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THE EFFECT OF WATER CIRCULATION AND AERATION ON WATER QUALITY AND PRODUCTION OF CATFISH IN A CLOSED SYSTEM

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VITA

Catalino del Rosario dela Cruz, son of Francisco and Eufrocina (del Rosario) dela Cruz, was born on 30 April, 1942 at Bicos, Rizal, Nueva Ecija, Philippines. He was first educated at Bicos Elementary School, graduating in April, 1953. He attended Talavera Provincial High School, Talavera, Nueva Ecija, Philippines, graduating in April, 1957. From 1959 to 1964, he attended the Central Luzon State University, Nueva Ecija, Philippines and received the degree of Bachelor of Science in Agricultural Engineering in May, 1964. In August, 1967 he was awarded an AIT scholarship and enrolled at the Asian Institute of Technology (AIT), a graduate school in engineering in Bangkok, Thailand. He received his Master of Engineering degree, major in hydraulic engineering, in May, 1969. Since 1965, he taught in the Department of Agricultural Engineering, Central Luzon State University. In August, 1971, he was admitted to Auburn University to pursue a doctoral degree in fisheries management under the NEDA (Phil)-US/AID study grant. He married Celia, daughter of Constantino and Segunda (Tan) Derecho, on September 18, 1971,at Livingston, New Jersey, USA. They have a son, Constantine Francis (Bing-bong), who was born on May 28, 1972.

DISSERTATION ABSTRACT

THE EFFECT OF WATER CIRCULATION AND AERATION ON WATER QUALITY AND PRODUCTION OF CATFISH IN A CLOSED SYSTEM

Catalino del Rosario dela Cruz

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(B.S., Central Luzon State University, 1964)

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A series of experiments was conducted in 1/200-acre ponds in 1972 and 1973 to evaluate the effect of water circulation-aeration and filtration on water quality and catfish production. Circulation-aeration by paddle wheel, and by venturi pump through underwater and overhead gravel filters were tested.

The 1972 series was designed to determine the standing crop that each system could support. The paddle wheel and overhead filter systems utilized waste settlement ponds while the underwater filter did not. Water hyacinths were grown in each to remove nutrients. Each system was stocked with 100 lbs/pond in three replications.

The paddle wheel system had the greatest survival and maintained adequate water quality. Highest standing crop was attained in the underwater filter system. This sytem had water quality comparable to the paddle wheel system. The greatest standing crop produced in the overhead filter system was 134 lbs with an average of 64.4 lbs in three replications. Mortality was attributed to D.O. depletion and high CO_2.

The 1973 series was designed to produce harvestable size of fish from fingerlings over a six-month growing season. Each system was stocked with 200 or 400 fingerlings per replication.

The greatest net production of fish in the paddle wheel system was 38.8 lbs in 137 days. The underwater filter produced more fish and maintained the best water quality. Fish production was lowest in the overhead filter system. Extensive and chronic mortalities in the systems were significantly correlated with low D.O., high NH_3, NO_2, and CO_2.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

Considerable interest has been shown during recent years in the intensive culture of fishes and other aquatic animals using a closed system. It was demonstrated in the culture of catfish in ponds that production is limited to approximately 1.5 tons per acre per year. By effecting a water circulation, with air released near the bottom of ponds, approximately 2.5 tons per acre have been produced. Experimentally, Greene (1969) produced up to 19,300 lbs per acre of channel catfish in 0.005-acre concrete ponds by circulating water through gravel biofilters in a closed system. In addition to higher production, intensive catfish culture in a closed system has other attractive aspects. Feeding and harvesting operations can be simplified and more easily mechanized. The fish are more observable for disease control and growth rate measurements.

Closed system culture has as its objective maximum economical fish production in a given volume of water. This is achieved by stocking fish at a high rate which are entirely dependent on feeds rather than natural foods. The system works as long as the water quality is maintained within the limits necessary for the normal and healthy growth of fish. The cost of operating the water circulation and aeration equipment is a major consideration in the commercial production of channel catfish.

With high standing crop and heavy feeding, the water quality deteriorates rapidly with oxygen depletion and production of objectionable chemical substances such as carbon dioxide, nitrogenous compounds and other organic wastes. High concentrations of these substances cause fish mortality and abnormal or stunted growth. Oxygen depletion results from the respiration of fish, plankton, and the oxidation of organic wastes. Organic wastes such as excess feed, fecal matter and dead algae demand oxygen during microbial decomposition and by-products of microbial respiration, carbon dioxide, and ammonia are produced in significant amounts. The fish also produce carbon dioxide and ammonia. These compounds enrich the water, encouraging phytoplankton growth which is not desirable in a closed system due to high oxygen requirement at night. Furthermore, when poor quality of water prevails, fish are under stress and epizootics of parasites and diseases are likely.

The deterioration of water quality can be minimized with the use of appropriate devices for aeration and filtration. The aerating devices replenish oxygen, while the filtration process cleans the water by the removal of suspended solids and metabolic wastes and by facilitating its stabilization through the action of microorganisms. Spotte (1970) gave three types of filtration used in closed system culturing: biological, mechanical, and chemical filtration. Of these, biological is the most important. Combinations of any two or all of these are common in other systems requiring a high degree of water purification.

Data on the feasibility of intensive catfish culture in a closed system are limited to experimental models. Research findings indicate that some techniques have some potential in increasing fish production. Further explorations, modifications, and combinations of the promising methods will eventually lead to more profitable and simple closed system culturing.

The objective of this research was to investigate the performance of biological filtration, mechanical circulation-aeration, and the combination of both, coupled with waste disposal systems. Evaluation was based on the resulting water quality, mortality and growth of the fish population.

Catfish were chosen because of their high economic value not only in the United States and Asian countries, but in other parts of the world as well.

II. REVIEW OF LITERATURE

Aeration and circulation of water.

Some of the research on the mechanical aeration and circulation of water in lakes and reservoirs dealt with the prevention of oxygen depletion and improvement of water quality. Merna (1965) and Flick (1968) used aeration technique in the prevention of winterkill of fish. During the winter season, lakes in some places are covered with thick snow or ice which prevents light penetration for effective photosynthesis. Oxygen depletion occurs, resulting in winterkill of fish. During summer months, thermal stratification usually exists in lakes and reservoirs. Thermal stratification usually results in deterioration of drinking water quality, uneven distribution of ions, anaerobic and corrosive conditions, increased evaporation rate and other undesirable properties within the lake (Fast, 1966). Some investigators (Fast, 1966 and 1968; Wirth and Dunst, 1967; and Irwin, et al., 1967), made studies on artificial destratification of reservoirs through water circulation and aeration during the summer season, and on reservoirs having spring and autumn over-turns which suffered periodic stratification (Bryan, 1965). Practically, all of the above mentioned investigators claimed successful results in improving the quality of water, living environment of aquatic organisms and increasing fish production as a whole as a result of circulation and aeration techniques.

Mechanical methods of aeration and water circulation. The two principal means of producing water current and turbulence causing mixing are accomplished by introducing air at or near the bottom of water body and lifting the bottom water to the surface through mechanical means. For large lakes and reservoirs with stratification, air compressors and aero-hydraulic guns are more useful than water pumps. The latter are slow, inefficient, and costly (Fast, 1966). On the other hand, in small and shallow lakes, better results are obtained using centrifugal pumps to circulate the water than air compressors (Merna, 1965; Flick, 1968; and Hooper, et al., 1952). In an experimental fish pond situation, Jeffrey (1969) and Loyacano (1970) used a rotary-positive blowers to deliver air through plastic pipes to earthen ponds. Marek et al. (1971) used a small compressor with air being supplied through a network of space perforated tubes or pipes installed in parallel and connected perpendicularly from the larger main line. A closed system experiment was done by Busch, et al. (1973) and Pawaputanon (1972) using small capacity pumps to circulate water passing over different treatments, namely: splash boards, biofilters, through sprinkling, and by air-injection venturi as a means of aeration. These pond experiments all indicated highly significant differences in terms of fish production. In two different ponds, Jeffrey (1969) and Loyacano (1970) increased white catfish production from 2,020 lbs/acre to 2,710 lbs/acre and from 2,442 lbs/acre to 4,920 lbs/acre, respectively with the use of aeration. Marek, et al. (1971) reported an increase of 120 to 540 per cent above the maximal standard yield with aeration. The mean total production for the five aerating treatments ranged from 5,753 to 6,327 lbs per acre against no aeration of 1,260 lbs per acre in the experiment done by Busch, et al. (1973) and Pawaputanon (1972).

Biological purification and filtration. Since 1967, experiments in purifying pond water by means of living animals, plants and biofiltration have been conducted at the Fisheries Research Unit, Auburn University. Goldfish, Carassius auratus and Tilapia aurea, both filter feeders, were used in removing organic matter (anonymous, 1968). Results of studies (anonymous, 1968 and Smith, 1970) done in concrete and earthen ponds showed a higher production of fish in mixed culture of Tilapia and channel catfish than a monoculture production of channel catfish. Smith (1970) found that channel catfish production could be raised from 3,699 lbs/acre to 4,725 lbs/acre by adding Tilapia to the ponds.

The Asian clam, Corbicula manilensis (Philippi), found to be highly resistant to low oxygen concentration was used as a filter feeder of the detritus and organisms (Greene, 1969). Channel catfish and Corbicula were stocked in plastic pools with mud bottoms. The clams initially cleaned the water very well but rooted vegetation grew excessively. Clams later died because of unusually high temperature which reached 95°F or greater for two to three weeks.

According to Boyd (1970), water hyacinths are an ideal plant for removal of nutrients from enriched waters. Hyacinths float on the water surface and are able to remove nutrients directly from the water, thus, competing directly with phytoplankton for nutrients. McVea, et al. (1973) found that water hyacinths removed 239 pounds N and 32 pounds P per acre from the water over a five-month period. Phytoplankton population decreased with increasing amounts of hyacinths, causing a decreased fish production.

A number of studies was conducted on water circulation and biofiltrations. Greene (1969) studied various arrangements of filters, namely: elevated, rock and gravel filters, submerged gravel and gravel-charcoal filters, and submerged sand filter. The elevated filter indicated better fish production than the submerged filter. Further, gravel of 0.5 to 1 inch size used for filter gave the best results.

Spotte (1970) recommended that gravel for biological filters be 2 to 5 mm (0.08 to 0.20 inch) in size, with irregular and angular surface. He added that surface area of the filter bed is more important than the volume of water because most of the biological activity in the filter bed is concentrated in the upper layers. It was shown in a marine system that the population of ammonia and nitrite oxidizers was reduced by 90 per cent from the top portion of the filter to a depth of 5 cm (2 inches).

Green, et al. (1965) removed 49 to 95 per cent of organic matter and 40 per cent of ammonia at 20 and 30°C by trickling water through a biofilter using stainless steel screens in place of gravel.

Feeding, pond carrying capacity and water quality.

According to Shell (1966), the relationship between rate of feeding and rate of conversion is important in fish culture. If fish are fed at too high a rate, much of the food is wasted and even though growth may be excellent, the cost of production is excessive. Further, uneaten feed decaying in water may build up faster than they can be reduced, thus, essentially leading to oxygen depletion or other problems causing detrimental effect to fish growth (Shell, 1966 and Allen, 1971).

Gray (1969) mentioned that feeding should be reduced when there is a "heavy phytoplankton bloom" which frequently leads to low oxygen levels or to an oxygen depletion which will cause a fish kill. Boyd (1973) demonstrated that the rates of oxygen consumption by living planktonic communities ranged from 0.60 to 8.30 mg/1/24 hr at 30°C. The average was 3.24 mg/1/24 hr. Consumption of oxygen increased markedly with temperature between 15 and 35°C.

Andrews, et al. (1971) found that inefficient food conversion and decreased average weight per fish did not occur as a result of higher density (crowding effect) as long as adequate water quality was maintained. The Fish Farming Experimental Station at Stuttgart, Arkansas (1973) reported that net production was highest at densities between 360 and 575 fish/m^3. As stocking density increased, the average size, feed conversion efficiency and survival all decreased. Schmittou (1969) stated that the "space factor" often exhibited when crowding animals in a confined environment is more a reflection of waste disposal than that of confinement.

Itazawa (1971) stated that the carrying capacity of a fish pond or a fish farm is principally controlled by the amount of dissolved oxygen. If the "critical level for normal life" of the fish is known, an estimate of the carrying capacity can be determined for a given rate of oxygen supply. Similarly, Mayo (1971) stated that to increase the capacity of water for fish, it is necessary only to add oxygen except that the ability of water to raise fish is limited by its ability to carry away metabolic by-products. Allen (1971) showed that without agitation, one-half pound average weight of catfish stocked at the rate of 3.2 lbs/ft^3, reduced the oxygen level from 7.5 mg/l at the inlet to 2.8 mg/l at the outlet. With the aid of agitation, the same fish reduced the level of oxygen to only 5.6 mg/l at the outlet.

Tackett (1970) stated that chemical reactions occurring in ponds caused oxygen depletion, since the requirements of fish are small compared to the demand for oxygen by plankton, bacteria, and metabolic products of these and of the fish themselves. Murphy and Lipper (1970) revealed that the daily production of biochemical oxygen demand (B.O.D.) by channel catfish is 0.0049 lb/lb of live weight. Comparable figures for chickens, swine, and beef cattle are 0.0033, 0.00332, and 0.00102, respectively. A higher value for catfish was obtained at the Fish Farming Experimental Station, Stuttgart, Arkansas (1973), the maximum B.O.D. added to the environment being 1 kg/ 100 kg of fish/day (0.01 lb/lb of live weight).

According to King (1973), nitrogen appears first in recirculating systems as ammonia, the major metabolic waste of aquatic animals. Ammonia is extremely toxic to fish, and salmonaid fishes are sensitive to concentrations as low as 0.006 ppm. In the presence of oxygen, and bacteria called nitrifiers, ammonia is converted to nitrite and finally to the relatively non-toxic nitrate. Smith (1929), as referred to by Spotte (1970), found that in freshwater fishes he studied, ammonia accounted for 80 per cent of the total nitrogen excreted, with urea composing most of the remainder. Piper and Larmoyeux (1973) observed that the growth rate of rainbow trout was significantly reduced where oxygen was below 5 mg/l and ammonia was greater than 0.5 ppm. Examination of blood and kidney films showed an increase in number of immature RBC with successive water reuse. Spotte (1970) stated that dissolved oxygen and pH are the two most important factors affecting ammonia toxicity. The latter is important because only the un-ionized form of ammonia (NH_3) appears to be poisonous to aquatic animals. Ionized ammonia (NH_4^+) is unable to pass the tissue barriers and thus enter an aquatic animal from the external medium. The concentration of un-ionized ammonia on either side of a tissue barrier at a given moment depends upon the pH of the water. Usually, a gradient exists at these places where the pH of the extracellular fluid (water) and the intracellular fluid (blood) are not in equilibrium. When the pH of either fluid changes, there is a shift in the concentration of un-ionized ammonia on both sides of the barrier.

Burrows (1964), as cited by Spotte (1970), exposed salmon fingerlings to water of pH 7.8 in which the ammonium hydroxide levels were 0.3, 0.5, and 0.7 ppm. The fish showed definite signs of hyperplasia, or clubbing of their gill filaments within 4 weeks. The fish did not recover after being transferred to new water. When the experiment was repeated with larger fingerlings, they recovered after 3 weeks in new water. It is significant that the calculated concentrations of un-ionized ammonia at the given levels of ammonium hydroxide were only 0.006 and 0.008 at 0.3 ppm NH_4OH, 0.010 and 0.012 at 0.5 ppm, and 0.014 and 0.018 at 0.7 ppm. These values indicate that un-ionized ammonia, even in minute concentration, is damaging to the gill epithelium of fishes. Burrows also noted a reduction in the growth rate and stamina of salmon exposed to long-term, intermittent sublethal levels of ammonia. He suggested that exposure to ammonia in quantities sufficient to cause gill hyperplasia was the precursor of bacterial gill disease.

According to Piper and Larmoyeux (1973), Lloyd and Orr (1969) reported a diuretic response by rainbow trout to sublethal concentrations of ammonia. They suggested that exposure to ammonia increases the permeability of fish to water, and because there is little change in body weight, the fish responded by increased urine excretion.

Piper and Larmoyeux (1973) observed a congestion in the kidney glomeruli from fish where ammonia levels were relatively high. The hematological changes found in the fish were indicated to be probably due to response to hypoxia.

Swingle (1961) suggested that the pH of pond water may be an indicator of the type of water, its suitability for fish culture, its toxicity to fish, its potential productivity, its response to liming, and its response to fertilization. Waters ranging from pH 6.5 to 9.0 before daybreak are most suitable for pond fish culture.

Spotte (1970) stated that the pressure of free CO_2 may depress the affinity of fish blood for oxygen. Its effect may be significant in crowded systems with low oxygen tensions and weak buffering capacities. He cited Basu (1959) and Saunders (1962) who both found that oxygen consumption declined with an increase in carbon dioxide. The rate was linear function with the logarithm of oxygen uptake and increasing carbon dioxide.

Boyd (1972) found that the sources of CO_2 for nuisance blooms of algae in ponds were bacterial respiration, decomposition of organic matter in pond water and the carbonate-bicarbonate equilibrium system. Estimates of CO_2 production from decay of dissolved organic matter in six pond waters ranged from 0.32 to 3.53 mg/l per 24 hr.

Olson, et al. (1973) reported that at Alchesay-Williams Creek National Fish Hatchery, when turbidity exceeds 70 JTU, the fish feeding activity drops sharply. When water is turbid, the conversion ratio increases to 2.5 or more.

III. 1972 EXPERIMENT

MATERIALS AND METHODS

Introduction

The 1972 experiment was initiated [illegible] 1) a water circulating-aerating device called paddle wheel, 2) a modified design of underwater gravel filter with venturi aeration, and 3) the elevated gravel filter equipped with pumps for water circulation and aeration. It was intended to compare their performance in terms of fish production and effect on water quality under a closed system intensively stocked with various sizes and numbers of white catfish. Water hyacinths were grown in the ponds to remove dissolved nutrients.

The experiment was conducted from August 25, 1972 to November 1, 1972.

Experimental design and treatments

Twenty-four concrete ponds each with an area of 1/200 acre and filled with water to 2.5 ft depth were used for the closed system experiment. Treatments were applied without randomization since the ponds were uniform and environmental variations were negligible. The following five treatments were replicated three times:

1. Water circulation and aeration by means of an oxidation ditch rotor (hereinafter, called a paddle wheel), with water hyacinths for nutrient removal.

2. Underwater gravel filter with venturi aeration, with water hyacinths.

3. Underwater gravel filter with venturi aeration, without water hyacinths.

4. Water circulation through an overhead gravel filter, with water hyacinths.

5. Control circulation, with water hyacinths.

Oxidation ditch rotor (Paddle wheel). The paddle wheel was operated intermittently by 1/4 hp motor to recirculate the water. It was in operation 15 minutes and at rest for 45 minutes each hour during the day. At night, operation was continuous. It was installed in one side of the pond stocked with fish. An adjoining pond was used as a waste settlement basin. The paddle wheel was installed so that the blades touched the water surface to a depth of 3 to 4 inches. As the wheel rotated water was moved at the rate of approximately 500 gpm and particles of water were splashed into the air. A portion of the water splashing from the blades was thrown into the adjoining waste settlement pond by means of a small gutter. Water from the settlement pond flowed back by gravity to the pond where the paddle wheel was installed through a connecting 2-inch diameter PVC pipe. Water hyacinths for removing dissolved nutrients were grown at one end of the waste settlement pond covering about 10 per cent of the pond area. The 10 per cent area coverage of the plant was maintained throughout the experiment by thinning out excess vegetative growth.

Underwater gravel filters with venturi aeration. This was divided into two treatments. One treatment had water hyacinths growing at the end of the pond area. The other treatment had no water hyacinths but instead, a board covering about 10 per cent of the pond was provided at the end of the pond as shelter for the fish. Neither treatment had an adjoining pond for waste settlements.

The gravel filter was made of a layer of 0.25 to 1 inch gravel spread evenly over the pond bottom except for a small area provided for the pump compartment. The thickness of the gravel layer was about 7 to 8 inches. Underneath the layer were five lines of tile drains, 12 inches long x 4 inches inside diameter. The pump compartment was separated at the end of the pond by a board 9 ft wide x 3 ft high. The tile drains were extended into the compartments. The submersible pumps which were run by a 1/3 hp motor had a flow rate of 30 gpm. The discharge pipe of the pump made of PVC material was equipped with an orifice to provide a venturi effect which induced air into the flow through tubes extending above the water surface. The mixture of air and water was discharged below the water surface. Thus, the discharge pipe passed through the divider board into the pond.

Water circulation and aeration was accomplished by continuous operation of the pump. As it discharged air-water mixture into the fish pond, the water flowed back to the sump through the tile drains by gravity.

Overhead gravel filter. This was made of gravel-filled boxes 3 ft x 5 ft x 4 ft high located at the end of the adjoining settlement basin ponds. The size of gravel ranged from 0.5 to 3 inches. Continuous water circulation was accomplished by a 6-gpm pump run by a 1/4 hp motor. The screened intake pipe of the pump drew water from the pond bottom where the fish were stocked. The discharge pipe sprayed water on top of the gravel filter and the water trickled by gravity to the settlement pond and returned to the fish pond through a connecting pipe. However, the flow of water over the filter was not the total flow rate. Instead of allowing the whole rate of flow to pass over the filter, a flow divider was installed across the pipe line and a large portion of the discharge was directly sprayed to the air by perforated PVC pipes. This water fell back on the pond with fish. Water hyacinths were also grown in the settlement basin pond.

Control circulation. This operated much the same way as the overhead filter, except that there was no intermediate gravel filter. Water was also circulated by a 6-gpm capacity pump run continually by a 1/4 hp motor. A small portion of the flow was directly discharged on the waste settlement pond where water hyacinths grew. The large portion was sprinkled over the water surface of the fish pond.

The experimental pond layout and treatment distributions are shown in Figure 1. The schematic diagram of the treatments is illustrated in Figure 2.

Water supply

The water used in the experiment came from the deep wells of the experiment station. The water level of the ponds was maintained at approximately 2.5 ft depth. There was, however, a slight variation in the volume of water due to rainfall, evaporation and pond leaks. Losses due to evaporation and leakage were compensated by adding water whenever necessary.

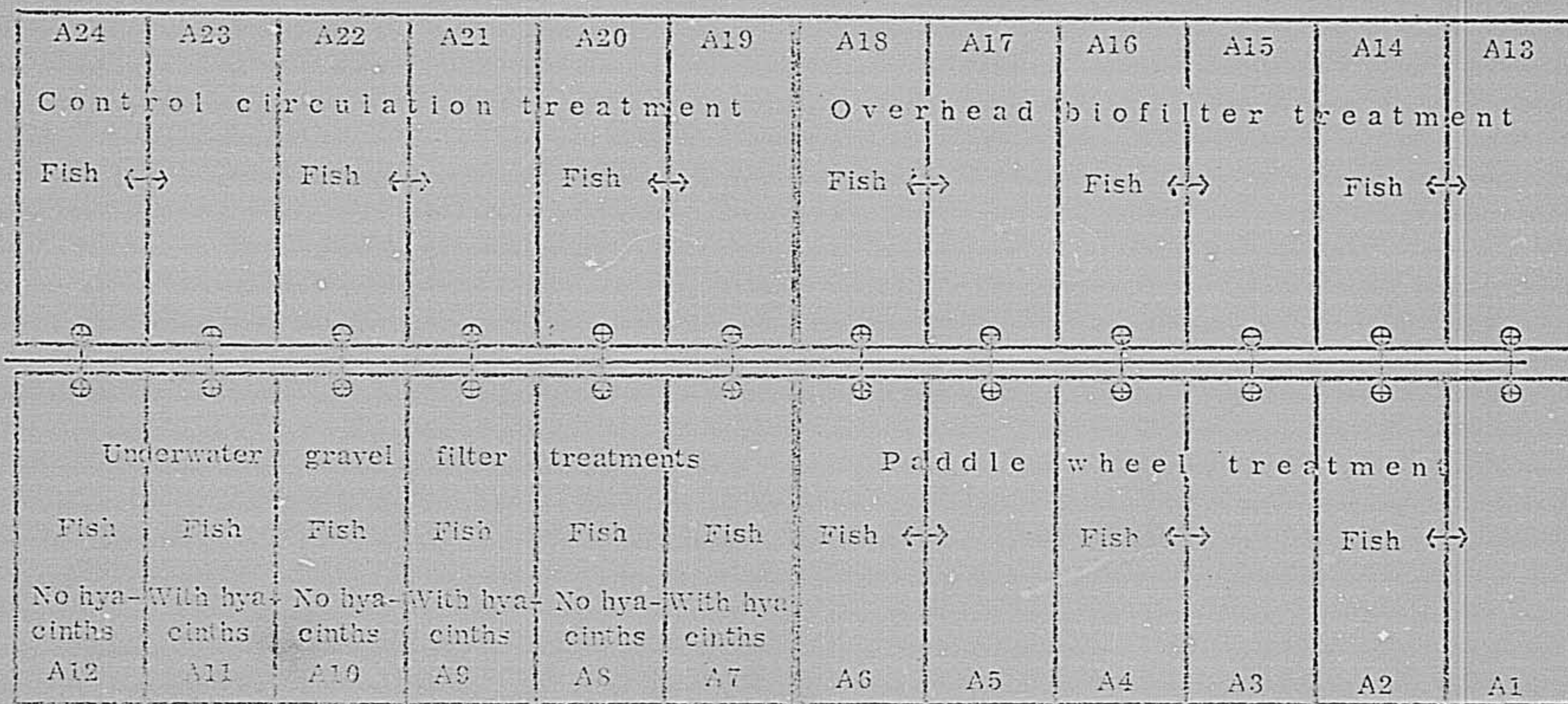
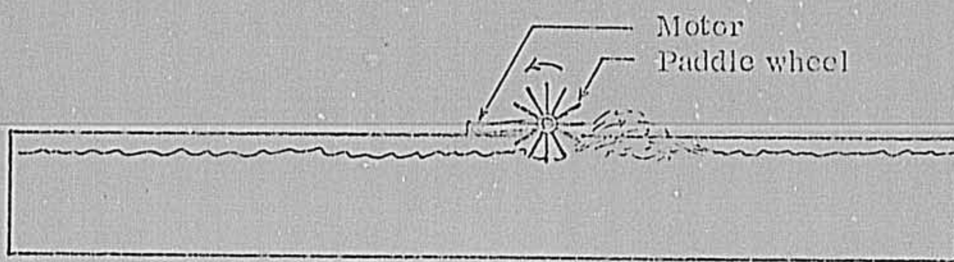
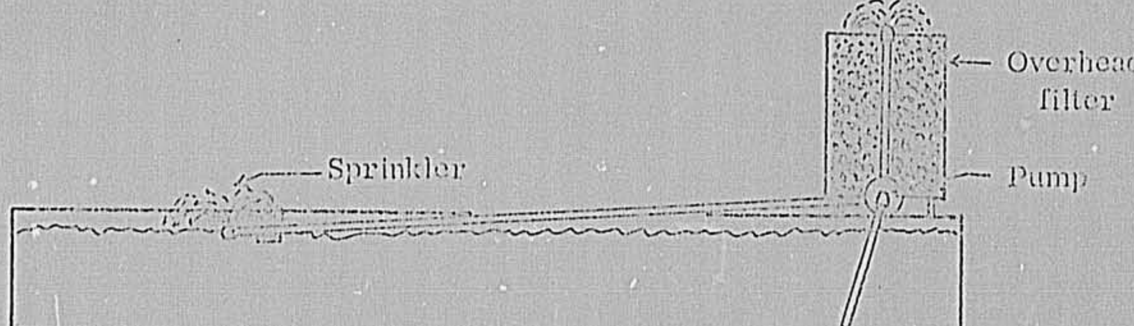


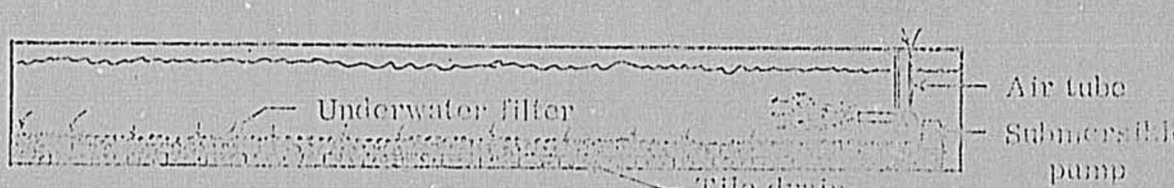
Figure 1. Layout of the concrete ponds and treatment distribution during the 1972 experiment



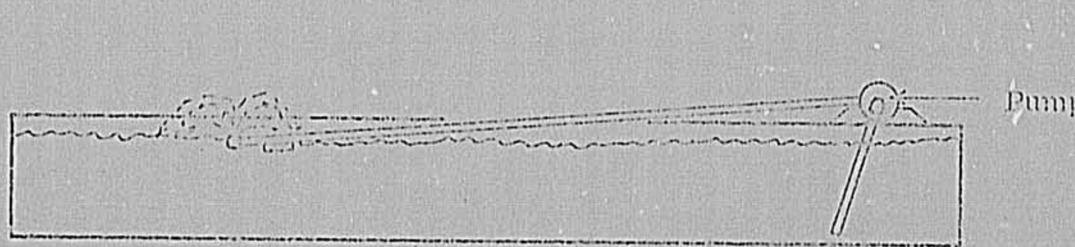
a. Water circulation by the paddle wheel



b. Water circulation through the overhead filter and surface sprinkling



c. Water circulation and venturi aeration through an underwater gravel filter



d. Water circulation and surface sprinkling as control treatment

Figure 2. Illustration of water circulation and aeration treatments

Experimental techniques

Stocking of fish. White catfish, *Ictalurus catus* (Linnaeus) were stocked at the rate of 100 lbs per replication or 20,000 lbs/acre. In terms of volume of water occupied by fish, this was approximately 0.184 lb/ft^3 for the paddle wheel treatment, overhead filter treatment and control circulation treatment. Since the volume of water in the underwater filter treatments was reduced considerably by the thickness of the gravel layer inside the pond, the stocking density became approximately 0.239 lb/ft^3 (without allowance for gravel particles pore spaces) for the same weight stocked. The number of fish stocked was not recorded. The stock was composed of sizes ranging from fingerling to harvestable size.

