zone did not

develop a high population of plant or animal forms because the water level of the lake was variable and steep rocky shores were wave swept. The abundance of bluegills, the principal forage fish of larger piscivores, was limited by low production of invertebrates in the littoral zone. As a result, the standing crop of sport fish was consistently low. The fish productivity of the lake could perhaps be increased by increasing fertility or by altering the species composition of fishes so that plants and invertebrates are preyed upon more efficiently. Introduction of gizzard shad was recommended.

Roseberry, D. A. 1950. Game fisheries investigations of Claytor Lake, a mainstream impoundment of the New River, Pulaski County, Virginia, with emphasis on Micropterus punctatus (Rafinesque). Ph.D. Thesis, Virginia Polytech. Inst., Blacksburg, Virginia. 235 pp.

290. Stocks of game fishes, their condition, age and size composition, and standing crop were studied. Seasonal changes in the distribution and behavior of fish were documented. Water levels were normally reduced by about 2 feet in February, but this drawdown did not significantly interfere with spawning of black basses or fry survival. Annual water-level fluctuation was about 8 feet; combined with wave action, it caused extensive shoreline erosion and thereby increased turbidity. Of the black basses, largemouth bass apparently was most affected by altered water levels because it generally spawned in shallower water than the other species. The slow growth of fish during their first 2 years of life was attributed to a lack of aquatic plants and sparse invertebrate fauna in the fluctuation zone.

Runnström, S. 1951. The population of char, Salmo alpinus, Linné, in a regulated lake. Rep. Inst. Freshwater Res. Drottningholm 32: 66-78.

291. The level of Lake Torrön was raised 8.25 m between 1937 and 1940 by the construction of a dam at the outlet. Water-level fluctuations caused the loss of littoral aquatic vegetation (Isoetes) and forced char to use new spawning sites formed by shoreline erosion which exposed suitable stone and gravel substrates. Although up to 50% of the spawn was dried and lost by declining water levels, the losses did not affect year-class strength. The mean weight and growth of char increased during the first few years of regulation and then declined greatly. The decisive factor controlling char yields was the limited production of fish food, as determined by water-level fluctuations and not by apparent limitations to reproduction.

Runnström, S. 1952. The population of trout, Salmo trutta, Linné, in regulated lakes. Rep. Inst. Freshwater Res. Drottningholm 33: 179-198.

292. The spawn of trout in rivers between regulated natural lakes in Sweden was frequently destroyed by regulation that caused tailwaters to dry up. After regulation the total catch of trout decreased relative to catches of other species. Extensive stocking of trout fry and fingerlings in the lakes was not successful in improving trout populations. Even with natural reproduction severely reduced, recaptures of marked trout that had been stocked were consistently less than 5% of the total population. Maintenance of minimum flows and the construction of fish ladders were suggested as ways of decreasing the damage of regulation.

Runnström, S. 1955. Changes in fish production in impounded lakes. Verh. Int. Verein. Limnol. 12: 176-182.

293. Changes in the abundance, standing crop and mean weight of char in Lake Torrön, Sweden, was examined to document the effects of fluctuations in water level on fish production. Annual 13-m fluctuations in water level ultimately eliminated littoral macrophytes and severely reduced the biomass of benthos. In the first year after lake damming, secondary production of most communities flourished, only to decline rapidly in successive years. There was no decrease in the number of fish harvested after regulation, in spite of the rather large proportions of eggs that were desiccated and killed by receding waters in the winter. The mean weight of fish harvested increased following regulation (probably in response to improved trophic conditions caused by flooding) but thereafter progressively declined to below pre-impoundment levels.

Runnström, S. 1964. Effects of impoundment on the growth of Salmo trutta and Salvelinus alpinus in Lake Ransaren (Swedish Lappland). Verh. Int. Verein. Limnol. 15: 453-461.

294. Field studies indicated fairly early that the abundance of fish species that spawn along shorelines were not reduced because of poor recruitment. Even if a high percentage of roe was destroyed by receding water levels, the number of fry remaining was sufficient to fulfill recruitment. These data suggest that regulation limits fish production by limiting food. In a number of lakes, growth of fishes accelerates during filling of the reservoir, but sharply declines thereafter. The fast growth of fish in the first year or two of impoundment can be attributed to good nutritive conditions and the production of strong year classes. Effects of water-level fluctuation usually are reflected in slow fish growth but can be masked by changes in climatic conditions such as relatively higher temperatures or longer growing seasons. Stocking of trout proved unprofitable: the weight of the catch was much less than the weight of the fish stocked.

Salyer, J. T. 1958. Factors associated with the decline of the largemouth bass, Micropterus salmoides (Lacepede), in San Vicente Reservoir, San Diego County, California. M. A. Thesis, San Diego State Univ., San Diego, California. 103 pp.

295. In addition to other possible problems confronting largemouth bass (lack of spawning habitat and cover) in San Vicente Reservoir, the harvest of bass apparently reduced predation on bluegills and allowed the bluegill population to increase greatly. The large population of bluegills may have limited the reproductive success of all centrarchids by preying on eggs and fry. Rapid drawdowns were recommended in late June and early July to control the spawning of bluegills by destroying their nests. Another recommendation was to maintain stable water levels during bass spawning, at least until mid-May. Increased bass fishing success in 1955 may have been related to stable water levels present when bass spawned in the spring of 1953.

Schryer, F., V. Ebert, and L. Dowlin. 1971. Determination of conditions under which northern pike spawn naturally in Kansas reservoirs. Kansas Forestry, Fish and Game Comm. Fed. Aid Proj. F-15-R-6. Job No. C-3. 37 pp.

296. A complete record is presented of northern pike stocking in Kansas. Natural reproduction and recruitment of northern pike cannot be expected to occur frequently enough after the early years of impoundment to maintain fishable populations. Supplemental stocking of fish 7 to 11 inches long is required. Several factors are responsible for unsuccessful reproduction, but all of them are related to water-level fluctuations. Extreme fluctuations can increase turbidity which is detrimental to egg and fry survival. The development of dense terrestrial vegetation in late summer or early fall (during low water) and inundation of this vegetation for 3 or 4 months, beginning in early to mid-March, provide conditions for successful reproduction of northern pike.

Schultz, C. A. 1966. Age and growth studies. Fisheries investigations on flood control reservoirs. Mississippi Game Fish Comm., Fed. Aid Proj. F-6-R. Job III. 47 pp.

297. Major variations in growth of white crappies, spotted bass, and largemouth bass coincided with simultaneous variations in the abundance of forage fishes and drastic fluctuations in water levels. Annual fluctuations in water levels were similar in magnitude and pattern for Sardis, Enid, and Grenada reservoirs. Growth was rapid when spring water levels reached maximum elevations in 1961 and 1964, and slowest when water levels were lowest (1959 and 1963). When water levels were high in 1962, only young fish grew rapidly. High spring water levels apparently increased the chances of rapid growth during the rest of the year, as drawdown of all reservoirs was to about the same level each

year, though growth rates varied. Fish sampling with rotenone showed a positive relation between water-level fluctuations and reproduction of shad and minnows, although other factors undoubtedly are involved.

Schultz, C. A. 1966. Evaluation of macrobenthos recovery on dewatered flats with relation to vegetative cover types. Fisheries investigations on flood control reservoirs. Mississippi Game Fish Comm., Fed. Aid Proj. F-6-R. Job XI. 7 pp.

298. Macrobenthos on mudflats in Sardis Reservoir, Mississippi, was sampled periodically after reflooding of these previously dewatered areas. After 8 days of inundation in February, chironomids and Chaoborus averaged 85 organisms m^{-2}. From 1 April to 30 May 1966 (48-107 days of inundation), an average of 139 organisms m^{-2} were present. Chaoborus and chironomids were no more abundant after several months of flooding than after 2 weeks. Permanently inundated areas supported an average of 281 organisms m^{-2} in the period November 1965 - February 1966. Although sampling periods for permanently inundated and seasonally inundated mudflats were not directly comparable, benthos on seasonally inundated mudflats apparently did not attain the densities observed on permanently flooded areas. Benthos numbers in different types of cover (cypress, buttonbush, and smartweed) were similar; density appeared to be more closely related to the type of substrate than to the type of vegetation present.

