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Pollution Aspects of Catfish Production ---Review and Projections

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POLLUTION ASPECTS OF CATFISH PRODUCTION--REVIEW AND PROJECTIONS

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ABSTRACT

A literature review and field study was undertaken to determine the waste concentrations and discharge loadings occurring in the waters from catfish-culturing ponds and raceways. Water quality analyses were performed on samples taken during a 240-day growing season and at drawdown (assuming drainage at harvest).

The natural biological degradation of the raw wastes in the ponds and raceway systems resulted in BOD reductions of 96.8% and 98.0% respectively when compared to waste levels produced in indoor single pass tank systems with no waste removal facilities. Reductions in total nitrogen of 97.2% and 97.7% occurred in ponds and raceways respectively, while ammonia nitrogen was reduced by 97.4% and 99.4% respectively. Sedimentation and biodegradation resulted in an 83.6% reduction in suspended solids in ponds and an 86.2% suspended solids reduction in raceways. Total phosphate levels were reduced by 98.5% and 97.4% in ponds and raceways respectively.

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CONTENTS

FIGURES

TABLES

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SECTION I

CONCLUSIONS

1. None of the water quality parameter concentrations recorded during the study period interfered with or presented difficulties in the culturing of catfish.

2. All pond water parameters except ammonia nitrogen when expressed as pounds parameter per 100 fish show decreasing trends as the culture season progressed. This is a result of the decrease in unit metabolic waste production as the fish increase in size. When the parameter concentrations are expressed as milligrams per liter the levels show an increasing trend as the season progresses.

3. Samples taken near the bottoms of ponds have, in general, the highest parameter concentrations. The lowest levels occur at mid-depth while those from the surface are in between. For example COD values from bottom, surface, and mid-depth were 41.0 mg/l, 35.0 mg/l and 30.8 mg/l respectively.

4. The total pounds of each parameter released from the pond during the drawdown for harvest can be closely estimated by using the mean of the surface, mid-depth and bottom concentrations in the pond prior to drawdown.

5. If preharvest drawdown requires drainage only to the mid-depth level, a slight reduction in total quantities of waste discharged can be attained by removing water from the mid-depth level as opposed to the bottom. For example a 2.5% BOD reduction and 8.4% total Kjeldahl nitrogen reduction were attained in this study.

6. Ponds have a high biological assimilative capacity for the wastes produced during the culture of catfish. BOD and total nitrogen levels are reduced by 96.8% and 97.2% respectively from the raw waste levels recorded in tank studies.

7. Pond drainage should be discontinued during seining operations. The waters discharged during harvest operations have the highest waste concentrations. Organic parameter concentration can be as much as 30% higher in the discharge occurring during seining.

8. Raceway water quality parameter concentrations when expressed as a function of fish density showed a slight tendency to increase during the growing season. This indicates that the systems did not have the biological capability to assimilate all of the wastes resulting in a net buildup of nutrients.

9. Recirculation raceway systems provide the highest degree of waste stabilization of any of the systems studied. For example, BOD, total nitrogen, and total solids were reduced by 98.0%, 97.7%, and 48.4% respectively when compared with the raw waste levels in tanks. This increase in waste reduction can be attributed to the increased mixing and aeration received by the water during pumping and gravity flow through the raceway.

10. Physical settling basins are not an effective means of removing suspended organic solids from the "continuous" flow in raceway systems for catfish production. Based on model studies a 78-ft. long trapezoidal shaped settling basin would remove only 4% of the total organic solids.

11. With the exception of ammonia nitrogen and total phosphate all water quality parameter concentrations obtained from ponds and raceways during the growing season were well within the permissible criteria for raw surface water for public supplies as set forth by the Federal Water Pollution Control Administration (FWPCA) in 1968.

SECTION II

RECOMMENDATIONS

1. Where topography and economics permit, effluents from catfish production ponds at the time of harvest should be released into a holding pond. This is especially important with regards to the final 2 to 3 feet of drawdown water which contains a higher waste concentration. The effluent in the holding pond should be retained until biodegradation of wastes improves the water quality to the extent that next season's fish crop could be stocked in these waters or the waters released to a receiving stream.

2. When the harvest of catfish production ponds can be achieved by draining to the mid-depth level the drain pipe intake should be located at mid-depth and not the bottom. This will reduce the waste discharge from the pond during drawdown.

3. Water should not be released from the pond during harvest operations. The physical agitation caused by the fish and the seining operation increase the solids and other waste parameter concentrations in the water. Allowing this water to remain in the pond for a month or more after harvest would allow sedimentation and biodegradation to take place prior to final drainage.

4. Further research is needed to establish the effectiveness and techniques for land disposing and land filtration (overland flow prior to entering receiving stream) of the drainage waters from catfish production ponds. This would prove to be an effective alternative to holding ponds for renovation of drainage waters.

5. Raceway systems for catfish production should be of the closed-loop recirculation type. When a recirculation reservoir does not have sufficient biodegradation capacity to prevent certain waste parameters from reaching toxic levels periodic wasting or drainage should be kept to a minimum.

6. Further research is needed in order to develop biological filtration and polyculture systems suitable for outdoor warm-water-culture raceway systems. If this can be successfully accomplished then it should be possible to increase the stocking intensities per unit of total water volume.

SECTION III

INTRODUCTION

"Fish" to the average reader, has a recreational connotation. To a small and rapidly expanding group, however, it has a vastly more important implication: the production of food and income. It has been demonstrated that a ton of fish may be produced in an area capable of yielding only 800 pounds of corn or 80 pounds of beef. The Chinese began developing the art of fish farming into a science more than 2000 years ago. Only in the past two decades, however, has intensive fish culture came into focus in the United States. Today's fish farmer is in the same position as the poultry farmer of 20 years ago who was changing from the back-yard flock to the highly specialized commercial poultry production we know today.

A sound catfish industry has great potential for meeting the growing demands for increased food supply at reasonable costs. Catfish, compared to other animals, are relatively efficient converters of feed to meat. The product, if properly produced and marketed, is a highly nutritious food--high in vitamins, minerals, and protein; yet low in carbohydrates and cholesterol. In 1970 approximately 45,000 acres were devoted to catfish farming primarily in one to twenty acre ponds in the southern states. This acreage yielded 54 million pounds of undressed catfish worth 35.7 million dollars on the retail market. The projected value of production in 1975 is 88 million dollars. Emphasis was placed on high-density production of catfish in flowing water earthen raceways in Georgia in 1969.

The mushrooming development of catfish farming has been paralelled by a strong supporting program of research with work on spawning of catfish, biological investigations, economics, and applied research as well as follow-up studies of all subjects of concern to catfish culturists. The primary emphasis of water quality work to date has been on the effects of pollutants on fish, rather than the effects of fish cultural activities on other beneficial uses downstream. The almost complete absence of literature on the subject suggests that the quality of effluents from catfish culture operations has not been considered a serious enough problem to warrant investigation. However, in 1970, an estimated 185,000 acre-feet of water was being used for catfish production with a projected usage of 400,000 acre-feet by 1975. This quantity of water qualifies the catfish industry as a significant water user. As a result of public interest in the discharge of wastes into natural waters, much concern has arisen in the nature of effluents from fish cultural activities. Due to threatening water shortages and water pollution control laws, maximum efficiency in the use of water for fish culture is being sought.

Cultured fish produce a relatively large amount of organic wastes (uneaten feed and metabolic byproducts). Murphy and Lipper (1970) indicated that the BOD production in a raceway containing 100,000 one-pound catfish would equal that of a flock of 150,000 one-pound chickens, 1,500 one-hundred-pound hogs, or 480 one-thousand-pound steers. The quantity of waste to be handled then is considerable irregardless of the type of culture system in use. These wastes will inhibit growth and create an environment conducive to disease problems or oxygen depletion.

The pollution potential could have decided effects on the quality of waters receiving fish culture effluents. A major portion of the catfish producers in Georgia harvest their ponds by releasing the contents (5-100 acre-feet) over a three- or four-day period into a small receiving stream nearby. This practice has the potential to create an immediate shock-loading effect on the receiving ecosystem. Chronic effects of waste water from open raceways flowing into small receiving streams are little understood. Concern regarding the release of such materials into the environment must be considered, as well as the biological effects of having such compounds remain in the system as is the case with closed raceway systems. Producers are asking if the water from cultural activities is nutrient-enriched, and if so, what should be done to minimize these pollutants and increase fish production.

There are three broadly grouped categories of factors associated with fish cultural effluents that have potential or known existing detrimental effects on the quality of the receiving waters. The first category includes pathogens and parasites passing from the fish production unit into natural waters. A second category consists of chemicals and drugs employed to control either prophylactically or therapeutically, diseases and parasites. The third group of factors include those that contribute to chemical and/or physical change of water quality. The first and second categories are sporadic in nature while the third group constitutes the most suspect and possibly significant sources of pollution.

OBJECTIVES

This study was initiated to present a state-of-the-art review of catfish cultural activities with regard to the production of waterborne waste and its ultimate disposition. The specific objectives follow:

1. To obtain a compilation and review of present information on the pollution aspects of commercial catfish production.
2. To survey and analyze representative effluent samples of various segments of the catfish production enterprise for the characterization and quantification of fish production wastes.
3. To evaluate pollution control methods and make research projections for the management of catfish production wastes.

SECTION IV

THE PRESENT STATUS OF CATFISH CULTURE

Despite its virtual overnight development in the United States, catfish culture is one of the most thoroughly documented forms of intensive fish culture. Success, however, is not inevitable for every farmer who stocks a pond. As the industry has progressed, four methods of catfish culture have developed (1) pond culture, (2) raceway culture, (3) cage culture, and (4) tank culture. However, the majority of cultured catfish are produced by the first three methods. Specific requirements of a fish farm depend upon local situations, but general management guidelines for the pond, raceway, and cage culture systems have been established.

SELECTION OF CATFISH SPECIES

Three principal species of catfish are adaptable to intensive culture--blue, white, and channel catfish. Of these three, the most widely used is the channel catfish (Ictalurus Punctatus) partly due to their superior taste, fast growth from feeding, resistance to crowding, and availability of information known about their culture. On the other hand, channel catfish are difficult to train to surface-feed, and they have a nervous temperament causing problems when handled.

Blue catfish (Ictalurus Furcatus) grow more uniformly, yield a marketable portion of about 60-62% of live weight compared to 56-58% for channel catfish, readily adapt to surface-feeding enabling the farmer to inspect his fish for health and feeding habits daily, and are easy to harvest by seining. Major disadvantages, however, are poorer conversion of most artificial feeds, greater age at maturity, and high mortality rates during handling and transportation. The white catfish (Ictalurus Catus) are among the hardier species of catfish, withstanding crowding, low dissolved oxygen concentrations, turbidity, and high temperatures much better than channel catfish. However, they dress out at less poundage than the other types of fish and do not grow nearly as rapidly as channel catfish. Hybridization is gaining in popularity with the most promising hybrid thus far being a male blue catfish crossed with a female channel catfish. This hybrid grows more uniformly and has shown 11-65% better growth rates than the parents.

SITE SELECTION AND DESIGN CRITERIA

Pond Culture

Geographic areas with long periods of warm temperatures are best suited for catfish culture. Optimum rates of growth require a water temperature of over 70°F for 180-210 days per year. Close proximity of fish farm to market eliminates long-distance fish transportation. Site selection depends primarily on soil characteristics, topography, water supply, and drainage-protection areas. A heavy soil capable of holding water is necessary to prevent seepage losses. Land previously used for crops has the advantage of being cleared of brush, trees, and roots, but there is the chance of residual herbicides and insecticides in the soil which may be toxic to fish. A thorough test of the soil is necessary for a fish operation planned on cropland where chlorinated hydrocarbon pesticides have been used.

Topography of the proposed pond-site should be suitable for proper drainage of the pond and adequate flood protection. Generally, flat well-drained land affords the most economical pond construction, but sufficient elevation is required so that each pond can be drained completely into an adequate disposal outlet. Pond construction may be simplified by placing a dam across a natural drainage basin, however, the main course of a stream should be avoided because of its flooding characteristics. On large watersheds, flood channels or diversion ditches that bypass the ponds may be necessary for protection of the structures against excessive overflow and loss of fish. On sloping lands ponds should be designed to fit the contour of the land and make maximum use of the water supply.

The shape and arrangement of catfish ponds affects their effectiveness and efficiency of production. A square-shaped pond is less expensive to construct, because it requires less levee than a rectangular pond for the same number of acres of water. Economy of harvesting plus a greater feed area usually favor rectangular-shaped ponds since less seine is required for harvesting. To secure the best aeration benefits, the pond should be laid out with the longer axis parallel with the prevailing wind direction. Larger ponds need a certain amount of protection from these winds, however, since wind traveling over a long water surface will create waves and erode the dams or levees.

In order to prevent loss of fish, spillways of dams should be wide enough to hold the depth of overflow to six inches or less during excessive rainfall and filling. Storage of storm water can be provided by setting the overflow pipe at a lower elevation than the spillway. To prevent trash fish from entering the pond from downstream, an overfall or weir constructed on the back slope of the spillway is essential. All slopes, tops of dams and levees, and disturbed areas should be vegetated immediately after construction to prevent erosion.

The size of a pond for catfish production may be a case of necessity rather than choice and will vary according to the slope and size of the site available. Ponds of less than one acre to more than 100 acres have been used for catfish production, but usually, a pond of 5-20 surface acres is characteristic of a successful operation. Small ponds are more expensive to construct and utilize more space for levees, but they provide more flexibility for management, harvesting, overcoming oxygen shortages, and treating for diseases and parasites. They also can be drained and refilled quickly. Recommended depths for catfish production ponds are 3-6 feet -- not less than 2 feet or more than 8 feet. A minimum depth of two feet is required to control vegetation. Ponds deeper than 6 feet are difficult to seine, drain slowly, and cost more to refill. However, depths of 6-8 feet may be necessary in states north of Arkansas to prevent winter kill.

After construction, the bottom of the pond is graded smooth with a slope of 0.2 ft. fall per 100 linear feet toward the deep end or harvesting basin. To facilitate harvesting, a harvest basin is constructed in the deep end of the pond 18-24 inches below the drainpipe base. A satisfactory harvest basin contains about 10% of the total bottom area in the pond. Ponds should be equipped with drainpipes large enough for prompt and complete drainage. One such device is a three-ring, turn-down pipe which acts as an overflow and drainpipe and can be adjusted to maintain desired water levels.

Raceway Culture

The production of catfish in earthen raceways is a new kind of fish culture in America referred to as "intensive production." To understand this type of flowing water culture, the following general definitions are helpful:

1. Raceway - A channel with a continuous flow of water constructed for growing fish.

2. Raceway Unit - One of the segments into which a raceway is divided by screen partitions or water control structures.

3. Open raceway system - An installation in which water flows from the water supply source through the raceways and waste treatment facilities without recirculation.