Feeding. Equal care was given to the fish in each treatment. They were fed seven days a week late in the afternoon with floating pelleted Purina Trout Chow. The rate of feeding was 3 per cent of the stocking weight per pond which was 100 lbs. Due to the short duration of the experiment, unknown number of stock, and to avoid further stressing the fish as a result of handling, no intermediate weight sampling was made.

Mortality. Mortality was recorded daily and dead or moribund fish were examined in the laboratory. The mortality record was used as a basis in the proportional reduction of the amount of feed in ponds suffering mortality.

Water analysis

The water quality variables considered were dissolved oxygen, temperature, oxygen consumption by the planktonic community, carbon dioxide, pH, total alkalinity, total hardness, calcium, and Secchi disk readings. Unfortunately, laboratory treatment for determining concentrations of nitrogenous compounds were not available.

The time, frequency, and methods of analyses were as follows:

1. The measurement of dissolved oxygen and water temperature were taken near the bottom of the ponds. Readings with a YSI Model 51 Oxygen meter were taken twice daily: once in the morning before sunrise and once in the afternoon at sundown.

2. Oxygen consumption by the planktonic community was determined weekly using the dark bottle method of Boyd (1973). Water samples were taken on sunny days in the morning at approximately mid-depth. Dark bottles were incubated in the ponds until early afternoon. Initial bottles were immediately titrated with Phenylarsene Oxide (PAO) for dissolved oxygen in the laboratory. Titration of the dark bottles was made immediately after the incubation period. The difference between the dissolved oxygen content of the initial and dark bottles was the oxygen consumption by plankton for specified length of time. Titration was done using standard Winkler method as described by Swingle (1969).

3. The concentration of carbon dioxide was determined once each week (American Public Health Association, 1971). The water samples for carbon

dioxide determination were siphoned beyond mid-depth of the ponds into B.O.D. bottles and allowed to overflow for 30 seconds. Time of sampling was before sunrise.

4. pH readings were obtained weekly at the same time with carbon dioxide determination. Excess water sample from the carbon dioxide analysis was also used for pH measurements with a Corning Model 7 pH meter.

5. Total hardness and calcium hardness were determined by the EDTA titration method as described by the American Public Health Association (1971). Total alkalinity was titrated with 0.02 N H_2SO_4, using methyl orange as the indicator. Water samples were taken in the early morning at mid-depth of the pond.

6. Secchi disk readings were taken weekly during the second half of the experiment.

Harvesting

The experiment was terminated when the temperature dropped so low that the fish stopped feeding. All ponds were drained and all fish recovered were counted and weighed.

RESULTS AND DISCUSSION

Mortality

Immediately after stocking, some ponds in both treatments with underwater gravel filters had extensive mortality. The fish continued to die in large numbers until September 12, 1972. At this time the weight of accumulated dead in ponds A7, A8 and A12 reached 59, 70, and 77 per cent of the stocked weight, respectively. Eighteen days after stocking, the mortality weight for the rest of the treatments in any replicate varied from 3 to 10 per cent.

All of the fish were removed from the two underwater filter treatments and restocked on September 13, 1972. After stocking, the same pattern of mortality took place as before in ponds A7 and A12. One week after restocking, the mortality for these two ponds was 40 and 78 per cent of the stocked weight, respectively. Pond A8 had approximately 10 per cent mortality at that time, while the rest of the replicates for the two treatments had less than 2 per cent. After September 19, no more mortality was observed that could be included in the pattern.

Fish samples were brought to the laboratory for parasite and disease examination. Results of the examination revealed that a moderate amount of Cleidodiscus on the gills and a moderate amount of Chilodonella on the skin. The parasite load was not sufficient to cause the massive mortality of the fish. Water quality tests for dissolved oxygen, pH, and carbon dioxide concentration were within permissible limits for fish survival.

In the course of the experiment, one cause of major fish kills was oxygen depletion and was probably associated with high carbon dioxide concentrations. Oxygen depletion occurred on September 17, 18, 21, 26, 27, and 29, in ponds A22, A16, A22, A14, A18, and A11, respectively. Dissolved oxygen dropped between 0.9 and 1.8 mg/l in these ponds. Carbon dioxide concentrations varied from 14.2 to 25.0 ppm (Table 30, Appendix). The weights and numbers of fish killed are presented in Table 1.

Pond A11 had mortality because Hydrodictyon, a filamentous algae, clogged the pump suction strainer. Other causes of explainable mortality were due to electric power failure, small fish clogging intake pipes, clogged water meter with detritus, malfunctioning of the pump and paddle wheel motors, breaking of paddle wheel chains, and overloading electrical line with the use of emergency pumps.

The extensive fish mortality in A24 which began on the sixth week (Table 1) cannot be associated with dissolved oxygen because values were high when mortality occurred (Table 2). However, the water quality had greatly deteriorated. In this pond, an obnoxious odor was detectable. The water color was brown and particulate matter was circulating with the water. Numerous large bubbles formed on the water surface during aeration. The probable water quality parameter that caused the mortality was not known. The gills of newly dead and moribund fish were brown in color. The blood that exuded from the fish

TABLE 1

WEEKLY MORTALITY IN INDIVIDUAL POND

Date 1972	Paddle wheel						Underwater filter (with hyacinths)[1]						Underwater filter (no hyacinths)[1]					
	A1-2		A3-4		A5-6		A7		A9		A11		A8		A10		A12	
	No.	Wt.[2]	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.
8/26-9/1	63	3.55	32	3.27	35	5.25	6	0.35	8	2.42	3	0.93	44	6.23	50	8.49	54	12.99
9/2-9/8	2	0.52	2	0.90	3	1.59	43	26.93	5	3.23	3	1.66	44	32.54	2	0.93	37	23.10
(9/9-9/12)[3]							60	22.19	1	0.74	12	7.92	48	32.50	2	1.22	54	32.20
9/13-9/15					2	0.57	67	27.59	2	0.04			17	5.70	5	0.17	182	56.03
9/16-9/22			1	1.16	12	1.02	37	13.51	5	0.65	20	1.50	18	4.75	25	1.76	65	22.91
9/23-9/29											204*	119.43						
9/30-10/6					2	1.32			2	0.11			2	0.15				
10/7-10/13	1	1.26			3	1.60												
10/14-10/20	7	6.85			1	0.70												
10/21-10/27																		
10/28-11/1					4	0.37												
Total	[illegible]	17.19	35	3.39	61	14.52	104	41.10	9	1.10	231	119.93	37	10.76	30	1.93	217	79.00

Date 1972	Overhead filter						Control circulation					
	A13-14		A15-16		A17-18		A19-20		A21-22		A23-24	
	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.
8/26-9/1	29	5.42	35	4.33	45	4.65	17	2.24	27	7.52	21	3.55
9/2-9/8	3	2.34	1	0.51	3	0.31	2	0.73			3	0.93
(9/9-9/12)[3]												
9/13-9/15	4	3.06			2	1.65	1	0.02	8	3.59	5	3.80
9/16-9/22			135*	73.06			6	0.13	54*	26.42	1	0.50
9/23-9/29	25	17.36			278*	137.68	1	0.08				
9/30-10/6											10	7.62
10/7-10/13											25	20.92
10/14-10/20	1	0.25									175	83.05
10/21-10/27							8	0.34			2	0.23
10/28-11/1			1	0.10			4	2.67				
Total	62	28.43	175	83.09	325	143.69	39	12.21	93	39.53	245	123.56

* Fish kill due to dissolved oxygen depletion.

1/ Completely restocked on September 13, 1972.

2/ All weights in pound.

3/ Accumulated mortality for underwater filter treatments not included in total mortality after restocking.

also had this color. Laboratory findings for parasites and diseases indicated moderate infection with Lernea. Bacteriological examination was negative. Upon draining, two fish were recovered alive.

Water quality

Dissolved oxygen. The weekly average and minimum-maximum of the morning and afternoon dissolved oxygen readings for each treatment are presented in Table 2. From the minimum-maximum values in the table and Figures 3 and 3a, it is evident that oxygen level declined with time for all treatments. The control circulation treatment was the first to show declining oxygen level during the second week of the experiment. The condition continued to deteriorate as a result of increasing biochemical oxygen demand (B.O.D.) until the fifth week (Table 2 and Figure 3). During this span of time, fish mortality due to oxygen depletion occurred. Emergency pumps helped to alleviate this condition.

The overhead gravel filter treatment had insufficient aeration during the fourth week of the experiment and a fish kill took place because of this condition.

Water quality was better in the underwater gravel filter treatments than the overhead filter and control circulation treatments. However, with the lapse of time, the oxygen level in the former treatments also dropped low from the fourth to sixth week (Table 2). During the sixth week, dissolved oxygen dropped to 1.8 mg/l in the paddle wheel treatment. On September 29, 1972, the condition was corrected by advancing the starting time for overnight

TABLE 2

WEEKLY AVERAGES OF DISSOLVED OXYGEN CONCENTRATION, mg/l
WITH MINIMUM-MAXIMUM VALUES IN PARENTHESES

No. of Weeks	Date 1972	Paddle wheel AM 1/	Paddle wheel PM 1/	Underwater filter (with hyacinths) AM	Underwater filter (with hyacinths) PM	Underwater filter (no hyacinths) AM	Underwater filter (no hyacinths) PM	Overhead filter AM	Overhead filter PM	Control circulation AM	Control circulation PM
1	8/24-8/30	7.4(6.4-9.0)	10.3(7.4-13.9)	5.1(3.4-6.7)	8.1(7.0-8.5)	6.1(5.1-7.2)	8.1(6.6-9.4)	4.8(3.7-5.6)	14.7(11.0-17.8)	4.1(3.3-6.2)	13.2(11.0-16.4)
2	8/31-9/6	7.0(6.0-7.8)	8.5(6.9-10.9)	5.0(3.7-6.5)	7.2(5.9-9.2)	5.0(3.8-6.6)	8.0(4.9-12.5)	4.9(3.0-5.2)	13.1(8.8-16.8)	2.5(0.8-6.5) 2/	10.3(5.7-14.2)
3	9/7-9/13	6.7(5.7-7.8)	8.3(6.4-10.2)	4.7(3.6-5.6)	6.7(4.5-8.5)	5.0(3.5-6.1)	7.3(6.6-8.2)	3.0(2.1-3.3)	17.1(10.0-20+)	3.4(0.5-6.5) 2/	12.7(4.5-17.2)
4	9/14-9/20	5.9(4.3-7.3)	8.2(4.6-12.5)	4.0(2.7-6.2)	9.5(4.0-12.0)	2.7(1.0-4.0)	9.6(2.8-10.9)	2.9(1.4-4.5) 3/	20+(6.6-20+)	3.1(0.7-6.7) 4/	14.3(2.0-19.2)
5	9/21-9/27	5.0(3.6-5.6)	5.7(3.8-9.7)	2.7(2.0-4.0)	7.3(5.1-9.3)	3.9(2.4-5.9)	7.3(5.5-8.5)	1.6(1.4-1.9) 5/	11.0(7.5-17.8)	1.9(0.4-3.4) 4,2/	8.7(3.0-13.2)
6	9/28-10/4	6.0(4.9-7.7)	6.9(1.8-9.5) 6/	3.4(1.5-4.4) 7/	4.3(3.0-5.6)	3.5(1.3-5.9)	3.8(2.2-5.5)	5.7(3.2-9.2)	6.3(3.6-8.3)	2.8(0.8-6.3)	5.7(3.2-9.4)
7	10/5-10/11	7.3(5.8-9.2)	8.8(7.5-10.4)	4.0(2.6-5.5)	5.8(5.2-6.7)	4.9(3.7-5.9)	6.2(5.7-6.4)	7.0(6.6-9.5)	5.9(3.0-10.0)	3.5(2.2-6.1)	7.9(5.0-10.5)
8	10/12-10/18	7.1(5.2-8.0)	7.6(6.9-8.5)	3.7(2.8-5.0)	4.7(4.2-5.7)	4.4(4.0-5.2)	6.5(5.0-8.0)	6.4(5.8-7.0)	8.2(8.0-8.4)	3.6(2.5-4.6)	8.5(7.2-10.0)
9	10/19-10/25	8.7(6.6-11.2)	9.5(7.2-11.0)	5.9(2.7-7.6)	6.2(4.6-7.2)	5.9(3.5-7.5)	9.5(8.5-11.2)	8.4(6.4-11.0)	10.0(8.2-12.0)	5.0(1.5-8.5)	8.5(4.2-11.5)
10	10/26-11/1	8.7(7.5-9.7)	8.8(7.2-9.7)	6.2(5.0-7.6)	6.4(5.8-6.9)	6.1(5.1-7.5)	7.4(6.4-8.6)	8.3(6.8-9.4)	9.6(5.8-10.1)	6.2(3.6-8.4)	9.6(5.5-12.4)

1/ Dissolved oxygen readings taken before sunrise and at sundown.

2/ Supplementary pumps operated.

3/ Fish kill; oxygen depletion in pond A15.

4/ Fish kill; oxygen depletion in pond A22.

5/ Fish kill; oxygen depletion in pond A19.

6/ Paddle wheel operation time moved from 6:30 PM to 4:00 PM, extended overnight operation.

7/ Fish kill; oxygen depletion in pond A11.

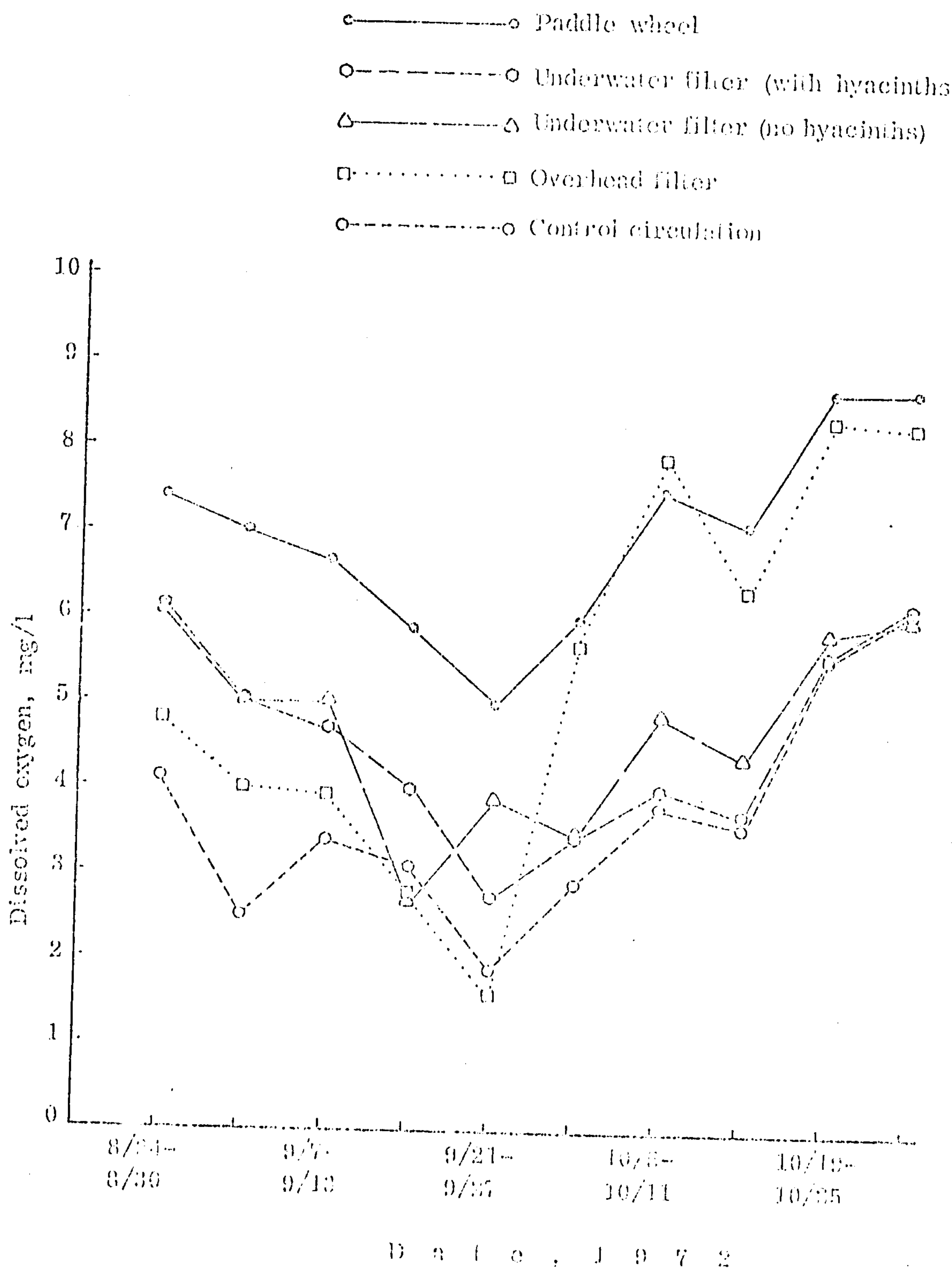


Figure 8. Weekly dissolved oxygen in various treatments (AM)

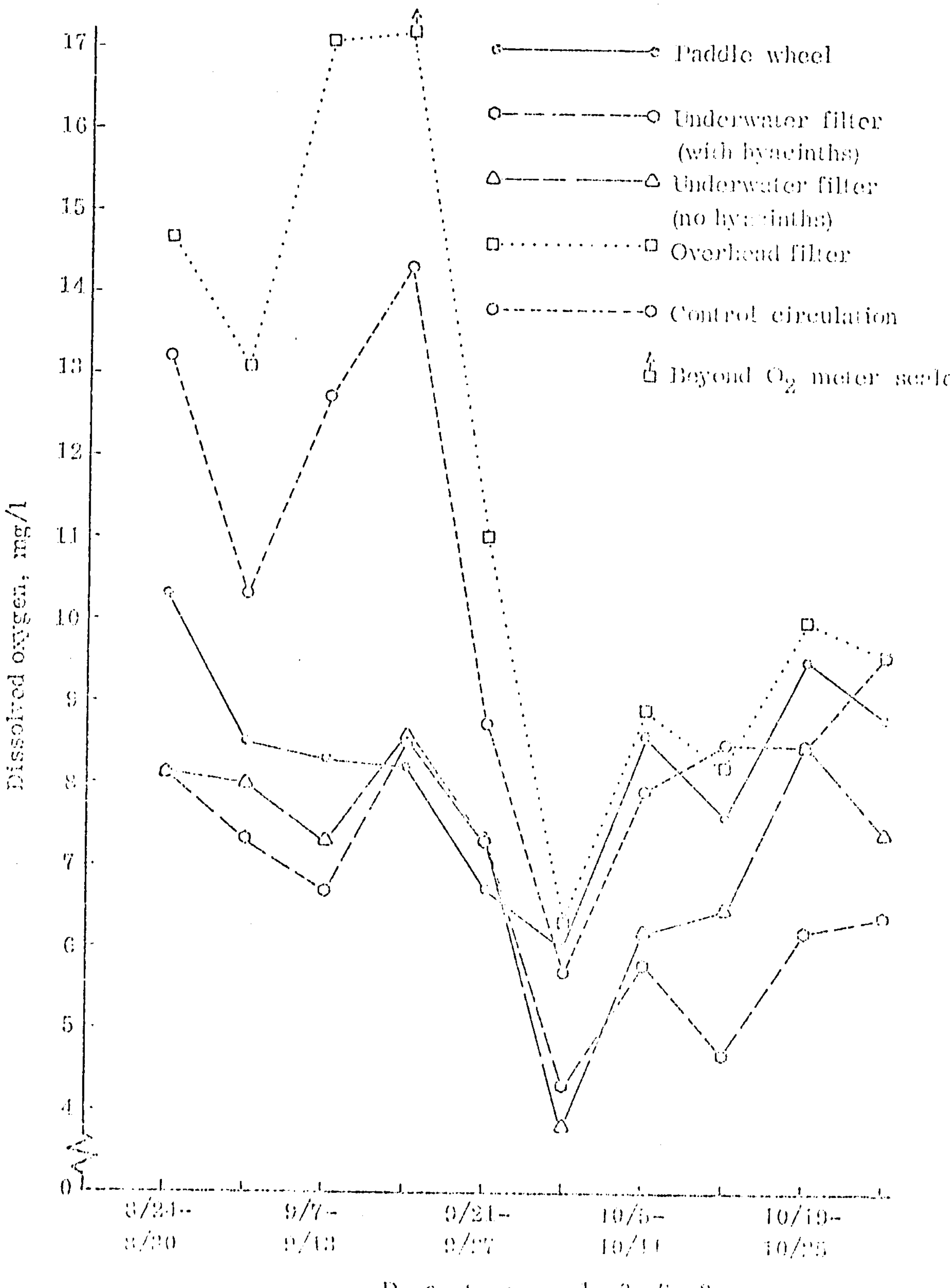


Figure 3a. Weekly dissolved oxygen in various treatments (PM)

operation of the paddle wheel from the original setting of 6:30 PM to 4:30 PM. After the adjustment of the time, dissolved oxygen level became high. Dissolved oxygen level generally became higher for all treatments during the month of October. This was caused, at least in part, by the decrease in number of fish in ponds suffering high mortality. Supplementary pumps were in operation, and further, the mean temperature decreased, thus, increasing the solubility of oxygen in water for all treatments.

The principal reason for the marked difference in dissolved oxygen level among the treatments was attributed to the capacity of the water circulating and aerating units used for each treatment. The significant effect of the capacities of the aerating units was demonstrated with the lapse of time. Means of morning dissolved oxygen during the fourth to sixth week of the experiment dropped to 5.0, 2.7, 1.6, and 1.9 mg/l, for the paddle wheel treatment, underwater gravel filter treatments, overhead filter treatment and control circulation treatment, respectively (Table 2).

The afternoon dissolved oxygen values (Table 2) for the overhead filter and control circulation treatments revealed the inadequacy of these water circulation and aerating devices. When the 6-gpm pumps were in operation, the water became saturated with oxygen indicating that a significant amount of dissolved oxygen came from photosynthesis by phytoplankton. This excess dissolved oxygen cannot be removed by agitation. However, with the installation of the emergency pumps of 30-gpm capacities, the supersaturated condition occasionally appeared (Figure 3a). This indicates that oxygen produced by photosynthetic activity is dissipated to the atmosphere by the agitation.

The efficacy of the equipment was determined by a five-day dissolved oxygen measurement inside the pump sump of the gravel filter and the portion of the pond where the fish lived during the month of September (Table 26, Appendix). There was approximately 2.5 mg/l difference of dissolved oxygen concentrations in the early morning between these two compartments, which were separated by a divider board. This indicates that during the time of measurement, the fish and other organisms steadily demanded about 2.5 mg/l dissolved oxygen.

Temperature. Graphs of temperature readings are presented in Figures 4 and 4a. The change of temperature with time was evident.

Duncan's new multiple range test was applied to compare treatment means. Comparison of means appearing in Tables are in lower case letters. Means followed by the same letter are not significantly different at the 5 per cent level.

Comparison of treatment means (Table 3) at the 5 per cent level confirmed that there was no significant temperature difference among the two underwater filter treatments and the control circulation treatment. The three former treatments were significantly different from the overhead filter treatment and the paddle wheel treatment. Further, there was a difference between the paddle wheel treatment and the overhead filter treatment. Thus, the paddle wheel has the lowest water temperature, followed by the overhead filter, and the other three treatments had the highest values.