Scully, R. J. 1972. Physical chemical parameters and gill net catches at four flood plain habitats on the Kafue Flats, Zambia. M. S. Thesis, Univ. of Idaho. 59 pp.

299. The catch of fishes in flood plain areas varied with time and habitat. Dissolved oxygen tensions were more closely related to the catch of fish than to other physicochemical factors monitored, and oxygen concentration was largely a function of the length of time areas were inundated and the type and quantity of aquatic vegetation present.

Serruya, C. and U. Pollingher. 1977. Lowering of water level and algal biomass in Lake Kinneret. Hydrobiologia 54: 73-80.

300. Water levels of Lake Kinneret decreased rapidly from 1972 to 1975 as a result of drought. Lowering of the lake produced a number of events: (1) it reduced the volume to area ratio which in turn increased the input of mechanical energy (wind) per unit volume, which accelerated heat transfer by increasing the volume of water mixed; (2) it decreased the volume of the hypolimnion as thermocline depth increased; (3) it increased concentrations of nutrients due to decay of organics, improved solubility of salts such as calcium phosphate, and increased release of orthophosphate because of more effective oxidation of sediments at turnover; (4) it altered the species composition of algae (diatoms and green

algae replaced Peridinium); and (5) it reduced algal biomass because of a lower biomass-to-phosphorus ratio and the fact that diatoms and green algae were grazed by zooplankton whereas Peridinium was not.

Sharonov, I. V. 1958. Fish culture in Lake Sevan following draining operations. Rybn. Khoz. 8: 31-34. (In Russian)

301. Lowering of water levels of Lake Sevan reduced the spawning area of Salmo ischchan, Coregonus lavaretus, Varicorhinus capoeta sevangi, and Barbus goktshchaicus. Fish being harvested were recruited from populations spawning in tributaries or raised in hatcheries. Culture operations are described. (From Referat. Zhur. Biol. 1960, No. 6528; Biol. Abstr. 46: 9755.)

Sharonov, I. V. 1963. The effect of the water level on the formation of fish stocks in the Kuibyshev Reservoir. Materials First Sci. Tech. Conf. for the Study of Kuibyshev Reservoir. Kuibyshev 3: 126-132. (In Russian)

302. Low-value fishes are replacing valuable commercial fishes because the present water level regime adversely affects the reproduction of valuable species. At low water levels in the winter, many fish are killed by suffocation. Sediments in shallow areas are dried and frozen. Apparently, requirements for reproduction are less stringent for fishes of low value than for the valuable species, and conservation measures to remove low-value fishes by netting and predator control should be implemented. (From Referat. Zhur. Biol., 1964, No. 5I56; Biol. Abstr. 46: 14422.)

Shields, J. T. 1955. Carp control through water drawdowns, Fort Randall Reservoir, South Dakota. South Dakota Dep. Game, Fish, and Parks. Fed. Aid Proj. F-1-R-5. 10 pp.

303. By predicting when common carp began heavy spawning and requesting a drawdown of lake levels, some success was obtained in controlling common carp populations. Temperature apparently is the primary stimulant for spawning, but rising waters that flood grassy or weedy areas seem to have some effect. Eggs are adhesive and cling to vegetation in shallow areas (0.5 - 2 feet deep). When water levels were reduced rapidly in 1955, no egg survival was evident during the heaviest spawning. During a second drawdown in 1955, no spawning success was observed. Poor year classes of common carp in 1954 and 1955 were attributed to poor hatching success as a result of timely rapid drawdown of water.

Shields, J. T. 1957. Carp control through water drawdowns, Fort Randall and Gavins Point Reservoirs, South Dakota. South Dakota Dep. Game, Fish, and Parks. Fed. Aid Proj. F-1-R-7. 10 pp.

304. Poor reproduction of common carp in the main body of Fort Randall Reservoir was attributed to rapid drawdown of water during the spawning period. About two-thirds of the spawn hatched before a 1.5-foot drawdown, but the rest were destroyed. Poor survival of fry was believed to be the result of poor food availability or other biological conditions caused by reduced water levels during a critical stage of fry development. Planned drawdowns from 1955 to 1957 also may have adversely affected the reproduction of gars and buffaloes. Poor reproduction of all species of fish in Gavins Point Reservoir probably resulted (directly or indirectly) from periodic reductions of water level throughout the summer.

Shields, J. T. 1957. Experimental control of carp reproduction through water drawdowns in Fort Randall Reservoir, South Dakota. Trans. Am. Fish. Soc. 87: 23-33.

305. Major spawns of common carp were predicted by sampling, gonad inspection, and monitoring water temperatures to permit the use of rapid drawdown as a method of controlling the abundance of carp. Spawning was induced by rapidly rising water that inundated shallow vegetated areas, at the appropriate temperature. In 1955, levels were reduced 1.5 feet in 5 days. Freshly spawned eggs were located in areas less than 1 foot deep, and receding waters exposed and killed most of them. Because many carp spawned in the upstream end of the reservoir, where drawdown had less effect, significant numbers of young carp were caught later in the season. However, survival of young carp was poor because the drawdown apparently upset some biological condition (such as food availability) at a critical stage in the life of fry. The year classes of carp produced in the drawdown years of 1955, 1956, and 1957 were relatively weak, suggesting that planned drawdowns were primarily responsible for limited reproduction.

Shields, J. T. 1958. Fish management problems of large impoundments on the Missouri River. Trans. Am. Fish. Soc. 87: 356-362.

306. Major management problems identified in six large Missouri River reservoirs include inadequate harvest, development of efficient commercial gear and markets, and overabundant populations of undesirable fishes. Planned manipulation of water levels is a powerful management tool, especially in the integrated system of Missouri River reservoirs where increased flexibility of reservoir operations may allow manipulation of water levels for fish management. Drawdown may be used to control spawning of rough fishes or to improve the spawning conditions for desirable fishes. Production of fish-food organisms can be increased by raising water levels to flood naturally or artificially vegetated areas.

Shirley, K. E. and A. K. Andrews. 1977. Growth, production, and mortality of largemouth bass during the first year of life in Lake Carl Blackwell, Oklahoma. Trans. Am. Fish. Soc. 106: 590-595.

307. Mark-recapture methods were used to evaluate first-year recruitment, growth, net production, and mortality of largemouth bass in the 1972 and 1973 year classes. The 1972 year class was a failure; whereas, the 1973 year class was highly successful. Differences in the number, growth, and production of largemouth bass in the two year classes were directly related to differences in water level in the two years. In 1973, water levels rose and inundated terrestrial vegetation. Flooding improved growth and lessened mortality by providing a temporary increase of food in the form of terrestrial invertebrates, by increasing cover (flooded terrestrial vegetation) for nests and nursery areas (by reducing wave action and predation), and by increasing nutrient levels (from decaying vegetation).

Siefert, R. E. 1969. Biology of the white crappie in Lewis and Clark Lake. U. S. Bureau Sport Fish. Wildl., Tech. Pap. No. 22. 16 pp.

308. The life history of the white crappie in Lewis and Clark Lake is described. No relation between year-class strength and water-level fluctuations was documented, but survival of white crappie nests may have been adversely affected by water-level fluctuations when crappies nested in shallow water because of lower than normal water temperatures during the spawning season.

Silvertsen, E. 1962. Namsvatn - fishery biological investigations after regulation of the lake. Kgl. Norske Videnskabers Selsk., Museet Arbok. 37-66 pp. (In Norwegian)

309. Lake Namsvatn in central Norway was raised 13 m in 1952 for hydroelectric development. Investigations of stomach contents of brown trout and char in 1945 and in 1951-61 showed that Gammarus pulex disappeared after impoundment, while densities of Lepidurus glacialis increased. Trout ate primarily insects; whereas, char diets were dominated by entomostraca. The average size and condition of trout was stable throughout the study. The average weight of char increased from 238 g in 1951 to 273 g in 1953 and then decreased successively to only 132 g in 1961. Decreased size was correlated with decreased condition and an increase in the number of mature char. Tagging experiments showed that char moved over the entire lake; whereas, trout were more locally bound. (Abstract from K. W. Jensen, Vollebekk, Norway, as adapted from Fraser 1972.)