4. Closed raceway system - An installation in which water is recirculated from the water supply reservoir through the raceways and waste treatment facilities and returned to the supply reservoir.

The water temperature of raceways is influenced by the water source more than the external environment. Unless some form of heated water is available, raceway culture of catfish is restricted to the extreme southern states due to relatively cool water temperatures experienced in other geographical locations. Rough terrain with cross slopes greater than 7% should be avoided, otherwise excessive land grading is required and objectionable cuts and fills are necessary. Other geographic, topographic and soil characteristics and requirements are much the same as for pond culture.

Most raceways usually consist of from 10-20 rectangular units each 100 feet long. All channels should be aligned as straight as possible to achieve uniform flow throughout the channel cross section. Necessary curves should have a relatively flat curvature to avoid eddy flow and dead areas. The recommended channel grade is from 1-2%. Channel flow is dependent on weir flow and the volume of water moved through the system rather than the channel grade. Typical channel cross sections are trapezoidal and consist of a 10-foot bottom width, 4-foot maximum depth, and 1:1 side slopes. Low channel velocities of 0.025 feet per second result from a recommended raceway flow of 530 gallons per minute. At this exchange rate, each raceway unit has a water retention time of approximately one hour. The dike crowns should have a minimum width of 12 feet to allow service vehicle access.

Water control structures are installed to provide water aeration, to subdivide the raceway into 100-foot units, and to create channel flow. A water fall of 1-2 feet per raceway unit is recommended. Water discharge from each raceway unit should be taken from near the channel bottom elevation to aid in flushing metabolic wastes and to remove water with a low level of dissolved oxygen. A vertical adjustable baffle located on the upstream side of the water control structure serves this purpose. Some of the more successful water aerators are the conventional splash board, a transversely corrugated inclined plane with holes, and a riser pipe with perforated collars.

An alarm system should be installed on each raceway to notify the operator of any flow stoppage. In the event of a power failure, an auxiliary pumping system or a storage reservoir capable of supplying a 12-hour emergency supply of water by gravity is imperative to prevent rapid oxygen depletion and fish kills.

<u>Cage Culture</u>

Cage culture is used mostly in natural bodies of water such as rivers, lakes, reservoirs, rock quarries, canals, and ponds that are otherwise unsuitable because of poor harvesting capabilities, excessive flooding, and the presence of other undesirable fish. Adequate circulation of water supplies or supplemental aeration is necessary to maintain sufficient levels of oxygen and to avoid a buildup of body wastes and parasites. The influence of the geographic area is the same in cage culture as in pond culture of catfish. Other advantages of cage culture include less expensive treatment for parasites and diseases, complete harvesting, manipulation of harvest to meet market demands, and ease of observation.

The most popular cage size appears to be 36 cubic feet with dimensions of 3 ft. x 4 ft. x 3 ft. deep. Depth in water may exceed three feet in very clear lakes where adequate oxygen is known to exist. Cage materials are usually one-half by 1-inch square mesh aluminum or galvanized wire attached to wooden or steel rod frames. Vinyl or "net set" coatings should prolong the life of any material used. The top should be constructed of some light solid material such as marine plywood or aluminum sheeting. Styrofoam, small drums, or other buoyant material provide flotation for the cages which are anchored or tied to a cable spanning the water impoundment.

WATER MANAGEMENT

Water Supply

Water, to a fish farmer, is what soil is to the rowcrop farmer. A dependable supply of good quality water is essential for catfish culture since it is the medium in which the fish lives, reproduces, and grows. Well water and spring water are the most dependable sources of good quality water since they are usually free of such impurities as parasites, diseases, pesticides, turbidity, and trash fish. Well water may be deficient in oxygen and supersaturated with nitrogen, carbon dioxide, and iron. Aeration of the water by splashing the flow over baffles and screens before it enters the culture system increases the oxygen content and significantly decreases the nitrogen and carbon dioxide levels. Well water is usually more expensive than other sources because of drilling and pumping costs. Spring water has the same characteristics as well water and may be used if an adequate volume is available year round. Springs, however, tend to yield water which is too cold for catfish culture unless some type of warming procedure is employed.

Runoff, streams, and reservoirs provide the most economical sources of water, however, the best known management precautions should be understood and followed. Runoff from cropland and watersheds may carry pesticide residues and may not provide an adequate amount of water. Water secured from streams or reservoirs may introduce diseases, parasites, sediment-laden water, or undesirable fish. The impurities may be toxic to fish, reduce production, or cause a bad taste in the fish flesh. Meshed screen or saran sock filters may be placed over the ends of water inlets to prevent the entry of trash fish.

Water Quantity

The amount of water needed for growing catfish depends on the size of the fish farm and the type of operation, that is, pond or raceway. Enough water is required for filling ponds in a reasonable time and for replacing water lost through evaporation and drainage when oxygen depletion occurs. A normal water requirement is 25-30 gallons per minute (gpm) per surface acre of pond culture. A well producing 1,000 gpm will produce 4.4 acre-feet in 24 hours. A 1,000-1,200 gpm well is generally considered adequate for a 40-acre catfish farm.

Raceways with 100-foot segments use a flow rate of 530 gpm with a unit retention time of 60 minutes. When supply reservoirs are utilized the storage capacity should be sufficient to fill the raceways and auxiliary pools, offset evaporation and seepage losses, and maintain a reasonable volume of storage below the pump intake to avoid reservoir pollution. Storage reservoirs should provide a minimum of one acre-foot of water for every 4,500 cubic feet within a closed raceway system. When the source is from wells, springs, or streams, open raceway systems should be designed to keep within the minimum seasonal flow.

In summary the average volume of water needed during a growing season to grow a harvestable crop of catfish is: (1) 85 ft^3/lb fish for ponds, (2) 60 ft^3/lb fish for raceways, and (3) 1.7 ft^3/lb for tanks.

Water Quality

Whatever the source of water, its quality should be carefully checked. Well and spring water usually has excessive carbon dioxide, nitrogen, or iron. Catfish can withstand 12-15 parts per million (ppm) of carbon dioxide but will usually die if concentrations exceed 25-30 ppm. Toxicity of ammonia nitrogen depends upon water pH. Total ammonia concentrations above 2-4 ppm may be toxic if the pH is above 8.5. The most toxic form of ammonia, un-ionized ammonia, becomes toxic to salmonids at levels of 0.5 ppm and greater. The amount of total ammonia that is in the un-ionized form increases as the pH increases. Combinations of low oxygen and high carbon dioxide and nitrogen gases are usually lethal to catfish. Waters which contain high ferrous iron concentrations can cause mortality by iron oxidizing and settling on the gills in amounts that interfere with fish respiration. Aeration of the water usually eliminates excessive amounts of carbon dioxide and nitrogen.

Water hardness is expressed as the amount of calcium carbonate in the water. Desirable ranges for catfish culture are 20-150 ppm total hardness and 30-200 ppm total alkalinity. If water is too soft (less than 15 ppm total hardness) the addition of agricultural limestone or hydrated lime is recommended. Sulfate of ammonia fertilizer may be used for water which is too hard (more than 200 ppm). Rapid changes in pH may severely stress the fish. Toxic levels are below 4 and above 11 with the desirable pH range being 6.5 - 8.5 for catfish production.

Chlorides in water combine with sodium, potassium, and magnesium to form salts. Catfish, when slowly acclimated, have been raised successfully in water averaging 2,500 ppm of salt as NaCl. Chlorine may be a problem where municipal water supplies are used for fish production since toxic levels to catfish are 0.1-0.2 ppm and above. Hydrogen sulfide is sometimes found in bottom water of ponds low in oxygen and high in organic matter. In such cases 1-2 ppm may be toxic to catfish, especially smaller ones.

Catfish take food very sparingly at water temperatures below 60°F and grow most efficiently at temperatures between 75°F and 85°F. During periods of higher water temperatures, feeding rates should be regulated to the amount the fish will eat. Muddy water may reduce fish yields and impart an undesirable flavor to the fish. Proper pond and raceway construction should include complete grass coverage of all bare or disturbed areas. Ponds may be cleared of muddiness by scattering hay on the water around the pond edges every 10 days except during hot weather. Gypsum may also be scattered over the surface at rates of 200-800 pounds per acre at 7-10 day intervals. Density of plankton and algae growth is a good index to water quality. A bright object immersed in water should be visible to a depth of 12 inches. Deterioration of a dense bloom of algae could cause an oxygen depletion.

Oxygen Maintenance

Oxygen depletion is the most common cause of sudden massive fish kills. Fish will die when the dissolved oxygen level falls below 1.0 ppm. Water should contain 4-5 ppm oxygen at 6 inches below the surface of the water for optimum fish growth. Decaying organic matter such as weeds, leaves, feed, and metabolic wastes as well as a sudden die-off of plankton and algae tend to rapidly deplete oxygen from water. A heavy fish population may use oxygen faster than it is added. Chemical reactions tend to tie up elemental oxygen. Water at 80°F when in atmospheric equilibirum, will hold only 8.1 ppm dissolved oxygen, whereas at 40°F it will hold 13.0 ppm. Water can be supersaturated with oxygen produced by algae to levels of 20-30 ppm. Adding water which is initially low in oxygen to a production unit reduces the amount of dissolved oxygen per volume of water.

Oxygen should be monitored at dawn since concentrations are usually lowest at this time because aquatic plants and animals have been using it during darkness without replenishment. Sunlight permits photosynthetic aeration, and, also at dawn a slight wind usually occurs physically mixing air with water at the water surface. Oxygen concentrations are highest at midafternoon and begin decreasing. Photosynthesis does not occur during the night causing reduced oxygen levels from plant and animal respiration. Oxygen depletions can take place most readily during hot cloudy days with very little wind.

When fish show signs of distress and oxygen levels fall below 3 ppm, measures should be taken immediately to restore oxygen to the water. One of the most common ways of supplying oxygenated water is to remove the lower dead water from the pond bottom and add fresh water high in oxygen to the surface. Pumps are used to aerate the water by spraying it into the air or splashing it off boards or concrete. Mechanical devices attempt to mix air with water or bubble air through perforated hoses located on the pond bottom, but these methods are quite expensive.

STOCKING

Prior to stocking any pond, all trash fish present should be destroyed. A growing season of 180-210 days is usually required for growing marketable size catfish. The spring months of March and April are the most preferable stocking times since water temperatures are increasing to the point where fingerlings start feeding immediately. When there is a significant difference in water temperatures, it is important to acclimate the fish when moving them from one impoundment to another.

Fingerlings for stocking should be carefully selected according to uniformity of size, health conditions, and reputation of fingerling producer. Uniformity in size at stocking results in equal competition for food and better feed utilization. Also, a uniform harvest of marketable-sized fish is achieved. Fingerlings which are 4-6 inches in length are preferable for stocking. Catfish fingerlings should be obtained only from reliable sources where treatments are provided for diseases and parasites. Treatment again at stocking time is desirable.

The preferred rate of stocking open growing ponds without aeration ranges between 1,500 and 2,500 fingerlings per surface acre of water. The beginning fish culturist should not stock more than 1,500 fish per acre because higher stocking rates tend to decrease water quality, increase disease problems, and give less efficiency in feed conversion. At this stocking rate for a 210-day growing season, fish will average 1.25 pounds at harvest. As the culturist gains experience a stocking rate of 2,000 per acre will yield more total pounds per acre but each fish will be smaller (about 1 pound). Stocking rates of 3,000-4,000 per acre are possible where there is adequate controlled flow through the pond or if aeration is provided.

The stocking density for flowing raceways should not exceed one pound of fish per 2 cubic feet of water at a flow rate of 530 gallons per minute. For a raceway unit 100 feet long, 10-foot bottom width, 1:1 side slopes, and a water depth range of 2-4 feet, the approximate volume of storage is 4,000 cubic feet. Therefore, 2,000 fingerlings stocked in this unit and fed properly for 210 days should yield 2,000 pounds of marketable-size fish. Cages can normally support 10 pounds or more of fish per cubic foot of enclosed water. The production potential of cage culture is approximately the same as that of open pond culture (1,500-2,000 pounds per surface acre).

FEEDS AND FEEDING

Catfish grown on fish farms are placed in ponds at high population densities, thus making the supply of food naturally available inadequate to meet the needs of the fish. Sufficient protein in the form of supplemental feeding of commercially prepared feed rations must be supplied. Good growth is obtained when catfish are fed diets containing 28-32%

protein. Common sources of protein from both plant and animal origin are fish meal, corn gluten meal, soybean meal, feather meal, blood meal, and poultry by-product meal. The amount of fish meal used in a feed ration should not exceed 12% as larger amounts may cause excessive accumulation of fat and strong flavors in fish. Raceway and cage culture requires more nutritionally complete feeds containing about 36% protein. A vitamin premix, when added to commercial rations, may improve catfish growth by as much as 15%.

Many fish culturists prefer floating feeds, because they can readily observe the amount of feed being utilized and can adjust feeding rates accordingly. Floating feeds cost about 10% more than sinking feeds but permit better feed utilization and less wasted feed. Catfish are usually fed by hand, by mechanical blower-feeders, or by self feeders or demand feeders. If fed by hand, fish should be fed at the same time and location each day and in shallow water along entire sides of ponds. Catfish can cause the release of feed from demand feeders by bumping trigger mechanisms when hungry. Advantages of self feeders include an avoidance of overfeeding and a reduction in labor. A disadvantage in some cases is reluctance of the channel catfish to adapt to self-feeding thereby failing to achieve optimum growth due to insufficient feed.

Overfeeding wastes feed and increases the chances of oxygen depletion. Catfish should be fed only what they will consume in 15-20 minutes and should never be fed more than 35 pounds of feed per surface acre per day in a stillwater pond. Feeding in raceway units should not exceed one pound of feed per 100 cubic feet of water per day at a flow rate of 530 gallons per minute. Catfish consume the most feed and make the best gains when the water temperature is between 70 and 90°F. Within this temperature range the fish are fed at the rate of 2.5%-3.5% of their body weight daily with the proportion decreasing as the fish grow larger in size. Samples of fish should be seined and accurately weighed regularly to determine the amount of feed to be fed. Catfish should be fed every day in the early morning and late afternoon during warm weather and only in the late afternoon during cool weather. When the water temperature falls below 60°F, catfish feed sparingly and should be fed only on warm days once or twice per week at a rate not more than 0.5% of their body weight. The rate of feeding may also be reduced during unusually warm weather, rainy days, or when plankton bloom is heavy.

The feed conversion ratio refers to the amount of feed required to produce one pound of fish. Since pond waters provide a limited amount of natural food an incomplete ration is generally fed to catfish of this culture with an average feed conversion of 2.0:1. More intensive culture systems (raceway and cage) require nutritionally complete rations with a 1.5:1 feed conversion. Feed utilization depends to a large extent on management practices.