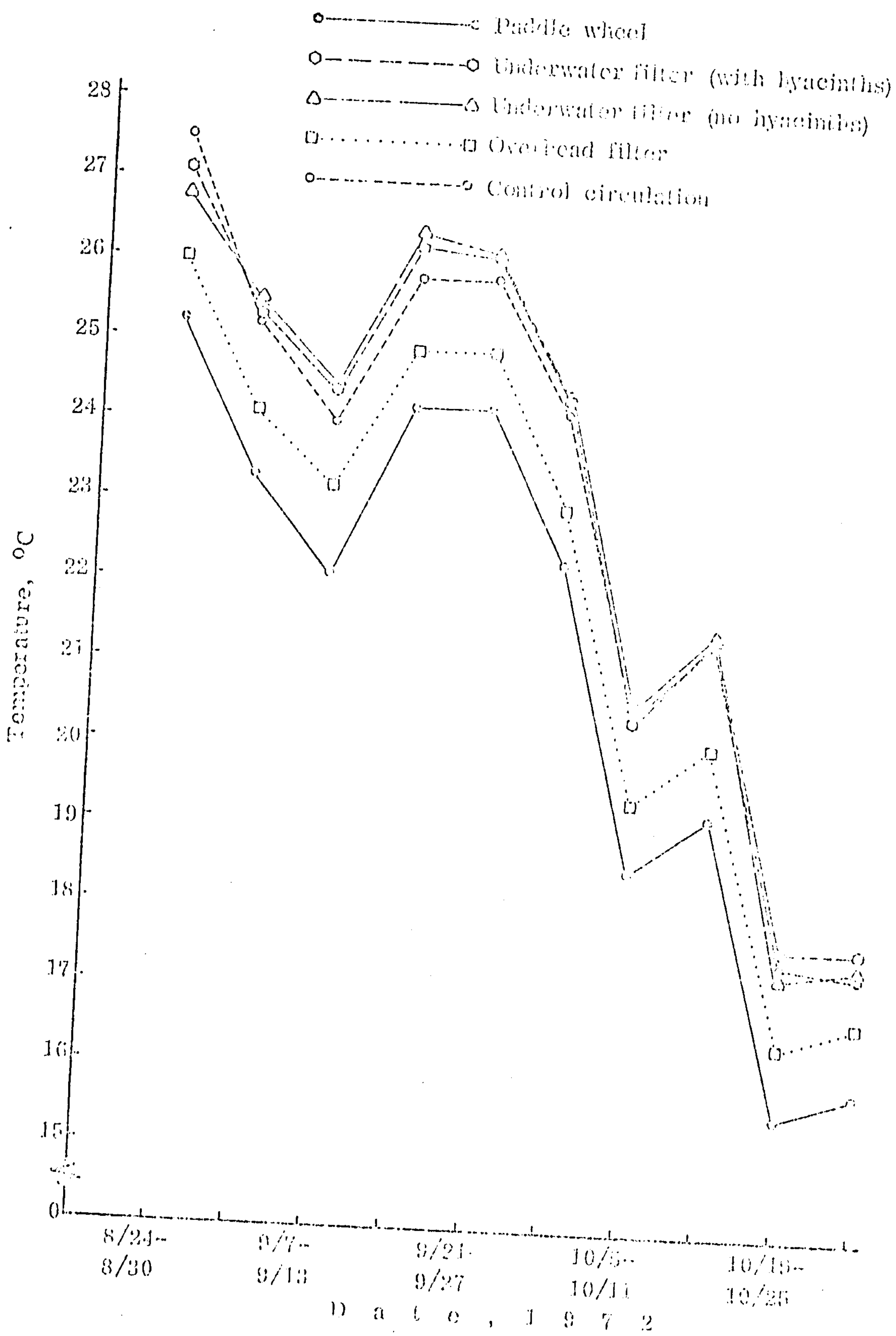


Figure 4. Weekly temperature in various treatments (AM)

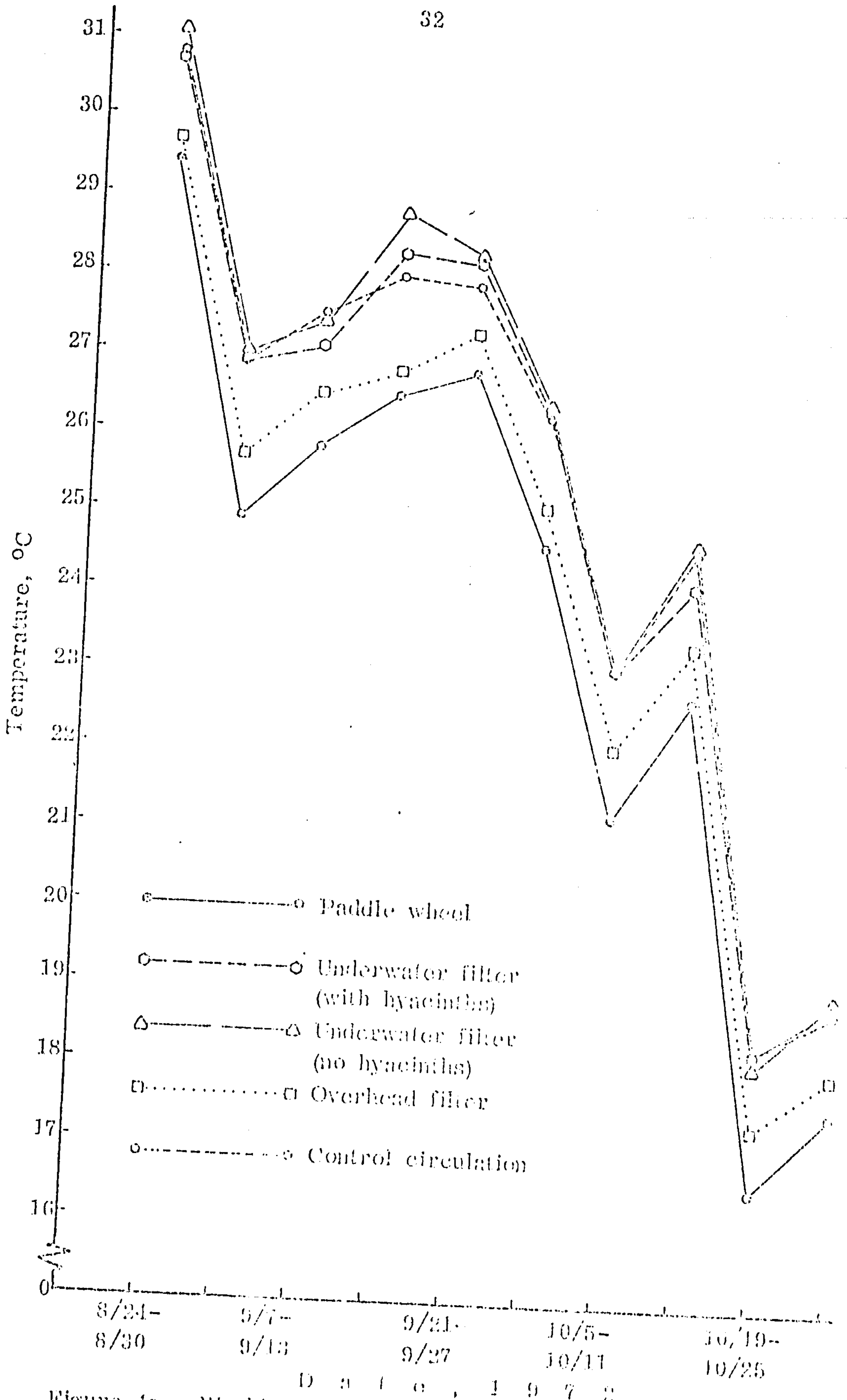


Figure 4a. Weekly temperature in various treatments (PM)

TABLE 3

MEAN TEMPERATURE, °C FOR THE DIFFERENT TREATMENTS

Replication	Paddle wheel		Underwater filter (with hyacinth)		Underwater filter (no hyacinth)		Overhead filter		Control Circulation	
	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
1	20.8	22.6	22.9	24.3	23.2	24.6	21.9	23.7	22.8	24.7
2	20.9	22.8	23.2	24.7	23.1	24.8	21.8	23.8	22.7	24.9
3	21.1	23.0	22.7	24.8	22.6	25.0	21.7	24.0	22.9	25.1
Total	62.8	68.4	68.8	73.8	68.9	74.4	65.2	71.5	68.4	74.7
Mean	20.93	22.80	22.93	24.60	22.97	24.80	21.73	23.80	22.80	24.90
Mean Comparison[1/]	b		a		a		c		a	

1/ Means followed by the same letter are not significantly different ($P < 0.05$) as determined by Duncan's multiple range test.

During daytime, if the air temperature is greater than water temperature, water absorbs heat from the atmosphere due to temperature gradient. Conversely, temperature inversion at night produces cooler ambient air than the pond water. The paddle wheel operated intermittently during daytime and continuous at night time. Therefore, heat dissipation of the water is more significant at night than the heat absorption during the day. Water agitation by the paddle wheel was much stronger than the rest of the treatments. The continuous agitation by the rotating paddle blades was seemingly effective in dissipating the heat at night. In overhead filter treatment the sprinkling and trickling flow through the filter hastened and gave more time for the heat to dissipate.

With regard to the weekly temperature range (Table 28, Appendix) or fluctuation during the day for each treatment, an analysis of variance showed no significant difference among the treatments. It suggests that during the day the rate of heat absorption by the water for all of the treatments was the same. Thus, water cooling at night by the treatments made the difference.

Dissolved oxygen consumption by planktonic community

The incubation time for the dark bottle in the determination of dissolved oxygen consumption by plankton ranged from 6.0 to 12.5 hours. No provision was made to exclude the organic matter during measurements. Therefore, the values presented included the oxygen demand of the organic matter and planktonic community, but will be referred to as plankton consumption.

Graphical comparisons of the treatments with respect to time are shown in Figure 5. The treatment means shown in Table 4, revealed that the underwater filter with water hyacinths had the least amount of plankton consumption of oxygen. This was followed by the filter without water hya-cinths treatment, paddle wheel treatment, overhead filter treatment, and the highest consumption was recorded from the control circulation treatment. The mean values ranged from 0.146 to 0.534 mg/l/hr. On a 24-hr basis these values were 3.504 to 12.816 mg/l. Comparison among mean values showed that the three treatments namely: control circulation, overhead filter and paddle wheel, did not differ from each other at the 5 per cent level. The former three treatments, however, were significantly different from the filter with water hyacinths. The response to filter without water hyacinths treatment was not different from the response to the paddle wheel treat-ment. Further, neither of the underwater filter treatments showed marked difference from each other.

The values of plankton consumption of oxygen approximated the values reported by Boyd (1972). His maximum value of 3.3 mg/l per 24-hr was exceeded, however. This may be due to a higher plankton level and B.O.D. effect of organic matter in the agitated pond water.

Filamentous algae grew in the two underwater filter treatments. No attempt was made to avoid algae in the determination of the oxygen consumption. It was probable that either small or large quantity of algae was able to enter into the dark bottle which could be a source of variation in the measurement.

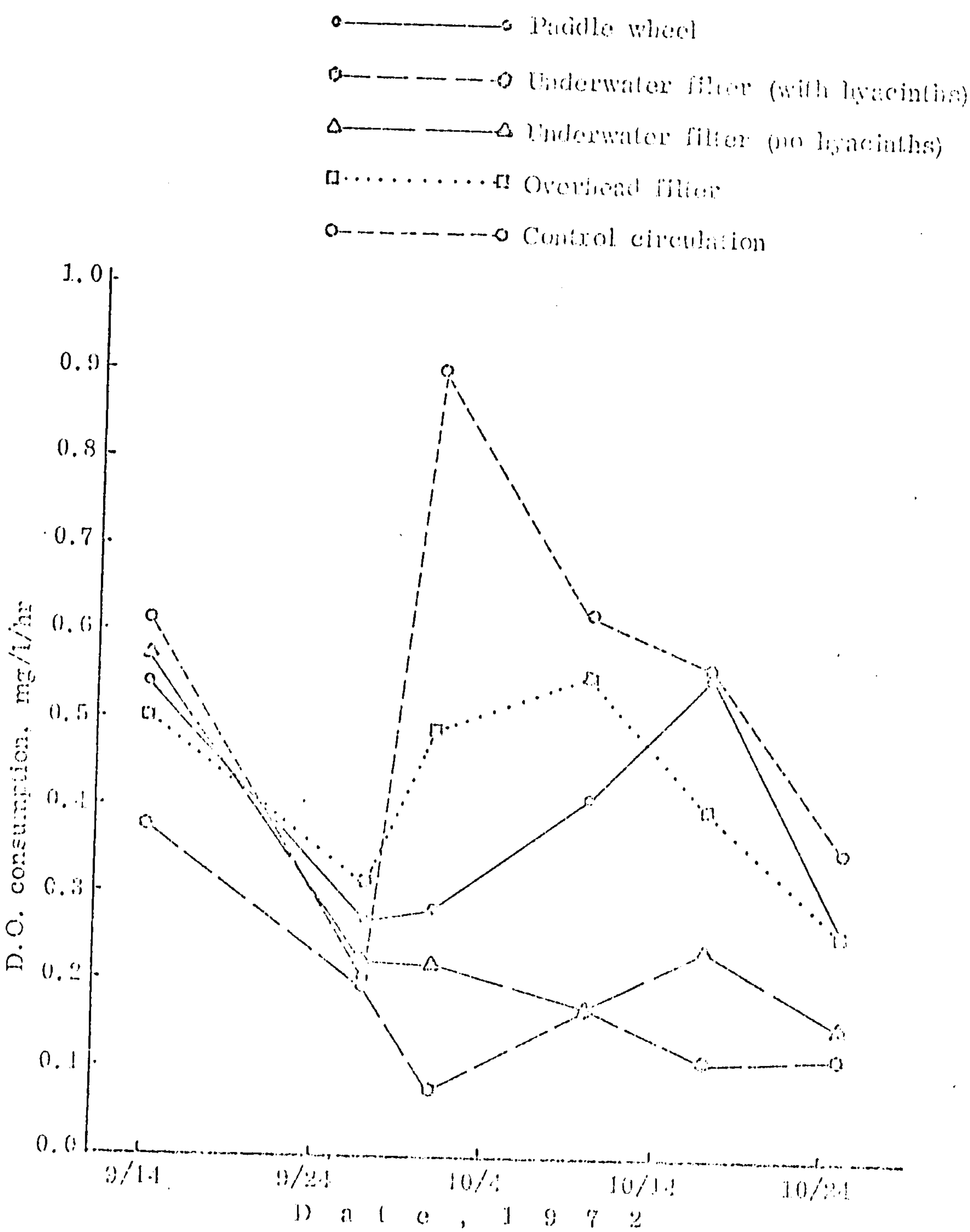


Figure 5. Dissolved oxygen consumption by planktonic community

TABLE 4

DISSOLVED OXYGEN CONSUMPTION BY PLANKTON COMMUNITY

Treatment	Pond No.	DATE, 1972 9/14	9/27	10/1	10/10	10/17	10/25	Pond Mean mg/l per hr	Treatment Mean mg/l per hr	Treatment Mean mg/l per 24 hr	Mean Comparison
Paddle wheel	A1-2	0.544	0.414	0.443	0.712	0.769	0.217	0.515			
	A3-4		0.216	0.157	0.157	0.245	0.203	0.196	0.359	8.616	ab
	A5-6		0.181	0.259	0.376	0.659	0.360	0.367			
Underwater filter (with hyacinths)	A7		0.086	0.109	0.248	0.189	0.214	0.169			
	A9	0.378	0.150	0.086	0.096	0.100	0.101	0.152	0.146	3.504	c
	A11		0.339	0.037	0.183	0.040	0.018	0.117			
Underwater filter (no hyacinths)	A8		0.292	0.423	0.259		0.314	0.322			
	A10		0.245	0.080	0.139	0.315	0.114	0.179	0.233	5.592	bc
	A12	0.578	0.135	0.131	0.131	0.165	0.040	0.197			
Overhead filter	A13-14		0.182	0.637	0.677	0.621	0.274	0.478			
	A15-16	0.504	0.357	0.546	0.385	0.357	0.374	0.471	0.409	9.816	ab
	A17-18		0.414	0.294	0.312	0.235	0.131	0.277			
Control circulation	A19-20	0.618	0.289	0.674	0.578	0.427	0.569	0.525			
	A21-22		0.187	1.131	0.604	0.571	0.171	0.545	0.534	12.816	a
	A23-24		0.198	0.906	0.645	0.591	0.384	0.548			

To some degree, the effect of water hyacinths in reducing dissolved nutrients was demonstrated by the fact that the gravel filter with water hyacinths treatment was significantly different from the paddle wheel treatment with respect to consumption of oxygen by plankton. On the other hand, the paddle wheel treatment and the filter without water hyacinths treatment did not differ when consumption of oxygen by plankton was compared.

Depth of visibility

The depth of visibility of the pond waters was determined using a Secchi disk. The readings obtained during the month of October are shown in Table 5. A graphic comparison of these treatments is presented in Figure 6.

The underwater filter treatments had the clearest water. Since they were shallow, the Secchi disk could still be seen to the bottom. There were two ponds, however, one for each treatment, that were not as clear as the other ponds in the treatment. Following the underwater filter treatments in water clarity was the paddle wheel treatment, then the overhead filter treatment, and the control circulation treatment.

Comparison among means showed that the four treatments, both underwater filters, paddle wheel and the overhead filter were better than the control. The four treatments did not differ from each other in water clarity. The distinct difference between the underwater filter treatments and the latter two treatments was not shown by the Secchi disk because of the limited depth of the ponds.

TABLE 5

SECCHI DISK READINGS

Treatment	Pond No.	DATE - 1972 10/1	10/7	10/13	10/21	10/28	Pond Mean	Treatment Mean Meter	Treatment Mean Feet	Mean Comparison
Paddle wheel	A1-2	0.30	0.30	0.25	0.23	0.30	0.28			
	A3-4	0.74	0.70	0.73	0.70	0.60	0.69	0.45	1.48	a
	A5-6	0.50	0.70	0.30	0.29	0.25	0.39			
Underwater filter (with hyacinths)	A7	0.55*	0.50	0.40	0.45	0.35	0.45			
	A9	0.55*	0.55	0.55	0.53	0.55*	0.55	0.52	1.71	a
	A11	0.55*	0.55*	0.55*	0.55*	0.55*	0.55			
Underwater filter (no hyacinths)	A8	0.50	0.45	0.30	0.20	0.30	0.35			
	A10	0.55*	0.55*	0.55*	0.53	0.55*	0.55	0.46	1.51	a
	A12	0.50	0.30	0.55*	0.55*	0.55*	0.49			
Overhead filter	A13-14	0.20	0.30	0.25	0.30	0.35	0.28			
	A15-16	0.21	0.20	0.25	0.23	0.20	0.22	0.30	0.98	a
	A17-18	0.31	0.30	0.35	0.45	0.60	0.40			
Control circulation	A19-20	0.23	0.30	0.30	0.10	0.13	0.22			
	A21-22	0.15	0.15	0.25	0.30	0.35	0.24	0.20	0.66	b
	A23-24	0.10	0.20	0.10	0.10	0.15	0.13			

*Still clearly visible at pond bottom

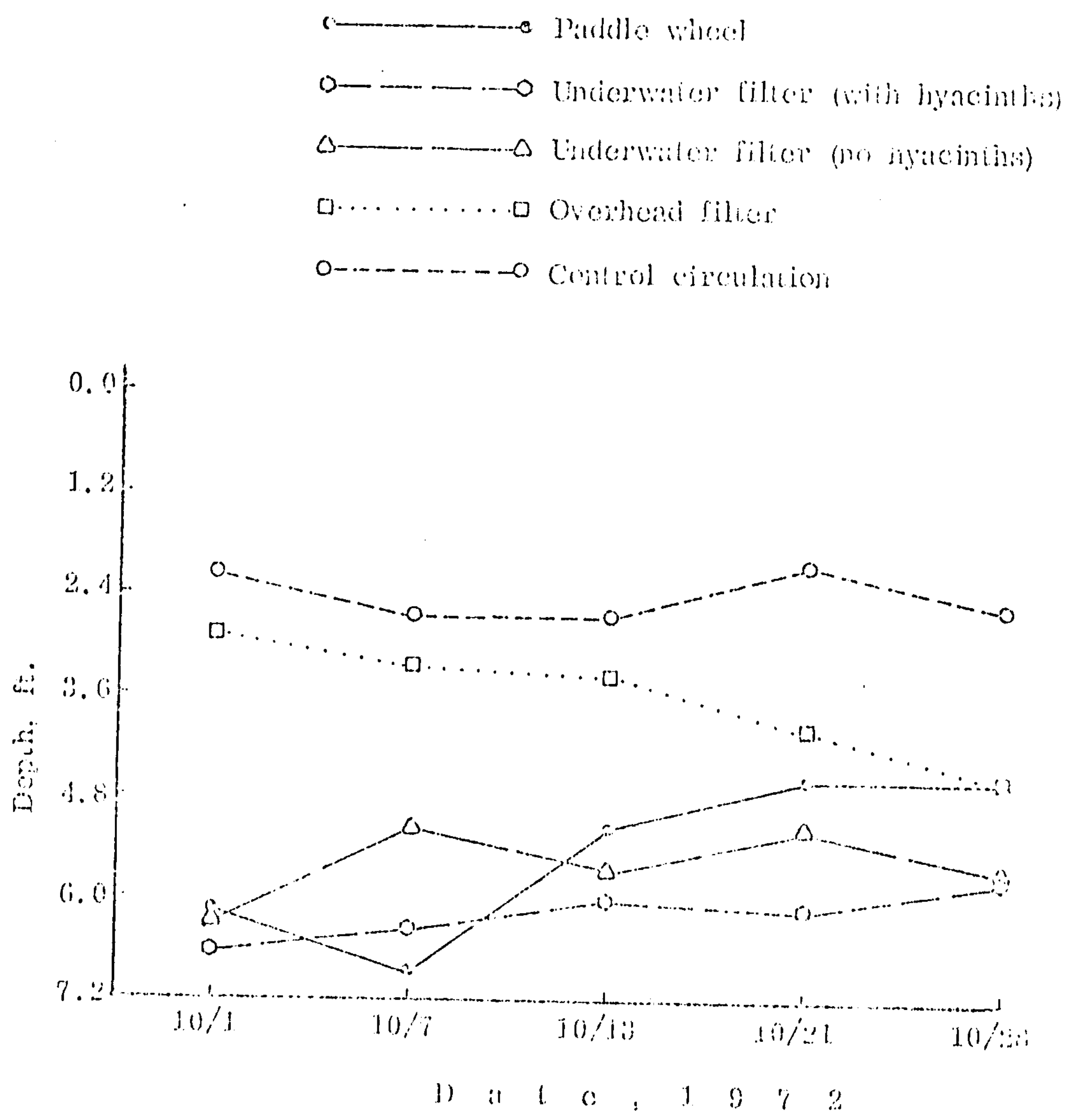


Figure 6. Secchi disk readings for the different treatments.

pH

The pH values during the experimental period varied from 6.1 to 9.6 (Table 29, Appendix). Generally, however, the pH values did not fluctuate (Figure 7).

Treatment means ranged from 7.2 to 7.7 (Table 6). The overhead filter treatment had the highest value, followed by the paddle wheel treatment, control circulation treatment, underwater filter without water hyacinths and filter with water hyacinths treatments. The values obtained were within the desirable range of 6.5 to 9.0 for fish culture as given by Swingle (1961).

Comparison of treatment means indicated significant difference in pH at the 5 per cent level among treatments. The pH values for the underwater filter with water hyacinths was different from the pH readings of all treatments except the filter without water hyacinths. Underwater filter without water hyacinths treatment had a lower pH than the paddle wheel treatment and overhead filter treatment but was not different from the pH of the control circulation treatment. The pH of the control circulation treatment was not the same as the pH of the paddle wheel and overhead filter treatments. There was no significant difference between the paddle wheel and overhead filter pH values.

Carbon dioxide

Individual values for carbon dioxide (CO_2) concentrations were high (Table 30, Appendix). Values for each sampling date varied among treatments (Figure 8).

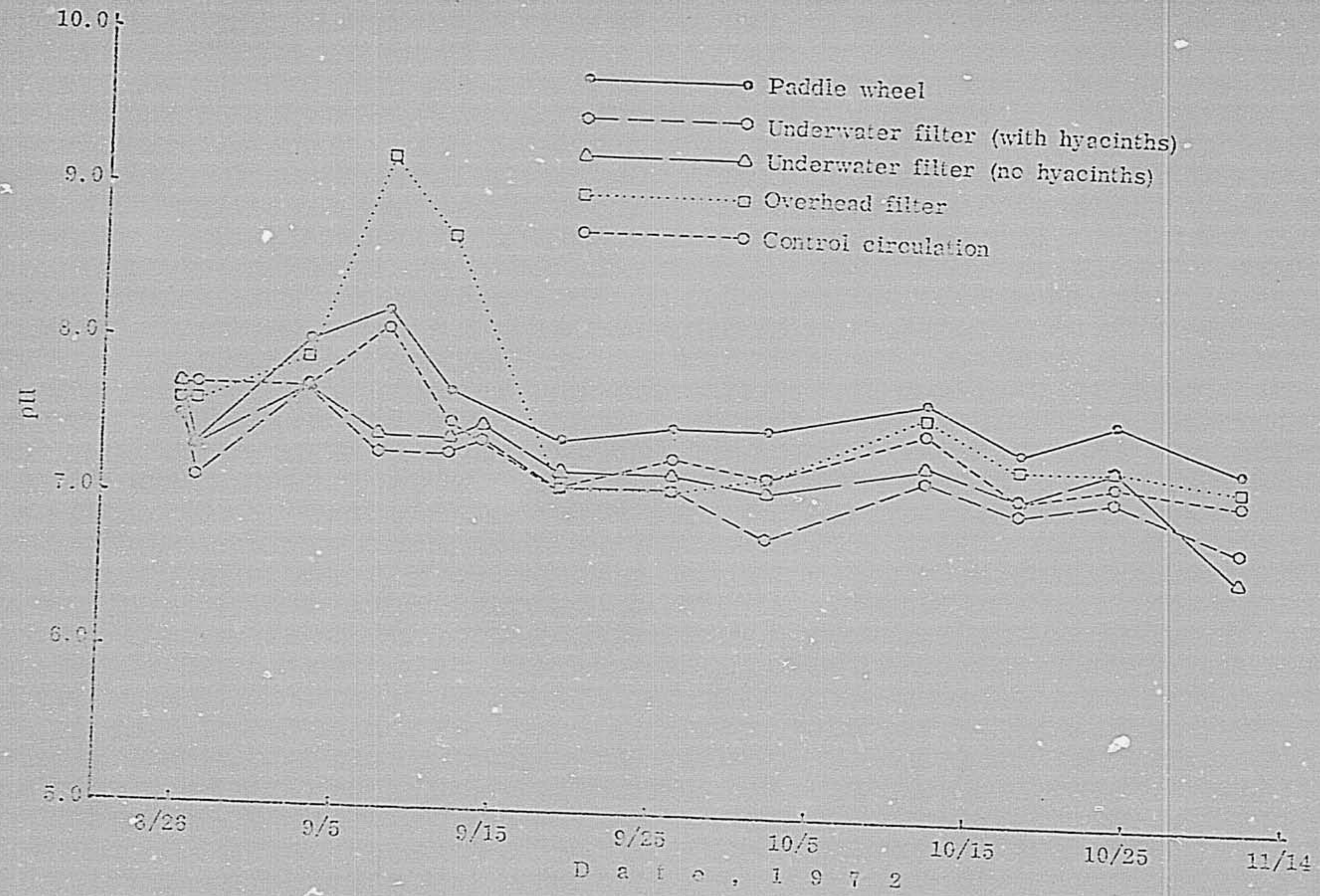


Figure 7. Morning pH in various treatments

TABLE 6

TREATMENT MEANS OF EARLY MORNING pH

Replication	Paddle wheel	Underwater filter (with hyacinths)	Underwater filter (no hyacinths)	Overhead filter	Control
1	7.6	7.1	7.3	7.6	7.4
2	7.6	7.3	7.3	7.6	7.4
3	7.6	7.1	7.2	7.8	7.5
Mean	7.6	7.2	7.3	7.7	7.4
Mean comparison	a	c	bc	a	b

Treatment means ranged from 12.6 to 21.4 ppm (Table 7). The paddle wheel treatment had the lowest concentration. In the ascending order, it was followed by the overhead filter treatment, underwater filter with water hyacinths treatment, filter without water hyacinths treatment, and the control circulation treatment.