Smirnov, A. F. 1964. The importance of the fisheries in the reservoirs of North Karelia. In Fisheries of Karelia. Petrozavodsk 8: 123-129. (In Russian)

310. The anticipated development of fish stocks in flooded lakes in

basins of Iovskoe and Pyaozerskoe reservoirs is discussed. Favorable feeding conditions for ciscoes, smelts, and other young fishes will be created by increased input of organic matter and increased zooplankton populations. Sea trout, trout, and whitefish populations (typical lake and river forms) should decline. During early years of flooding of the new impoundments, reproduction of pike, perch, and roach should be excellent, and bream (*Abramis*) abundance will increase after the shore zone is established. After the construction of a hydroelectric power plant in Pyaozerskoe Reservoir, the water level of Topozero Lake will be reduced 20%, and low water in the fall and winter will probably hinder the spawning of ciscoes, char, lake whitefish, and spring-spawning fishes. (From Referat. Zhur. Biol., 1965, No. 4I86 and Biol. Abstr. 47: No. 75781.)

Smith, J. 1975. Evaluation of fish populations in Greenleaf Lake. Oklahoma Dep. Wildl. Conserv., Fed. Aid Proj. No. F-26-R. Job No. 2. 73 pp.

311. Because previous surveys indicated overabundant populations of rough fish and stunted game fishes, this study was designed to evaluate the combined effects of drawdown, rough-fish removal, rye planting, and stocking of 17,000 catchable-sized catfish. Other management measures included construction of 27 brush shelters and stocking of largemouth bass. The lake was lowered 18.5 feet below normal pool in September 1966 and was refilled in February 1967. Growth of most species improved after refilling of the lake, and the sport fishery apparently improved for 3-4 years before returning to pre-drawdown conditions. Because many management techniques were employed, effects of the drawdown alone cannot be evaluated.

Snow, H. E. 1971. Harvest and feeding habits of largemouth bass in Murphy Flowage, Wisconsin. Wisconsin Dep. Nat. Resour., Tech. Bull. No. 50. 25 pp.

312. The harvest and food habits of largemouth bass were analyzed from 1955 through 1969, a period of liberal fishing regulations and compulsory creel census. Crayfishes were the most important food consumed by bass before winter drawdown; bullheads were selected as food by bass and bluegills were not. After drawdown, which reduced growths of aquatic vegetation and apparently the populations of crayfish, bass ate more bluegills. Drawdown may be used to increase selective predation on bluegills in lakes where bullheads or crayfish are abundant.

Sparrow, R. A. H. 1966. Comparative limnology of lakes in the southern Rocky Mountain Trench, British Columbia. J. Fish. Res. Board Can. 23: 1875-1895.

313. Standing crops of plankton were related to oxygen deficits and

perimeter-to-area ratios in nine lakes. Although primary factors such as mean depth, climate, and total dissolved solids may be important in influencing productivity in broad geographical areas, other factors (e.g., water-level fluctuation, perimeter-to-area ratios, basin shape, and the size and nature of the drainage area) modify the expression of the primary factors within a restricted geographic region. Lazy and Horseshoe lakes have seasonal water-level fluctuations that may contribute to the low-to-moderate standing crops of benthos. Rooted macrophytes, which increase the production of benthos, also were lacking in Lazy and Horseshoe lakes, possibly because of the amplitude of water-level changes.

Sreenivasan, A. 1966. Limnology of tropical impoundments. I. Hydrological features and fish production in Stanley Reservoir, Mettur Dam. Int. Revue ges. Hydrobiol. 51: 295-306.

314. The impact of physicochemical features on fish production in Stanley Reservoir, India, is discussed. Fish yield was relatively low (21.3 pounds per acre), but had not declined with increased reservoir age. Although nutrients were constantly leached out and discharged downstream, plant growth was frequently lacking because of rapid fluctuations in water level. The littoral zone was sterile. Rapid fluctuations also appeared to adversely affect fish spawning. Discharge of plankton-rich surface waters when water levels were high and generally rapid rates of water exchange limited productivity. Limited drawdown may help retain nutrients and plankton.

Sreenivasan, A. 1974. Limnological features of a tropical impoundment, Bhavanisagar Reservoir (Tamil Nadu), India. Int. Revue ges. Hydrobiol. 59: 327-342.

315. Physicochemical features of Bhavanisagar Reservoir are described and related to primary production and harvest of fish. The only factors likely to negatively affect fish populations and yield are the failure of monsoons (and therefore fish spawning) and parasitic infections.

Starrett, W. C. and A. W. Fritz. 1965. A biological investigation of the fishes of Lake Chautaugua, Illinois. Illinois Nat. Hist. Surv. Bull. 29. 104 pp.

316. The relative abundance, biomass, and commercial harvest of fishes of Chautaugua Lake were studied from 1950 to 1959. Water level probably was the most important factor affecting the dynamics of fish populations in the lake. During periods of low stable water levels, sago pondweed became abundant, turbidity decreased, large populations of benthic insects developed, and many bluegills and crappies were collected by seining. When vegetation was abundant in low-water years, the carrying capacity for fish probably was greater than in years of high or fluctuating water

levels. Water levels affected the needs of fish such as food, cover, space, and spawning. In one year, several largemouth bass nests were stranded when water levels fell. Receding water levels also destroyed many common carp eggs. High turbidity, associated with high water, may have hampered the feeding of some fishes. Water levels affected the growth and condition of bluegills, crappies, and possibly other species. The growth index of bluegills was negatively correlated with water levels ($r = -0.46$) as was the coefficient of condition ($r = -0.81$). Condition of white crappies and black crappies was negatively correlated with summer water levels ($r = -0.79$ and -0.73, respectively). Similar, but less significant relations were found for the growth and condition of channel catfish. Growth rates and condition of freshwater drum were independent of water levels.

Starrett, W. C. and P. L. McNeil, Jr. 1952. Sport fishing at Lake Chautaugua, near Havana, Illinois, in 1950 and 1951. Ill. Nat. Hist. Surv. 30: 31 pp.

317. The creel survey of 1950-51 revealed that angler success was influenced by water levels, season, and the relative abundance of various fishes. Fishing success in general and for freshwater drum and channel catfish in particular, improved with rising water levels. Fishing for bass, however, was best when water levels were falling or low and stable.

Starzykowa, K. 1972. Populations of Cladocera and Copepoda in dam reservoirs of southern Poland. Acta Hydrobiol. 14: 37-55.

318. The composition of crustacean zooplankton was influenced by the rate of water exchange in reservoirs. In general, more euplankton was present in large reservoirs with standing water than in reservoirs with swiftly flowing water; littoral species were most abundant in the reservoir at Wisla-Czarna which had a rapid rate of water exchange. Zooplankton production was influenced by rate of water exchange and reservoir age.

Stepanova, N. A. 1966. The Katta-Kurgan Reservoir. Pages 108-119 *in* P. V. Tyurin, ed. *The Storage Lakes of the U.S.S.R. and Their Importance for Fishery*. (Transl. from Russian) Israel Program Sci. Transl. Cat. No. 1638-50. U. S. Dep. Commerce

319. An overview of the Katta-Kurgan Reservoir is presented, and many topics such as purpose, geography, geology, and climate of the area are included. Discussion of the reservoir proper includes topics on morphometry, hydrology, chemistry, and biology. Due to marked fluctuations in water level, the Katta-Kurgan Reservoir is almost devoid of higher aquatic vegetation. The density of benthos is low and concentrated in deep sections. Marked water-level fluctuations that expose extensive areas of bottom have limited the biomass of benthos.

Stewart, R. W. 1967. The development of a management program for Spruce Run Reservoir. New Jersey Conserv. Dep. Rep. 13 pp.

320. When Spruce Run Reservoir, New Jersey, was drawn down in spring and summer 1966, receding water levels (1 foot per week) adversely affected the spawning of bluegills and pumpkinseeds by dewatering nests. Sunfishes spawned from about mid-June when water temperatures reached 77°F to mid-July. Reproduction of largemouth bass (May 20 - June 20), which began when water temperatures reached 65°F, was almost complete before the drawdown and therefore was largely unaffected by receding waters.

Stewart, R. W. 1971. Survey of Spruce Run Reservoir. New Jersey Div. Fish, Game, and Shellfisheries. Fed. Aid Proj. F-23-R-6. Job I-5. 44 pp.