DISEASES AND PARASITES

The intensive culture of catfish tends to enhance the incidence and spread of fish diseases and parasites. The best chance of avoiding a disease problem is by stocking properly treated fish that are free of diseases. Stress caused by low oxygen, high temperature, malnutrition, excessive handling, and poor water quality are major causes of fish diseases. Diseased catfish show a number of symptoms such as changes from normal behavior, reduced vitality, failure to consume feed, lesions, and death. The most common bacteria diseases are hemorrhagic septicemia, columnaris (saddleback) disease, gill disease, and fin and tail rot. The channel catfish virus disease is highly infective and contagious. There is no known treatment for this disease and the only methods of control are isolation and sanitary measures designed to prevent further spread. Fungus infections are usually secondary, taking place in necrotic tissue associated with injuries or other diseases.

The losses due to parasites in food fish production are usually not as great as with diseases, except with "Ich" disease. More channel catfish die because of Ichthyophtirius multifilis (Ich) than all other diseases combined. Other important protozoan parasites especially troublesome in raceways are Trichodian, Scyphidia, Trichophrya, Chilodonella, Costia, and gill worms.

Prevention is the best treatment for disease problems. Many authorities recommend prophylactic treatments monthly or bi-monthly to prevent serious outbreaks. Before any treatment can be considered, a thorough knowledge of the water chemistry, fish, disease, and treatment agent is essential since interactions can produce unwanted effects. When a problem is suspected, the fish culturist should get the advice of a fisheries consultant on the type of disease and administration of treatment.

HARVESTING

For complete fish harvest, the only effective method available is seining. Seining can be done in ponds up to 8 feet deep without de-watering or can be combined with pond drainage. Draining water from ponds so that the catfish are concentrated in a small area or catch basin is a widely used practice for small operations and in ponds that cannot be drag seined because of obstructions and hangs. Small seins and dip nets are then used to remove the fish from the pond for transport. Draining usually produces a higher percentage of the fish than other methods, but it also presents some disadvantages. The major disadvantage is that water is wasted necessitating a rather rapid and costly refilling operation with good quality water. Pumping costs for water range between $3 and $15 per acre-foot, thus to fill a 10-acre pond to a depth of 4 feet would cost between $120 and $600. Crowding the fish into a small area for seining increases the danger of oxygen depletion.

In large operations where the costs of drainage are prohibitive, large seines are used to drag the entire pond without water drawdown. Seines are made of 1 inch bar mesh nylon material with floats located at the top and weights at the bottom to keep the seine upright. Seines are normally 10 feet wide and in 200-foot sections. Usually about three feet of seine is required for every 2 feet of pond width. In larger ponds seines are usually pulled by mechanical equipment to the collection area. Fish are dipped from the collection area into brailing baskets and lifted by a powered boom into hauling trucks. Mechanical harvesting by seining reduces labor requirements, conserves water, and eliminates the danger of oxygen depletion due to overcrowding. Complete harvest usually is not achieved, however, since 15-30% of the fish may escape seining.

Movement of fish over long distance requires good hauling facilities and good handling techniques. Truck-mounted tank compartments equipped with agitators or aerators generally permit the transport of up to 8 pounds of 1-2 pound fish per gallon of water at 65°F. Fish should not be fed for 24 hours before handling and transport to prevent a buildup of fecal material and wasted feed in the transport water. At lower temperatures more fish can be hauled successfully, and usually short-distance transport would require only the placement of fish on ice.

SECTION V

CATFISH WASTES AND WASTEWATER QUALITY

In properly managed ponds, wastes are diluted and gradually reduced to harmless materials or cycled back into phytoplankton or other plant or animal life. However, organic materials may build up faster than they can be reduced due to overfeeding or crowding and eventually lead to oxygen depletion. Feed should not be fed in amounts more than the fish can clean up or more than the pond can assimilate. If the oxygen supply problems are overcome, the next limiting factor will likely be metabolic wastes. Ammonia, hydrogen sulfide, and to a lesser extent carbon dioxide, are directly toxic to fish.

In open flowing water systems, wastes are flushed out with the waste water. These systems require large volumes of water and will subject the downstream environment to a pollutional loading. However, a continuous water supply may not be available, or the economic utilization of water and nutrients in water may demand that the water not be wasted. Closed system recirculation and/or biofiltration minimizes both the amount of water used and downstream pollution. In most existing closed raceway systems large reservoirs are utilized to assimilate wastes retained within the system and reduced them to harmless products. Closed tank and cage culture systems employ mechanical and biological filtration to break down nitrogenous products such as ammonia. Filtration, however, is an area that is open for development.

PRODUCTION OF METABOLIC WASTES

Murphy and Lipper (1970) determined the solid waste and BOD production of two adult channel catfish each weighing approximately 1,840 grams and maintained in a 250-gallon recirculating tank under controlled conditions. They found that the channel catfish produced 4.9 grams BOD and 92 milliliters solids per kilogram live weight per day. These wastes occurred in two forms: a soluble form comprising 58% of the total waste BOD and a flocculate that settles readily in still water comprising the remaining 42% of the total. Compared with commercial animals, they found channel catfish waste to have about one and one-half times the pollution potential of poultry and swine wastes and about five times that of beef cattle on a per-kilogram live-weight basis.

Harris (1972) conducted a laboratory investigation to determine the levels of BOD and oxygen utilization, ammonia, and suspended solids produced by catfish in a single pass tank system. Four plywood tanks 8 feet long by 20 inches wide by 14 inches deep were stocked with approximately 25 pounds of channel catfish each. The fish had an average weight of 150 grams. The fish were fed 1% of their body weight per day for seven days and then 2% for seven days.

At the 1% feeding rate the suspended solids production was 0.35 lbs/100 lbs. fish/day on a fish weight basis or 0.36 lbs/lb. food/day on a fish food weight basis. The 2% feeding rate resulted in a suspended solids production of 0.80lbs/100 lbs. fish/day or 0.41 lbs./lb. food/day. The suspended solids production peaked approximately 4-6 hours after each feeding period.

BOD production at the 1% feeding rate was 0.40 lbs./100 lbs fish/day or 0.40 lbs/lb. food/day. At the 2% rate 0.91 lbs BOD/100 lbs fish or 0.46 lbs BOD/lb food were produced per day. It was found that any uneaten food exerts the same BOD per pound as the fecal material but with no resultant weight gain to the fish and no reduction through fish metabolism.

Ammonia nitrogen was produced at the rate of 0.019 lbs/100 lbs fish/day or 0.019 lbs/lb food/day at the 1% feeding rate while at the 2% rate 0.024 lbs.NH_3-N/100 lbs fish or 0.013 lbs NH_3-N/lb food were produced per day. Harris concluded that the waste parameters measured per pound of fish food were independent of the feeding rate. More emphasis should be placed on the mass balance concept of determining the pollutional potential of a fish production system.

In a recent study, Page and Andrews (1973) analyzed effluents from high density tank culture of channel catfish to determine the production of metabolic wastes by catfish. Duplicate sets of tanks containing 3.0 cubic meters (793 gallons) of water each were stocked with 160 large catfish and 1,200 small catfish averaging 940 grams and 60 grams, respectively. The daily BOD production rate was determined to be 3.5 grams per kilogram fish for 60-gram fish and 1.1 gram per kilogram for 940-gram fish. These values are lower than that reported by Murphy and Lipper (1970). This difference is probably due to the fact that Murphy and Lipper's work was restricted to only two fish under laboratory conditions, whereas, this study was performed under simulated commercial-type high density conditions.

When the data from Page and Andrews' study were expressed as grams waste product per day per kilogram fish, production rates in most cases were higher for 60-gram fish than for 940-gram fish. When results were expressed as grams waste product per day per kilogram feed, production rates approached the same value for both size fish. These observations tend to support the belief that the quantity of metabolic waste products is directly proportional to the amount of food eaten and inversely proportional to the size of fish. Average values (grams per day per kilogram feed) for both size fish were as follows:

Ammonia Nitrogen (as N)	20
Nitrate Nitrogen (as N)	100
Nitrite Nitrogen (as N)	1
BOD	98
Total Solids	180
Total Nitrogen (as N)	67
Total Phosphorus (as P)	15
Total Potassium	18

The production of solid wastes was dependent on feeding time with the highest production immediately following feeding. BOD, ammonia, and nitrate levels peaked only in late afternoon approximately 6-8 hours after feeding. The solids contained relatively high levels of nitrogen and phosphorus while most of the potassium was in the filtered water.

CATFISH EFFLUENT WATER QUALITY

Very little information is available on the discharge water from intensive culture of catfish. Such data would be useful in determining the effect of effluents from commercial catfish production units on stream water quality and in the design of wastewater treatment systems. The available effluent water quality data along with the results of this study are presented in Table 1.

In 1970 the Soil conservation Service and the University of Georgia Agricultural Experiment Station cooperated in a joint field trial to determine the effects of production of channel catfish in earthen raceways upon dissolved oxygen, temperature, pH, carbon dioxide, BOD, total hardness, nitrates, and water turbidity. The study was made on three catfish farms with closed raceway systems ranging from 17-25 units per raceway. The method of aeration was water pouring over the top of the control weir, falling one foot, and splashing on a board the length of the weir. Chapman et al. (1971) reported the results of this study and indicated that the present recommended level of stocking (one-half pound fish per cubic foot of water) did not overtax the raceway systems' ability to maintain desired oxygen levels. Raceways where sinking feed was fed had 15 inches of waste deposited in the lower ends of the units at harvest. These raceways exhibited the poorest water and fish quality, slowest rate of fish growth, and highest plankton fertility. Where floating feeds were fed, only three inches of waste were deposited in the lower ends of the raceway units.

Table 1. CATFISH EFFLUENT WATER QUALITY

Investigators / Year of Study / Culture Method / Type of System / Treatment	Barker et.al. 1974 Pond Open	Beasley & Allen 1973 Pond Open	Greene 1969 Pond Closed Filtered	Greene 1968 Pond Closed Filtered	Barker et.al. 1974 Raceway Closed OxPond	Allen 1974 Raceway Closed OxPond	Harris 1972 Raceway Open	Chapman et.al. 1971 Raceway Closed OxPond	Parker & Simco 1973 Raceway Closed Filtered	Broussard et.al. 1973 Tank Closed Filtered	Murphy & Lipper 1972 Tank Closed Filtered	Murphy Lipper 1970 Tank Closed
Fish Density	0.0097	0.014	0.038	0.024	0.34	3.0	1.9	0.37	7.2	3.1	3.1	0.24
Dissolved Oxygen			4.2	7.5	7.3	5.2	4.4	6.1	7.2	5.0	5.6	6.3
BOD	6.4	6.5			7.0	5.9	8.0	10.1			13.1	19.1
COD	33.	55.			37.							
Kjeldahl Nitrogen	8.21		14.2	7.85	9.28							
Organic Nitrogen	7.44		13.3	7.40	8.66							
Ammonia Nitrogen	0.77	0.09	0.92	0.45	0.62	0.43	0.25		1.00	1.50	0.62	0.30
Nitrate+Nitrite-N	0.12	1.27	0.63		0.24	0.29		2.16			1.10	1.46
Total Solids	140.	275.			165.							
Dissolved Solids	78.				98.							
Volatile Solids	80.	134.			84.							
Suspended Solids	63.	56.			69.	29.						
Settleable Solids	44.				48.							
Total Carbon			87.7	91.8								
Dissolved Carbon			33.8	41.1								
Carbon Dioxide								17.4	1.0	32.0	29.4	26.2
Total Phosphorus	0.24	0.17			0.76							
Orthophosphate	0.08				0.11							
Turbidity			29.2	22.4		43.4		19.1				
pH	7.4	8.2	7.7		7.2		7.1	6.9	8.7	7.0	6.8	7.2
Hardness	64.0		78.9		44.2			27.7		162.		
Alkalinity										31.5		
Chlorides	14.1				12.2							
Water Temp. °F					82.		73.	81.		71.	80.	75.
Total Coliform		3300				32900						
Fecal Coliform		2.0										

(a) All parameter units are in mg/l except coliform and turbidity

(b) Number of marketable-size fish per ft.^{3} of water

(c) Jackson Turbidity Units

(d) Number of bacteria colonies per 100 ml of sample

Indications were that closed systems with storage capacities less than one acre-foot of water for every 4,500 cubic feet within the raceway reached high fertility and algae buildup early in the growing seasons. Where supply reservoirs were fertilized and/or stocked with fish, poor water quality resulted.

Beasley and Allen (1973) analyzed water samples collected from several catfish ponds in both the Mississippi and Arkansas Delta areas for chemical, biochemical, and physical characteristics. The ponds ranged in size from 10-40 acres, and the stocking rates included 1,800, 2,000 and 3,000 catfish per acre. Samples were collected prior to harvesting and draining periods. They found that the pond water quality usually met or exceeded standards set forth for recreational waters by the Mississippi Air and Water Pollution Control Commission. The few exceptions occurred when the pH exceeded the allowable standard of 8.5 or when there was high turbidity caused by heavy algae blooms or muddy water. There was almost a total absence of fecal coliform bacteria which would indicate no sewage pollution. Most of the coliform bacteria present were probably soil bacteria. Ponds stocked at higher rates usually had slightly higher levels of BOD, nutrients, and total solids. Samples collected near the bottoms of ponds exhibited slightly higher parameter concentrations than those taken at the surface.

Boyd (1973), Department of Fisheries and Allied Aquaculture at Auburn University, evaluated the contribution of phytoplankton, to the COD of pond waters and the amount of oxygen required to completely decompose various organisms. Thirteen of the ponds investigated received daily applications of fish feeds, 11 received inorganic fertilization, and two received no nutrient addition. In the ponds which received applications of feed, plant production within the pond was the major source of COD. Water samples contained fairly unialgal blooms of green or blue-green algae, blooms containing several species of green algae, and mixed-species phytoplankton communities of low density. The COD of high protein content fish feeds was similar to that of phytoplankton. The soluble organic matter in pond waters had an average COD of 19.9 mg/liter.

Allen (1974), Fisheries Biologist at Fish Farming Experiment Station near Stuttgart, Arkansas, studied the effects of stocking size and rate on the growth of channel catfish using mini-raceways approximately 9 feet long, 1.5 feet wide, and 0.75 foot deep. Each raceway unit had an approximate water inflow of 6 gallons per minute which was recycled through three acres of ponds and back into the raceways. Raceway containers were stocked with 2-4 pounds of catfish per cubic foot of water. Lower stocking rates and stocking larger-sized fish yielded larger fish at harvest. Water quality data showed that orthophosphate and pH were negatively correlated with standing fish crop, and total coliform bacteria and alkalinity were positively correlated. Maximum BOD added to the environment was 1 kg per 100 kg of fish per day.