Comparison of means at 5 per cent level indicated no significant difference among the first four treatments, but they are all significantly lower than the control circulation in carbon dioxide concentration. The high level of carbon dioxide in the control circulation was probably due to the decomposition of wastes, uneaten feeds, and respiration. These data indicate that the control circulation had the least effective aeration and it was probable that more wasted feed accumulated and decomposed in this treatment. When the fish were under stress, feeding declined.

Without agitation, the ponds of the paddle wheel treatment would probably have had a higher rate of carbon dioxide production, due to a significant amount of carbon dioxide from fish respiration and decomposition of wasted feed from inefficient conversion (Table 11). The paddle wheel was able to move a large volume of water and carbon dioxide concentrations were the lowest in these treatments.

Concentrations of carbon dioxide in ponds with paddle wheels were comparable to those in ponds with gravel filters. This was probably an effect of the biological activity of the gravel filter and efficient conversion of feed.

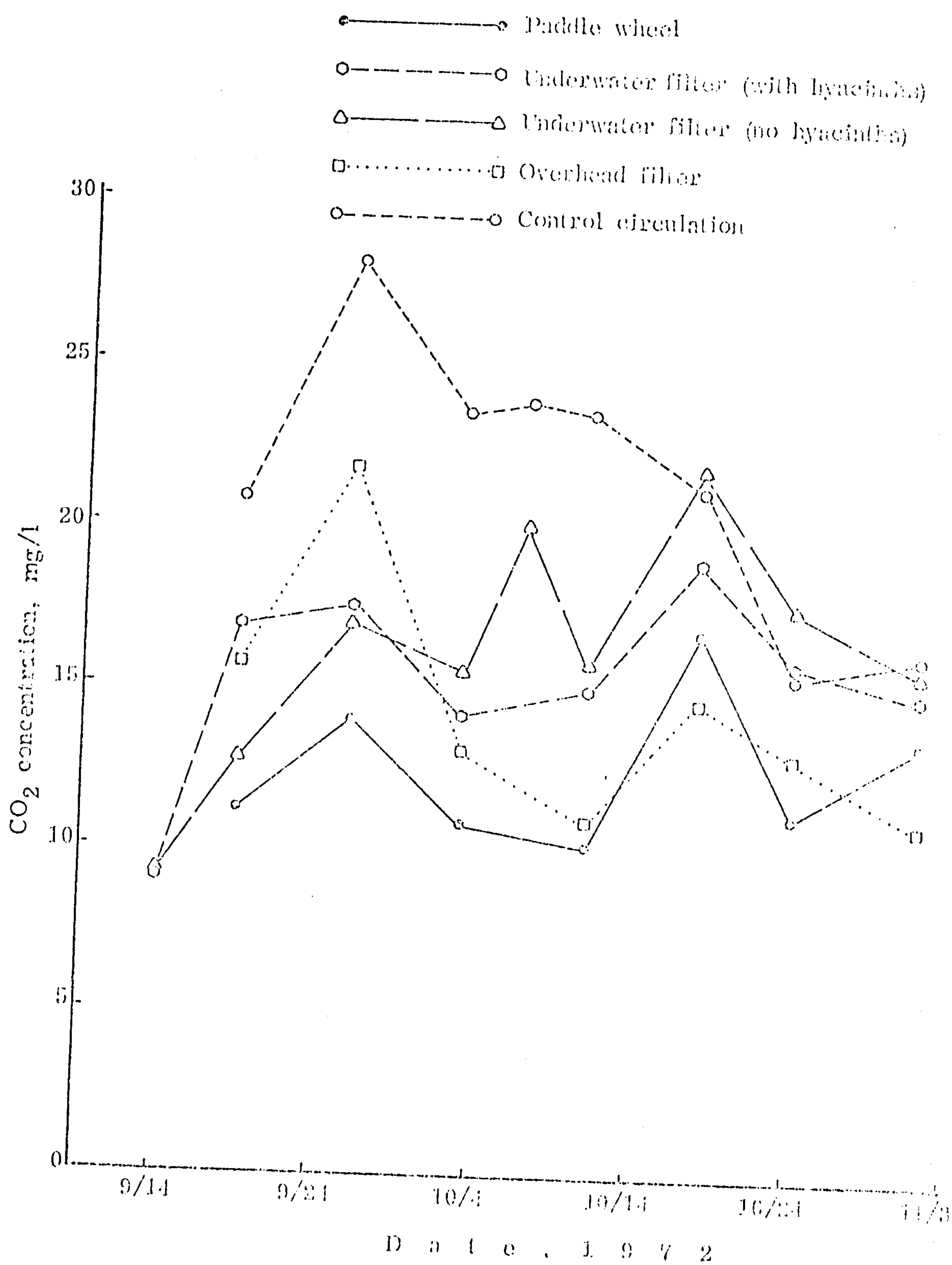


Figure 8. Carbon dioxide concentration in different treatments

TABLE 7

TREATMENT MEANS OF CARBON DIOXIDE CONCENTRATION, ppm

Replication	Paddle wheel	Underwater filter (with hyacinth)	Underwater filter (no hyacinth)	Overhead filter	Control circulation
1	13.7	15.0	20.5	15.4	22.9
2	9.1	16.4	15.0	15.6	20.4
3	15.0	14.6	11.6	12.0	21.0
Mean	12.6	15.3	15.7	14.3	21.4
Mean Comparison	a	a	a	a	b

Two replications of the underwater filter without water hyacinths had good yield (A8 and A10). One pond (A8) had consistently high carbon dioxide concentration as compared to the other (A10). This difference can be attributed to the difference in number and weight of fish in the ponds. Pond A8 produced 334 fish weighing 153.5 lbs. Pond A10 had 278 fish weighing 138.7 lbs.

The overhead filter treatment suffered from extensive mortality except in one replication (Table 11). In this replication, a higher level of carbon dioxide could be expected as compared with the other two replicates within the treatment, due to the higher density of fish. The relatively low carbon dioxide was due to the efficacy of the filter providing more time for the carbon dioxide to escape to the atmosphere as the water flows through the filter.

Without oxygen depletion, no fish kill was associated with high carbon dioxide concentrations. On the other hand, these high concentrations had probably affected the respiration of fish in ponds which suffered low dissolved oxygen most of the time. Basu (1959), in an experiment using four species of fish, namely: speckled trout, brown bullhead, carp and goldfish found a general trend of reduction in the active metabolic rate as the oxygen concentrations in the medium decreased with an increasing carbon dioxide concentration. Spotte (1970), stated that the presence of free carbon dioxide may depress the affinity of fish blood for oxygen especially in crowded systems with low oxygen tensions.

Total alkalinity

There was a wide range of values obtained during the measurement period varying from 10 to 172 mg/l as $CaCO_3$ (Table 8). There was a marked distinction between the values of ponds with good fish survival and those which suffered heavy fish mortality. Pond having harvested weights of 100 lbs or greater had mean total alkalinity values between 54 to 164 mg/l as $CaCO_3$. Ponds with high fish mortality and harvested weights of 54 lbs or less, had values ranging from 22 to 99 mg/l as $CaCO_3$. Elevated alkalinity in ponds with high densities of fish was probably related to the reaction of abundant carbon dioxide with the calcium silicate of the pond surfaces to form bicarbonate.

The mean alkalinity values for each replication and treatment are presented in Table 8. No difference among the treatment means was found significant.

In general, the range of values obtained for the total alkalinity was within the desirable limit of 20 to 150 mg/l as $CaCO_3$ (Boyd, personal communication, 1974) for good plankton growth.

Hardness and calcium concentrations

Total and calcium hardness concentrations in the water ranged from 33 to 122 mg/l and from 22 to 86 mg/l, respectively (Tables 9 and 10). The two minimum and maximum limits occurred in two ponds, A11 and A23-24, that had high fish mortality. However, pond A23-24 had the largest mortality during the eighth week or two weeks before the experiment ended, while A11 had a kill on the third week after stocking.

TABLE 8

TOTAL ALKALINITY, mg/l AS $CaCO_3$ FOR EACH POND

Treatment	Pond No.	DATE 10/11	10/19	10/26	Replication Mean	Treatment Mean
Paddle Wheel	A1-2	113.6	115.4	80.0	103	
	A3-4	116.8	139.6	123.0	127	131
	A5-6	160.2	172.0	161.0	164	
Underwater filter (with hyacinths)	A7	57.4	63.0	41.0	54	
	A9	135.0	170.0	143.0	149	78
	A11	30.5	32.0	34.0	32	
Underwater filter (no hyacinths)	A8	170.0	134.0	123.0	142	
	A10	111.8	110.0	63.0	95	86
	A12	39.2	17.5	10.0	22	
Overhead filter	A13-14	89.6	87.0	105.0	94	
	A15-16	110.0	95.0	92.0	99	94
	A17-18	93.2	92.0	84.0	90	
Control Circulation	A19-20	139.5	125.0	96.0	120	
	A21-22	151.8	136.4	131.8	140	117
	A23-24	163.0	50.0	57.0	90	

Values for calcium hardness were almost as great as values for total hardness indicating that most of the hardness was calcium hardness. Non-significant difference was found among treatment means with regard to total and calcium hardness.

Production, survival, and conversion

The harvested weight and observed total mortality data from each replication of the treatments are presented in Table 31, Appendix. Due to excessive mortality in several replications of different treatments, each replication was examined.

Gross and net yields are presented in Table 11. The formula for the gross yield was applied to the underwater filter treatments that were stocked with fish (Table 30, Appendix). For the remaining treatments, the paddle wheel, overhead filter, and control circulation, where fish had been added to compensate their accumulated mortality during the time of restocking, a modification of the computation became necessary. Using the formula as before, the value obtained for each replicate is corrected by subtracting the amount of added weight at the time of restocking.

The net yield under the conditions of the experiment cannot be an effective measure in the analysis. It did not consider mortality which was important under the circumstances as a part of production.

Paddle wheel. This treatment had the most uniform production and best survival (Table 12). The paddle wheel was superior in aerating and circulating the water and this treatment exhibited the lowest water temperature.

TABLE 9

TOTAL HARDNESS, mg/l AS $CaCO_3$ FOR EACH POND

Treatment	Pond No.	DATE 10/2	10/11	10/19	10/26	Replication Mean	Treatment Mean
Paddle wheel	A1-2	78	80	88	70	79	
	A3-4		66	72	69	69	79
	A5-6	82	80	92	96	88	
Underwater filter (with hyacinths)	A7	82	76	67	60	71	
	A9	109	112	116	110	112	73
	A11	53	33	25	29	35	
Underwater filter (no hyacinths)	A8	104	109	107	108	107	
	A10		90	68	66	75	78
	A12	55	42	50	66	53	
Overhead filter	A13-14	57	74	69	85	71	
	A15-16	68	77	81	75	75	74
	A17-18	78	82	80	69	77	
Control circulation	A19-20	94	93	100	114	100	
	A21-22	97	91	94	99	95	99
	A23-24	76	97	116	122	103	

TABLE 10

CALCIUM CONCENTRATION, mg/l AS $CaCO_3$
FOR EACH POND

Treatment	Pond No.	DATE, 1972 10/11	10/19	10/26	Replication Mean	Treatment Mean
Paddle wheel	A1-2	70	68	52	63	
	A3-4	58	62	58	59	62.7
	A5-6	68	62	68	66	
Underwater filter (with hyacinths)	A7	56	34	26	39	
	A9	80	64	60	68	42.7
	A11	24	22	18	21	
Underwater filter (no hyacinths)	A8	83	64	66	78	
	A10	62	38	32	44	52.7
	A12	34	44	30	36	
Overhead filter	A13-14	56	54	64	58	
	A15-16	70	68	64	67	62.7
	A17-18	68	62	60	63	
Control circulation	A19-20	78	84	82	81	
	A21-22	85	80	84	83	82.0
	A23-24	78	82	86	82	

Underwater gravel filters. The best individual performance for a pond was a replication of the underwater filter with water hyacinths which yielded 170 lbs at harvest with a survival of 97.3 per cent. However, the growing period for the two underwater filters was only 49 days as compared to 68 of the other treatments (Table 11). In terms of supporting fish growth, another replication in the same treatment performed well until the pump strainer was clogged with filamentous algae that resulted in pump failure.

Two replications (A8 and A10) of the filter without water hyacinths had survival of 90.0 and 90.3 per cent, respectively.

There was no significant difference between the two underwater filter treatments with regard to the water quality parameters or production values. The water hyacinths in one treatment had negligible effect, therefore, the two filters can be treated as a single treatment. Eliminating the replication in the two treatments that had high mortality, the three remaining replications are comparable to the paddle wheel. The harvested weight for the three ponds varied from 138.7 to 170.3 lbs. The net conversion was 1.46 to 2.66 (Table 11) as compared to 3.13 to 4.66 of the paddle wheel. An additional asset of the underwater filters was the clear water and the least growth of phytoplankton. One of the main problems was the growth of filamentous algae such as Hydrodictyon and Pithophora which became a problem in water circulation and limited the available space for the fish.

The poor conversion in the paddle wheel treatment and occasional mechanical trouble of the machine were major problems. The inefficient

TABLE 11

INDIVIDUAL TREATMENT YIELDS, FEED CONSUMPTION AND CONVERSION

Treatment	Pond No.	Gross yield[1] lbs	Net yield[2] lbs	Feed consumed lbs	Conversion Gross[3]	Conversion Net[4]	Growing period days
Paddle wheel	A1-2	53.81	44.80	140.6	2.61	3.14	68
	A3-4	46.06	44.90	140.6	3.05	3.13	68
	A5-6	38.08	30.20	140.6	3.69	4.66	68
Underwater filter (with hyacinths)	A7	41.20	0.10	59.0	1.43		49
	A9	71.4	70.30	102.9	1.44	1.46	49
	A11	29.23	-90.70	50.9	1.74		49
Underwater filter (no hyacinths)	A8	64.26	53.50	102.9	1.60	1.92	49
	A10	40.65	38.70	102.9	2.53	2.66	49
	A12	14.10	-64.90	36.0	2.55		49
Overhead filter	A13-14	52.88	34.10	134.6	2.55	3.95	68
	A15-16	37.35	-45.90	96.9	2.59		68
	A17-18	42.18	-94.90	88.7	2.10		68
Control circulation	A19-20	34.26	25.10	140.6	4.10	5.60	68
	A21-22	37.12	7.30	121.7	3.28		68
	A23-24	19.31	-98.10	133.4	6.39		68

1/ Gross yield = Final wt. - (Stocked wt. - mortality wt.).

2/ Net yield = Final wt. - stocked wt.

3/ Conversion (gross) = Feed added/gross yield.

4/ Conversion (net) = Feed added/net yield.

TABLE 12

FISH MORTALITY AND SURVIVAL

Treatment	Pond No.	Estimated no. of stocked fish	No. of observed mortality[1/]	Per cent mortality	Per cent survival
Paddle wheel	A1-2	301	9	3.0	97.0
	A3-4	264	1	0.4	99.6
	A5-6	295	24	8.1	91.9
Underwater filter (with hyacinths)	A7	320	104	32.5	67.5
	A9	330	9	2.7	97.3
	A11	387	284	73.4	26.6
Underwater filter (no hyacinths)	A8	371	37	10.0	90.0
	A10	308	30	9.7	90.3
	A12	268	217	81.0	19.0
Overhead filter	A13-14	278	29	10.4	89.6
	A15-16	316	139	44.0	56.0
	A17-18	344	328	95.4	4.6
Control circulation	A19-20	281	18	6.4	93.6
	A21-22	319	56	17.6	82.4
	A23-24	257	245	95.3	4.7

1/ From the date of restocking, September 13, 1972.

conversion indicated that some factors in the environment were not conducive for fish growth. Considering that feeding rate was not adjusted during the entire experimental period, their feeding efficiency should have been high, due to lesser food given in comparison to their increasing weight and higher demand for food. It was also noted that some fish in the paddle wheel treatment died at harvest (Table 1).

Overhead gravel filter. This treatment had one replication (A13--14) that had a harvested weight of 134 lbs and survival of 89.6 per cent. The net conversion of 3.95 was in the range of the paddle wheel treatment. Water hyacinths grew vigorously in all treatments, except those grown in the waste settlement basin of the overhead filter treatment. The water hyacinths in other treatments had thick growth that thinning was made at least twice. Most plants in the overhead filter treatment were stunted in growth. It is probable that the filter is effective in retaining the organic wastes from the flowing water.

Control circulation. This treatment gave the poorest results among the five treatments. One replication produced a harvested weight of 125 lbs and survival of 93.6 per cent. The fish survival in the pond was due to the supplementary pump with venturi system installed independent of the treatment as originally designed. Net conversion of 5.6 was very inefficient.

At draining time the water in the control circulation and the paddle wheel treatments had the worst odor due to the decomposing wastes. To a lesser extent, the overhead filter water had some foul odor as well. This is an indication of insufficient waste disposal.

IV. 1973 EXPERIMENT

MATERIALS AND METHODS

Introduction

The planning of activities for 1973 considered results from the previous experiment. Improvements were introduced to alleviate some of the problems that hindered the effective performance of each treatment.

The small capacity pumps that were a major limiting factor in supplying sufficient dissolved oxygen to some treatments were changed to larger ones. Also, more attention was focused on determining the cause of fish mortality other than that caused by oxygen depletion.

The treatments that were considered to have potential value were studied further and treatments that gave poor results were discarded. The 1973 experiment was designed to verify past results, and to explore methods for further improvements.

It was determined in 1972 that some treatments were capable of supporting a standing crop of 170 lbs composed of a wide range of sizes and numbers in 44 days. The succeeding study envisioned to raise intensively stocked fish from fingerlings to marketable size in six months. The stocking rate fixed the number of uniform size fish.

The experiment began on June 5, 1973 and was terminated October 21, 1973.

Experimental design and treatments

Twenty one concrete ponds each having an area of 1/200 acre were used in this study. The ponds were filled to a depth of approximately 2.5 ft. The treatments were distributed in a completely randomized fashion among the ponds. However, prior consideration was given to the pairing of the ponds to suit the needs of the treatments. Some treatments required single ponds while others required dual ponds. The pond layout and treatment allocations are shown in Figure 8. The control treatment was not used since it was shown in the previous experiment that an untreated control cannot produce large numbers of fish in a closed system.

As a result of the excellent performance of the paddle wheel, two treatments were established using this device. Similarly, the underwater gravel filter was used at two stocking rates. Otterbine submersible pumps with venturi aeration were used in all treatments, except the paddle wheel treatments. Water hyacinths were not used in any of the treatments. Instead, a board placed at the end of the ponds covering about 10 per cent of the pond area provided shelter for the fish in all treatments.

The following five treatments were replicated three times:

1. Underwater gravel filter, single pond with venturi aeration, stocked with 400 fish.

2. Underwater gravel filter, single pond with venturi aeration, stocked with 200 fish.

3. Water circulation with paddle wheel, dual ponds, stocked with 400 fish.

4. Water circulation with paddle wheel, single pond, stocked with 400 fish.

5. Water circulation through an overhead filter, dual pond, stocked vith 400 fish.

The same design of underwater gravel filter as used in 1972 was used n the study. The submersible pumps, driven by 1/2 hp motors, had a larger 'low rate than pumps used in 1972. The full rate of flow was used in circu-ating and aerating the water through the underwater filter. The only difference etween treatments 1 and 2 was the stocking rate.

The paddle wheel treatments 3 and 4 differed only by way of the waste ettlement basin provided for treatment 3.

A minor modification was made in the overhead filter as compared to he 1972 experiment. In the 1973 experiment, approximately 10 gpm flow as discharged on top of the filter while the remainder was circulated and enturi-aerated within the production pond.

All treatments were equipped with clock timers which were set for ther 15 minutes on and 45 minutes off (8:00 AM to 8:00 PM) or continuous peration (8:00 PM to 8:00 AM). Adjustment of this schedule was needed in me ponds during the course of the experiment.

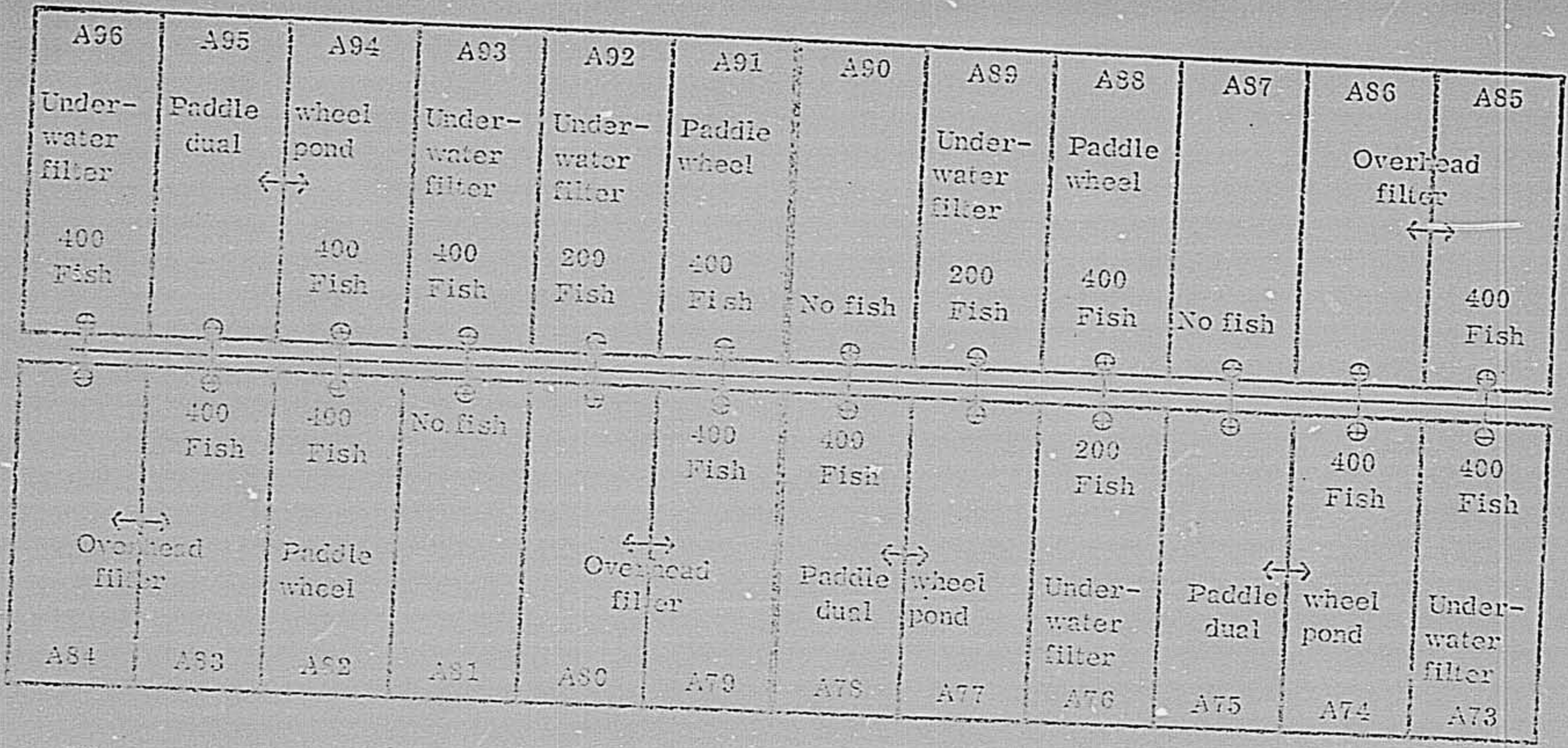


Figure 9. Pond layout and treatment distribution during the 1973 experiment.

Water supply

The same source of water as used in the preceding year was used for the experiment. Whenever necessary, water was added to the ponds to compensate for evaporation and leakage in order to maintain the depth at approximately 2.5 feet.

Experimental techniques

Stocking of fish. Channel catfish, *Ictalurus punctatus* (Rafinesque) fingerlings 4 to 6 inches long were stocked in the ponds. The number of fish per pond was fixed. One underwater filter treatment was stocked with 200 catfish, with the rest of the treatments stocked 400 each. The weights of the fish stocked per pond were fairly uniform (Table 42, Appendix). The fingerlings came from a common fish population.

Feeding. The fish were fed seven days a week during the late afternoon with floating pelleted Purina Trout Chow. The rate of feeding varied from 5 to 3 per cent of the body weight of stocked fish. From June 11 to July 13, 1973, the fish received 5 per cent feeding rate; July 14 to August 13, 4 per cent; and August 14 until the end of the experiment 3 per cent. Feeding was adjusted weekly using the method described by Swingle (1967). Equal amounts of feed were given to all treatments at the beginning of the experiment. During the course of the experiment, it was allowed to vary depending on the growth rate and conversion as determined by weight sampling. The faster growing fish received more feed than the slower ones. This was done so as not to suppress the rapid growth of the fish which could possibly be due to a favorable environment provided by the treatment. The maximum accumulated amount of feed given for a growing period of 101 days was 193.6 lbs or 38,720 lbs/acre. The maximum daily ration given for one week reached 4.7 lbs or 940 lbs/acre. Feed rationing was made difficult due to day to day mortality.

Fish sampling and growth. The growth rate of fish was measured by seining fish at monthly intervals and weighing them. Fifty per cent or more of the fish population were weighed each time. The fish were anethesized with quinaldine while handling to avoid stress. The fish were counted and weighed in mass as quickly as possible. From the sampled weight, an estimate of the feed conversion for each treatment was obtained and used in feeding computations.

Water analysis

In addition to dissolved oxygen, temperature, oxygen consumption by planktonic community, carbon dioxide, pH, total alkalinity, total hardness, the pond waters were analyzed for turbidity, ammonia and nitrite concentrations.

The time, frequency, and method of analysis were as follows:

1. Turbidity was expressed in terms of Jackson Turbidity Unit (JTU). The turbidimeter used in the laboratory was Hach, Model 1860. Water samples were taken from the middle depth of pond. Determinations were made twice a month.

2. Ammonia (NH_3) concentration was determined at bi-weekly intervals by distillation and spectrophotometer methods as described by Swingle (1969).

More determinations were made in ponds having mortality that was not caused by oxygen depletion.

3. Nitrite (NO_2) concentration was measured as frequently as ammonia by the sulfanilic acid method (Swingle, 1969). The water sample was filtered through a 10 u millipore filter facilitated by using a suction mechanism. Nitrite and ammonia concentrations were analyzed at the same time immediately after taking water samples early in the morning. Analysis was usually finished within eight hours.