321. This baseline study described the physicochemical characteristics, harvest statistics, and data on fish populations of Spruce Run Reservoir, New Jersey, from 1965 to 1969. Water levels declined significantly during the summer and fall of each year except 1967. Dewatering destroyed much of the aquatic vegetation (primarily Elodea) and suppressed its growth. The lack of vegetation seemed to provide predators with easier access to prey fishes.

Stewart, R. W. 1979. Survey of Rising Sun Lake. New Jersey Div. Fish, Game, and Shellfisheries. Fed. Aid Proj. F-23-R-14, Job I-9. 10 pp.

322. Data are presented on the physicochemical limnology and the development of fish populations of Rising Sun Lake in 1978. Terrestrial vegetation, which developed when water levels were low in the spring of 1977, affected O_2 tensions and water clarity throughout the summer of 1978, after the lake was filled in the spring. However, oxygen tensions were at least 4 mg ℓ^{-1} at depths above 15 feet, and no deleterious effects on fish resulted.

Stroud, R. H. 1948. Growth of the basses and black crappie in Norris Reservoir, Tennessee. J. Tenn. Acad. Sci. 23: 31-99.

323. Growth of black basses and black crappies from Norris Reservoir from 1942 to 1946 was determined by the scale method. All species studied grew rapidly during the first 3 years of impoundment, but growth rates slowed in the fourth or fifth and sixth years. Growth improved in the seventh year and decreased again in the eighth and ninth years. Changes in growth were correlated with a long-term cycle of spring and

early summer water levels. Rapid growth occurred when water levels flooded exposed areas of the littoral zone. Apparently, beneficial effects of fluctuation resulted from the addition of organic nutrients from decaying terrestrial vegetation that developed when waters were low. The presence of vegetation undoubtedly enhanced survival of young fishes.

Stube, M. 1958. The fauna of a regulated lake. Rep. Inst. Freshwater Res. Drottningholm 39: 162-224.

324. An extensive survey of plant and animal life before and after regulation of Lake Borgasjön formed the basis for evaluating the effects of annual 18-m fluctuations in water level. Most emphasis centered on the periphyton in the summer before regulation, but benthos and fish also were sampled. In the third year of regulation, belts of aquatic vegetation and benthos in the delta area had completely disappeared. The dominant taxa of benthos shifted from a community dominated by Phyllopoda, Ephemeroptera, Oligochaeta, Diptera, and Trichoptera before regulation to one dominated by Nematoda, Oligochaeta, and Diptera after regulation. Trout that flourished in the delta before regulation (perhaps because of the abundant vegetation that provided refuge), no longer inhabited the area after regulation. After 5 years of fluctuation, char invaded the former delta. Stomach analyses indicated that char consumed more planktonic food than trout, and that trout diets were dominated by benthos (mayfly and caddisfly larvae). Bottom samples of 1954 indicated that regulation had reduced the abundance of benthos. Growth of trout increased immediately after regulation began, due to the addition of flooded terrestrial foods, but decreased after 1955.

Summerfelt, R. C. 1975. Relationship between weather and year-class strength of largemouth bass. Pages 166-174 in H. Clepper, ed. Black Bass Biology and Management. Sport Fishing Inst., Washington, D. C.

325. Observations presented support the hypothesis that year-class strength of largemouth bass is related to weather, especially frontal systems. In Lake Carl Blackwell, Oklahoma, where extreme variations in the abundance of young-of-year bass occur, limiting environmental factors included a sharp decline in water temperature (which can result in nest dessertion) and wind action. Spawning success was greatest when weather (wind and air temperature) and factors affected by weather (water temperature, water level, and turbidity) were stable. Water levels strongly influenced year-class strength. When surface area was reduced by 50% in 1972, recruitment of young bass was negligible. Water levels may have caused disjunct spawning, exposed nests, or increased the effect of wave action and temperature change at nest sites.

Summerfelt, R. C. and K. E. Shirley. 1978. Environmental correlates to year-class strength of largemouth bass in Lake Carl Blackwell. Proc. Oklahoma Acad. Sci. 58: 54-63.

326. The density of young-of-year largemouth bass in an area of suitable habitat was determined in August for 11 consecutive years and considered to be representative of year-class strength. Year-class strength was positively correlated with water level, change in water level, and turbidity, and negatively correlated with water hardness, alkalinity, and pH. The four smallest year classes occurred when water levels decreased in May and June. Strongest year classes occurred in years when water levels where high and flooded terrestrial areas, thereby simulating conditions present in new impoundments. Water levels were negatively correlated with hardness and alkalinity. Turbidity occasionally was affected by changes in water level.

Svärdson, G. and G. Molin. 1973. The impact of climate on Scandinavian populations of the sander, Stizostedion lucioperca (L.). Rep. Inst. Freshwater Res. Drottningholm 53: 112-139.

327. Yields of sander in six lakes are discussed, as are the climatic factors that affected their population dynamics in Lakes Hjälmaren and Mälaren from 1955 to 1972. The strength of 15 year classes in the separate lakes fluctuated in a similar manner, indicating a climatic influence. Year-class strength was correlated with temperatures during some summer months (especially June through August) and was associated with high water levels in the spring. The two best year classes occurred in years when water levels were highest in spring. High water in May 1966 also produced a very dominant year class of pike in Lake Mälaren. In lakes where sander numbers are low for years until they suddenly explode in a single strong year class, water levels may be an important factor regulating reproductive success.

Swanson, G. A. 1967. Factors influencing the distribution and abundance of Hexagenia nymphs (Ephemeroptera) in a Missouri River reservoir. Ecology 48: 216-225.

328. The abundance and distribution of burrowing mayfly nymphs were affected by a number of factors including season, depth, current, wind, substrate, and water levels. Substrates normally inhabited by Hexagenia nymphs were not disturbed by fluctuations of water level except in shallow bays and backwater areas. From May to September, the maximum range of fluctuations was 1.5 m. Nymphs may have responded to minor, slow drawdowns by migrating over the bottom. A normal drop of water levels in Lewis and Clark Lake limited the abundance of nymphs by exposing reservoir substrates to increased wave action.

Swee, U. B. and H. R. McCrimmon. 1966. Reproductive biology of the carp, Cyprinus carpio L., in Lake St. Lawrence, Ontario. Trans. Am. Fish. Soc. 95: 372-380.

329. Temperature and water levels were major environmental factors affecting the spawning of common carp and the survival of their eggs in marsh areas. Frequent summer fluctuations of water levels of 6 to 12 inches destroyed millions of eggs by exposure, but reproduction was not completely controlled by fluctuations. Examination of gonads revealed that males could release sperm over an extended period of time, and experiments showed that females could spawn twice. Although no population estimates were made, spot poisoning showed that a substantial number of young-of-year common carp hatched at various times in May, June, and July and survived at least until mid-Autumn.

Sylvester, R. O. and R. W. Seabloom. 1965. Influence of site characteristics on quality of impounded water. J. Am. Water Works Assoc. 57: 1528-1546.

330. Inundation of vegetation and bottom areas with fertile soils may produce undesirable water quality by (1) ion exchange through clay and humic colloids; (2) microbial degradation of organic matter from soil or vegetation, thereby releasing dissolved materials, CO_2, and minerals; (3) leaching of organic and mineral compounds that enhance algal growth; and (4) microbial activity at the soil-water interface, thereby creating anoxic conditions and altering the products of decay processes. The three effects of soils on water quality are physical (color, turbidity, taste, odor), chemical (pH, dissolved solids, and gases), and biological (enhanced growth of algae and other aquatic organisms). Most changes are associated with the decomposition of organic matter in soil and water. Howard A. Hanson reservoir was studied to document effects of basin characteristics (site preparation, vegetation, and soils) and filling regime on reservoir water quality. Soil organic content was most responsible for undesirable effects on overlying water, but its effects depended on time, temperature, and light. The effect of organic content was proportional to the age or state of decay of organics. Repeated leaching of soils by flushing (rapid water exchange) reduced the effect of organic soils on water quality. Wood, bark, grasses, leaves, and ferns have a high biological oxygen demand and adversely affected water quality.

Thompson, J. D. 1964. Age and growth of largemouth bass in Clear Lake, Iowa. Proc. Iowa Acad. Sci. 71: 252-258.

331. Age composition and growth of 281 largemouth bass were determined from scales collected from 1947 to 1963. Growth rate was below the average for the 17-year period in 1957-60, when water levels were decreasing and the lake volume was 30% below normal. Annual growth was correlated with water levels but not with temperature or turbidity.