BIOLOGICAL FILTRATION

Green (1970), in an experiment at Auburn University, investigated the use of biofilters, settling basins, and aeration for renovating wastewater from recirculating catfish culture systems. Replicate rectangular concrete ponds with capacities of 4,080 gallons were stocked with 2,000 pounds per acre (low rate) and 4,000 pounds per acre (high rate) of catfish. Each pond had a filter with a surface area of 15 square feet filled with 2"-4" gravel to a depth of 4 feet. Water was pumped from the pond and sprayed continuously over the gravel at the rate of 650 gallons per hour. In a biofilter, or trickling filter, the wastewater is sprayed over filter media that is coated with a living film of aerobic microorganisms actively feeding upon and oxidizing the organic matter and ammonia in the water. Recirculation and biofiltration of the water in fish ponds yielded a net production of over 19,300 pounds per acre with channel catfish and white catfish responding similarly. Filtration improved the water quality in the pond by reducing the levels of ammonia, organic carbon, nitrate, and turbidity, and possibly increasing dissolved oxygen. At the high stocking rate, a settling basin in series with the filter had no effect on the fish production, but it did cause a 20% increase in production at the low stocking rate.

Three types of biofilters in a recirculating-water fish production system were compared by Murphy and Lipper (1971). Wastewater passed through rock filters, settled in rectangular sedimentation tanks, and percolated through sand filters before returning to a common reservoir. Flow rates through the filtering systems were approximately 3.3 gallons per minute. Average fish density was 103 pounds of fish per 250-gallon tank.

The filter material providing the best substrate for the decrease of BOD and conversion of ammonia to nitrates was the one-half-inch rock according to Murphy and Lipper's results. Sand percolation removed a high percentage of BOD while the filter was building up to a stable bacterial population. However, it soon became a trap for dead bacterial masses which added pollutional load on the system and could only be removed by backwashing. The one-half-inch rock biofilter was self-cleaning in that it had large enough voids to allow bacterial masses to be washed through without additional backwashing. Problems encountered included a high ammonia concentration which developed due to a collapse of the bacteria population in the biofilters. Subsequent investigation revealed that the bacteria normally present on the rock surfaces had been devoured by the larvae of the common "filter fly". A solution to this problem was to completely submerge the biofilters which worked satisfactorily until another buildup of ammonia caused another major fish kill. The submerged biofilter had trapped the solids in the rocks, and excess ammonia resulted from the breakdown of the solids. Larger rocks would have prevented this problem. Based on the results of their study, Murphy and Lipper suggested that a biofilter operating under a normal fish load should maintain the water at about 0.5 mg/l ammonia nitrogen, 5 mg/l dissolved oxygen, 1.1 mg/l nitrate nitrogen, 20 mg/l carbon dioxide, and 15 mg/l BOD.

Fish densities in excess of 7 pounds per cubic foot of water have been obtained by Parker and Simco (1973) in recirculating systems employing biological filters, settling chambers, and foam strippers. Fish survival during the 142-day study was more than 99% with a net gain of 318 pounds and a standing crop density of 7.2 pounds per cubic foot. Average food conversion for the growing period was 1.75.

Parker and Simco concluded that the simplest and least expensive method of solids removal was sedimentation. A mechanically cleaned settling chamber with large internal surface areas separated by weirs allowed for the progressive removal of solids from the water. Nitrogen levels decreased as water passed through the filter since biofilters can detoxify ammonia through the nitrogen cycle first to nitrites and then to nitrates in the presence of oxygen. Dissolved oxygen levels decreased as water passed through the updraft filter but increased after passing through the trickling filters.

Final clarifiers removed particulate matter and extended the life of the biofilters. The addition of foam strippers for the removal of foam caused by vigorous agitation of water high in organic matter content reduced the BOD load in the system. Water exchange rates of 6-7 minutes per tank maintained adequate water quality, but lower rates allowed waste metabolites to accumulate. In any recirculating system water quality is controlled by the fresh water inflow or exchange rate, the flow rate per tank, and the filter size.

Andrews et al. (1970) investigated two pilot model culture systems at Skidaway Institute of Oceanography. A rectangular concrete block culture pool had a total volume of 164 cubic feet. Water from this tank circulated through two rock and gravel filters having a combined filter area of 25 square feet. These filters were replaced during the study with a B. F. Goodrich PVC artificial media filter containing a settling basin. The systems were initially stocked at a density of 10 channel catfish per cubic foot of water with an average weight of 276 grams each. After the gravel filter became functional, a filtration rate of one gallon per minute per square foot of filter area was maintained.

Experimental results of Skidaway Institute indicated that although aerated water was added to the top of the gravel and oyster shell filters, conditions became anaerobic near the bottom and ammonia was produced rather than removed. It was necessary to remove the solids before addition of the wastewater to the filters and to continuously inject air into the bottom of the filters to keep the system aerobic. The artificial media filtration system offered several advantages over the gravel system. At high ammonia levels the artificial media filter was more efficient for removing ammonia than the gravel type. The artificial media was much easier to clean requiring less water, however, daily backflushing was still recommended. The most important advantage of the artificial media filter system was its reliability.

Researchers at Skidaway determined that 1.0 ppm ammonia is a level that is acceptable for catfish culture, and a commercial recirculating system should be designed with this in mind. At 1.0 ppm ammonia in the system, the artificial filter media will remove ammonia at a rate sufficient to accommodate 40 pounds of fish per square foot of filter area based on data which indicate the channel catfish produce approximately 0.1 mg ammonia per minute per pound of fish. Results from other studies indicated that about 5 pounds of fish per cubic foot of water was the maximum practical stocking density of intensive culture of catfish. Assuming a culture pool depth of 4 feet, 5 pounds of fish per cubic foot of water, and a filter system approximately 5 feet deep, the ratio of filter to pool on a surface area basis should be 0.5:1 Supplemental aeration will be needed in the system to maintain a minimum dissolved oxygen level of 5 ppm.

The prototype for an environmentally controlled closed loop catfish production system was designed and constructed by Hall (1972) and associates at Macomb, Illinois. Steel tanks stacked five high inside an insulated building provided fish with a constant fresh water supply. A sand filter removes solid wastes which are backflushed to a septic tank where they are anaerobically biodegraded before being conveyed to an aerobic lagoon outside the building. A limestone-filled biofilter removes soluble wastes from the circulated water. The unit has proved that fish can be successfully grown in a closed-loop confinement system.

Harry Dupree (1972) conducted research in 5-foot diameter fiberglass raceway tanks. Water for the tanks was obtained from a screened box located in a 4-acre earthen pond adjacent to the tank site. To remove waste materials, and to retard the large fluctuations in water temperature and pH, the pond was permitted to grow up with native forms of rooted and submerged vegetations including hyacinths, paspalm, smartweed, and Najas. Water was pumped from the screened box and jetted through various sized orifices into each tank before draining back into the pond. The earthen oxidation pond proved satisfactory for waste removal in a closed catfish production system.

The effect of water hyacinth on water quality and subsequent plant production in conjunction with fish culture was pursued by Wahlquist (1972). Nine 0.1 acre ponds were stocked with water hyacinths and nine ponds without plants served as controls. The water hyacinths were confined within floating wooden rafts (495 ft^2) covering 11.3% of the pond's total surface area. Data presented in the study indicated that the plants did not create water quality parameters that were detrimental to the fish.

The South Carolina Agricultural Experiment Station at Clemson University conducted similar experiments with Chinese water chestnuts as a means of increasing production of pond-raised catfish.

Chinese water chestnut corms were planted in rafts filled with vermiculite and floated near the surface of pools in which channel catfish were fed from March through October. The plants grew well and mature corms were produced by September with an average production of 2,835 pounds per acre. Average production of channel catfish was 1,100 pounds per acre in control pools and 1,740 pounds per acre in pools with water chestnuts.

SECTION VI

RESEARCH METHODS AND FACILITIES

The commercial catfish installations selected for this study included four ponds located in the Coastal Plains area of south Georgia. Three of these ponds produced food-fish and were harvested by drawdown and seining. The fourth pond contained several pairs of broodfish used for spawning. In addition, two flowing water earthen raceway systems located in central and south Georgia were selected for study. All installations were stocked with channel catfish fingerlings and produced crops of marketable size fish in one growing season. These six installations were chosen because they represent a diversity of production levels, feeding programs, and operational practices.

POND DESCRIPTIONS

Table 2 provides a physical description of the commercial catfish production ponds used in this study.

Pond GK was rectangular shaped and stocked with 36 pairs of brood fish. This pond was used for spawning and fingerling production utilizing demand type feeders. Samples were collected from the pond during the growing season to compare the water quality parameter concentrations with those of food fish production ponds.

Pond C was a 4-acre production pond located below three smaller food fish ponds (all in series) which drained into it. The smaller ponds (which were not sampled) had a combined surface area of 3.5 acres and a total water volume of 7.5 acre-foot. The large pond (C)was stocked January 1, 1973 with 8,000 channel catfish fingerlings approximately 6 inches in length. The pond was irregular in shape and had an effective water depth of 4-6 feet. The ponds were filled by introducing well water into the initial small pond of the series and successfully filling each of the subsequent ponds. After the initial filling, only enough fresh water was added to the ponds during the

Table 2. POND DESCRIPTIONS

Sample No.	Sample Collection Point	Pond Location (Ga.)	Surface Area (acres)	Effective Depth (ft.)	Volume of Water (ac.-ft.)	Stocking Rate (no. fish per acre)
GKS	Surface	Quitman	1.25	5	5	30 prs.
GKB	Bottom					
CS	Surface	Morven	4	5	15	2000
CB	Bottom					
BS	Surface	Sylvester	10	6	36	1600
BB	Bottom					
WS	Surface	Rochelle	10	8	48	1800
WB	Bottom					

growing season to offset evaporation and seepage losses. One serious oxygen depletion during the summer killed about 2,000 fish in Pond C. Emergency aeration was achieved by spraying water from the pond into the air with a tractor-driven irrigation pump. Feed was introduced through demand type feeders.

Pond B was a new pond in its second year of catfish production with a surface area of 10 acres. The pond surface was triangular in shape, and the water depth ranged from 3-8 feet. Well water was used to fill the pond and maintain the water level. Pond B was stocked with 16,000 channel catfish fingerlings on April 1, 1973. A massive fingerling kill occurred soon after stocking, most probably due to stresses incurred during stocking and the lack of medicated feeding. This occurrence emphasizes the importance of purchasing fingerlings from a reliable source where treatments for parasites and diseases have been provided. Another loss of fish through an unscreened emergency spillway occurred early in the season during a period of heavy rainfall. The extent of the losses was not known until harvest, but due to the lack of feed being consumed from the demand feeders, it was suspected that the majority of the fish had either died or been washed out the spillway.

Pond W was a 10-acre food fish pond which has been in production several years. It was the deepest pond of the study with a depth range of 5-12 feet. The grower believes that the added depth is needed to effectively assimilate wastes from the catfish. Water from a nearby well was used for filling and water level maintenance. The pond was stocked April 1, 1973 with 18,000 channel catfish fingerlings.

RACEWAY DESCRIPTIONS

Table 3 presents a summarized description of the flowing water earthen raceway systems used in this study. Raceways EG, EF, and ED were part of a large commercial catfish production facility located in central Georgia. A line diagram and flow chart for the system is

Table 3. RACEWAY DESCRIPTIONS

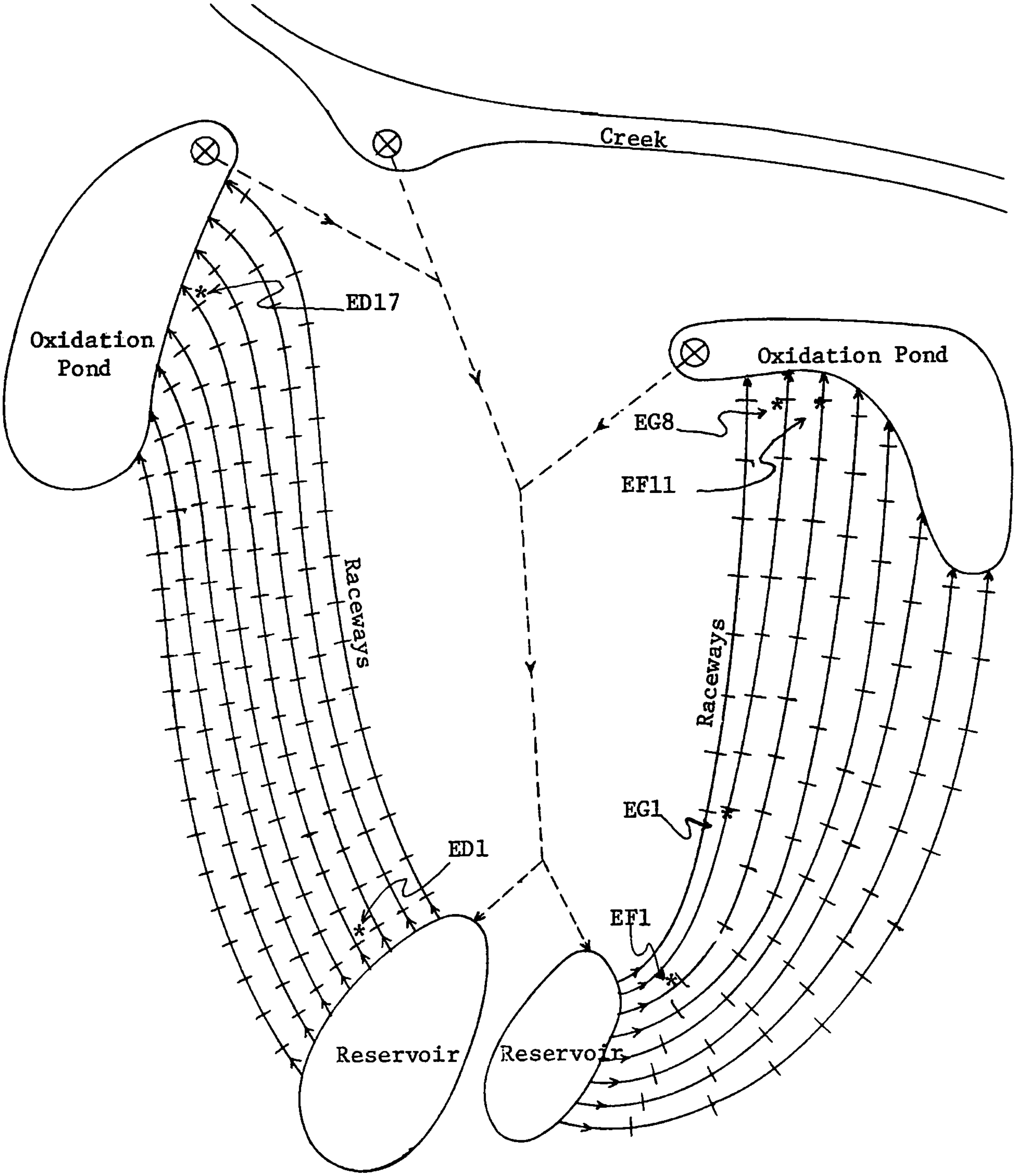
Sample No.	Sample Collection Point	Raceway Location (Ga.)	No. of 100-ft units	Effective Depth (ft.)	Volume of Water: Per 100-ft. unit ($ft.^3$)	Volume of Water: Total System (ac-ft)	Flow Rate (gpm)	Stocking Rate (no. fish per unit)
EG1	Influent	Mayfield	7	4	5600	30.6	350	2000
EG8	Effluent							
EF1	Influent	Mayfield	10	4	5600	31.0	350	2000
EF11	Effluent							
ED1	Influent	Mayfield	16	4	5600	65.5	350	1500
ED17	Effluent							
TR1	Influent	Tifton	8	3	4800	21.0	530	2250
TR8	Effluent							

shown in Figure 1. The operation is corporation-controlled and consists of its own brood ponds, hatchery, fingerling ponds, food fish production units, and processing plant. The semi-closed-loop system utilizes supply reservoirs to furnish water to the raceways and oxidation ponds to store the raceway effluents for recirculation. The system is not completely closed since periodically a portion of the wastewater is released to an adjoining stream and replenished by fresh water from upstream.