Draining

Some ponds were drained earlier than others because of heavy mortality leaving but few fish in the pond. Further, the underwater gravel filter stocked with 400 fish reached a point where it could not conduct water into the pump sump as fast as the pumping rate. As a result, oxygen concentration declined as shown in Figures 10 and 10a. These ponds were drained on September 19, 1973. The remaining ponds with more fish were drained on October 21, 1973.

The recovered fish were counted and weighed. These data are recorded in Table 42, Appendix.

RESULTS AND DISCUSSION

Mortality

Irregular mortalities occurred in all but one treatment (Table 13). Mortality was highly correlated with dissolved oxygen, ammonia and carbon dioxide. The correlation coefficients were -0.61, 0.57, and 0.45, respectively. Nitrite was significantly correlated with mortality in the paddle wheel with dual pond treatment with a coefficient of 0.68. The 5 per cent nortality in the underwater filter treatment with 200 fish was not correlated vith any of the water quality parameters.

A regression analysis of mortality as dependent variable against ndependent variables, namely: treatments, time, interaction between time nd treatments, dissolved oxygen and temperature showed a highly significant elationship. A 70 per cent explained variation was attributed to these variables.

The underwater filter with 400 fish had a major fish kill in one replication after 86 feeding days. Fish in the two remaining replications suffered average mortality of 5.3 per cent.

Fish of all replications of the underwater filter treatment with 200 fish rvived 131 feeding days. There was an average mortality of 5 per cent.

The paddle wheel with dual pond treatment, had a complete fish kill in replication due to oxygen depletion during the late afternoon. This was ociated with an increasing ammonia concentration. A dense algal bloom developed in this replication and sudden phytoplankton die-off resulted in

TABLE 13

WEEKLY MORTALITY, NUMBER AND WEIGHT, lbs IN EACH POND

Date 1973	Underwater filter single pond (400 fish)						Underwater filter single pond (200 fish)						Paddle wheel dual pond (400 fish)						Paddle wheel single pond (400 fish)						Overhead filter dual pond (400 fish)					
	A73		A83		A96		A76		A89		A92		A74-75		A77-78		A94-95		A82		A88		A91		A79-80		A83-84		A85-86	
	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.
6/23-6/29													337*	14.60																
6/30-7/6									7	0.24													4	0.03						
7/7-7/13											7	0.26																		
7/14-7/20																														
7/21-7/27	2	0.03																	3	0.12	9	0.36	57	3.67						
7/28-8/3																			132	9.59	19	1.58	33	2.21						
8/4-8/10															1	0.03			49	2.69	7	0.52	2	0.07						
8/11-8/17													6	0.56	407	39.30			41	2.61	16	1.47	4	0.14						
8/18-8/24	1	0.07			1	0.06							1	0.10					9	0.35	1	0.48	30	1.34	1	0.04			2	0.15
8/25-8/31					1	0.06							255	45.50			1	0.06	46	2.48	2	0.11	21	0.87	1	0.06			3	0.16
9/1-9/7			294	67.40													139	21.50	3	0.12	7	0.33	10	0.44	350	73.95	374	108.40	3	0.15
9/8-9/14			4	0.53									56	13.10			45	5.75	78	12.29	120	29.17	12	0.51	2	0.50			30	3.39
9/15-9/21																	36	5.78					80	7.84					338	93.55
9/22-9/28																	15	2.25												
9/29-10/5																	2	0.27												
10/6-10/12									1	0.10							8	1.47			1	0.13	3	0.02						
10/13-10/21																	6	0.92			1	0.11	2	0.24						
Total	3	0.15	298	67.93	2	0.12	0	0	8	0.34	7	0.26	345	59.28	408	39.33	250	38.00	351	30.45	183	34.28	258	17.58	354	74.55	374	108.40	376	97.40

* Mortality occurred on June 23, 1973; pond was restocked.

ligh B.O.D. The action of the paddle wheel, apparently, was not sufficient o meet oxygen demand of decomposition. The paddle wheel was set to operate ntermittently during the day and continuously at night, 8:00 PM to 8:00 AM. uring the day, it was in operation for 15 minutes out of each hour. A longer eriod of rest was fixed during feeding time. The low oxygen reading was aken about feeding time. The timer setting was changed so that the paddle heel ran 30 minutes out of each hour during the day.

Chronic mortalities occurred in all replications of the paddle wheel with ingle pond treatment. Mortalities began during the fifth week of the experiment nd continued through the thirteenth week.

Most of the fish in both paddle wheel treatments developed a blood ondition similar to that which occurred in 1972. This condition may have een caused by ammonia and nitrite. Neither of these treatments had filtra- on devices for removing wastes. The dual pond of the paddle wheel did not nction adequately in the capacity of removing organic wastes.

The fish in the overhead filter treatment grew well in two replications til the eleventh week. The fish in the third replication survived until the elfth week. Several dead fish were sucked into the pumps which decreased water flow. The pumps continued to run until the following morning but flow rates were very low and most of the fish in all replications died. The ortality was attributed to the increased ammonia and oxygen depletion.

Water quality

Dissolved oxygen (D.O.). All of the treatments received adequate aeration most of the time. The weekly averages of the dissolved oxygen are presented in Table 32, Appendix. The minimum and maximum values for the week are also indicated. A graph of dissolved oxygen versus time is shown in Figures 10 and 10a.

Irrespective of treatments, the correlation analysis showed that dissolved oxygen was negatively correlated with mortality, ammonia, carbon dioxide and temperature. The corresponding correlation coefficients were -0.64, -0.46, -0.36, and -0.27, respectively. These coefficients show that a decrease in dissolved oxygen concentration is associated with an increase in mortality, ammonia, carbon dioxide, and temperature or vice versa.

Fish kills associated with oxygen depletion are indicated in footnotes of Table 32, Appendix. The dissolved oxygen levels during the time of mortalities were low except in a single case which occurred on September 15, 1973 where dissolved oxygen was 3.2 mg/l in pond A85-86 at the time of measurement. Water analysis for ammonia and carbon dioxide in this pond indicated high concentrations of 4.56 and 20 ppm, respectively (Tables 37 and 39, Appendix).

In general, the overall means of dissolved oxygen in each treatment were high and seemed close to each other (Table 14). The means ranged from 6.2 to 7.3 mg/l. The underwater filter with 200 fish treatment had the highest value followed by the paddle wheel with single pond treatment , overhead filter

TABLE 14

TREATMENT MEANS OF DISSOLVED OXYGEN CONCENTRATION, mg/l

Replication	Underwater filter; single pond (400 fish)		Underwater filter; single pond (200 fish)		Paddle wheel dual pond (400 fish)		Paddle wheel single pond (400 fish)		Overhead filter dual pond (400 fish)	
	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
1	6.40	7.75	7.26	9.21	6.50	9.10	7.35	8.18	6.72	9.43
2	6.66	7.87	7.33	9.48	6.22	8.97	7.36	8.35	6.98	10.13
3	6.46	8.01	7.22	8.79	6.00	9.73	7.08	8.01	7.02	9.67
Mean 1/	6.51		7.27		6.24		7.26		6.91	
Mean Comparison	b		a		b		a		c	

1/ Data considered for all mean computations were until September 18, 1973.

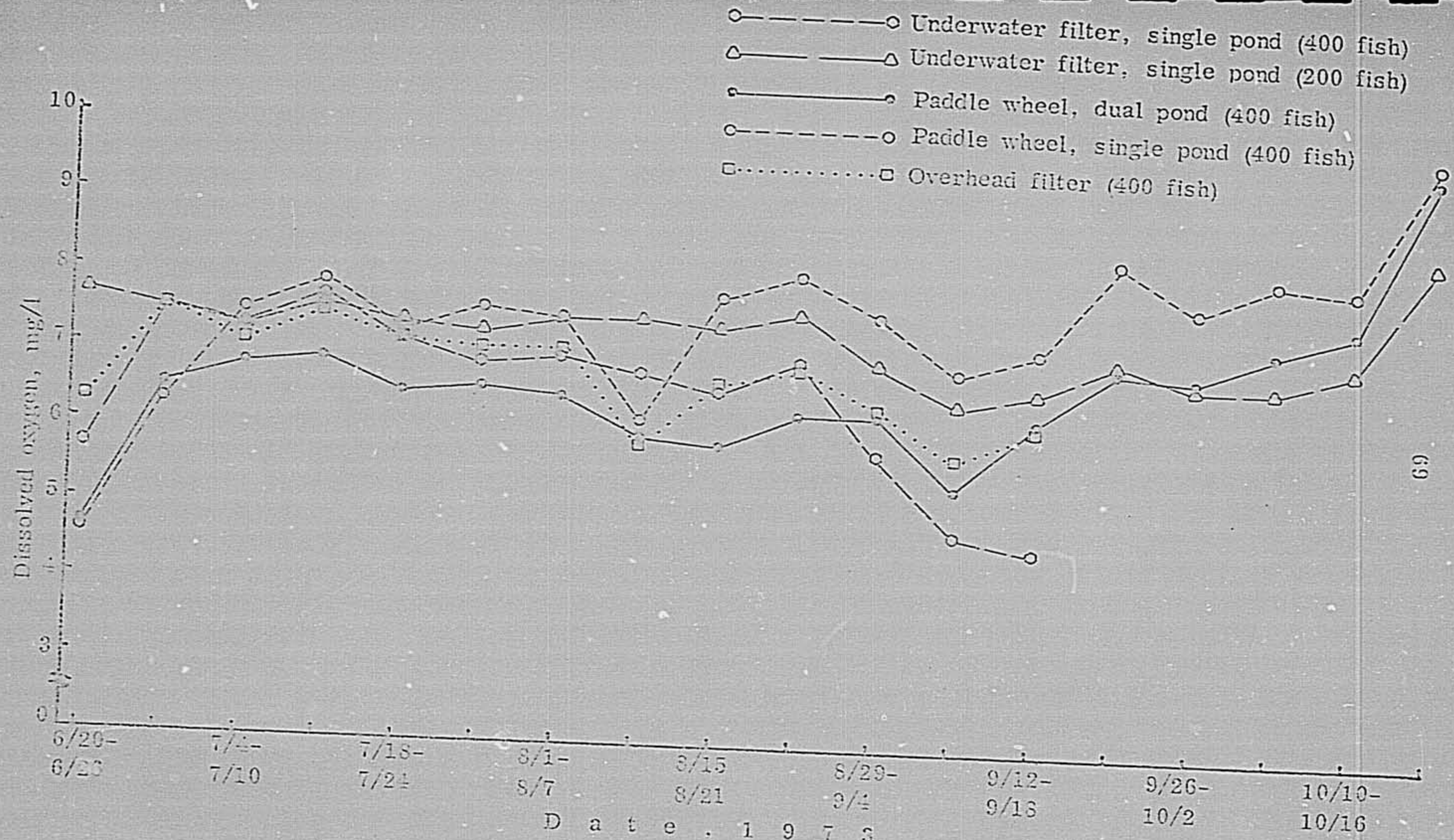


Figure 10. Weekly dissolved oxygen in various treatments (A.M.)

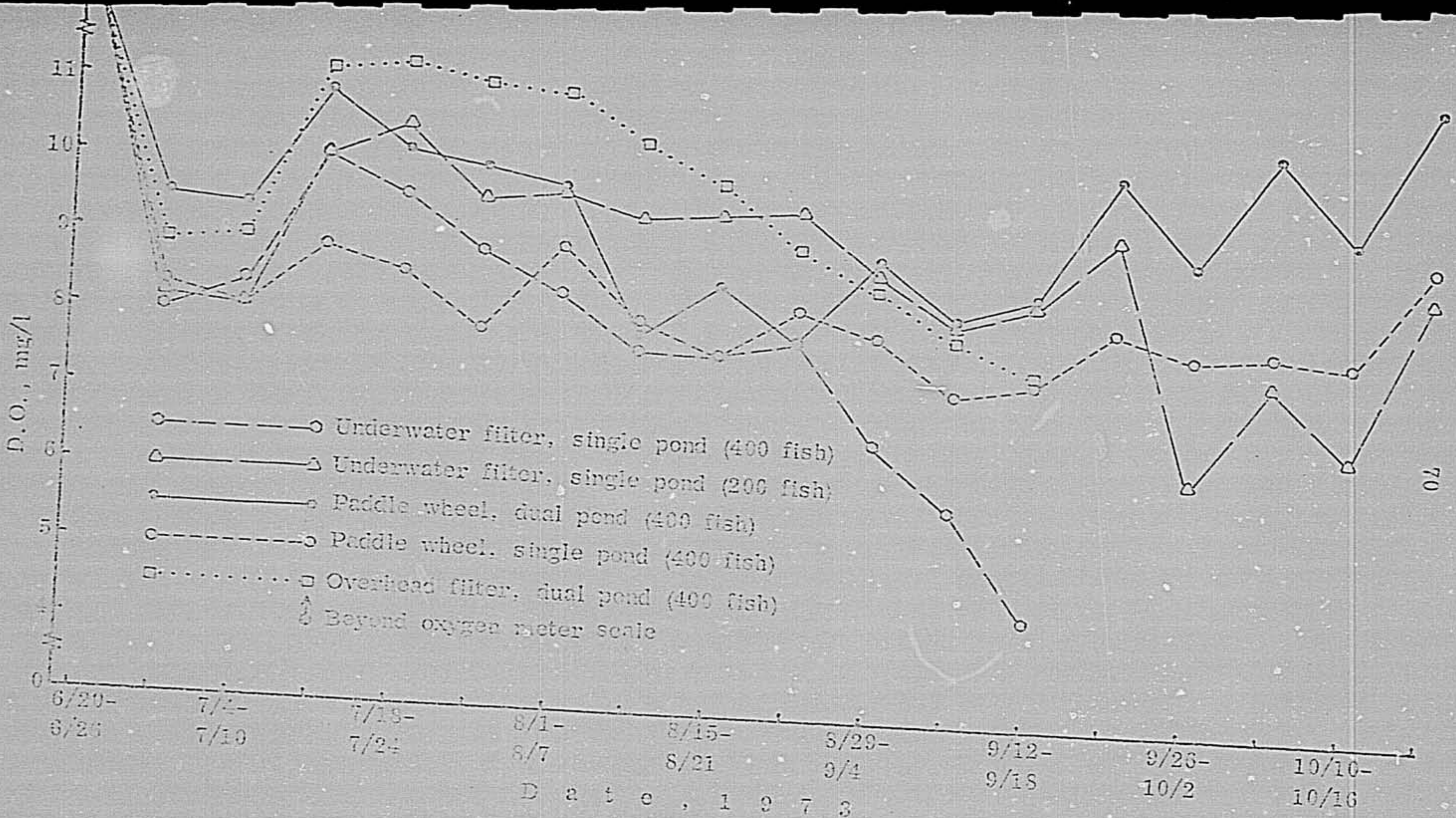


Figure 10a. Weekly dissolved oxygen in various treatments (P.M.)

treatment, underwater filter with 400 fish treatment and paddle wheel with dual pond treatment.

Analysis of variance for dissolved oxygen showed high significant difference among the treatments at 1 per cent level. Comparison among means at the 5 per cent level (Table 14) showed that dissolved oxygen in the underwater filter with 200 fish treatment and the paddle wheel with single pond treatment was not significantly different. These two treatments were different from the other three treatments. The overhead filter treatment mean showed narked difference from the other four treatments. No distinct difference was ioted between the underwater filter with 400 fish treatment and the paddle wheel with dual pond treatment.

Probably, the higher level of dissolved oxygen in treatments with underwater filter with 200 fish and the paddle wheel with single pond was due o the lower density of stocked fish and the lesser volume of water. The ponds of the paddle wheel with single pond treatment were stocked with 400 fish at he beginning but these fish populations suffered from extensive and chronic nortality (Table 13). Further, this treatment had the lowest water temperature iroughout (Figures 11 and 11a), thus, solubility of oxygen was increased.

The statistical difference in treatment means may not be important ie to the fact that high oxygen levels were maintained in all treatments. he high dissolved oxygen level suggests that the capacity of the aeration iits was adequate in all treatments.

The decline of oxygen concentration in the underwater filter treatment as shown in Figures 10 and 10a was caused by obstruction of the filter by filamentous algae and organic material.

Temperature. The average weekly morning and afternoon temperatures are presented in Table 33, Appendix. The temperature variation among the replications within each treatment was small. The computed treatment means of temperature are shown in Table 15. Decrease of temperature with time was evident in Figures 11 and 11a. The significant correlation coefficient between time and temperature was -0.62.

Analysis of variance for water temperature revealed a high significant difference (1 per cent level) among the treatments. Comparison of means (Table 15) indicated that the two underwater filter treatments and the overhead filter treatment were not different from each other. Water temperatures of the former three treatments were markedly different from that of the paddle wheel treatments. Further, a significant difference between the water temperatures of the two paddle wheel treatments was found when their means were compared.

Grouping the treatments, the highest water temperature values were recorded in the ponds with the three gravel filters, followed by the ponds in the paddle wheel with dual pond treatment, and the lowest value in the ponds for paddle wheel with single pond treatment. These results corroborated the data of 1972 experiment. Although no distinct difference between the

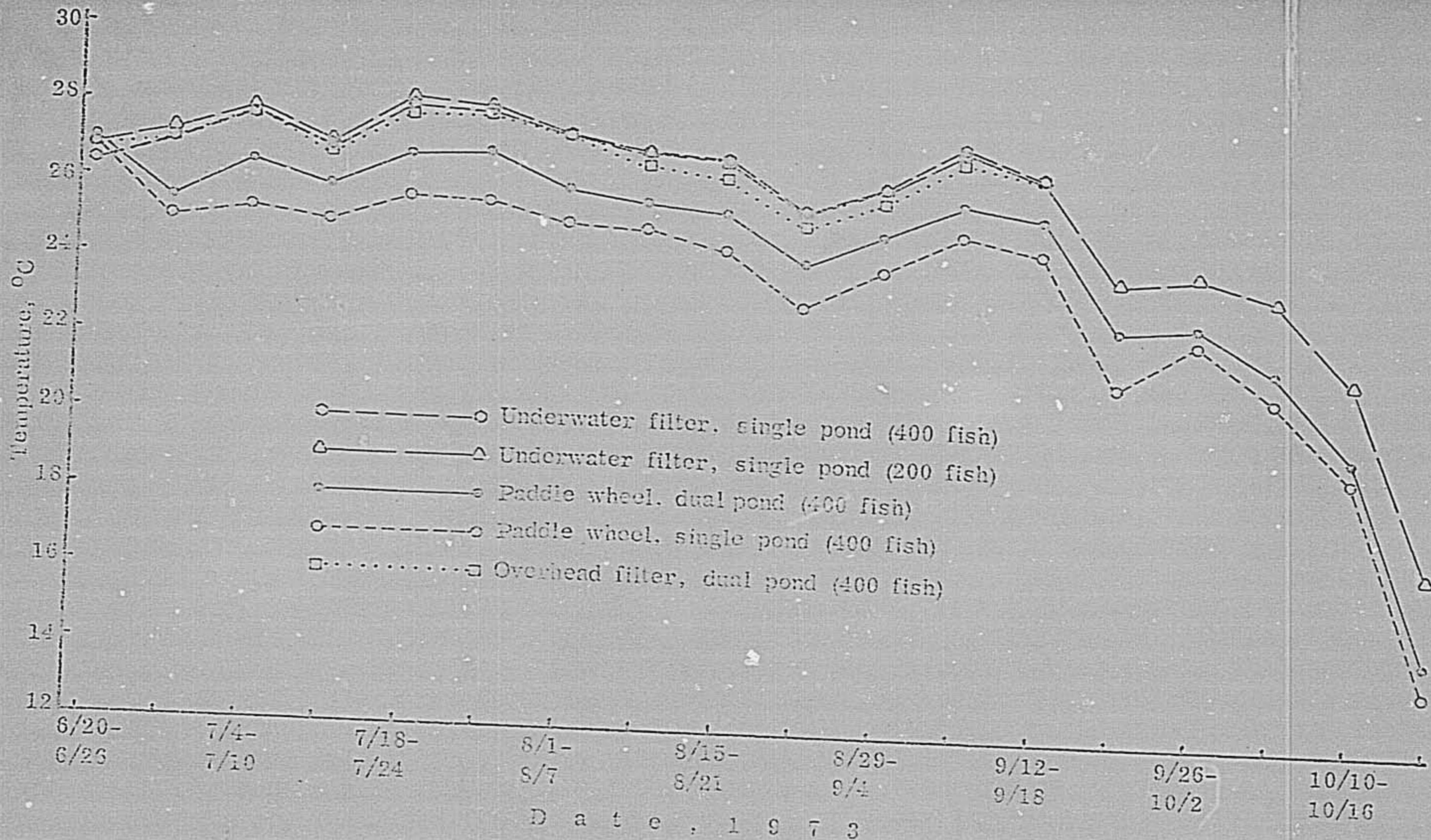


Figure 11. Weekly temperature in various treatments (AM)

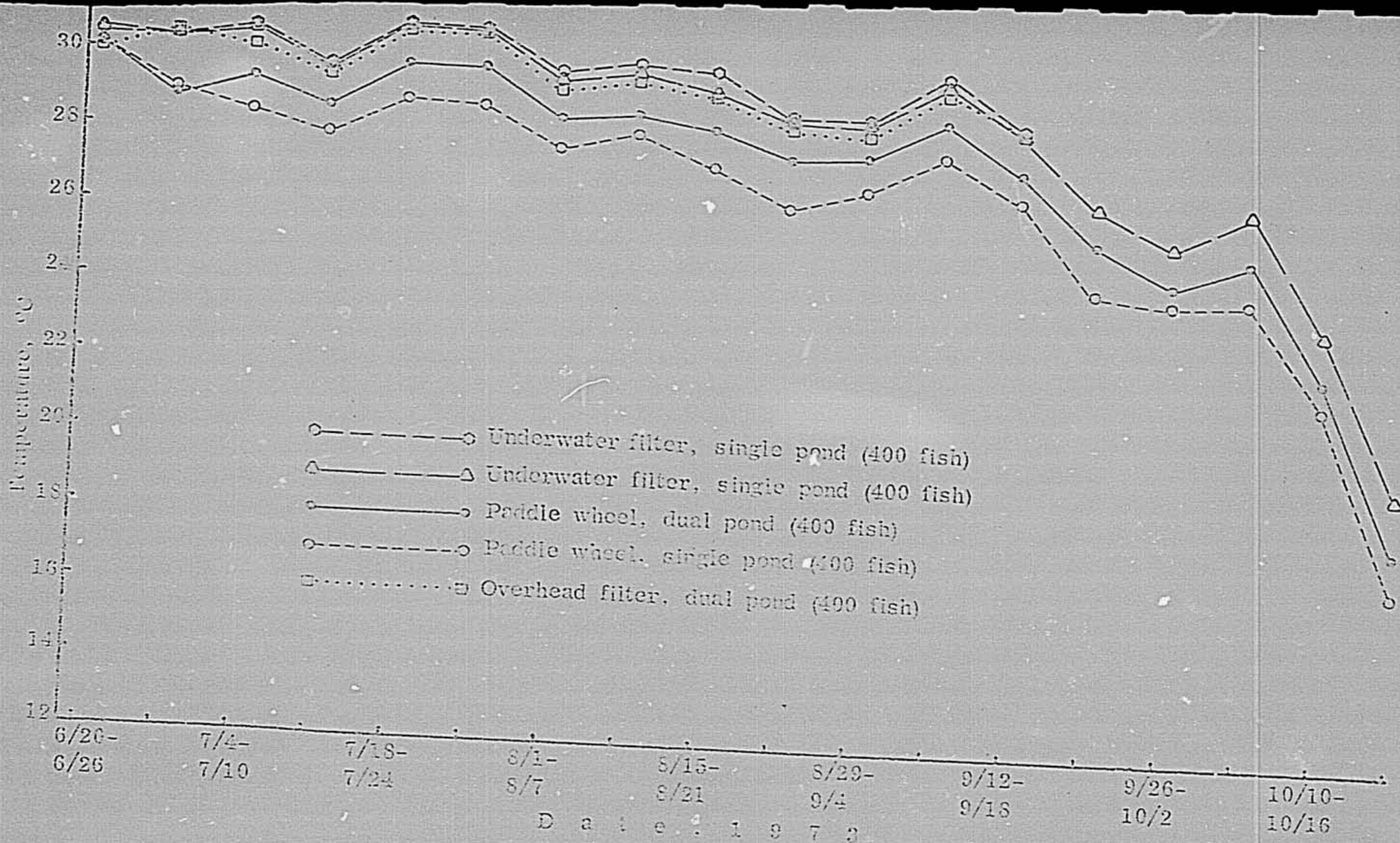


Figure 11a. Weekly temperature in various treatments (PM)

TABLE 15

TREATMENT MEANS OF WEEKLY TEMPERATURE, °C

Replication	Underwater filter; single pond (400 fish)		Underwater filter; single pond (200 fish)		Paddle wheel dual pond (400 fish)		Paddle wheel single pond (400 fish)		Overhead filter dual pond (400 fish)	
	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
1	26.9	29.9	27.2	29.9	25.8	28.8	24.9	28.1	27.0	29.8
2	27.2	30.1	27.0	29.8	26.1	29.1	24.9	28.0	26.7	29.6
3	26.9	29.9	27.1	29.8	25.9	28.9	25.2	28.2	26.8	29.8
Mean[1/]	27.0		27.1		25.9		25.0		26.9	
Mean Comparison	a		a		b		c		a	

[1/] Data considered in mean computation were until September 18, 1973.

underwater and overhead filter treatments was found in the present experiment, the ranking of values was in agreement with the previous experiment.

Dissolved oxygen consumption by planktonic community. The oxygen consumption by plankton as measured by the dark bottle technique is presented in Table 34, Appendix. The incubation time of the dark bottle ranged from 6 to 7 hours.

Oxygen consumption versus time for each treatment is shown graphically in Figure 12. Ranking of treatment means (Table 16) revealed that the highest consumption of oxygen by plankton was measured in the paddle wheel with dual pond treatment, followed by the overhead filter treatment, paddle wheel with single pond treatment, underwater filter with 400 fish treatment and the underwater filter with 200 fish treatment. Comparison of treatment means did not show any significant difference among the treatments except that of the underwater filter with 200 fish.

The values obtained in the previous experiment closely agreed with the present experiment. Mean values of the previous experiment ranged from 0.146 to 0.534 mg/l/hr or 3.504 to 12.816 mg/l/24 hr. Ranking of values in each treatment means agreed with the trend obtained in the 1972 experiment.

Turbidity. The values of water turbidity in JTU for each replication are shown in Table 34, Appendix. The change of turbidity with time in various treatments is presented in Figure 13.