Timmons, T. J. and W. L. Shelton. 1980. Differential growth of largemouth bass (Micropterus salmoides) in West Point Reservoir, Alabama - Georgia, USA. Trans. Am. Fish. Soc. 109: 176-186.

332. A bimodal length-frequency distribution of young largemouth bass, evident by the fall of 1977, resulted from differences in the availability of suitable-sized prey, rather than from disrupted spawning as caused by fluctuations in water temperatures or lake levels.

Triplett, J. R., D. A. Culver and G. B. Waterfield. 1980. An annotated bibliography on the effects of water-level manipulation on lakes and reservoirs. Ohio Dep. Nat. Resour., Fed. Aid Proj. F-57-R. Study No. 8. 50 pp.

333. This bibliography lists 348 annotated references dealing directly or indirectly with the effects of water-level fluctuations on the physical, chemical, and biological components of lakes and reservoirs. Emphasis is placed on references pertaining to fish management in reservoirs, but many related topics are included.

Tyurin, P. V. 1961. Effect of the water-level regime in reservoirs on the formation of fish stocks. Izv. Gos. Nauchno-Issled. Inst. Ozern. Rybn. Khoz. 50: 395-410.

334. Three types of reservoirs are recognized in relation to their seasonal decline of water level. Reservoirs with stable water levels throughout the year are the most favorable for raising fish, but those that have maximum water levels in the spring and an appreciable summer, fall, and winter drawdown also are favorable, at least in principle. Commercially valuable fish such as bream (Abramis), common carp, and pike spawn in the spring in shallow-water areas (0.2-1.0 m) with soft vegetation. Reservoirs with stable water levels during the open season and large drawdown in the winter are unfavorable for natural reproduction.

Tyurin, P. V. 1966. Piscicultural classification of reservoirs and procedures for determining fish yield. Pages 225-238 in P. V. Tyurin, ed. The Storage Lakes of the U.S.S.R. and Their Importance for Fishery. (Transl. from Russian) Israel Program Sci. Transl. Cat. No. 1638-50, U. S. Dep. Commerce.

335. A system to classify reservoirs according to fish harvest and a method of estimating fish yield from the standing crop of fish foods are presented. Two factors adversely affecting fish yield are wave action and seasonal and long-term fluctuations in water level that increase shore erosion. The growth of aquatic vegetation is impeded as

a result of these factors, and the biomasses of benthos and plankton are low. These shortcomings are compensated for in part by the high yield of nearshore area (2-3 times that in natural lakes). Large annual water-level fluctuations adversely affect fish yield; whereas, stable levels or fluctuations less than 0.5-1.0 m are favorable. In late summer or fall, a drawdown exceeding 1 m is favorable, and no drawdown is unfavorable. In the winter no drawdown is favored and considerable winter drawdown is believed to be harmful. Diurnal and weekly fluctuations greater than 10 cm during the spawning season were classified as adverse; the lack of daily or weekly fluctuations was deemed favorable.

Vogele, L. E. 1975. Reproduction of spotted bass, _Micropterus punctulatus_, in Bull Shoals Reservoir, Arkansas. U. S. Fish Wildl. Serv., Tech. Pap. No. 84. 21 pp.

336. Environmental requirements of spotted bass for spawning and their reproductive potential were evaluated from underwater observations along a steep bluff and in shallow coves of Bull Shoals Reservoir from 1966 to 1971. In years of low water, nest densities were greatest along the bluff. In 1968 and 1969, when high water afforded heavy cover (in the form of flooded terrestrial vegetation) to spotted bass nesting in coves, bass did not spawn along the bluff.

Vogele, L. E. and W. C. Rainwater. 1975. Use of brush shelters as cover by spawning black basses (_Micropterus_) in Bull Shoals Reservoir. Trans. Am. Fish. Soc. 104: 264-269.

337. Brush shelters placed along the shoreline were observed during the spawning of three species of black bass to evaluate preferences for sheltered and unsheltered habitat. During the study, rising water levels flooded shoreline vegetation, which furnished abundant cover for late-spawning bass and for schools of fry. When shelters were no longer the most obvious cover available, fry also used the vegetation. Half of the schools of fry observed were in flooded terrestrial vegetation.

von Geldern, C. E., Jr. 1971. Abundance and distribution of fingerling largemouth bass, _Micropterus salmoides_, as determined by electrofishing at Lake Nacimiento, California. Calif. Fish Game 57: 228-245.

338. Findings are summarized on the efficiency of electrofishing for fingerling bass, the effort required to obtain meaningful indices of abundance, and the factors controlling the abundance and distribution of fingerling bass in Nacimiento Reservoir. Large numbers of fingerlings were collected in years when water levels were stable or rising during the spawning period, when the elevations of surface waters were high in April and May, and when the densities of threadfin shad were low. Poor year classes of 1966 and 1968 were associated with declining water levels

between May and June, but there was no evidence of exposed nests before the hatching and development of sac fry. The distribution of brush and other forms of cover were such that more cover was available when water levels were high. Increased cover may have provided increased shoreline stability by reducing wave action and thereby enhancing the survival of eggs and fry. Although the production of large year classes in alternate years suggests that yearling bass may have depressed fingerling survival, the effect is considered minor. An inverse relation between the abundance of fingerling bass and adult threadfin shad suggests that food competition is an important factor limiting bass year classes.

von Geldern, C. E., Jr. and D. F. Mitchell. 1975. Largemouth bass and threadfin shad in California. Pages 436-449 in H. Clepper, ed. Black Bass Biology and Management. Sport Fishing Inst., Washington, D. C.

339. Early introductions of threadfin shad in California reservoirs were generally successful, resulting in increased forage for predators and increased production by black basses. Several studies discussed show that shad compete with young bass for food (primarily zooplankton) and that survival of young-of-year bass is greatly reduced as a result. Age-0 shad did not provide forage for bass that hatched late in the spawning season. Management programs to improve survival of young-of-year bass are recommended. Reducing water-level fluctuations during the spawning season is one measure that is expected to improve survival of newly hatched bass.

Wajdowicz, Z. 1964. The development of ichthyofauna in dam reservoirs with small variations in water level. Acta Hydrobiol. 6: 61-79.

340. The development of fish populations in the Goczalkowice and Kozlowa Góre reservoirs -- two large, shallow impoundments with stable water levels -- is described. In reservoirs, water-level fluctuations play a decisive role in the formation of fish populations. In reservoirs with slight water-level fluctuations (unlike those with extensive fluctuations) the decline of northern pike is gradual after its exponential expansion during the years of reservoir filling. The rapid and extensive development of pike populations results from excellent spawning conditions when rising water levels inundate grassy terrain. Fluctuations in water level, loss of original turf, and angling all reduce populations. In stable reservoirs, shallow areas develop aquatic and semi-aquatic vegetation which provides new spawning areas for pike. The loss of rheophilic fishes is complete and more rapid in reservoirs with stable water levels than in those with fluctuating levels.

Wajdowicz, Z. 1979. Development of the ichthyofauna in the cascade of the San River. Acta Hydrobiol. 21: 73-90.

341. The development of the fish fauna in reservoirs at Solina and Myczkowce, Poland, was studied by analyzing fish harvest. These two mountain impoundments have high long-term and daily water-level fluctuations that influence the species composition and relative abundance of fish.

Walburg, C. H. 1972. Some factors associated with fluctuation in year-class strength of sauger, Lewis and Clark Lake, South Dakota. Trans. Am. Fish. Soc. 101: 311-316.

342. Strength of sauger year classes in Lewis and Clark Lake has fluctuated widely since the reservoir was inundated in 1956. Year classes were above average in years when power-peaking operations (at Fort Randall Dam, during the spawning season) and water exchange rate (of Lewis and Clark Lake in June) were minor. About 80% of the variation in year-class strength (estimated from catches of fish of age 7 or older) was explained by changes in four variables: (1) water level over spawning grounds, (2) reservoir water temperature in June, (3) the rate of water exchange, and (4) the minimum daily air temperature for 21 days after initial spawning.

Walburg, C. H. 1976. Changes in the fish population of Lewis and Clark Lake, 1956-74, and their relation to water management and the environment. U. S. Fish Wildl. Serv., Res. Rep. No. 79. 34 pp.