A 9.5-acre-foot reservoir supplies water to two 7-unit (EG) and six 10-unit raceways (EF) at the rate of 350 gpm per raceway. Each raceway unit is 100 feet long, 10 feet wide, 4 feet deep, and has a 1:1 sideslope. Each unit has an approximate water holding capacity of 5,600 cubic feet and a hydraulic detention time of two hours. Water aeration is achieved by an 18-inch waterfall between each unit. Some weirs have conventional splash boards with bottom-water take-off sleeves installed. The effluent from these raceways is collected by a 20.2 acre-foot oxidation pond where it has a 1.6-day detention time before being pumped back to the supply reservoir for recirculation. Each unit of Raceways EG and EF were stocked April 1, 1974 with 2,000 five-inch channel catfish fingerlings.

A 16.5-acre-foot reservoir supplies water to eight 16-unit raceways (ED) at a flow rate of 350 gpm. The units were identical to those in the 7 and 10-unit raceways except that each unit was stocked with 1,500 fingerlings. The effluent was collected by a 47 acre-foot oxidation pond where it had a detention time of 3.8 days before being returned to the supply reservoir.

No rigid schedule was adhered to for replacing the recirculating water with fresh water, however, it was estimated that one quarter of the total system capacity was replaced at a frequency of once every two weeks. Therefore, the entire system water capacity would be exchanged once every two months.



⊗ Pump Location

* Sampling Location

Figure 1. Flow diagram for Raceway System E

An experimental raceway system (TR) was put into catfish production in the summer of 1971 at the University of Georgia Coastal Plains Experiment Station, Tifton, Georgia. The raceway (Figure 2) is a closed-loop recirculation system with a very minimum of overflow (from watershed) being discharged to the waterway below the system. Water from a nearby 600-gpm well is used to maintain the water level in the system reservoir which serves as a source of recirculating water and as an effluent collector for waste assimilation.

The system reservoir has a surface area of 5 acres and a water holding capacity of 20 acre-feet. This provides an 8.5-day hydraulic detention time for a 530-gpm raceway pumping rate. The raceway is an earthen channel with a bottom slope of 1.5 percent divided into 8 units. Each unit has a 100-foot length, 10-foot bottom width, 3-foot depth, and 2:1 sideslopes. The units have a water holding capacity of 4,800 cubic feet and a hydraulic detention time of slightly more than one hour. Water from the reservoir is pumped into the initial unit through a 12-foot high corrugated metal riser pipe fitted with three aeration collars. Each raceway unit is separated by a concrete headwall provided with a weir over-flow notch. Affixed to the downstream side of each headwall is a transversely corrugated inclined plane aerator. A bottom-water take-off sleeve is attached to the upstream side of each headwall to force water with the lowest dissolved oxygen concentration at the channel bottom to flow up and over the weir and aerator. The raceway was stocked April 1, 1974 with an average of 2,250 eight-inch channel catfish fingerlings per unit.

WATER QUALITY MEASUREMENTS

Water quality samples were collected from the surface and near the bottom of each pond on the average of every three weeks during the growing season. These samples were "grab" samples collected near midday from two to four locations (horizontal) over the pond. The

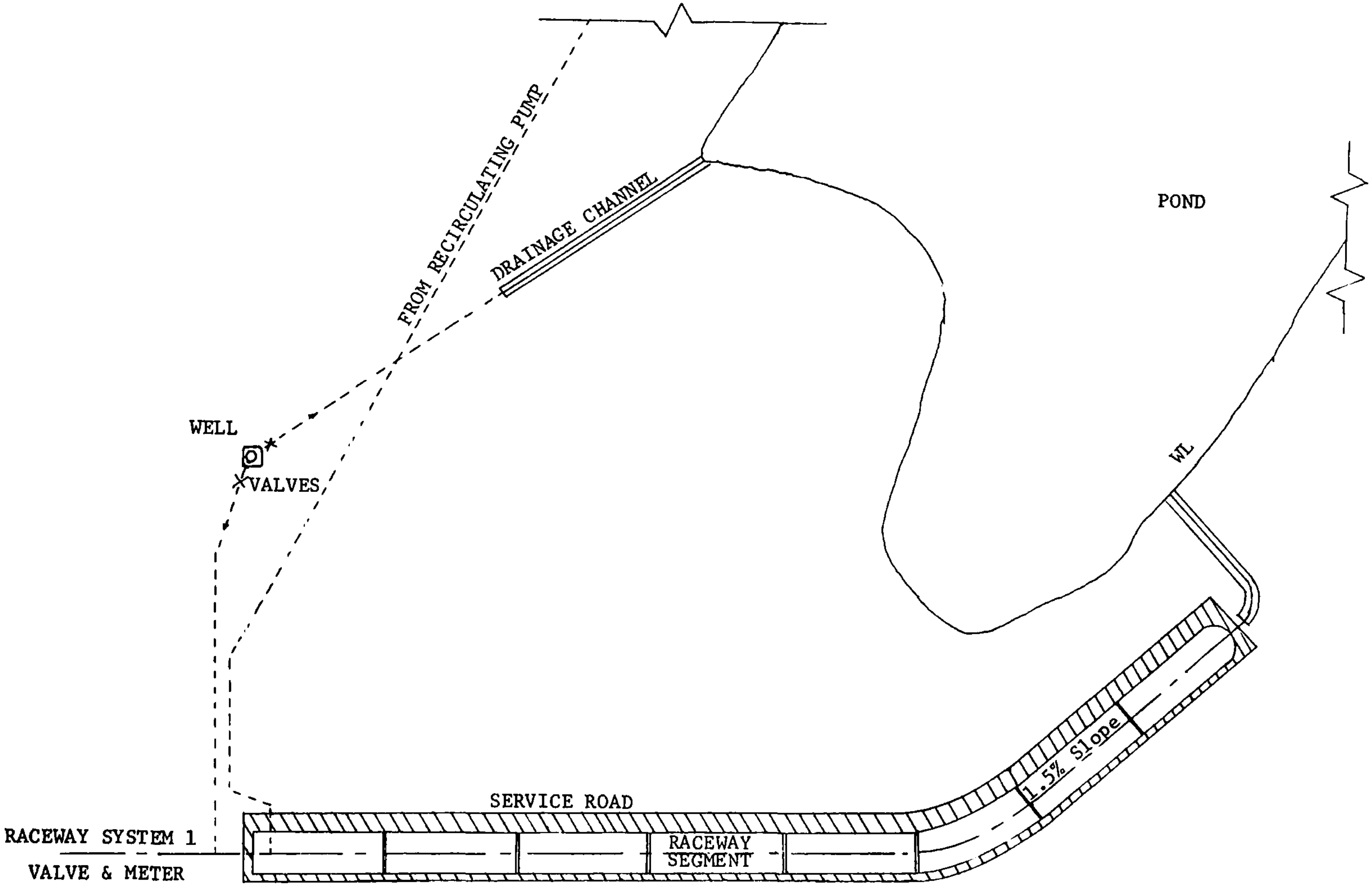


Figure 2. Flow diagram for Raceway System TR

composite samples (comprising the grab samples) were stored in polypropylene gallon jugs and "iced down" for transportation back to the laboratory. At harvest time composite samples were obtained during pond drawdown. All samples were analyzed within 72 hours after collection.

Raceway influent and effluent composite samples were collected and analyzed on a bi-weekly basis. Additional samples over a 24-hour period were also taken to determine if diurnal changes in the effluent composition occurred. Dissolved oxygen and water temperatures were measured at the raceway sampling points using a YSI Model 51A Oxygen Meter.

Samples were analyzed at the Agricultural Engineering Center Laboratory for BOD, COD, total Kjeldahl nitrogen, ammonia nitrogen, nitrate nitrogen, complete residue analysis, total and orthophosphate, pH, total hardness, and chlorides. Analysis was according to procedures outlined in Methods for Chemical Analysis of Water and Wastes (1971) and Standard Methods for the Examination of Water and Wastewater (1971).

The numbers and total weights of the fish at stocking and at harvest were recorded for each pond and raceway. At the Tifton raceway the average weight of the fish was determined weekly. The pounds of feed fed at each installation during the growing season was also recorded.

SECTION VII

RESULTS

POND WATER QUALITY DURING GROWING SEASON

The basic water quality data collected during the growing season in the ponds are presented in the Appendix. The water quality parameter concentrations were converted from units of milligrams per liter (mg/l) to pounds parameter per 100 pounds of fish for each sampling date. Parameter concentrations were also calculated in terms of pounds parameter per pound of feed fed on each sampling date. Figures 3-13 graphically present the parameter concentrations in pounds per 100 pounds of fish as a function of the fish density in pounds of fish per acre-foot of water. The fish densities represent the estimated standing weight of fish on each sampling date and increase as the growing season progresses. Data presented are the mean values (for bottom and surface) for five sampling dates for Pond C and 6 sampling dates for Pond W covering the period from July 8, 1973 to November 9, 1973. Pond GK and Pond B were excluded from these calculations since Pond GK was a brood pond and Pond B had so few fish due to a massive fish kill early in the season. A linear regression analysis was run to obtain the curve of best fit for the plotted values. Correlation coefficients averaged 0.58 and ranged from 0.20 to 0.81. The reader is reminded at this point that the curves presented in Figures 3 through 24 <u>should</u> <u>not</u> be used for prediction purposes. They are intended only to show possible trends in parameter concentrations during the growing season.

The parameter concentrations expressed as milligrams per liter generally increased during the growing season, however, when expressed as pounds per 100 pounds fish, the concentrations decreased as fish densities increased. This trend supports the belief that smaller fish produce more metabolic waste products on a per-pound basis than do larger fish. The exception to this trend was ammonia nitrogen which