The analysis of variance for turbidity showed a significant difference among the treatments (Table 17) at the 5 per cent level. Comparison of

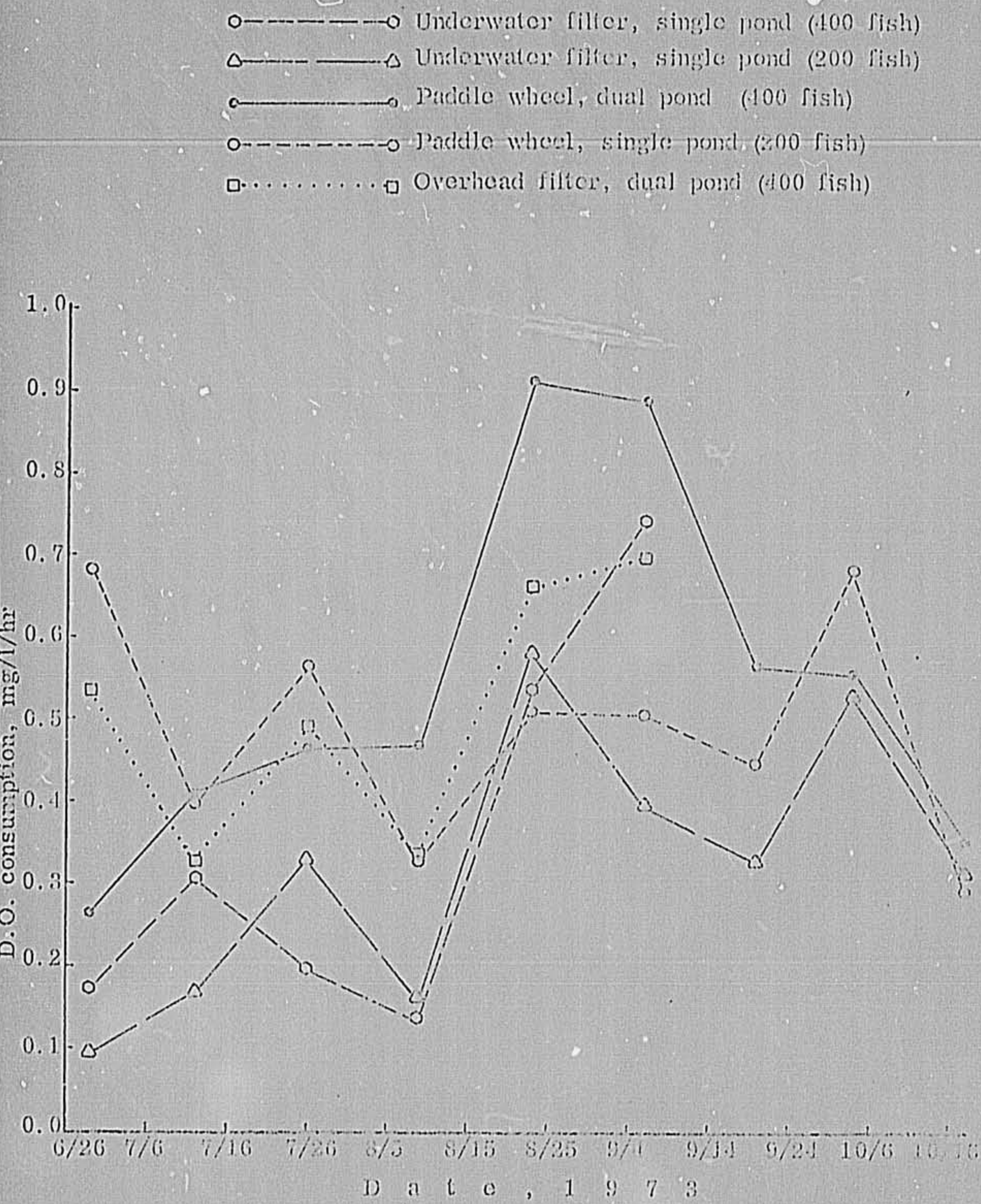


Figure 12. Dissolved oxygen consumption by planktonic community

TABLE 16

TREATMENT AND REPLICATION MEANS OF D.O. CONSUMPTION BY PLANKTON

Replication	Underwater filter; single pond (400 fish)	Underwater filter; single pond (200 fish)	Paddle wheel dual pond (400 fish)	Paddle wheel single pond (400 fish)	Overhead filter dual pond (400 fish)
1	0.2413	0.3965	0.4558	0.4170	0.6950
2	0.3347	0.1915	0.4824	0.5622	0.4115
3	0.4677	0.2807	0.6107	0.5138	0.4178
Mean[1/]	0.3479	0.2896	0.5163	0.4977	0.5081
Mean Comparison	ab	b	a	ab	ab

[1/] Data considered for all mean computations were until September 6, 1973

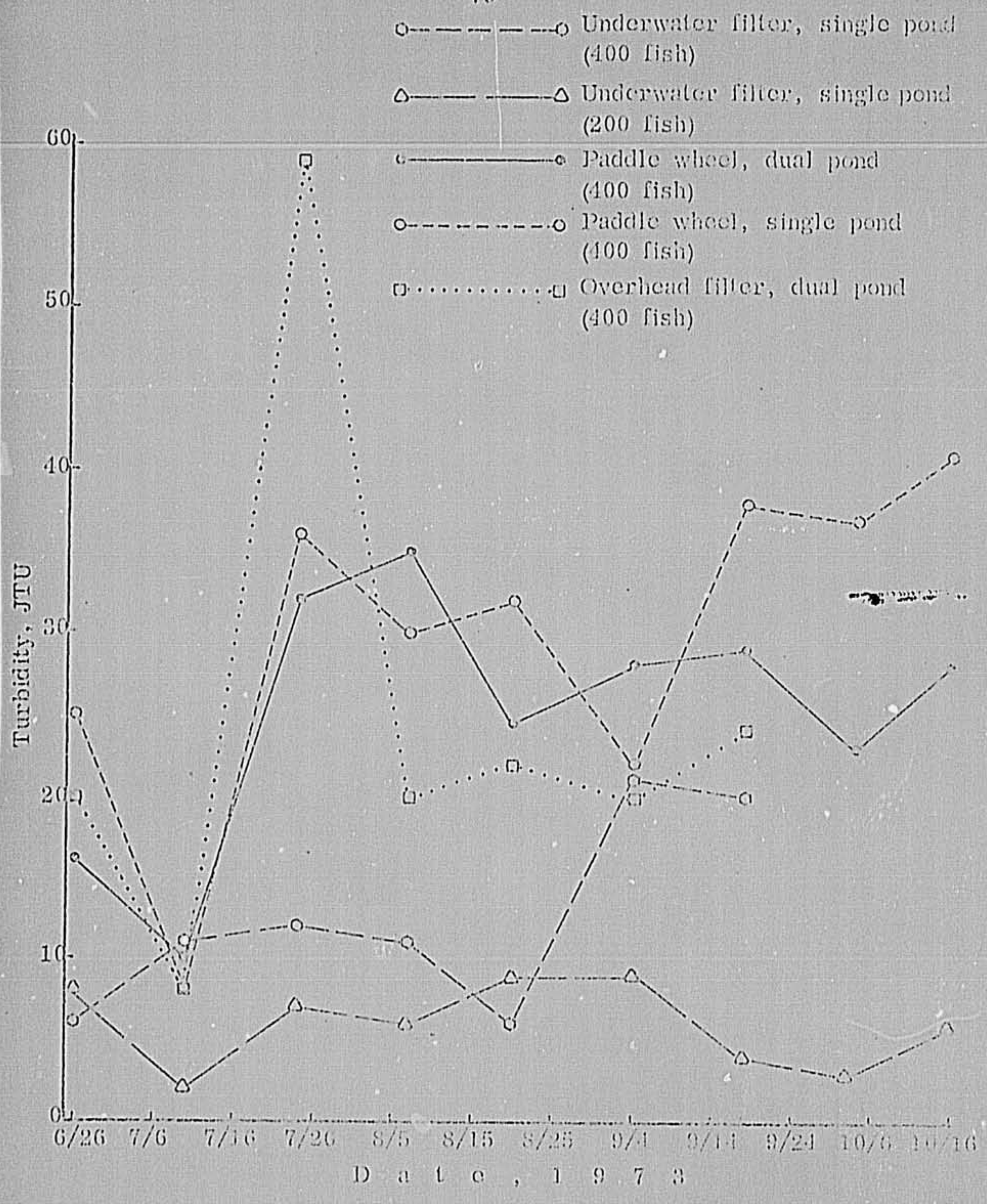


Figure 13. Turbidity in various treatments

TABLE 17

TREATMENT AND REPLICATION MEANS OF TURBIDITY, JTU

Replication	Underwater filter; single pond (400 fish)	Underwater filter; single pond (200 fish)	Paddle wheel dual pond (400 fish)	Paddle wheel single pond (400 fish)	Overhead filter dual pond (400 fish)
1	2.9	2.6	19.7	26.0	24.0
2	27.4	2.4	35.3	28.1	16.4
3	7.3	14.1	23.6	27.7	16.7
Mean 1/	12.5	6.4	26.2	27.3	19.0
Mean Comparison	ab	b	a	a	ab

1/ Data considered for mean computation were until September 18, 1973 treatment means revealed that, except the underwater filter with 200 fish treatment, no distinct difference was demonstrated among the four treatments. Likewise, the three gravel filter treatments did not show any difference among each other.

pH. There was a decrease in pH with time (Figure 14). The significant correlation coefficient between time and pH, regardless of treatment was -0.48. The decrease of pH with time was due to an increase in carbon dioxide concentration.

Values for all ponds recorded during the entire growing season varied from 6.2 to 9.6 which was practically the same as the 1972 experiment (Table 36, Appendix).

Analysis of variance for pH showed highly significant difference at 1 per cent level among the treatments. Comparison of means (Table 18) at 5 per cent level indicated that the paddle wheel with single pond treatment was not different from the paddle wheel with dual pond and overhead filter treatments. The overhead filter treatment was not different from either the paddle wheel with dual pond or underwater filter with 200 fish treatment. The underwater filter with 400 fish was found to be significantly different from the other treatments in terms of pH. The differences in the pH values among treatment means were small and would not affect fish production.

Ammonia. The values of ammonia (NH_3) concentrations in the individual replications of all treatments ranged from 0.04 to 17.60 ppm (Table 37,

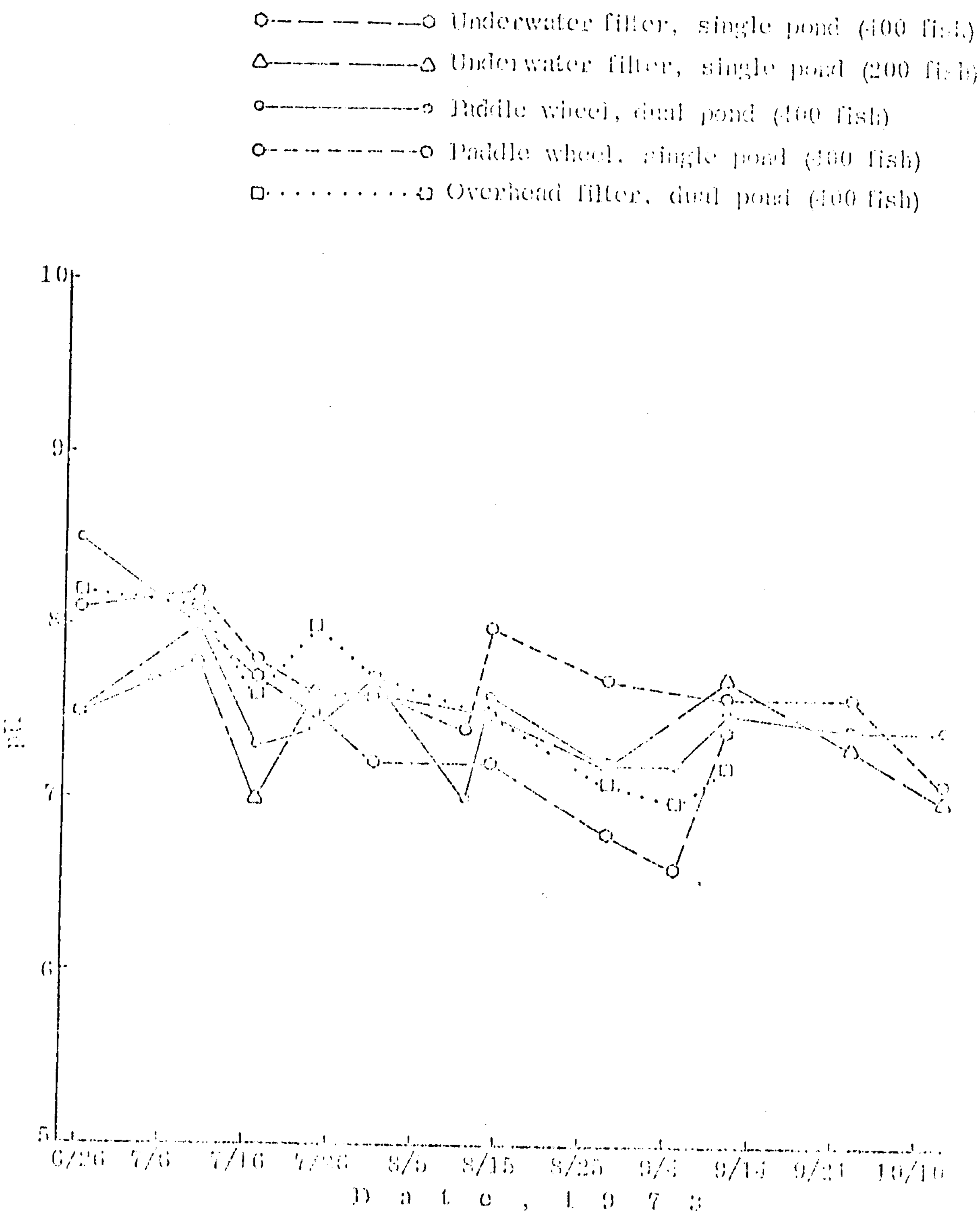


Figure 14. Morning pH in various treatments

TABLE 18

TREATMENT AND REPLICATION MEANS OF pH

Replication	Underwater filter; single pond (400 fish)	Underwater filter; single pond (200 fish)	Paddle wheel dual pond (400 fish)	Paddle wheel single pond (400 fish)	Overhead filter dual pond (400 fish)
1	7.19	7.51	7.57	7.59	7.68
2	7.36	7.49	7.63	7.79	7.78
3	7.36	7.45	7.54	7.92	7.48
Mean[1/]	7.30	7.48	7.58	7.77	7.65
Mean Comparison	c	b	ab	a	ab

[1/] Data for all mean computations were until September 11, 1973, except A78

Appendix). The average of the three replications of each treatment with minimum and maximum values is presented in Table 19.

Ammonia was highly correlated with mortality and dissolved oxygen. Corresponding coefficients were 0.57 and -0.46, respectively. With regard to the correlation between carbon dioxide and ammonia concentration, the coefficient of 0.55 was significant at a level of 5.11 per cent.

The fish mortality that occurred in ponds A77-78 and A93 was probably due to ammonia toxicity as one cause. The level of ammonia in the former pond increased from 0.43 to 4.84 ppm. The high B.O.D. of the decaying algae which produced ammonia, caused the dissolved oxygen level to drop to 1.7 mg/l in the late afternoon. This low dissolved oxygen concentration plus a high level of ammonia resulted in the death of all the fish. On August 10, three days before the kill, the dissolved oxygen was high 5.9 and 7.5 mg/l, in morning and afternoon, respectively. The following day, the dissolved oxygen level dropped to 4.1 mg/l in the afternoon and finally down to 1.7 mg/l in the next day. In A93, the level of ammonia increased from 0.43 to 1.79 ppm and the fish mortality was 74 per cent. Dissolved oxygen level during the preceding day was 5.2 mg/l in the morning and decreased to 4.6 mg/l in the afternoon. Under normal conditions, afternoon oxygen level is usually higher than morning value.

A comparison of treatment means (Table 20) showed that the only significant difference in ammonia concentration exists between the paddle wheel

TABLE 19

AMMONIA CONCENTRATIONS, ppm WITH MINIMUM-MAXIMUM VALUES IN PARENTHESES FOR EACH TREATMENT

Date 1973	Underwater filter; single pond (400 fish)	Underwater filter: single pond (200 fish)	Paddle wheel dual pond (400 fish)	Paddle wheel single pond (400 fish)	Overhead filter dual pond (400 fish)
7/17	0.41(0.3[illegible]-0.50)	0.50(0.43-0.52)	0.48(0.40-0.60)	1.44(0.52-2.40)	0.39(0.36-0.43)
7/27				0.47 (0.42-0.52)	
7/31	0.33(0.04-0.44)	0.29(0.23-0.30)	0.67(0.06-2.12)	0.42(0.28-0.68)	0.28(0.13-0.40)
8/11			4.84*	0.29(0.21-0.40)	
8/14	0.32(0.29-0.43)	0.62(0.14-0.30)	3.35(0.70-9.24)	0.24(0.22-0.26)	0.37(0.10-0.84)
8/23	0.45(0.28-0.82)	0.33(0.14-0.55)	0.43(0.23-0.63)	0.32(0.14-0.42)	0.57(0.23-0.87)
9/5	0.46(0.42-0.50)		1.37(0.48-2.25)		1.53(0.50-2.05)
9/7	1.34(1.04-1.79)		1.02*		1.96(1.22-2.82)
9/11	2.50(0.46-4.72)	0.65(0.56-0.74)	2.75(0.70-4.80)	2.95(0.46-4.40)	2.88*
9/15					4.56*
9/19	17.60*				
9/23		0.41(0.36-0.48)	0.40*	0.33(0.30-0.36)	
10/9		0.53(0.50-0.68)	0.40*	0.48(0.46-0.50)	

*Value of one replication only.

TABLE 20

TREATMENT AND REPLICATION MEANS OF AMMONIA CONCENTRATIONS

Replication	Underwater filter; single pond (400 fish)	Underwater filter, single pond (200 fish)	Paddle wheel dual pond (400 fish)	Paddle wheel single pond (400 fish)	Overhead filter dual pond (400 fish)
1	0.510	0.400	0.872	1.081	0.908
2	0.664	0.332	1.900	0.388	1.122
3	1.021	0.454	1.269	1.147	0.854
Mean 1/	0.732	0.395	1.347	0.872	0.961
Mean Comparison	ab	b	a	ab	ab

1/ Data for mean computations were until September 11, 1973.

with dual pond and the underwater filter with 200 fish treatments. Ammonia concentrations in all of the remaining treatments were non-significant.

Nitrite. Values of nitrite (NO_2) concentrations varied greatly among treatment replications (Table 38, Appendix). The replication means in each determination are given in Table 21, with the minimum and maximum values in parentheses. The highest mean value of nitrite concentration was recorded in the paddle wheel with single pond treatment and followed by the paddle wheel with dual pond, overhead filter, underwater filter with 400 fish, and underwater filter with 200 fish treatments.

Analysis of variance showed significant difference among the treatments at the 5 per cent level. Comparison of means (Table 22) indicated that both paddle wheel treatments and overhead filter treatment were not different. Both underwater filter treatments were distinctly different from the two paddle wheel treatments but not from the overhead filter treatment.

The general correlation analysis showed that ammonia was highly correlated with mortality but not with nitrite. Nitrite and dissolved oxygen concentration were significantly correlated with fish mortality of paddle wheel with dual pond treatment. The corresponding correlation coefficients were 0.68 and -0.63, respectively.

Some examples of fish mortality with a brief description of the pond conditions and values of ammonia, nitrite, dissolved oxygen and carbon dioxide are presented in Table 23.

TABLE 21

NITRITE CONCENTRATIONS, ppm WITH MINIMUM-MAXIMUM VALUES IN PARENTHESES FOR EACH TREATMENT

Date 1973	Underwater filter; single pond (400 fish)	Underwater filter; single pond (200 fish)	Paddle wheel dual pond (400 fish)	Paddle wheel single pond (400 fish)	Overhead filter dual pond (400 fish)
8/7			5.20*	7.10(7.000-7.300)	
8/11			2.00*	0.88(0.105-1.430)	
8/14	0.04(0.025-0.060)	0.01(0.004-0.020)	1.28(0.096-2.420)	0.25(0.040-0.546)	0.26(0.003-0.777)
8/28	0.16(0.041-0.230)	0.02(0.009-0.033)	1.50(0.570-1.930)	0.03(0.007-0.045)	1.32(0.730-2.320)
9/5	0.13(0.040-0.250)		0.30(0.230-0.320)		1.01(0.930-1.180)
9/7	0.14(0.140-0.150)		0.47*		0.90(0.670-1.120)
9/11	0.09(0.024-0.134)	0.04(0.015-0.060)	0.65(0.300-0.900)	0.50(0.210-0.780)	1.23*
9/15					4.02*
9/19	0.00*				
9/26		0.03(0.015-0.030)	0.16*	0.02(0.010-0.023)	
10/9		0.03(0.010-0.064)	0.02*	0.09(0.027-0.147)	

*Value of one replication only.

TABLE 22

TREATMENT AND REPLICATION MEANS OF NITRITE CONCENTRATIONS

Replication	Underwater filter; single pond (400 fish)	Underwater filter; single pond (200 fish)	Paddle wheel dual pond (400 fish)	Paddle wheel single pond (400 fish)	Overhead filter dual pond (400 fish)
1	0.0793	0.0217	1.1465	1.5320	0.8768
2	0.1508	0.0093	3.2067	1.7028	0.5833
3	0.1036	0.0592	0.3432	2.0202	1.6460
Mean[1/]	0.1113	0.0301	1.5655	1.7517	1.0354
Mean Comparison	b	b	a	a	ab

[1/] Data considered for mean computations were until September 15, 1973.

TABLE 23

FISH MORTALITY AS RELATED TO NITROGENOUS COMPOUNDS, CARBON DIOXIDE AND DISSOLVED OXYGEN

Treatment	Pond No.	Mortality Date	Pond condition
Underwater filter; single pond (400 fish)	A93	9/7/73	Water turbid, 54 JTU; afternoon D.O., 4.6 mg/l before mortality; uneaten feeds observed 2 days before death; CO_2, 14 ppm; NO_2, 0.140 ppm, NH_3, 1.79 ppm. Condition deteriorated possibly due to algal death; mortality, 74 per cent.
Paddle wheel dual pond (400 fish)	A77-78	8/12/73	Water turbid, 52 JTU; large bubbles on surface; afternoon D.O., 1.7 mg/l algal death; uneaten feeds observed August 6; NO_2, 2.000 ppm; NH_3, 4.84 ppm; CO_2, 9 ppm; mortality 100 per cent.
	A74-75	8/28/73	Uneaten feeds observed August 26; D.O., 5.9 mg/l; NO_2, 1.980 ppm; NH_3, 0.63 ppm; CO_2, 9 ppm; mortality, 64 per cent.
	A94-95	9/7/73	Uneaten feeds observed on September 5; D.O., 4.8 mg/l; NO_2, 0.280 ppm; NH_3, 2.25 ppm; CO_2, 14 ppm. September 7, D.O., 5.7 mg/l; NO_2, 0.470 ppm; NH_3, 1.02 ppm; mortality, 35 per cent.
Paddle wheel single pond (400 fish)	A82	7/23-8/3/73	Uneaten feeds observed; D.O., 7.5 mg/l; on July 31, NH_3, 0.68 ppm; CO_2, 6 ppm; August 7, NO_2, 7.0 ppm; chronic mortality, 58 per cent.
	A91	9/15-9/21/73	Uneaten feeds observed; accumulated mortality began September 13; D.O. 3.3 to 9.0 mg/l. On September 11, NO_2, 0.780 ppm; NH_3, 4.00 ppm; CO_2, 13 ppm.
Overhead filter dual pond (400 fish)	A79-80	9/7/73	Uneaten feeds observed September 5; D.O. before death, 5.5 mg/l; on September 5, NO_2, 0.93 ppm; NH_3, 2.05 ppm; CO_2, 13 ppm; on September 7, NO_2, 0.900 ppm; NH_3, 1.84 ppm. Initial mortality, sucked by pump which hampered aeration; oxygen depletion to 0.5 mg/l aggravated mortality up to 55 per cent.
	A83-84	9/7/73	D.O. before mortality, 5.4 mg/l; on September 5, NO_2, 0.93 ppm; NH_3, 2.05 ppm; CO_2, 8 ppm; on September 7, NO_2, 0.67 ppm; NH_3, 2.82 ppm. Same pattern of mortality as A79-80 resulting to 94 per cent mortality.
	A85-86	9/15/73	D.O. before mortality, 4.6 mg/l; NO_2, 4.020 ppm; NH_3, 4.56 ppm; CO_2, 20 ppm; initial mortality observed, September 14. Same pattern of mortality as A79-80 and A83-84; mortality 85 per cent.

Carbon dioxide. The carbon dioxide (CO_2) concentrations for all treatment replications varied from 0 to 23 ppm (Table 39, Appendix). The values were generally lower than the values obtained in the 1972 experiment. During the course of the experiment, only three values exceeded 15 ppm. The mean for each replication ranged from 3.7 to 9.6 ppm (Table 24). Carbon dioxide concentration in each treatment versus time showed a significant increase (Figure 15).

Comparison of means (Table 24) indicated that four treatments were non-significant with regard to carbon dioxide concentration. The underwater filter with 200 fish treatment was significantly different from all treatments except the paddle wheel with single pond.

Carbon dioxide concentration was significantly correlated with mortality with a correlation coefficient of 0.47.

Total alkalinity. The values of alkalinity for each treatment replication showed a wide range of values similar to the results of 1972 experiment (Table 40, Appendix). The values varied from 21.6 to 178.0 mg/l as $CaCO_3$. The range obtained in the previous experiment was 10.0 to 172.0 mg/l as $CaCO_3$. An increasing trend with time was observed (Figure 16).

Total hardness. Total hardness values obtained were similar to the 1972 experiment (Table 41, Appendix). An increasing trend of hardness with time was evident (Figure 17).

TABLE 24

TREATMENT AND REPLICATION MEANS OF CARBON DIOXIDE CONCENTRATIONS, ppm

Replication	Underwater filter; single pond (400 fish)	Underwater filter; single pond (200 fish)	Paddle wheel dual pond (400 fish)	Paddle wheel single pond (400 fish)	Overhead filter dual pond (400 fish)
1	9.6	3.7	6.8	5.9	8.1
2	7.4	4.0	8.6	6.9	5.1
3	7.4	5.7	7.5	8.1	9.1
Mean 1/	8.1	4.5	7.6	7.0	7.4
Mean Comparison	a	b	a	ab	a

1/ Data considered for mean computations were until September 18, 1973.