343. Sampling of fishes in Lewis and Clark Lake from 1956 to 1974 indicated that abundance decreased 66%, and the number of species decreased 20%. After 1969, a decrease in the rate of water exchange from 10 to 4 or 5 days was harmful to fish populations, partly because larval fish were discharged through the dam. The abundance of young-of-year fishes was directly related to the water exchange time ($\underline{P} < 0.02$, $\underline{r} = 0.73$), as was the catch of young fish by trawl ($\underline{P} < 0.05$, $\underline{r} = 0.68$). The year-class strength of freshwater drum and channel catfish was correlated with the mean rate of water exchange in July-August. Water levels late in the 1956-74 period were low and variable from 1 March through 15 July. This regime had a detrimental effect on spawning success of near-shore spawners such as gizzard shad, emerald shiners, white bass, white crappies, and yellow perch. The spawning success of nest builders such as white crappies was especially poor when water levels fluctuated in the spring, but was good in years when levels were stable or rose slightly. Year classes of fishes requiring inundated terrestrial vegetation were poor after normal operations (i.e., low, irregular water levels in the spring and summer) were established. Spawning success of some species was unaffected by water level (e.g., freshwater drum, which spawn pelagically; channel catfish, which spawn at depths exceeding those influenced by

fluctuations in water level; and walleyes and saugers which spawn in the Missouri River). Although the reproduction of walleyes and saugers was unaffected, the low abundance of young forage fish -- a direct result of water-level fluctuations -- may have influenced their growth and survival. Decreased growth of saugers paralleled the decreased abundance of small fishes in the reservoir.

Walburg, C. H. 1977. Lake Francis Case, a Missouri River reservoir: changes in the population in 1954-75, and suggestions for management. U. S. Fish Wildl. Serv., Tech. Pap. No. 95. 12 pp.

344. Twenty-three years of study of Lake Francis Case have documented a decreasing abundance of fish; 12 species were abundant in the 1950's, compared with only eight in the 1970's. Changes in the species composition and abundance were determined by reproductive success, as affected by water-level fluctuations and changes in spawning habitat. Water levels during spring and summer are determined primarily by reservoir operations and the amount of snowfall. In low-water years, such as those in 1968-70, terrestrial and semi-aquatic vegetation invaded shallow-water areas of embayments. When this vegetation was flooded in high water years such as 1971 -- especially in May and June -- excellent spawning and nursery conditions resulted in the production of enormous numbers of young-of-year (YOY) fishes. The annual catch of YOY fish from 1966 to 1975 was significantly correlated with changes in water levels between May and June ($\underline{r} = 0.80$; $\underline{P} < 0.01$). The abundance of YOY yellow perch and walleyes was closely correlated with water-level changes. Investigations demonstrated the detrimental effect of fall drawdowns on periphyton and benthos, and showed that the maintenance of high water levels in the fall significantly increased the standing crop of benthos. A 3-year cycle of pool-level management is recommended, as follows: maintenance of relatively low water levels for two consecutive years to encourage the development of shoreline vegetation, followed by high spring water levels maintained through July of the third year. Some independence from primary use requirements might be obtained in one reservoir if the series of Missouri River impoundments were operated as a system.

Walburg, C. H. and W. R. Nelson. 1966. Carp, river carpsucker, smallmouth buffalo, and bigmouth buffalo in Lewis and Clark Lake, Missouri River. U. S. Fish Wildl. Serv., Tech. Pap. No. 69. 30 pp.

345. Information on the age composition, growth, reproduction, and food habits of four species of fish in Lewis and Clark Lake is presented. Strong year classes of all species were produced in the first two years of impoundment, but later year classes were weak. Rising water levels during the spawning period apparently are important to successful spawning of common carp, river carpsucker, smallmouth buffalo, and bigmouth buffalo. Unsuccessful spawns were attributed to existing practices of water-level management, which resulted in low or fluctuating levels during the spawning season.

Webb, J. F. and D. D. Moss. 1967. Spawning behavior and age and growth of white bass in Center Hill Reservoir, Tennessee. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 21: 343-357.

346. From October 1965 to March 1967, studies were conducted to document spawning behavior, age and growth, and food of white bass in the headwaters of Center Hill Reservoir, Tennessee. A drop in lake level (4 feet in 22 days) exposed and destroyed millions of white bass eggs in 1966. Perhaps stable water levels during spawning would have improved the 1966 year class. Walleye eggs also were exposed, but few were seen.

Weber, D. T. 1968. Narrows pre-impoundment investigations. Colorado Dep. Game Fish Parks, Fed. Aid Proj. F-41-R-2. Progress Rep. 56 pp.

347. The principal emphasis in this study was pre-impoundment sampling of fish populations of the South Platte River near the proposed dam and the formation of preliminary recommendations for fishery management of the proposed reservoir. The impact of water-level fluctuations is discussed briefly, based on published information. A 15-year analysis of the hydrology of the South Platte River suggests that water levels rise from November to June and decrease from July through October. Receding water levels are expected to influence the survival of certain species, if they recede during spawning. Most game species are expected to spawn successfully if colder waters do not delay spawning into the fall drawdown phase. The author suggests that the spawning time of most species can be estimated by knowing reservoir water temperatures, and that the water levels can be controlled more precisely to enhance or control the reproductive success of selected species.

Wegener, W. and V. Williams. 1974. Fish population studies. Florida Game Fresh Water Fish Comm., Fed. Aid Proj. F-29. Job No. I. 28 pp.

348. Drawdown and reflooding of Lake Tohopekaliga has had little effect on the condition of black crappies, bluegills, and redear sunfish. Overall, success of fishermen increased from 1.6 fish per hour before drawdown to 3.0 afterward. Low water levels limited access for fishermen, and total effort and harvest remained below pre-drawdown levels. Effort and harvest of largemouth bass consistently increased after drawdown and reflooding, although the success rate of anglers remained unchanged. Harvest of black crappies declined substantially and remained low until 2 years after the drawdown (winter of 1973-74), when harvest exceeded pre-drawdown levels and angler success was the highest observed during the study. Harvest and effort by panfish anglers declined during and after reflooding of the lake, but success increased slightly.

Wegener, W. and V. Williams. 1974. Organic deposition studies. Florida Game Fresh Water Fish Comm., Fed. Aid Proj. F-29. Job No. 4. 18 pp.

349. Dewatering reduced the depth of organic sediments by 50 to 80%. New organic materials deposited after reflooding consisted primarily of decomposing water hyacinth and algae. Observations on sediment decomposition indicated that improved condition of littoral sediments will last only a few years, and this fact shows the importance of frequent drawdowns in the future. Appreciable amounts of CO_2 were released from drying organic sediments.

Wegener, W. and V. Williams. 1974. Algae monitoring studies. Florida Game Game Fresh Water Fish Comm., Fed. Aid Proj. F-29. Job No. 5. 28 pp.

350. Responses of algae populations to dewatering and reflooding of Lake Tohopekaliga were variable. Diversity of green and blue-green algae increased when littoral areas were initially flooded. Diversity of other major groups remained essentially the same. Bloom conditions became more frequent as the study progressed (especially for blue-green algae), as a result of increased nutrient concentrations that originated from sewage effluent.

Wegener, W. and V. Williams. 1974. Water chemistry studies. Florida Game Fresh Water Fish Comm., Fed. Aid Proj. F-29. Job No. 6. 22 pp.

351. Concentrations of most chemical constituents increased during drawdown and decreased as Lake Tohopekaliga was refilled, though concentrations on refilling of the lake were higher than before drawdown. Although most physical and biological characteristics improved after drawdown, water quality deteriorated due to sewage-plant discharges into the lake.

Wegener, W. and V. Williams. 1974. Extreme drawdown, a working fish management tool. Florida Game Fresh Water Fish Comm., Fed. Aid Proj. F-29-R. 11 pp.

352. Fishery data collected from Lake Tohopekaliga indicated that drawdown apparently funneled energy flow into the fishery, inasmuch as standing crops and yields of fish increased after drawdown. Some benefits derived from drawdown were short-lived, and therefore extreme drawdowns should be repeated about every 7 years.

Wegener, W. and V. Williams. 1974. Fish popolation responses to improved lake habitat utilizing extreme drawdown. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 28: 144-161.