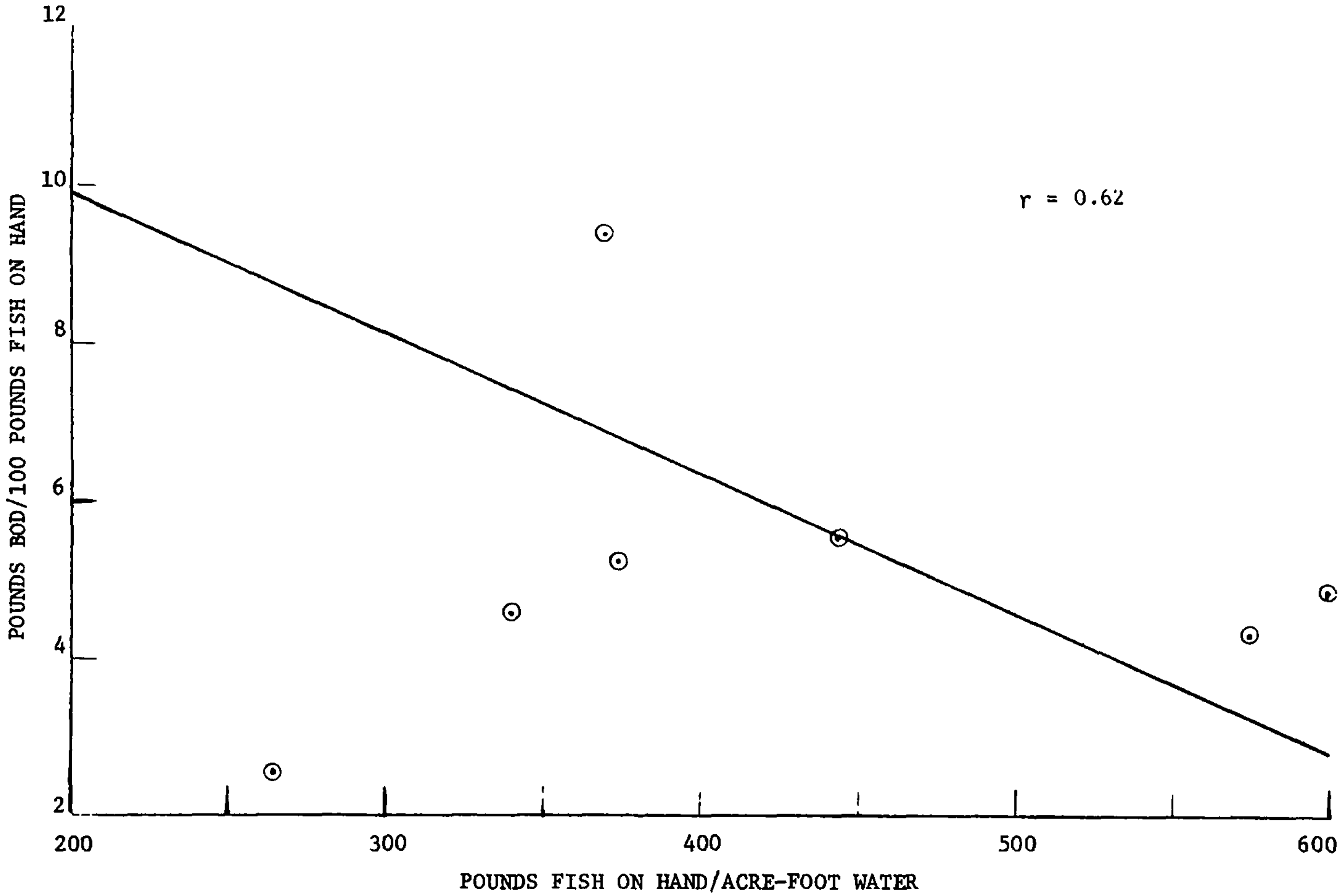


Figure 3. BOD concentration as a function of standing fish density in ponds

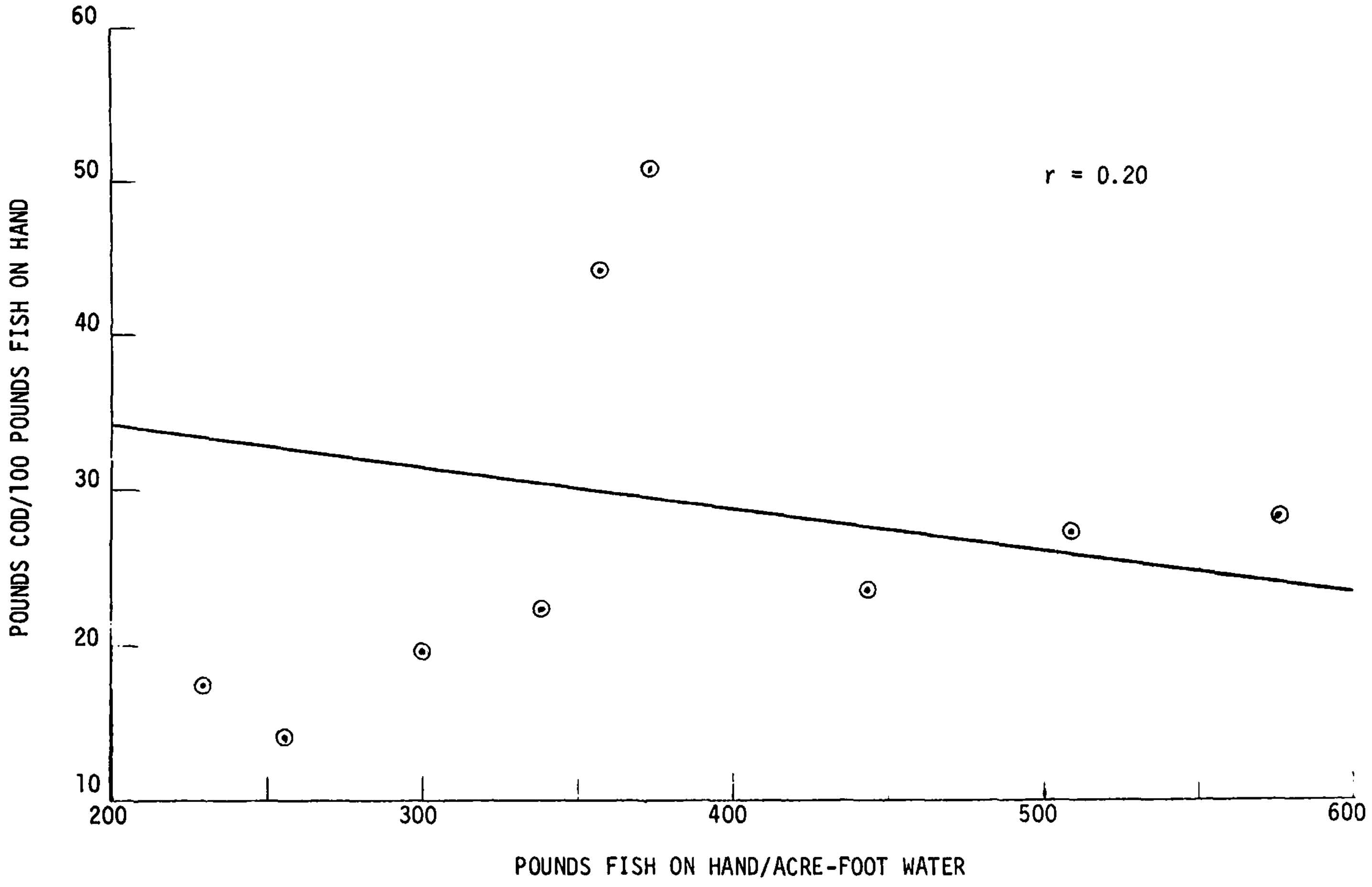


Figure 4. COD concentration as a function of standing fish density in ponds

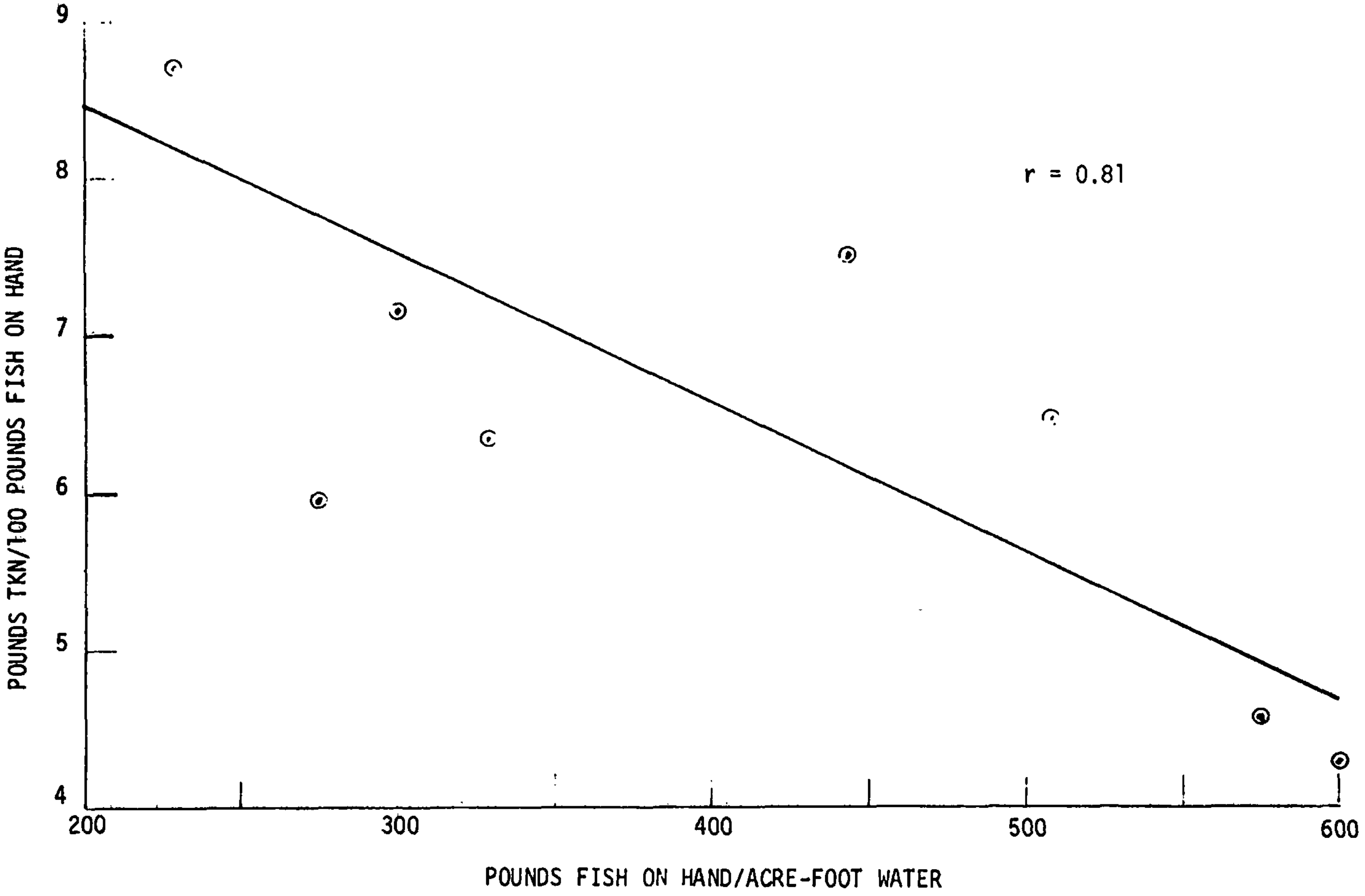


Figure 5. Total Kjeldahl nitrogen concentration as a function of standing fish density in ponds

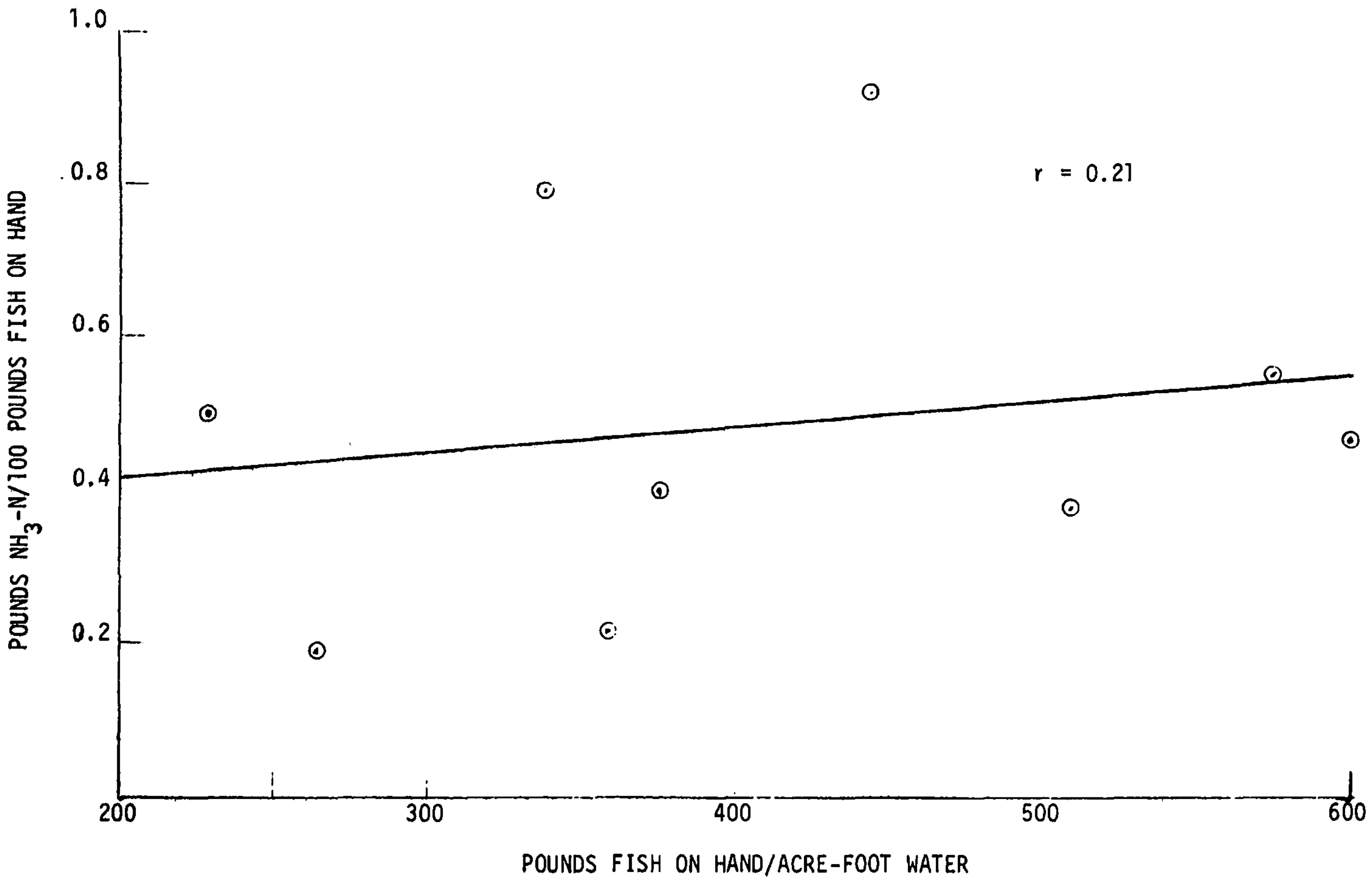


Figure 6. Ammonia nitrogen concentration as a function of standing fish density in ponds

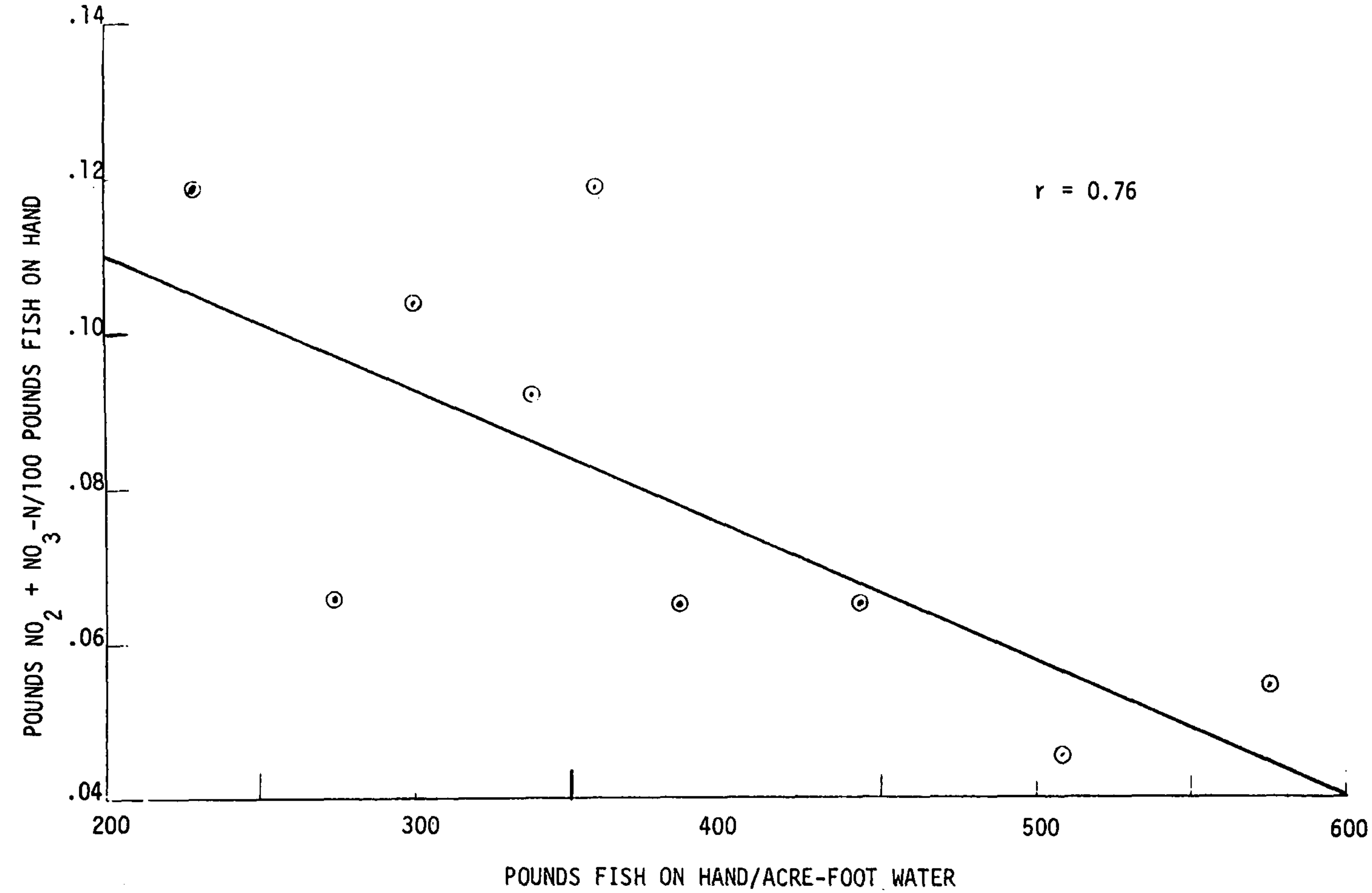


Figure 7. Nitrite + nitrate-nitrogen concentration as a function of standing fish density in ponds