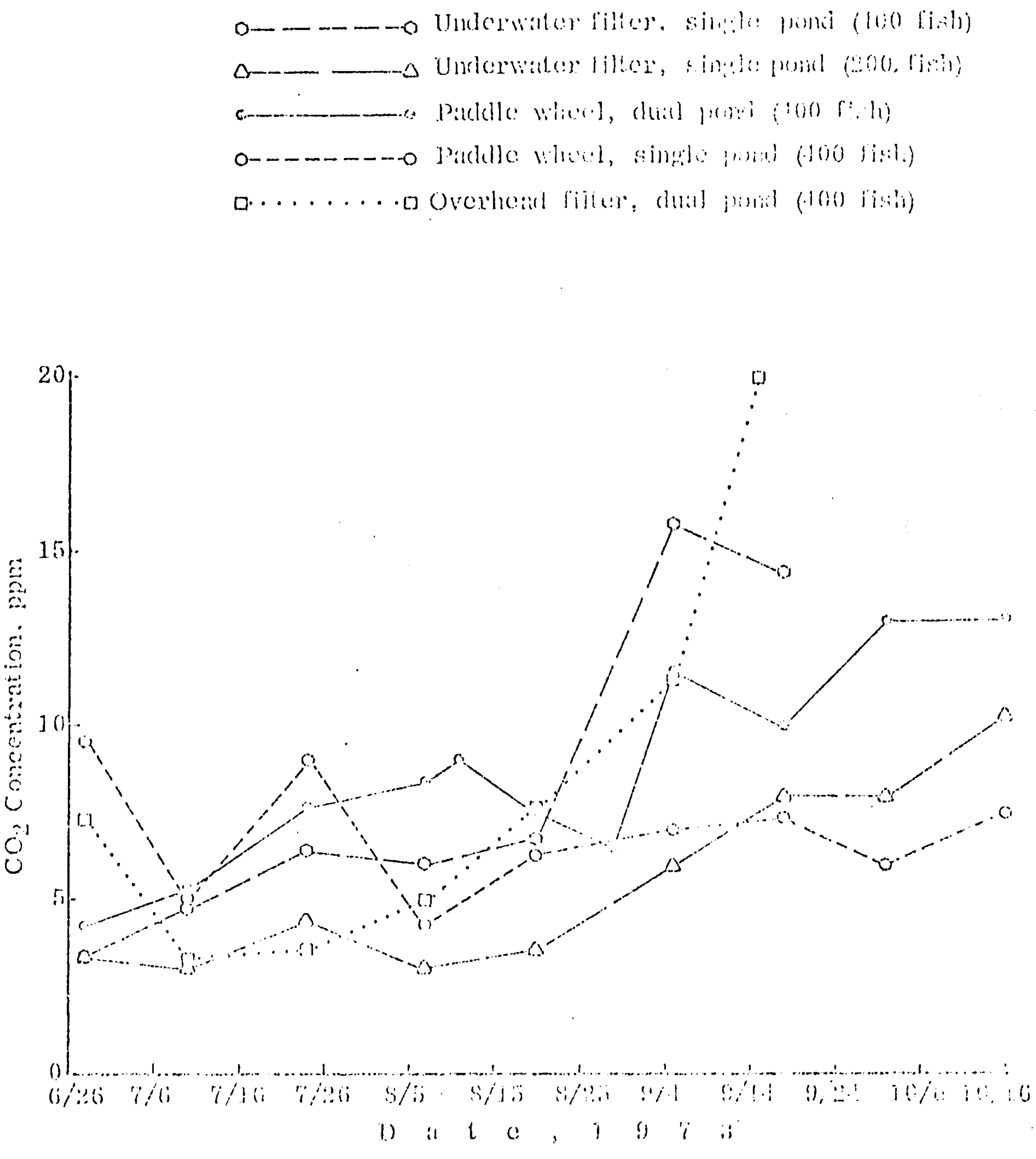


Figure 15. Carbon dioxide concentration in various treatment

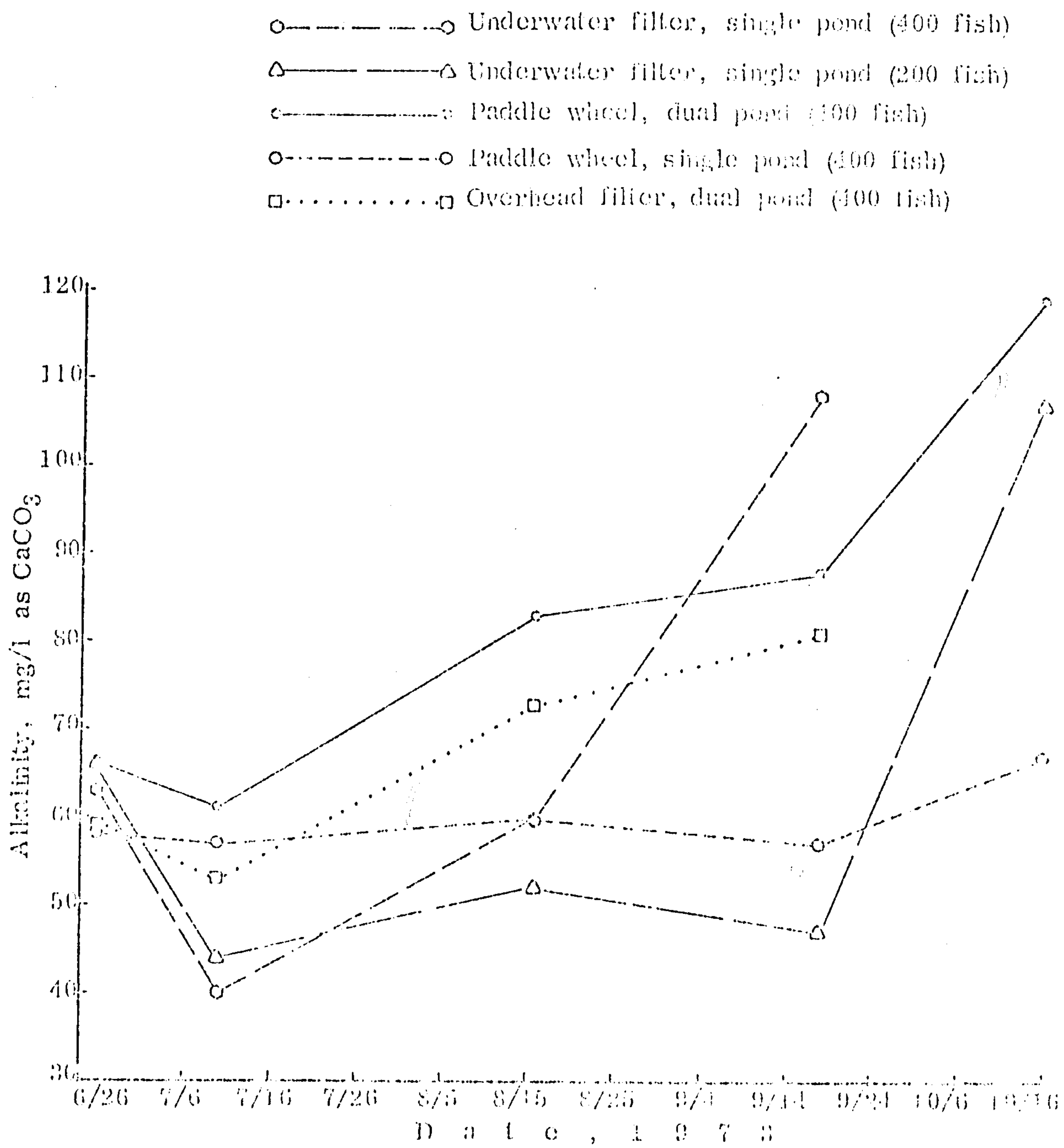


Figure 16. Total alkalinity in various treatments

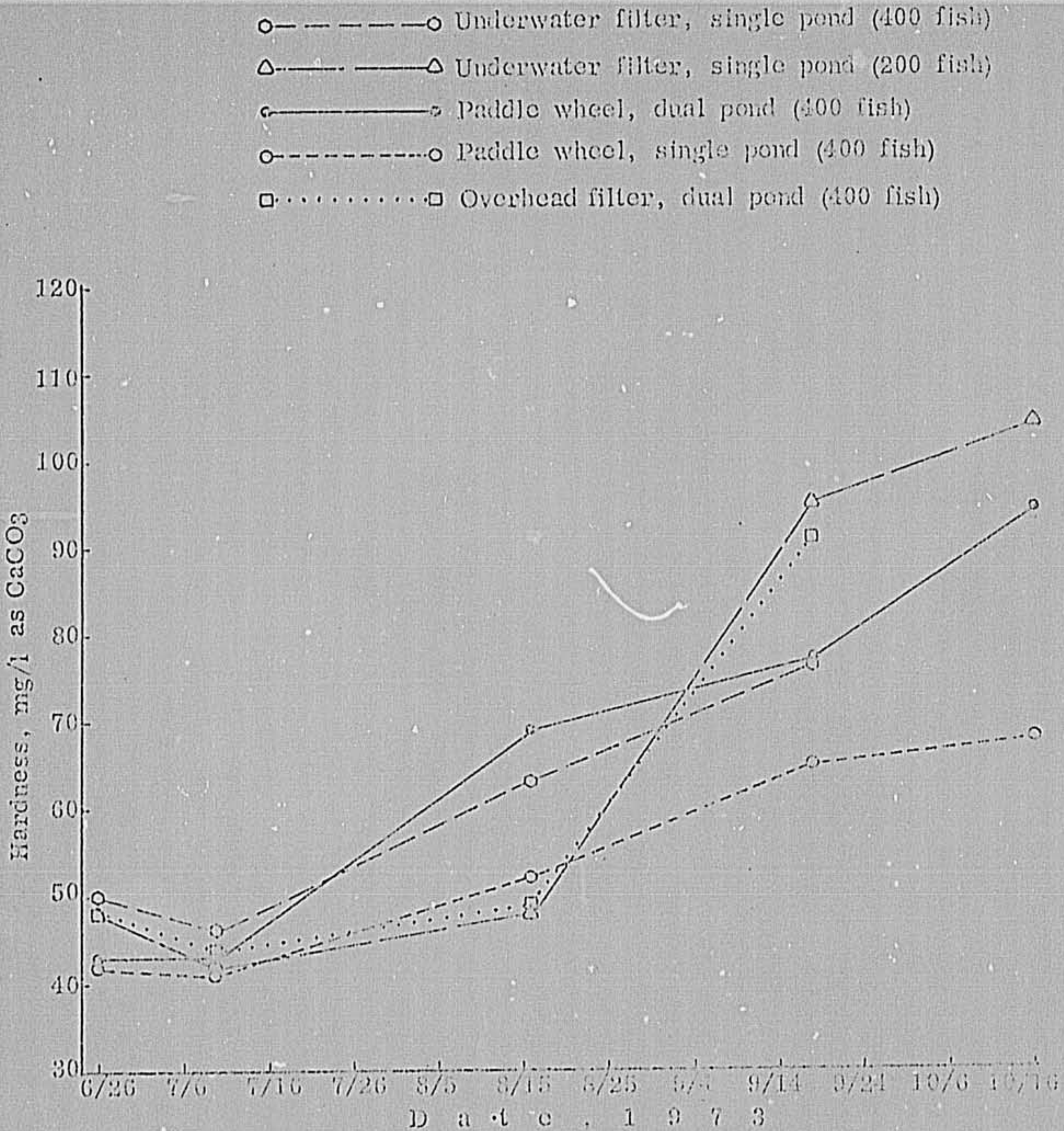


Figure 17. Total hardness in various treatments.

Yields, conversion, and survival

Some or all replications in each treatment had to be discontinued after 105 days because of stress factor. Eight replications of the five treatments were continued for 137 days or until water temperatures dropped so low that the fish did not respond to daily feeding. Treatment yields cannot be compared because of irregular mortality that occurred in all but one treatment. The potential productivity of each treatment can best be seen by examining the results from individual replication within treatments (Table 25).

Underwater filter with 400 fish. Two replications of this treatment produced an average standing crop of 79.8 lbs of fish (74.2 to 85.4) at the end of 99 feeding days. The average net gain was 68.35 lbs with a net conversion ratio of 1:2.8. The average survival in these two replications was 94.4 per cent.

Underwater filter with 200 fish. An average of 95 per cent of the fish in all three replications of this treatment survived 131 feeding days. The average standing crop was 84.5 lbs (66.7 to 101.7), with a net productivity of 78.5 lbs. The net conversion ratio was 1:2.2.

The two underwater filter treatments were identical except for the number of fish stocked. The standing crop produced is much lower than that of the previous year. In the previous year, a standing crop of 170 lbs and a net gain of 70 lbs was attained. In the present experiment, the underwater filter performed well for more than half of the experimental period. During this period, the water remained clear, due to the excellent performance of the

TABLE 25

INDIVIDUAL POND YIELDS, FEED CONSUMPTION, CONVERSION, AND SURVIVAL

Treatment	Pond No.	Gross Yield 1/	Net Yield 2/	Feed Consumed	Conversion (Gross) 3/	Conversion (Net) 4/	Growing 5/ period days	Observed Survival, %
1. Underwater filter; single pond (400 fish)	A73	63.00	62.80	190.56	3.02	3.03	105	91.0
	A93	69.40	1.50	159.66	2.30		93	19.0
	A96	74.00	73.90	190.56	2.58	2.58	105	97.8
2. Underwater filter; single pond (200 fish)	A76	79.10	79.10	165.30	2.09	2.09	137	96.0
	A89	61.10	60.70	165.30	2.71	2.72	137	93.5
	A92	96.00	95.70	165.30	1.72	1.73	137	95.5
3. Paddle wheel dual pond (400 fish)	A74-75	48.55	-10.75	135.18	2.78		105	1.3
	A77-78	28.15	-11.25	63.96	2.27		68	0.0
	A94-95	57.80	19.80	227.21	3.93		137	29.5
4. Paddle wheel single pond (400 fish)	A82	23.00	- 7.50	98.98	4.30		105	4.0
	A88	68.60	38.80	169.56	2.47	4.37	137	52.5
	A91	36.85	19.15	145.78	3.96		137	33.0
5. Overhead filter dual pond (400 fish)	A79-80	66.90	- 7.70	160.70	2.40		105	2.8
	A83-84	99.80	- 8.60	160.70	1.61		105	2.3
	A85-86	87.80	9.70	193.60	2.21		105	0.8

1/ Gross yield, lbs = Final wt - (stocked wt - mortality wt)

2/ Net yield, lbs = Final wt - stocked wt

3/ Conversion (gross) = Feed added/gross yield

4/ Conversion (net) = Feed added/net yield

5/ Based on stocking date June 5, 1973; feeding started June 11, 1973 filters. As the dissolved nutrient increased, dense growth of filamentous algae developed. These algae and other organic material eventually clogged the filtering action of the gravel.

This sytem has an excellent potentiality for producing large quantities of fish in a closed system. However, it will be necessary to devise some means of removing the dissolved nutrients from the water and controlling the filamentous algae and solid wastes settling on the bottom for the underwater filter system to perform efficiently. This could be accomplished through the addition of a species which would feed on algae and organic detritus.

Paddle wheel with dual pond (400 fish). This treatment did not yield a significant weight of fish in any of the three replications. During the first seven weeks of the experiment, this treatment gave the best performance with regard to weight gains and feed conversions as determined from sampling.

The total productivity in ponds A74-75, A77-78, A94-95 based upon the weight of the observed mortality and the weight of fish recovered upon draining was 59.8, 39.4, and 68.0 lbs, respectively. The gross gain in the same order was 48.5, 28.2 and 56.8 lbs. In this case, the total productivity is dependent upon the time at which mortality occurred. For example, the replication producing only 39.4 lbs had a complete kill during the eighth week of the experiment. At this time, 408 fish weighing 39.4 lbs were recovered. The average weight of these fish was 0.09 lb. This weight compares favorably with the average weight of fish in other treatments at this time. The replication producing 59.8 lbs suffered a mortality of approximately 50 per cent of the population during the tenth week of the experiment. The remaining replication had a mortality of 34 per cent during the eleventh week of the experiment. Upon draining, the percentage survival in the two remaining replications was 1.3 and 29.5, respectively.

Paddle wheel with single pond (400 fish). This was the least successful treatment in terms of productivity. No replication had a significant weight of fish upon draining. When the weight of the observed mortality was added to the weight of fish recovered upon draining, the total productivity was 33.0, 79.8, and 47.7 lbs, respectively for ponds A82, A88, and A91. The gross gain was 23.0, 68.6, and 36.9 lbs. At draining time, survival was 4.0, 52.5, and 33.0 per cent, respectively.

Overhead filter, dual pond (400 fish). No replication in this treatment produced a significant weight of fish upon draining due to mortalities during the eleventh and twelfth week. Survival at draining time ranged from 0.8 to 2.8 per cent for the three replications. When the weight of observed mortality was added to the weight recovered upon draining, the total productivity was 76.6, 110.0, and 98.1 lbs, respectively for ponds A79-80, A83-84, and A85-86. The gross gain was 66.9, 99.8, and 87.7 lbs, respectively. Under these considerations, the average productivity was 94.9 lbs and the average gross gain was 84.8 lbs.

V. SUMMARY

The effects of water circulation and aeration on water quality and production of catfish in 1/200-acre ponds were studied in a series of experiments conducted in 1972 and 1973. The treatments tested were:

1. Water circulation and aeration by means of an oxidation ditch rotor (paddle wheel).

2. Water circulation and aeration by underwater gravel filters with venturi aeration.

3. Water circulation and aeration through an overhead gravel filter.

The 1972 series was designed to determine the standing crop that each system was capable of supporting. A control circulation treatment was tested along with the given treatments. The paddle wheel, overhead gravel filter, and control circulation treatments utilized waste settlement ponds while the underwater gravel filters did not. Water hyacinths were grown in all treatments except in one of the underwater gravel filter treatments. Each treatment was stocked with 100 lbs of fish per pond in three replications. Fish in the paddle wheel, overhead gravel filter, and control circulation treatments had a 68-day growing period while the underwater gravel filters had 49 days. The fish were fed seven days a week with Purina Trout Chow at the rate of 3 per cent of stocked weight.

The objective of the 1973 series was to produce harvestable fish from fingerlings over a six-month growing season. The treatments of the 1972 series which showed satisfactory performance were considered for further study. The control circulation treatment was eliminated. Each treatment in the 1973 series was stocked with either 200 or 400 fingerlings per replication. The fish were fed seven days a week from 5 to 3 per cent of the body weight.

The effects of water circulation and aeration with regard to mortality, water quality, and fish production are summarized as follows:

1. Mortality

Extensive fish mortalities occurred in some replications of all treatments except the paddle wheel treatment during the 1972 series. Mortality was caused by oxygen depletion associated with high concentration of carbon dioxide.

During the 1973 series, extensive mortalities occurred in all replications of the paddle wheel and overhead filter treatments and also in some replications of the underwater gravel filter treatments. Mortalities were significantly correlated with low dissolved oxygen, high ammonia, carbon dioxide, and to some extent, nitrite concentrations.

2. Water quality

a. Dissolved oxygen. During the 1972 series, the paddle wheel treatment and the underwater gravel filter treatment gave adequate aeration. The size of the aerating unit became a limiting factor for the overhead filter and control circulation treatments resulting in inadequate aeration. During the 1972 series, aeration in all treatments was adequate.

b. Temperature. During both years, water temperature was significantly lower in the paddle wheel treatments, followed by the overhead filter, with the underwater filter treatments having the highest value.

c. Dissolved oxygen consumption by planktonic community. During both years, the underwater filter treatments had the least consumption of oxygen by plankton. No significant difference was found between the paddle wheel and overhead filter treatments. Values in all treatments ranged from 3.5 to 12.8 mg/l/24-hr and from 7.0 to 12.4 mg/l/24-hr during the 1972 and 1973 experiments, respectively.

d. Clearness of water. During both years, the underwater filter treatments had the clearest water. No significant difference was noted between the paddle wheel and overhead filter treatments.

e. pH. Values during both years for all treatments varied from 6.1 to 9.6 The numerical differences in pH means among the treatments were small and did not affect fish production.

f. Ammonia. Valued ranged from 0.04 to 17.60 ppm. Correlation analysis indicated that ammonia was associated with mortality. Significant difference was found among treatments.

g. Nitrite. Concentrations varied from 0.000 to 7.500 ppm. Significant difference existed among treatments and analysis showed that nitrite affected mortality. Chronic mortalities were attributed to both nitrite and ammonia.

h. Carbon dioxide. Concentrations ranged from 6.0 to 29.0 and from 0.0 to 23.0 ppm for the 1972 and 1973 experiments, respectively. High concentrations of carbon dioxide were associated with mortalities in both experiments. Significant difference existed among treatments.

i. Total alkalinity. Values ranged from 10.0 to 172.0 and from 21.6 to 178.0 mg/l as $CaCO_3$ for the two experiments. No significant difference was observed among treatments in either series.

j. Total and calcium hardness. Values ranged from 25 to 116 and from 33 to 142 mg/l as $CaCO_3$ for total hardness in the two experiments. No significant difference was found among treatments for either series. Values for calcium hardness ranged from 18 to 86 mg/l as $CaCO_3$. No significant difference was found among treatments.

3. Production, survival, and conversion

The paddle wheel treatment showed the most consistent yield and greatest survival in the 1972 experiment. The standing crop attained varied from 130.2 to 144.9 lbs with a net gain of 30.2 to 44.9 lbs. No significant yield was produced during the following year because of low survival of 0 to 52.5 per cent. Feed conversion was inefficient during both years.

The underwater gravel filter treatment attained the highest standing crop of 170 lbs and a net gain of 70 lbs in one replication during the first year. Replications which produced significant yield had better feed conversion than the paddle wheel treatments. During the second year, the average standing crop in two replications of the underwater gravel filter treatment with 400 fish was 79.8 lbs (74.2 to 85.4) with a net gain of 68.4 lbs. The net conversion ratio was 1:2.8 and the average survival was 94.4 per cent. The treatment with 200 fish produced an average standing crop of 84.5 lbs (66.7 to 101.7) with a net yield of 78.5 lbs. The average survival was 95 per cent and the net conversion ratio was 1:2.2.

The overhead gravel filter treatment attained a standing crop of 134 lbs and a net gain of 34 lbs in one replication during the first year. The survival was 89.6 per cent. Feed conversion was 1:3.95. During the second year, mortality in all replications occurred a few weeks before the experiment ended and survival varied from 0.8 to 2.8 per cent.

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APPENDIX

TABLE 26

DIFFERENCE OF DISSOLVED OXYGEN CONCENTRATION IN FISH POND AND PUMP SUMP OF UNDERWATER FILTER

Date	Underwater Filter With Hyacinths						Underwater Filter. NoHyacinths					
	A7		A9		A11		A3		A10		A12	
	Fish Pond	Pump Sump	Fish Pond	Pump Sump	Fish Pond	Pump Sump	Fish Pond	Pump Sump	Fish Pond	Pump Sump	Fish Pond	Pump Sump
9/2	5.4	3.7	4.5	1.6	6.5	5.5	4.7	3.1	5.6	3.3	6.6	4.6
9/3	5.0	2.0	4.0	1.0	5.1	2.2	4.0	1.5	4.6	1.2	5.1	2.2
9/4	4.7	1.9	3.7	0.7	4.5	2.2	3.8	1.3	4.3	1.0	4.7	1.4
9/6	5.2	2.6	4.4	2.1	5.1	3.8	4.5	1.7	4.6	1.4	5.6	2.6
9/7	5.4	2.7	4.1	2.2	5.1	3.6	4.5	1.7	4.9	2.0	5.7	3.0
Rep. Mean	5.1	2.6	4.1	1.5	5.3	3.5	4.3	1.9	4.8	1.8	5.5	2.8
Difference	2.5		2.6		1.8		2.4		3.0		2.7	
Trt. Mean			2.3						2.7			
Grand Mean						2.5						

TABLE 27

WEEKLY TEMPERATURE, °C IN VARIOUS TREATMENT

Date	TREATMENT									
	Paddle wheel		Underwater filter (with hyacinth)		Underwater filter (no hyacinth)		Overhead filter		Control circulation	
	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
8/24- 8/30	25.2	29.4	27.1	30.7	26.8	31.1	26.0	29.7	27.5	30.8
8/31- 9/6	23.3	24.9	25.3	26.9	25.5	27.0	24.1	25.7	25.2	26.9
9/7 - 9/13	22.1	25.8	24.4	27.1	24.5	27.4	23.2	26.5	24.0	27.5
9/14- 9/20	24.2	26.5	26.2	28.3	26.4	28.8	24.9	26.8	25.8	28.0
9/21- 9/27	24.2	26.8	26.1	28.2	26.1	28.3	24.9	[illegible]	25.8	27.9
9/28-10/4	22.3	24.6	24.3	26.3	24.4	26.4	23.0	[illegible]	24.2	26.3
10/05-10/11	18.5	21.2	20.4	23.1	20.6	23.1	19.4	[illegible]	20.5	23.1
10/12-10/18	19.2	22.7	21.5	24.2	21.5	24.7	20.1	23.4	21.4	24.6
10/19-10/25	15.5	16.5	17.6	18.3	17.3	18.1	16.4	17.3	17.4	18.3
10/26-11/01	15.8	17.5	17.6	18.9	17.4	19.0	16.7	18.0	17.3	18.8
Mean	21.0	23.6	23.0	25.2	23.0	25.4	21.9	24.2	22.9	25.2

TABLE 28

MEAN TEMPERATURE RANGE[1/] °C FOR EACH REPLICATION

Replication	Paddle wheel	Underwater filter (with hyacinth)	Underwater filter (no hyacinth)	Overhead filter	Control circulation
1	1.8	1.4	1.4	2.0	1.9
2	1.9	1.5	1.7	2.0	2.2
3	1.9	2.1	2.4	2.3	2.2
Total	5.6	5.0	5.5	6.3	6.3
Mean	1.87	1.67	1.83	2.1	2.1
Mean Comparison	a	a	a	a	a

1/ Fluctuation of temperature is the difference between morning and afternoon readings.

TABLE 29

WEEKLY MORNING pH FOR EACH POND[1/]

Treatment	Pond No.	DATE, 1972														Rep. Mean	Treatment Mean
		8/26	8/27	9/3	9/5[2/]	9/8	9/12	9/14	9/19	9/26	10/2	10/12	10/18	10/24	11/1		
1. Paddle wheel	A1-2	7.6	7.4	8.1	7.1	7.6	7.9		7.4	7.5	7.4	7.5	7.3	7.5	7.2	7.6	
	A3-4	7.5	7.9	7.9	8.6	8.3	7.7		7.4	7.5	7.6	7.7	7.5	7.7	7.4	7.6	7.6 a
	A5-6	7.3	7.4	8.0	7.8	8.4	7.6		7.3	7.5	7.5	7.8	7.5	7.6	7.3	7.6	
2. Underwater filter (with hyacinths)	A7	7.4	7.1	7.7	6.8	7.3	7.4	7.5	7.3	7.2	6.6	7.0	6.9	6.9	6.5	7.1	
	A9	7.6	7.1	7.7	6.5	7.4	7.3	7.6	7.1	7.2	7.0	7.4	7.3	7.4	7.0	7.3	7.2 c
	A11	7.7	7.2	7.6	6.3	7.2	7.2	7.1	6.9	7.0	6.8	7.3	6.9	7.1	6.8	7.1	
3. Underwater filter (no hyacinths)	A8	7.5	7.1	7.8	6.4	7.3	7.5	7.6	7.1	7.2	7.2	7.4	7.3	7.3	7.1	7.3	
	A10	7.8	7.3	7.7	6.9	7.4	7.3	7.5	7.1	7.3	7.0	7.2	7.2	7.0	6.7	7.3	7.3 bc
	A12	7.8	7.4	7.7	6.8	7.4	7.4	7.4	7.3	7.1	7.0	7.2	6.7	6.5	6.1	7.2	
4. Overhead filter	A13-14	7.6	7.5	8.1	7.0	8.8	8.7		7.0	6.9	7.2	7.3	7.2	7.3	7.0	7.6	
	A15-16	7.6	7.6	7.9	8.4	9.6	8.3		7.2	7.2	6.9	7.3	7.2	7.3	7.2	7.6	7.7 a
	A17-18	7.6	7.5	7.8	7.4	9.1	9.1		7.1	7.1	7.4	8.1	7.4	7.4	7.3	7.8	
5. Control circulation	A19-20	7.7	7.6	7.8	7.5	8.2	7.4		7.2	7.1	7.1	7.4	7.3	7.2	7.0	7.4	
	A21-22	7.7	7.6	7.7	6.9	7.5	7.4		7.0	7.3	7.2	7.4	7.3	7.5	7.1	7.4	7.4 b
	A23-24	7.8	7.9	7.7	8.0	8.5	7.6		7.0	7.4	7.3	7.6	6.8	7.0	7.1	7.5	

1/ Water sample taken before or at sunrise.