353. Water levels of Lake Tohopekaliga were limited to a 3-foot annual

fluctuation by the Central and Southern Florida Flood Control District. In 1971, a drawdown that exposed 50% of the lake bottom was effected to improve the sport fishery and water quality of the 22,700-acre reservoir. The drawdown pool was maintained for 6 months, and refilling of the reservoir to normal pool required another 6 months. Water levels continued to rise above normal pool throughout the following year. Fish samples from coves (by application of rotenone within a blocked area) indicate that littoral standing crops increased from 191 to 455 pounds per acre within 2 years after the basin was reflooded. Biomass of sport-fish almost doubled, though forage fish accounted for a higher percentage of community biomass after reflooding of the impoundment. Numbers of harvestable-sized sport fish increased, as did the monetary value of the fishery (by 37%). Chain pickerel was the only sport fish that was adversely affected by dewatering. Bluegill populations declined during drawdown and early reflooding, but strong year classes were produced in the spring of the next two years (1972 and 1973). Redear sunfish seemed to benefit by dewatering and low water levels.

Wegener, W. and V. Williams. 1977. The effect of extreme lake drawdown on largemouth bass populations. Paper presented at Big Bass Seminar, December 2-4, 1977. Florida Game Fresh Water Fish Comm. 25 pp.

354. Largemouth bass reproductive success, survival, and growth rates improved after a 7-foot drawdown of Lake Tohopekaliga, Florida. Flocculent organic sediments in exposed areas were reduced 50 to 80%. Desirable aquatic vegetation expanded and became more diverse. As a result, production of fish-food organisms was stimulated: within 1 year, numbers of amphipods per standard sample unit (5 net sweeps = ca. 1.38 m^3) increased from 178 to 465; grass shrimp increased from 2.6 to 65.8, water boatmen from 0 to 61.1; and crayfish from 0 to 0.2. Standing crop of fishes increased 138% in 3 years, from 191 to 455 pounds per acre. Bass biomass increased from 35 to 60 pounds per acre in the first year after drawdown. Angler harvest of largemouth bass decreased slightly during the drawdown of 1971, but increased thereafter and peaked in 1975. The harvest was 4 times greater than in 1970. On this basis, extreme drawdown is recommended every sixth year. The number of bass caught during reflooding of Lake Kissimmee increased 18% over that before the drawdown.

Wegener, W., V. Williams, and T. D. McCall. 1974. Aquatic macroinvertebrate responses to an extreme drawdown. Proc. Annu. Conf. Southeast. Assoc. Game Fish. Comm. 28: 126-144.

355. Water levels of Lake Tohopekaliga were drawn down 7 feet from the maximum pool elevation in 1971, exposing 50% of the basin bottom for 6 months. Because of drought, the lake was not completely refilled for an entire year. Drawdown improved littoral substrate and increased the density and diversity of aquatic macrophytes and benthos. After reflooding of the basin, the density of benthic macroinvertebrates per square foot increased from 98 to 244 (limnetic), 154 to 250 (littoral),

and from 304 to 1364 (on or associated with macrophytes). Densities returned to levels characteristic of the pre-treatment period within 2 years. The decline in numbers was associated with increases in the number of fish and invertebrate predators. Sport fishes that ate macroinvertebrates nearly doubled in weight, from 151 to 236 pounds per acre in the littoral zone and from 34 to 54 pounds per acre in the limnetic zone.

White, D. S. and S. J. White. 1977. The effect of reservoir fluctuations on populations of Corbicula manilensis (Pelecypoda: Corbiculidae). Proc. Oklahoma Acad. Sci. 57: 106-109.

356. Fluctuations in water level greatly reduced populations of the Asiatic clam in Lake Texoma, Oklahoma. Clams were most numerous near the shore in 2-30 cm of water. A drop in water level from August through February 1976 stranded so many clams that their shells formed wind rows along beaches. Laboratory experiments showed that clams exhibited 50% mortality after 4 days of desiccation, 75% after 6 days, and 90 to 98% after 10 days.

Whitehouse, J. W. 1971. Some aspects of the biology of Lake Trawsfynydd; a power station cooling pond. Hydrobiologia 38: 253-288.

357. In Lake Trawsfynydd, Wales, water levels fluctuated ± 1.5 m about mean sea level in response to water discharge for generating electric power. Beginning in 1962, the lake also provided cooling water for a nuclear power plant. Rising and falling lake levels intermittently exposed and reflooded the shore and prevented the growth and survival of aquatic macrophytes and the development of littoral benthos. There was no true profundal fauna, and the abundance of sub-littoral benthos (chironomids and oligochaetes) was patchy. Zooplankton did not seem to be affected by fluctuating water levels.

Wickliff, E. L. 1932. Are newly impounded waters in Ohio suitable for fish life? Trans. Am. Fish. Soc. 62: 275-277.

358. Fish productivity of 12 Ohio impoundments was compared on the basis of physical, chemical, and biological variables. Substantial populations of crustaceans and algae were found in all reservoirs, regardless of reservoir age. The number of benthic animals was as high in new as in old reservoirs. Detrimental effects of fluctuating water levels are mentioned in relation to fish spawning and the establishment of aquatic vegetation.

Wiebe, A. H. 1938. Limnological observations on Norris Reservoir with special reference to dissolved oxygen and temperatures. Trans. North Am. Wildl. Conf. 3: 440-457.

359. Thermal stratification and the distribution of dissolved oxygen, free carbon dioxide, pH, and total alkalinity were studied in Norris Reservoir. A dissolved oxygen minimum at 40 feet was caused by subsurface movements of stagnant water from the head of the reservoir to the dam. These subsurface movements were accelerated by drawdown. In the fall, as drawdown continued, the depth of the thermocline and oxygen minima increased due to the influx of fresh water from inflows. Eventually the thermocline disappeared and summer stratification ended before the normal fall turnover.

Wiebe, A. H. 1960. The effects of impoundments upon the biota of the Tennessee River system. Seventh Tech. Meeting, Internat. Union for Conserv. of Nature and Natural Resour., Greece, 1958. Vol. 4: 101-117.

360. Operations of reservoirs on the Tennessee River are described. Effects of impoundment on invertebrates, fisheries, and waterfowl are discussed. Water levels are manipulated to provide for flood control, hydropower generation, and mosquito control. Annual patterns of water-level fluctuation are related mainly to the hydrological cycle -- waters usually rise to a maximum in March due to spring rains and recede to some minimum level in December. The extent of drawdown varies greatly among reservoirs -- from less than 10 feet in mainstream reservoirs to as much as 150 feet in storage reservoirs during severe drought. By maintaining water at some constant level late into the growing season, terrestrial plants that provide mosquito habitat do not develop in dewatered areas, and fish spawning and early growth stages of fish benefit.

Wilson, K. D. 1959. Report of the second fall and winter drawdown on Blue Mountain Lake. Arkansas Game Fish Comm., Fed. Aid Proj. F-1-R. 8 pp.

361. The second drawdown of Blue Mountain Lake was designed to aerate bottom muds, remove rough and commercial fishes, concentrate forage fishes for greater predation by sport fishes, and allow seeding of rye grasses. Preliminary results indicate that the drawdown augmented low flows downstream and improved the flood-control capacity of the impoundment, at least for one year. Fishing on the main body of the lake decreased greatly during drawdown, but remained relatively stable in upstream areas. Population samples contained a larger proportion of predators (by number and weight) than samples taken a year before drawdown. Fishing pressure may have become less seasonal, as suggested by a poll of boat-dock operators.

Wood, R. 1951. The significance of managed water levels in developing the fisheries of large impoundments. J. Tenn. Acad. Sci. 26: 214-235.