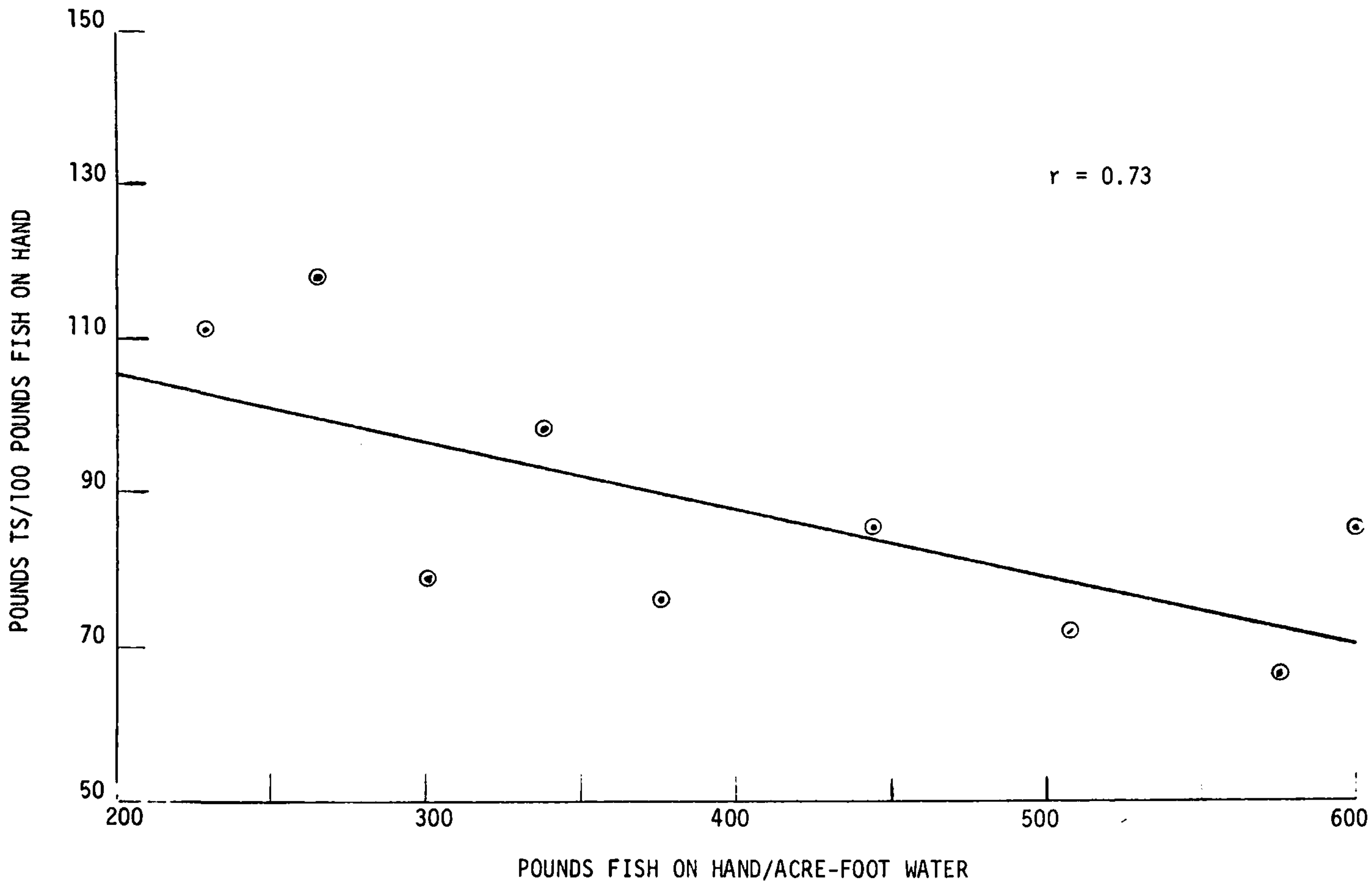


Figure 8. Total solids concentration as a function of standing fish density in ponds

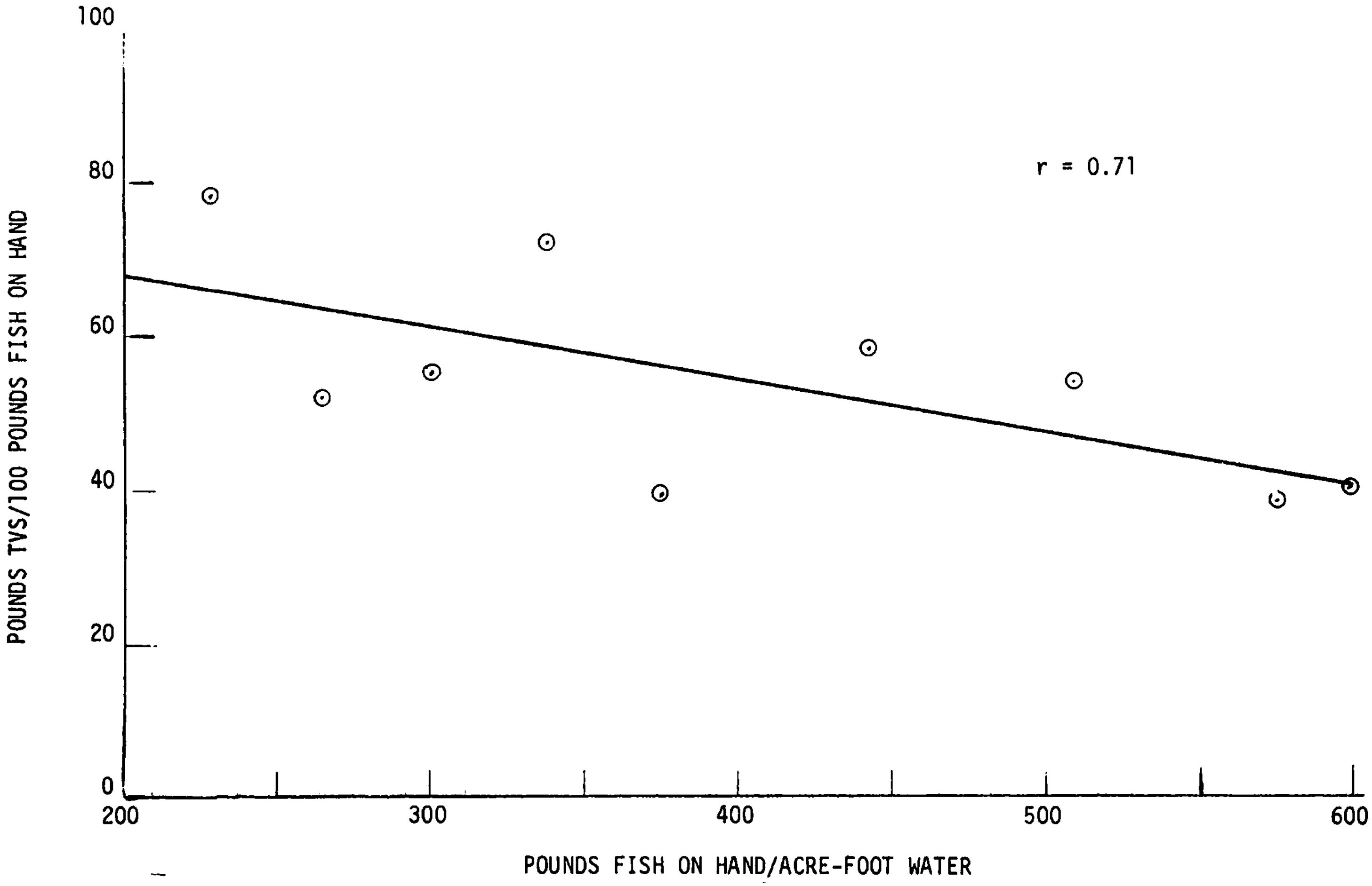


Figure 9. Total volatile solids concentration as a function of standing fish density in ponds

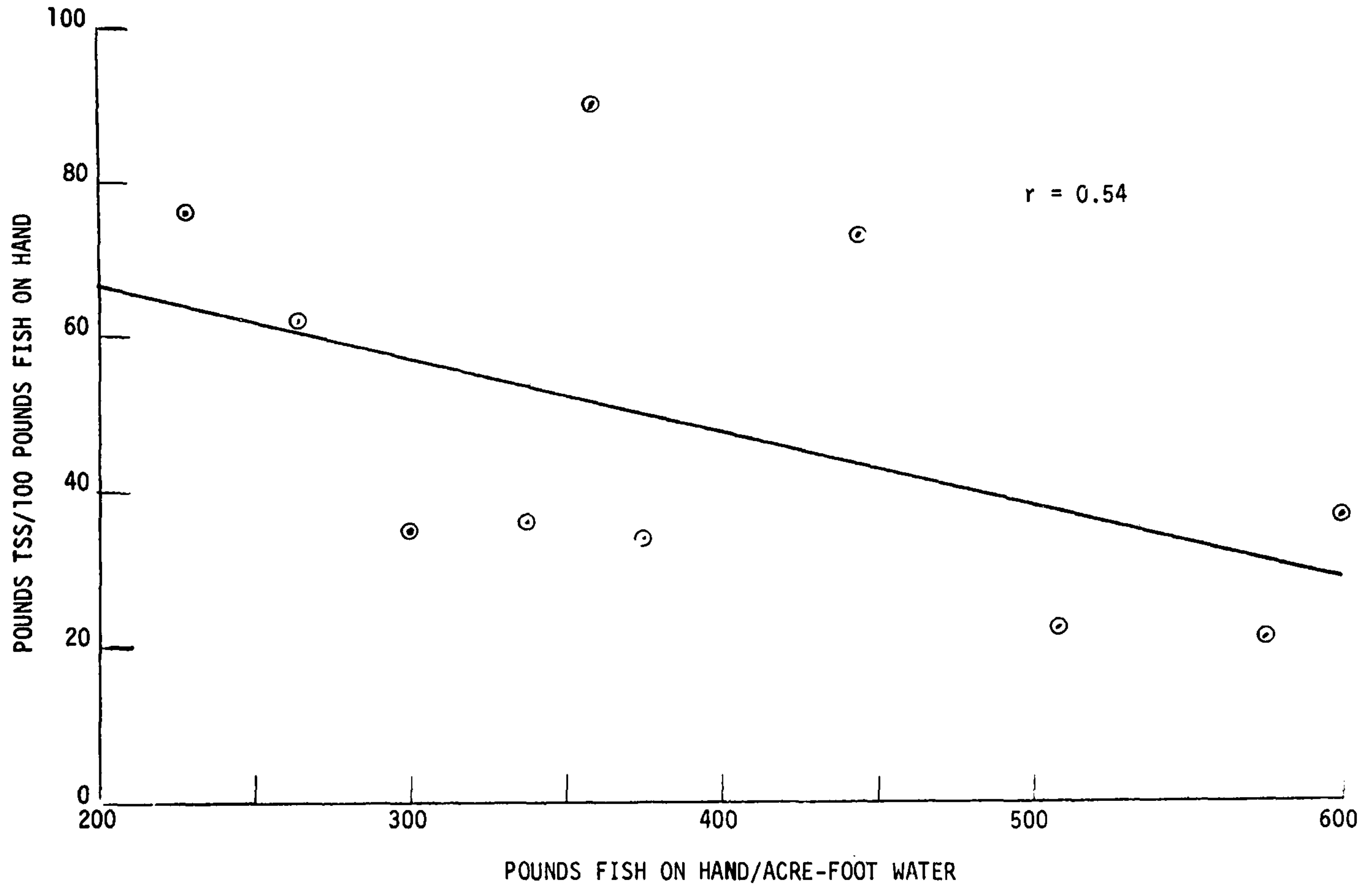


Figure 10. Total suspended solids concentration as a function of standing fish density in ponds