2/ Water sample taken about 10:00 AM, cloudy weather; not included in mean computation.

TABLE 30

WEEKLY CARBON DIOXIDE* ppm CONTENT OF WATER IN THE DIFFERENT TREATMENTS

Treatment	Pond No.	DATE - 1972 9/14	9/19	9/26	10/3	10/7	10/11	10/18	10/24	11/1	Mean
Paddle wheel	A1-2		12.0	18.2	11.4		12.4	17.0	10.5	14.5	13.7
	A3-4		8.8	9.5	8.6		8.0	11.0	8.5	9.0	9.1
	A5-6		13.2	14.4	12.4		10.5	22.5	15.0	17.0	15.0
Underwater filter (with hyacinths)	A7	9.4	9.0	13.0	12.4		16.0	21.0	19.0	20.0	15.0
	A9	9.0	15.2	20.8	17.4		17.0	19.0	17.5	15.0	16.4
	A11	8.8	26.2	19.0	13.0		12.0	17.0	11.0	10.0	14.6
Underwater filter (no hyacinths)	A8	10.0	16.4	25.8	24.0	20.2	23.2	28.0	22.0	15.0	20.5
	A10	8.8	14.0	14.2	12.2		14.0	22.5	17.0	17.0	15.0
	A12	9.0	8.4	11.0	10.4		10.0	15.0	14.0	15.0	11.6
Overhead filter	A13-14		15.8	25.0	14.8		11.0	15.0	13.0	13.0	15.4
	A15-16		14.2	16.0	17.0		14.0	18.0	16.0	14.0	15.6
	A17-18		17.2	24.4	7.6		8.0	11.0	10.0	6.0	12.0
Control circulation	A19-20		16.4	29.0	22.6		22.0	28.0	18.5	24.0	22.9
	A21-22		22.4	28.0	27.0		23.5	16.0	13.0	13.0	20.4
	A23-24		23.4	27.5	21.0	23.8	25.0	20.0	15.0	12.0	21.0

*Water samples were collected before sunrise.

TABLE 31

STOCKING, MORTALITY AND HARVESTED WHITE CATFISH, ICTALURUS CATUS (LINNAEUS) IN VARIOUS TREATMENTS

Treatment	Pond No.	Stocked weight lbs	Restocked or added weight *	Observed mortality No.	Observed mortality Wt.	Harvested catfish No.	Harvested catfish Wt.
Paddle wheel	A1-2	100	8.17	78	17.18	223	144.8
	A3-4	100	4.23	35	5.39	229	144.9
	A5-6	100	6.64	60	14.52	235	130.2
Underwater filter (with hyacinths)	A7	100	100.00	104	41.10	216	100.1
	A9	100	100.00	9	1.10	321	170.3
	A11	100	100.00	284	119.93	103	9.3
Underwater filter (no hyacinths)	A8	100	100.00	37	10.76	334	153.5
	A10	100	100.00	30	1.95	273	138.7
	A12	100	100.00	217	79.00	51	35.1
Overhead filter	A13-14	100	9.65	62	28.43	216	134.1
	A15-16	100	4.84	175	68.09	141	54.1
	A17-18	100	6.61	328	143.69	16	5.1
Control circulation	A19-20	100	3.05	39	12.21	242	125.1
	A21-22	100	9.71	99	39.53	220	107.3
	A23-24	100	7.92	245	125.56	12	1.9

* All weights in pounds.

* The bottom biofilters were completely restocked on September 13, 1972 due to high mortality of unknown cause.

* Fish were added to compensate mortality in other ponds at the time of restocking.

TABLE 32

WEEKLY AVERAGES OF DISSOLVED OXYGEN CONCENTRATION, mg/l
WITH MINIMUM-MAXIMUM VALUES IN PARENTHESES

No. of Wks.	Date 1973	Underwater filter single pond (400 fish)		Underwater filter single pond (200 fish)		Paddle wheel dual pond (400 fish)		Paddle wheel single pond (400 fish)		Overhead filter dual pond (400 fish)	
		AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
1	6/20-6/26	5.7(1.0-9.6)	20+(17.0-20+)	7.7(1.0-9.9)	20+(17.2-20+)	4.7(0.6-8.3) 1/	20+(17.0-20+)	4.6(2.4-8.9)	20+(16.6-20+)	6.3(2.8-11.2)	20+(16.5-20+)
2	6/27-7/3	7.5(6.5-8.2)	8.0(7.5-9.1)	7.5(6.5-8.0)	8.2(7.4-9.5)	6.5(4.0-8.2)	9.5(6.5-11.0)	6.3(2.6-8.4)	8.3(7.6-9.4)	7.5(6.8-8.0)	8.9(7.5-10.5)
3	7/4-7/10	7.3(6.5-7.9)	8.4(6.2-12.8)	7.3(6.8-7.6)	9.1(6.5-10.8)	6.8(5.5-7.5)	9.4(7.8-11.8)	7.5(6.4-8.0)	8.1(6.4-10.4)	7.1(6.5-7.6)	9.0(7.5-10.5)
4	7/11-7/17	7.7(7.1-8.5)	10.1(9.1-11.8)	7.6(7.2-8.0)	10.1(8.3-12.9)	6.9(6.0-7.0)	10.0(8.2-12.6)	7.9(7.2-8.5)	8.9(7.9-9.7)	7.5(7.0-8.1)	11.2(9.9-12.7)
5	7/18-7/24	7.2(6.9-7.3)	9.6(8.4-11.1)	7.4(6.9-7.7)	10.5(9.0-13.3)	6.5(5.5-7.1)	10.2(7.8-13.2)	7.3(6.7-7.8)	8.6(7.0-10.0)	7.2(6.8-7.8)	11.3(8.7-14.2)
6	7/25-7/31	6.9(2.5-8.0) 2/	8.9(6.7-12.0)	7.3(6.5-8.0)	9.6(7.9-12.1)	6.6(5.9-7.4)	10.0(7.5-13.9)	7.6(6.7-8.6)	7.9(5.9-10.0)	7.1(6.6-7.8)	11.1(9.3-13.4)
7	8/1-8/7	7.0(6.4-8.1)	8.4(6.3-10.8)	7.5(7.0-8.4)	9.7(8.3-11.8)	6.5(5.5-7.7)	9.8(6.7-13.5)	7.5(6.5-8.4)	9.0(7.6-12.4)	7.1(6.3-8.1)	11.0(8.8-12.9)
8	8/8-8/14	6.8(6.2-7.5)	7.7(6.6-9.0)	7.5(7.0-7.8)	9.4(6.9-11.8)	6.0(5.5-6.7)	7.9(1.7-11.0) 3/	6.2(5.4-8.0)	8.1(6.2-11.0)	6.9(6.2-7.4)	10.4(6.7-12.8)
9	8/15-8/21	6.6(6.0-7.4)	7.7(6.0-9.0)	7.4(6.4-7.9)	9.5(7.6-12.0)	5.9(1.5-7.7) 4/	8.6(5.7-10.4)	7.8(7.3-8.3)	7.7(6.9-8.8)	6.7(6.0-7.3)	9.9(6.7-12.2)
10	8/22-8/28	7.0(5.6-10.6)	7.9(6.2-9.9)	7.6(6.9-9.5)	9.6(5.6-12.6)	6.3(5.3-7.9)	7.9(6.2-9.3)	8.1(7.3-8.7)	8.3(7.5-9.1)	6.9(6.1-7.7)	9.1(7.6-11.2)
11	8/29-9/4	5.9(5.2-6.6)	6.6(4.5-7.6)	7.0(6.7-7.3)	8.3(6.6-11.0)	6.3(5.4-7.1)	9.0(8.2-11.0)	7.6(1.9-8.1) 5/	8.9(6.9-9.9)	6.4(5.9-7.1)	8.6(6.1-10.7)
12	9/5-9/11	4.3(0.1-6.7)	5.8(1.7-8.5)	6.6(6.0-7.2)	8.2(6.1-10.3)	5.4(2.5-6.6) 6/	8.3(5.9-9.1)	6.9(2.1-7.6) 7/	7.3(4.9-8.2)	5.8(0.5-7.1) 8/	8.9(3.0-10.9)
13	9/12-9/18	4.6(1.8-7.0) 9/	4.4(1.8-6.5)	6.7(6.2-7.9)	8.5(6.1-11.2)	6.3(4.7-7.3)	8.6(5.0-11.0)	7.2(3.3-8.2)	7.5(4.8-9.3)	6.2(3.2-7.4) 10/	7.6(5.5-10.8) 11/
14	9/19-9/25			7.1(6.3-7.9)	9.4(7.6-10.3)	7.0(6.5-7.7)	10.4(9.5-11.4) 12/	8.4(8.0-9.0)	8.2(7.7-8.8) 13/		
15	9/26-10/2			6.8(5.7-7.4)	6.3(5.0-8.7)	6.9(6.5-7.4)	9.1(6.7-10.8)	7.8(7.4-8.2)	7.9(6.3-8.7)		
16	10/3-10/9			6.6(6.1-7.5)	7.9(6.0-9.3)	7.3(7.0-7.7)	10.6(10.0-11.6)	8.2(7.9-8.5)	8.0(7.2-8.8)		
17	10/10-10/16			7.1(6.4-7.7)	6.7(4.7-8.5)	7.6(6.9-8.0)	9.5(8.5-11.0)	8.1(5.5-8.7)	7.9(6.9-8.6)		
18	10/17-10/21			8.5(6.5-9.2)	8.8(6.0-10.2)	9.9(7.7-10.0)	11.3(10.0-11.8)	9.3(8.6-10.2)	9.2(8.4-9.4)		

1/ Fish kill in one replication. D.O. = 0.6 ppm.

2/ Fish surfaced with few mortality; electricity tripped off; D.O. = 2.5 ppm.

3/ Fish kill; sudden death of algal bloom demanded high O_2; D.O. = 1.7 ppm.

4/ O_2 deficiency in one replication; D.O. = 1.5 ppm; few mortality; paddle wheel chain broke.

5/ Fish kill in one replication; D.O. = 1.9 ppm; paddle wheel chain broke.

6/ Fish kill in one replication; D.O. = 2.5 ppm.

7/ Fish kill in two replications; D.O. = 2.8 and 2.1 ppm; paddle wheel trouble.

8/ Fish kill in two replications; D.O. = 0.5 and 0.6 ppm; pump clogged with dead fish.

9/ Fish kill; dead fish clogged pump in one replication.

10/ Fish kill in one replication; D.O. = 3.2 ppm; pump clogged with dead fish.

11/ One replication left; subsequent values for overhead filter are single observations.

12/ Value of one replication left.

13/ Values of two replications left.

TABLE 33

AVERAGE WEEKLY TEMPERATURE, °C IN VARIOUS TREATMENTS

No. of Weeks	Date 1973	Underwater filter; single pond (400 fish)		Underwater filter; single pond (200 fish)		Paddle wheel dual pond (400 fish)		Paddle wheel single pond (400 fish)		Overhead filter dual pond (400 fish)	
		AM	PM	AM	PM	AM	PM	AM	PM	AM	PM
1	6/20 - 6/26	26.4	30.4	26.9	30.5	27.0	30.2	27.0	30.1	26.8	30.0
2	6/27 - 7/3	27.0	30.4	27.3	30.4	25.5	28.8	25.0	29.0	27.0	30.5
3	7/4 - 7/10	27.8	30.7	27.9	30.6	26.5	29.4	25.3	28.5	27.8	30.2
4	7/11 - 7/17	26.9	29.8	27.1	29.8	25.9	28.7	25.0	28.0	26.8	29.6
5	7/18 - 7/24	28.0	31.0	28.3	30.9	26.8	29.9	25.7	29.0	27.8	30.8
6	7/25 - 7/31	28.0	30.9	28.1	30.8	26.9	29.9	25.6	28.9	27.9	30.8
7	8/1 - 8/7	27.4	29.8	27.4	29.6	26.0	28.6	25.1	27.8	27.5	29.4
8	8/8 - 8/14	27.0	30.1	27.0	29.9	25.7	28.8	25.0	28.3	26.7	29.7
9	8/15 - 8/21	26.9	30.0	26.8	29.5	25.5	28.5	24.5	27.5	26.4	29.4
10	8/22 - 8/28	25.6	28.9	25.6	28.7	24.2	27.8	23.1	26.5	25.2	28.6
11	8/29 - 9/4	26.3	28.9	26.3	28.8	25.0	27.9	24.1	27.0	25.9	28.5
12	9/5 - 9/11	27.4	30.1	27.3	29.9	25.9	28.9	25.1	28.0	27.0	29.7
13	9/12 - 9/18	26.7	28.8	26.7	28.6	25.6	27.6	24.7	26.9	26.7	28.8*
14	9/19 - 9/25			24.0	26.8	22.7	25.8	21.8	24.5		
15	9/26 - 10/2			24.2	25.8	22.9	24.8	22.5	24.3		
16	10/3 - 10/9			23.7	26.8	21.8	25.5	21.1	24.4		
17	10/10 - 10/16			21.6	23.7	19.6	22.4	19.1	21.7		
18	10/17 - 10/21			16.7	19.4	14.4	17.9	13.6	16.8		

*Value of one replication left.

TABLE 34

DISSOLVED OXYGEN CONSUMPTION BY PLANKTON COMMUNITY, mg/l/hr

Treatment	Pond No.	DATE, 1973								
		6/20	7/12	7/26	8/9	8/23	9/6	9/20	10/4	10/18
1. Underwater filter; single pond (400 fish)	A73	0.000	0.256	0.102	0.047	0.293	0.750			
	A93	0.309	0.275	0.358	0.280	0.253	0.533			
	A96	0.211	0.387	0.128	0.077	1.060	0.943			
2. Underwater filter; single pond (200 fish)	A76	0.074	0.326	0.653	0.073	0.880	0.373	0.467	0.960	0.073
	A89	0.063	0.003	0.166	0.280	0.120	0.517	0.367	0.523	0.233
	A92	0.154	0.173	0.166	0.137	0.747	0.307	0.153	0.113	0.640
3. Paddle wheel dual pond (400 fish)	A74-75	0.171	0.480	0.237	0.137	0.847	0.863			
	A77-78	0.389	0.333	0.570	0.560	0.560				
	A94-95	0.223	0.416	0.582	0.703	0.833	0.907	0.567	0.553	0.353
4. Paddle wheel single pond (400 fish)	A82	0.706	0.205	0.461	0.207	0.473	0.450			
	A88	0.557	0.582	0.614	0.500	0.613	0.507	0.267	0.880	0.240
	A91	0.783	0.403	0.621	0.273	0.440	0.563	0.647	0.493	0.355
5. Overhead filter dual pond (400 fish)	A79-80	0.914	0.422	0.698	0.573	0.733	0.830			
	A83-84	0.480	0.205	0.390	0.327	0.460	0.607			
	A85-86	0.211	0.352	0.390	0.114	0.793	0.647			

TABLE 35

TURBIDITY IN JTU FOR EACH POND

Treatment	Pond No.	DATE, 1973								
		6/26	7/10	7/24	8/7	8/20	9/4	9/18	10/2	10/16
1. Underwater filter; single pond (400 fish)	A73	2	3	2	2	2	6	3		
	A93	8	18	20	27	14	54	51		
	A96	8	12	15	4	3	4	5		
2. Underwater filter; single pond (200 fish)	A76	9	1	2	2	1	2	1	1	4
	A89	4	1	2	4	2	2	2	1	1
	A92	12	4	17	11	25	22	8	6	13
3. Paddle wheel dual pond (400 fish)	A74-75	8	12	18	21	24	28	27		
	A77-78	23	12	54	52					
	A94-95	16	7	25	32	25	28	30	23	28
4. Paddle wheel single pond (400 fish)	A82	28	7	30	33	30	17	37		
	A88	31	11	36	29	34	20	36	37	38
	A91	15	7	41	29	32	29	41	37	44
5. Overhead filter dual pond (400 fish)	A79-80	30	8	24	24	21	27	34		
	A83-84	17	8	22	14	24	12	18		
	A85-86	13	7	13	21	22	22	19		

TABLE 36

EARLY MORNING pH VALUES FOR EACH POND

Treatment	Pond No.	6/26	7/10	7/17	7/24	7/31	8/11	8/14	8/23	9/5	9/11	9/26	10/9
		DATE, 1973											
1. Underwater filter; single pond (400 fish)	A73	8.0	7.6	7.3	7.4	7.3		7.0	6.2	6.7			
	A93	7.2	7.9	7.7	7.5	7.3		7.7	7.0	6.5	7.4		
	A96	7.2	8.5	8.1	7.5	6.9		7.0	7.1	6.6	7.3		
2. Underwater filter; single pond (200 fish)	A76	7.3	8.1	7.2	7.5	7.6		7.7	7.2		7.5	7.2	7.0
	A89	8.0	7.6	6.4	7.7	7.6		7.6	7.0		8.0	7.3	7.1
	A92	7.3	7.6	7.4	7.5	7.5		7.3	7.5		7.5	7.3	6.8
3. Paddle wheel dual pond (400 fish)	A74-75	9.6	7.9	6.7	7.4	7.7		7.3	7.0	7.0	7.5		
	A77-78	8.7		7.3	7.5	7.7	7.0	7.6					
	A94-95	7.2	8.0	7.8	7.4	7.6		7.8	7.3	7.3	7.5	7.4	7.4
4. Paddle wheel single pond (400 fish)	A82	7.2	8.3	7.6	7.7	7.4	7.2	7.9	7.5		7.5		
	A88	8.4	8.2	7.7	7.5	7.7	7.2	7.9	8.0		7.5	7.6	7.0
	A91	8.7	8.1	8.1	7.6	7.7	7.7	8.2	7.5		7.7	7.6	7.1
5. Overhead filter dual pond (400 fish)	A79-80	8.0	8.4	7.3	7.9	7.7		7.6	7.5	7.0			
	A83-84	8.1	8.5	8.0	8.2	7.9		7.3	7.2	7.0			
	A85-86	8.5	7.4	7.6	7.8	7.6		7.5	6.7	7.0	7.2		

TABLE 37

AMMONIA CONCENTRATION, ppm FOR EACH POND

Treatment	Pond No.	DATE - 1973												
		7/17	7/27	7/31	8/11	8/14	8/28	9/5	9/7	9/11	9/15	9/19	9/26	10/9
Underwater	A73	0.50		0.44		0.20	0.30	0.42	1.20			17.60 [1/]		
filter; single	A93	0.38		0.26		0.48	0.82	0.46	1.79	0.46				
pond (400 fish)	A96	0.34		0.04		0.28	0.23	0.50	1.04	4.72				
Underwater	A76	0.52		0.26		0.18	0.30			0.74			0.38	0.68
filter; single	A89	0.52		0.30		0.14	0.14			0.56			0.36	0.57
pond (200 fish)	A92	0.46		0.30		0.30	0.55			0.66			0.48	0.50
Paddle wheel	A74-75	0.60		2.12		0.70	0.63	0.48		0.70				
dual pond	A77-78	0.43		0.43	4.84	9.24 [1/]								
(400 fish)	A94-95	0.40		0.06		0.12	0.23	2.25	1.02	4.80			0.40	0.40
Paddle wheel	A82	1.40	0.52	0.68	0.21	0.22	0.14			4.40				
single pond	A88	0.52		0.31	0.40	0.24	0.40			0.46			0.36	0.46
(400 fish)	A91	2.40	0.42	0.28	0.25	0.26	0.42			4.00			0.30	0.50
Overhead	A79-80	0.36		0.13		0.84	0.23	2.05	1.84					
filter dual pond	A83-84	0.43		0.40		0.16	0.87	2.05	2.82					
(400 fish)	A85-86	0.38		0.30		0.10	0.60	0.50	1.22	2.88	4.56 [1/]			

1/ Not included in mean computation

TABLE 38

NITRITE CONCENTRATION, ppm FOR EACH POND

Treatment	Pond No.	DATE, 1973										
		8/7	8/11	8/14	8/28	9/5	9/7	9/11	9/15	9/19	9/26	10/9
Underwater	A73			0.034	0.041	0.100	0.142			0.000		
filter; single	A93			0.030	0.150	0.250	0.140	0.154				
pond (400 fish)	A96			0.025	0.280	0.040	0.150	0.024				
Underwater	A76			0.010	0.023			0.032			0.029	0.027
filter; single	A89			0.004	0.009			0.015			0.015	0.010
pond (200 fish)	A92			0.029	0.038			0.060			0.030	0.064
Paddle wheel	A74-75			1.386	1.980	0.320		0.900				
dual pond	A77-78	5.200	2.000	2.420								
(400 fish)	A94-95			0.006	0.570	0.280	0.470	0.390			0.160	0.023
Paddle wheel	A82	7.000	0.105	0.040	0.007			0.510				
single pond	A88	7.000	1.090	0.176	0.038			0.210			0.023	0.147
(400 fish)	A91	7.300	1.430	0.546	0.045			0.780			0.010	0.027
Overhead filter	A79-80			0.777	0.900	0.930	0.900					
dual pond	A83-84			0.003	0.730	0.930	0.670					
(400 fish)	A85-86			0.006	2.320	1.180	1.120	1.230	4.020			

TABLE 39

CARBON DIOXIDE CONCENTRATIONS, ppm FOR EACH POND

Treatment	Pond No.	DATE, 1973 6/28	7/10	7/24	8/7	8/11	8/20	8/29	9/5	9/15	9/18	10/2	10/16
1. Underwater filter; single pond (400 fish)	A73	0	5	5	5		6		23		23		
	A93	5	5	7	7		8		14		6		
	A96	5	4	7	6		6		10		14		
2. Underwater filter; single pond (200 fish)	A76	3	1	4	2		3		5		8	8	10
	A89	4	4	4	4		2		5		5	6	8
	A92	3	4	5	3		6		8		11	10	13
3. Paddle wheel dual pond (400 fish)	A74-75	4	5	6	4		8	9	9		9		
	A77-78	5	5	9	15	9							
	A94-95	4	6	8	6		7	4	14		11	13	13
4. Paddle wheel single pond (400 fish)	A82	10	5	8	4		6		4		4		
	A88	10	5	9	3		8		8		5	6	7
	A91	9	5	10	6		5		9		13	6	8
5. Overhead filter dual pond (400 fish)	A79-80	10	3	4	6		9	12	13				
	A83-84	4	3	0	5		7	9	8				
	A85-86	8	4	7	4		7	10	13	20			

TABLE 40

TOTAL ALKALINITY, mg/l $CaCO_3$ FOR INDIVIDUAL POND

Treatment	Pond No.	DATE, 1973 6/26	7/10	8/16	9/18	10/16	Mean*	Treatment Mean	Mean Comparison
1. Underwater filter; single pond (400 fish)	A73	56.6	21.6	25.0	81.2		46.10		
	A93	64.0	41.6	76.0	63.2		61.20	67.50	a
	A96	68.2	57.0	78.0	178.0		95.30		
2. Underwater filter; single pond (200 fish)	A76	65.2	33.1	32.0	36.6	151.0	41.73		
	A89	70.2	58.6	48.0	33.4	103.0	52.55	52.19	a
	A92	62.8	40.2	75.0	71.2	66.4	62.30		
3. Paddle wheel dual pond (400 fish)	A74-75	67.0	63.8	73.0	85.8		72.40		
	A77-78	65.2	59.2	92.0			72.13	73.03	a
	A94-95	65.2	58.4	84.0	90.6	119.0	74.55		
4. Paddle wheel single pond (400 fish)	A82	58.6	57.6	56.0	58.4		57.65		
	A88	64.6	56.0	59.0	61.2	74.8	60.20	57.95	a
	A91	51.4	56.0	65.0	51.6	59.2	56.00		
5. Overhead filter dual pond (400 fish)	A79-80	64.4	63.6	94.0	113.2		83.80		
	A83-84	64.2	45.2	65.0	87.8		65.55	66.17	a
	A85-86	46.8	49.8	59.0	41.0		49.15		

*Data for mean computation were until September 18, 1973.

TABLE 41

HARDNESS, mg/l AS $CaCO_3$ FOR INDIVIDUAL POND

Treatment	Pond No.	DATE, 1973 6/26	7/10	8/16	9/18	10/16	Mean*	Treatment Mean	Mean Comparison
1. Underwater filter; single pond (400 fish)	A73	49	52	53	65		54.8		
	A93	46	33	63	55		49.3	58.9	a
	A96	54	54	74	108		72.5		
2. Underwater filter; single pond (200 fish)	A76	49	41	53	123	142	66.5		
	A89	53	35	40	83	108	52.8	58.4	a
	A92	42	50	51	80	61	55.8		
3. Paddle wheel dual pond (400 fish)	A74-75	37	41	60	74		53.0		
	A77-78	46	39	85			56.7	56.6	a
	A94-95	47	49	63	80	94	60.0		
4. Paddle wheel single pond (400 fish)	A82	43	39	54	53		47.3		
	A88	49	41	52	56	70	49.5	50.2	a
	A91	35	43	51	86	65	53.8		
5. Overhead filter dual pond (400 fish)	A79-80	54	46	69	108		69.3		
	A83-84	52	41	41	82		54.0	57.7	a
	A85-86	37	44	36	82		49.8		

*Data for mean computation were until September 18, 1973.

TABLE 42

STOCKING, DRAINING, AND MORTALITY DATA FOR INDIVIDUAL POND

Treatment	Pond No.	Stocking*		Draining**		Observed Mortality		Percentage Mortality
		Wt. (lbs)	No.	Wt. (lbs)	No.	Wt. (lbs)	No.	
1. Underwater filter; single pond (400 fish)	A73	11.40	400	74.20	364	0.20	3	0.8
	A93	11.40	400	12.90	76	67.90	297	74.3
	A96	11.50	400	85.40	391	0.10	2	0.5
2. Underwater filter; single pond (200 fish)	A76	6.00	200	85.10	192	0.00	0	0.0
	A89	6.00	200	66.70	187	0.40	8	4.0
	A92	6.00	200	101.70	191	0.30	7	3.5
3. Paddle wheel dual pond (400 fish)	A74-75	11.25	400	0.50	5	59.30	354	88.5
	A77-78	11.25	400	0.00	0	39.40	408	100.0
	A94-95	11.20	400	30.00	118	38.00	250	62.5
4. Paddle wheel single pond (400 fish)	A82	10.00	400	2.50	16	30.50	381	95.3
	A88	11.20	400	50.00	210	29.80	183	45.8
	A91	10.85	400	30.00	132	17.70	258	64.5
5. Overhead filter dual pond (400 fish)	A79-80	9.70	400	2.00	11	74.60	356	89.0
	A83-84	10.20	400	1.60	9	108.40	374	93.5
	A85-86	10.30	400	0.60	3	97.50	377	94.3

* Stocking date: June 5, 1973.

** Drained September 19, 1973: All ponds of treatments 1 and 5, pond A74-75 of treatment 3, A82 of treatment 4. Drained October 21, 1973: All ponds of treatment 2, pond A94-95 of treatment 3, A88 and A91 of treatment 4.