362. Progress in developing fish and wildlife resources associated with impoundments has been impeded by a scarcity of sound techniques for management and by the fact that most management programs designed to enhance fisheries conflict with those designed to enhance wildlife. Programs to enhance fish and wildlife resources frequently conflict with the primary purpose of the project and with malaria control. To provide a basis for further study, the author reviews literature published before 1950 pertaining to water-level fluctuation and its relation to basic fertility of impoundments, fish populations and management, and increased yields of fish. Productivity of reservoirs depends on the fertility of the watershed and the availability of essential plant nutrients from bottom soils. Management of water levels to alternately expose and flood bottom soils can be a valuable method for maintaining productivity of large impoundments, especially if plants are introduced or permitted to grow on exposed soils, thereby enhancing the release of nutrients from soils. Upon reflooding, available nutrients and improved clarity of waters result in increased productivity. Fishing success and quality depend on the type of fish present and the productivity of the reservoir. The best fishing is provided by expanding populations (which are characteristic of new impoundments and which provide the best management possibilities) and by balanced populations, especially if most of the biomass is composed of game fishes. Drawdown has been effective in restoring the balance between predators and prey and between rough and game fishes, either by itself or as a facilitative technique. The composition of fish present will depend not only on the initial populations but also on habitat conditions for spawning and feeding and on rates of harvest. Habitat favorable to desirable fish populations may be produced by management of water levels. Manipulation of water levels may be used to increase fishing success and fish yield by concentrating sport fish around preferred habitat such as newly inundated areas or structures.

Wood, R. and D. W. Pfitzer. 1960. Some effects of water-level fluctuations on the fisheries of large reservoirs. Seventh Tech. Meeting, Internat. Union for Conserv. of Nature and Natural Resour., Greece, 1958. Vol. 4: 118-138.

363. Speculation, concepts, and experiments concerning the effects of water-level fluctuation on fish and fisheries are reviewed to evaluate the progress of biologists in developing an understanding of the relations. Fish-population data from five reservoirs with different patterns of fluctuation are presented. Data suggest that fish are affected by the season, frequency, stage, and duration of fluctuations, as well as by basin morphology. Different aspects of fluctuations (time, duration, rate, magnitude, and direction of changes) affect the productivity, species composition, and predator-prey ratios of fish communities. Evidence suggest that the ratio of area at maximum pool to that at minimum

pool is a good indicator of sport-fish productivity in most of the reservoirs discussed. High ratios indicate a great deal of overflow over relatively shallow areas; whereas, low ratios indicate steep-sided basins. Effects of water levels apparently depend more on the time and duration of flooding than on the degree of vertical fluctuation. Fertility of soils and basin topography are factors enhancing the effects of water-level fluctuations. When employed discreetly and carefully, manipulation of water levels can be an effective tool for fishery managers.

Wright, J. C. 1950. The limnology of Atwood Lake, a flood control reservoir. Ph.D. Thesis, Ohio State Univ., Columbus, Ohio. 157 pp.

364. A large volume of information is given on all aspects of the limnology of Atwood Lake, with special reference to the effects of limnological factors on production of sport fishes. Atwood Lake was drained in October 1964 to reduce the large population of common carp and to improve sport-fish production. When the lake was refilled to conservation pool it was stocked with bluegills, largemouth bass, yellow perch, and channel catfish. Productivity at all trophic levels was low prior to draining, but zooplankton biomass and growth rates of fish increased after water levels rose in 1947 and inundated large amounts of organic matter. Standing crops of zooplankton were high in 1948 but declined in 1949. Productivity -- not the activity of carp -- is believed to be the factor limiting sport-fish production.

Wright, J. C. 1954. The hydrobiology of Atwood Lake, a flood-control reservoir. Ecology 35: 305-316.

365. A two-year study of the physical, chemical, and biological characteristics of Atwood Lake, Ohio, provided the basis for evaluating game-fish production and the effects of draining the reservoir. Draining in 1946 revealed that fish populations consisted primarily of emaciated black crappies and white crappies, stunted bluegills, common carp, and gizzard shad. A small population of largemouth bass was present. Phytoplankton standing crops were low throughout the study, but phytoplankters were more abundant in 1949 than in 1948, the first year after refilling. When water levels rose in 1947, large amounts of organic matter were available to zooplankton. Zooplankton standing crops were high in summer 1948, particularly in areas flooded for the first time. Decreased zooplankton biomass in 1949 apparently was related to continued decay of inundated organic matter. The biomass of benthos was low throughout the study and correlated to the low production of phytoplankton. After the lake was reflooded, the growth of fish was rapid in the first year but declined in the second year. Largemouth bass was the only species that grew fast enough to provide good fishing.

Yakovleva, A. N. 1971. Natural reproduction of fish in the Volgograd Reservoir. Tr. Sarat. Otd. Gos. Nauchno - Issled Inst. Rechn. Ozern. Rybn. Khoz. 10: 107-128. (In Russian)

366. Upper, middle, and lower zones of the Volgograd reservoir were differentiated according to hydrological properties. Natural reproduction of fish was more efficient in the upper and middle zones than in the lower zone. Drops in the reservoir water level each spring disrupted spawning. In the middle zone, intensive erosion of shores and the resulting weak development of water plants adversely affected fish production. A decrease in water level by 1-1.5 m caused egg mortality and delayed spawning. The reservoir conditions were more favorable for Volga pike-perch, pike, and perch than for lithophilic and phytophilic fish, except for bream, catfish, and white bream. Among commercially valuable fish, wild carp and pike had very low spawning efficiencies. (From Referat. Zhur. Biol., 1971, No. 9I210; Biol. Abstr. 54: 18931.)

Zweiacker, P. L., R. C. Summerfelt, and J. N. Johnson. 1972. Largemouth bass growth in relationship to annual variations in mean pool elevations in Lake Carl Blackwell, Oklahoma. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 26: 530-540.

367. Growth of first- and second-year largemouth bass was related to mean annual water levels, as water levels declined from 1962 through 1967. The relation was positive in first-year bass ($r = 0.85$; $P < 0.035$) and negative for second-year bass ($r = -0.95$; $P < 0.004$). It was hypothesized that the growth of small bass declined because of the negative effect of dewatering on invertebrates in the littoral zone. The increased growth of second-year bass probably resulted from a greater vulnerability of forage fish to fish predators as water levels receded. Growth rates of third- and fourth-year bass were not significantly correlated with declining water levels.

APPENDIX A: SUBJECT INDEX TO ANNOTATIONS

1. This index has been included to facilitate use of the annotated bibliography. Topics have been broadly grouped into biological, taxonomic, and limnological areas to increase the flexibility of the index, allowing a user to identify citations on general or specific subject areas. For example, a user may require general information on the effects of drawdown on the reservoir ecosystem. By looking under "Drawdown" within the limnology section, the user can identify the following 106 citations (listed by paragraph number):

Drawdown 7, 22, 29, 30, 31, 32, 36, 37, 38, 39, 42, 46, 47, 49, 51, 54, 59, 61, 62, 67, 70, 72, 77, 78, 79, 84, 85, 88, 93, 98, 99, 102, 105, 108, 112, 113, 122, 124, 129, 130, 131, 139, 140, 145, 150, 151, 152, 156, 162, 164, 165, 168, 170, 183, 190, 191, 192, 193, 194, 202, 204, 206, 207, 213, 214, 221, 223, 226, 232, 253, 255, 260, 261, 265, 268, 272, 275, 282, 283, 286, 290, 295, 303, 304, 305, 306, 311, 212, 320, 328, 334, 335, 344, 347, 348, 349, 351, 352, 353, 354, 355, 359, 360, 361, 362, 365.

2. However, the user may require more specific information, such as the effects of drawdown on growth of reservoir fish. By selecting references that occur under both "Drawdown" and "Growth," the user can identify the following 23 citations (underlined):

Growth 6, 11, 12, 17, 20, 22, 32, 51, 52, 53, 54, 59, 63, 66, 71, 77, 95, 100, 104, 106, 109, 112, 116, 120, 130, 131, 137, 138, 140, 146, 149, 154, 164, 165, 166, 176, 177, 181, 182, 183, 185, 191, 192, 193, 205, 207, 208, 217, 219, 220, 221, 223, 229, 232, 234, 235, 241, 248, 250, 254, 258, 259, 267, 269, 274, 276, 281, 293, 294, 297, 307, 311, 316, 323, 324, 331, 339, 348, 354, 364, 365, 367.

3. Even more specific information may be obtained, such as the effects of drawdown on the growth of black basses. The following 11 (underlined) references were located by identifying citations under the above two areas and under "black basses" within the taxonomic section:

black basses 11, 12, 15, 20, 21, 22, 32, 34, 35, 37, 38, 39, 41, 49, 52, 66, 76, 80, 84, 100, 104, 117, 138, 139, 140, 146, 148, 151, 152, 164, 165, 168, 169, 170, 172, 175, 181, 185, 192, 193, 195, 201, 203, 204, 207, 215,

4. The subject index follows, beginning on the next page.

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