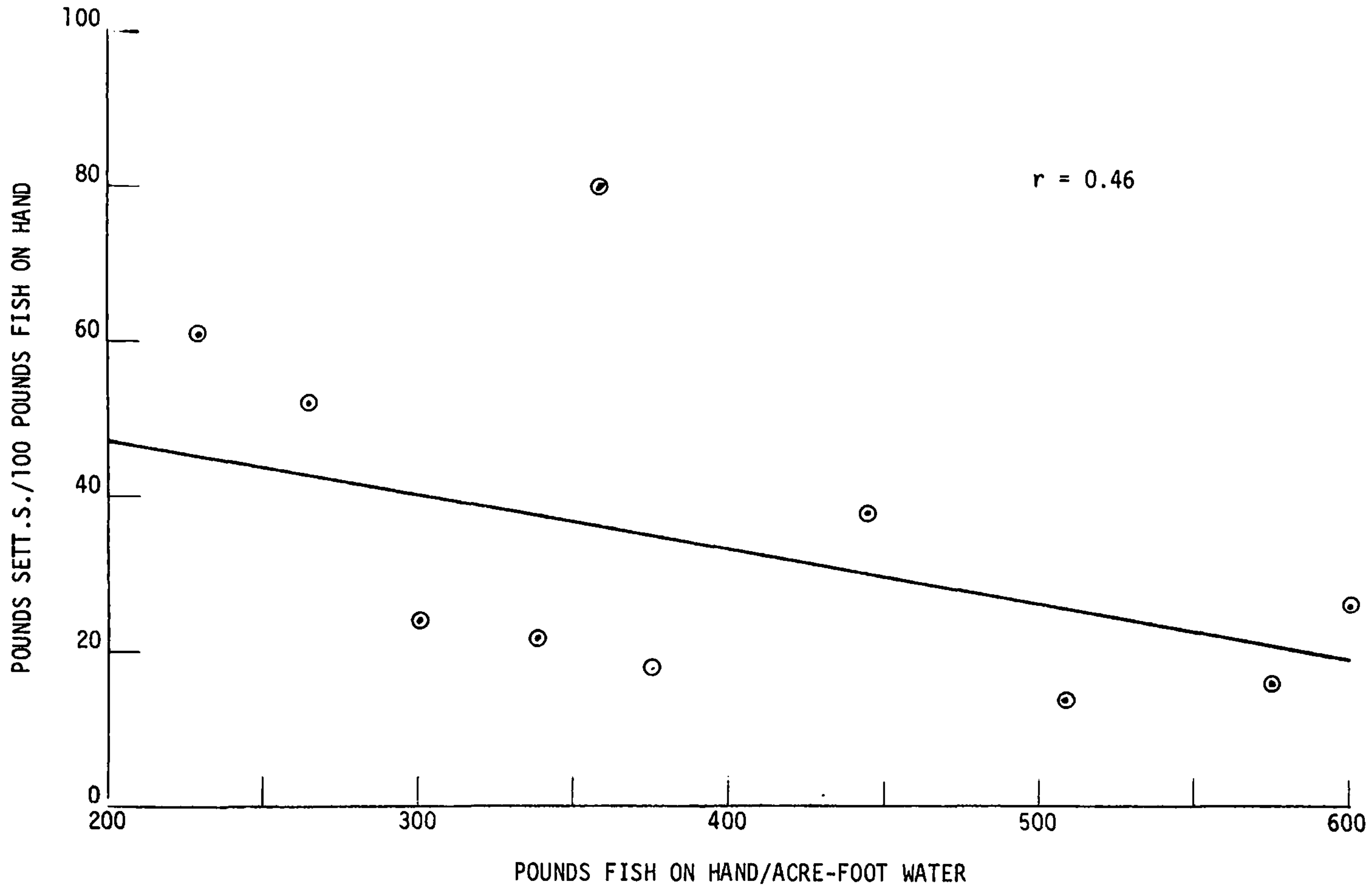


Figure 11. Settleable solids concentration as a function of standing fish density in ponds

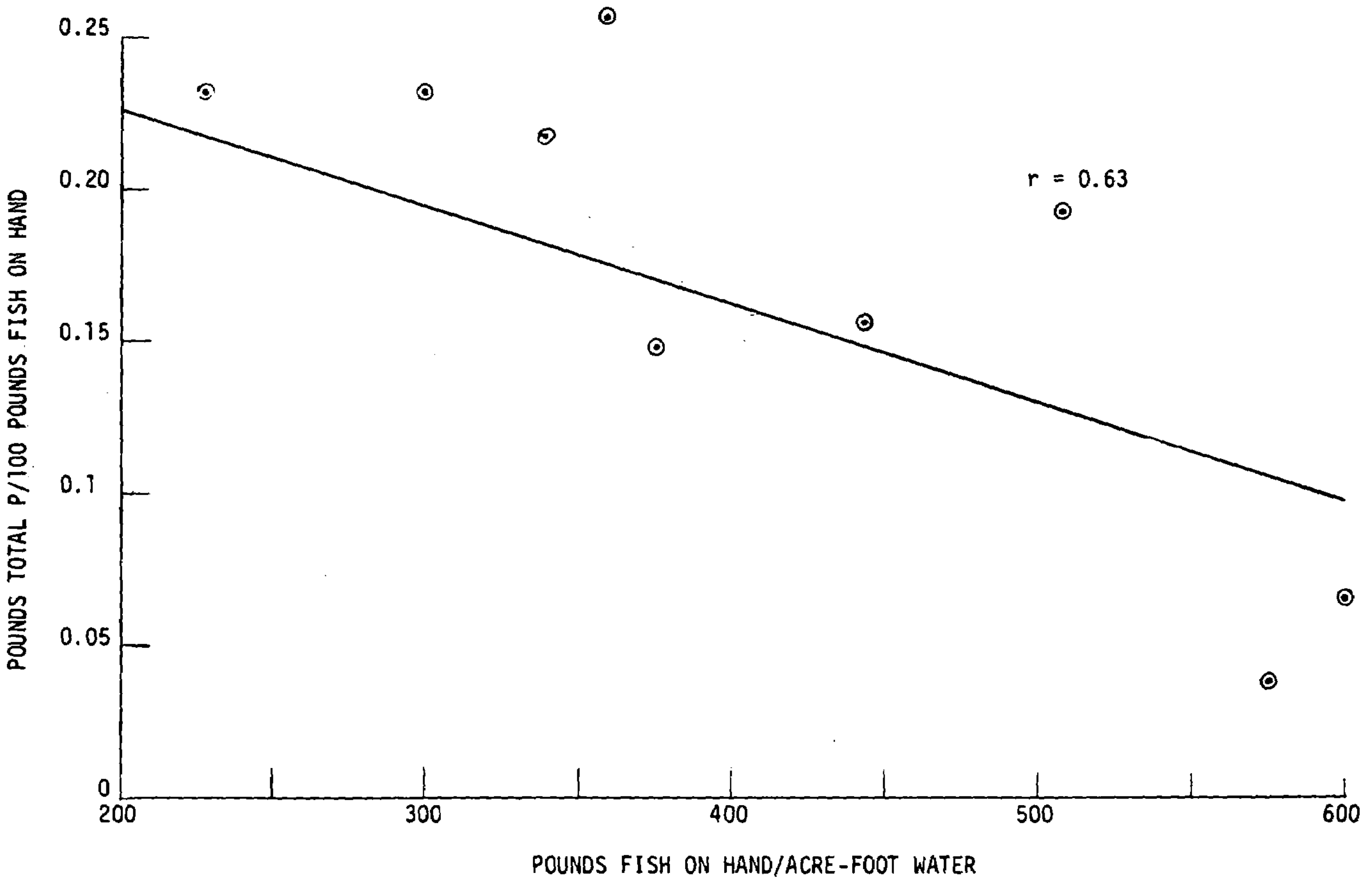


Figure 12. Total phosphate concentration as a function of standing fish density in ponds

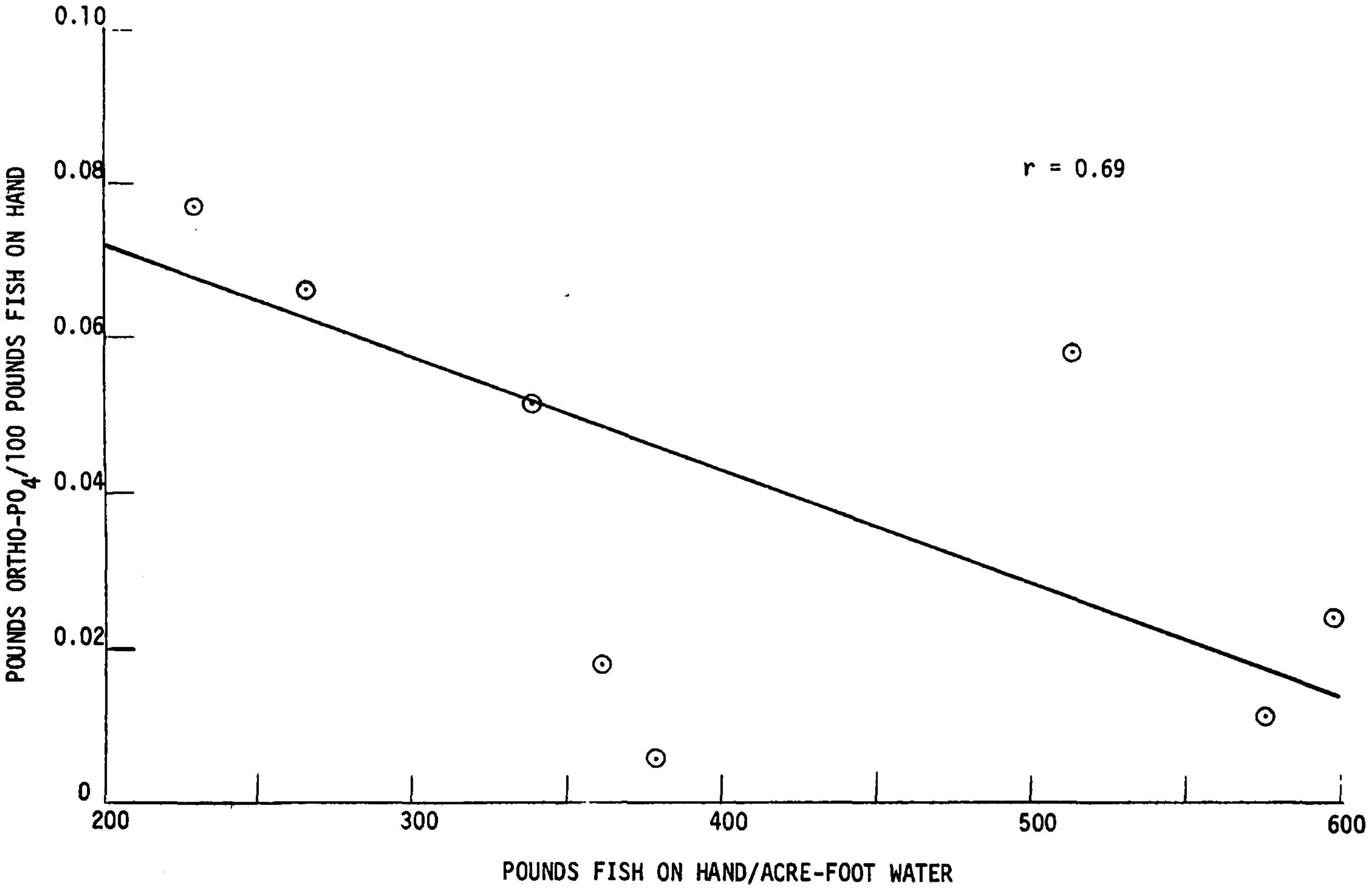


Figure 13. Orthophosphate concentration as a function of standing fish density in ponds

showed a slight increase in parameter concentrations as fish density increased.

The mean and extreme parameter concentrations for Ponds C and W are presented in Table 4. Average concentrations and average fish weights for the sampling period from July 18, 1973 to November 9, 1973 were used to calculate the means and extremes. The BOD/COD ratio was 0.19 which compares favorably with that of livestock wastes. A residue analysis revealed that approximately 62% of the total solids were volatile, 52% were suspended, and 36% settled in one hour. Total Kjeldahl nitrogen determinations indicated a ratio of 0.072 pounds nitrogen per pound total solids. Approximately 92.4% of the total Kjeldahl nitrogen was organic with the remaining 7.6% in the form of ammonia nitrogen. It is difficult to explain the high percentage of organic nitrogen although the same trend was observed by Greene (Table 1). Perhaps the abundant algae growth is a major contributor to the high organic nitrogen values. Further analyses indicated 0.0009 pounds nitrate plus nitrite nitrogen per pound total solids. The pond water contained approximately 0.002 pounds total phosphate per pound of total solids. Approximately 26% of the total phosphate existed in the form of orthophosphate.

Surface, Middepth, and Bottom Concentrations

Table 5 lists surface, mid-depth, and bottom water quality of Pond C and Pond W for the sampling period of July 18, 1973 to November 9, 1973. Bottom samples showed a 23% increase in organic parameter concentrations when compared to surface samples. This increase was primarily due to settling of metabolic waste products and uneaten feed. The presence of algae in the surface layer of the ponds probably influenced the COD and the solids concentrations. The total solids content of the bottom samples increased by 35%, and the suspended and settleable solids concentrations nearly doubled. This increase could again be attributed to settling and bottom sediment disturbance by the fish. The ammonia nitrogen concentrations of the bottom samples were nearly

Table 4. POND C AND W RANGE AND MEAN CONCENTRATIONS[a]

Parameter	Parameter Concentration, mg/l			lbs. Parameter/100 lbs. Fish			lbs. Parameter/lb. Feed		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
BOD_5	1.0	7.4	15.6	0.91	5.77	13.8	0.620	3.36	9.30
COD	20.	39.	84.	11.2	30.0	63.8	5.33	17.6	35.3
TKN	2.47	9.26	17.58	1.79	6.93	13.4	1.21	3.96	7.09
NH_3 - N	0.	0.77	2.99	0.	0.53	1.83	0.	0.310	0.970
NO_3 + NO_2 + N	0.05	0.12	0.39	0.03	0.09	0.100	0.018	0.050	0.090
TS	40.[b]	132.	242.	56.0	97.0	184.	29.0	56.0	101.
TDS	18.	66.	120.	11.0	47.0	84.0	5.00	27.0	46.0
TVS	24.	81.	145.	30.0	60.0	110.	17.0	34.0	70.0
TFS	14.	51.	117.	15.0	37.0	75.0	7.00	22.0	45.0
TSS	12.	66.	157.	6.00	50.0	111.	3.00	29.0	75.0
Sett. S.	3.	46.	122.	1.00	35.0	93.0	0.500	20.0	49.0
Total P	0.06	0.24	0.55	0.02	0.180	0.450	0.010	0.100	0.310
Ortho - PO_4	0.	0.07	0.35	0.	0.048	0.215	0.	0.028	0.102
pH	6.9	7.3	8.1	6.9	7.3	8.1	6.9	7.3	8.1
Hardness[c]	5.	53.	90.	7.00	36.0	65.0	5.00	21.0	44.0
Chloride	7.5	12.5	25.0	5.44	9.16	15.4	2.81	5.35	10.4

(a) Values are from five sampling dates in pond C and six in W.

(b) Sums of TVS + TFS and TDS + TSS do not necessarily equal TS for min and max values since extremes were from two different ponds.

(c) As $CaCO_3$

Table 5. POND C AND W; MEAN SURFACE, MIDDEPTH, AND BOTTOM CONCENTRATIONS

Parameter	Concentrations, mg/1			lbs Parameter Per 100 lbs Fish		
	Surface	Middepth	Bottom	Surface	Middepth	Bottom
BOD_5	6.9	5.8	7.6	5.66	4.58	5.88
COD	35.	31.	41.	27.9	24.0	32.2
TKN	8.69	7.86	10.53	6.48	5.62	7.38
NH_3 - N	0.37	0.72	1.15	0.31	0.52	0.75
NO_3 + NO_2 - N	0.10	0.09	0.12	0.08	0.07	0.10
TS	114.	116.	145.	82.0	84.0	111.
TDS	67.	78.	61.	48.0	56.0	46.0
TVS	76.	77.	90.	52.0	54.0	68.0
TFS	38.	39.	55.	30.0	30.0	43.0
TSS	47.	38.	84.	34.0	28.0	65.0
Sett. S.	34.	25.	58.	24.0	18.0	46.0
Total P	0.17	0.18	0.33	0.14	0.15	0.23
Ortho - PO_4	0.05	0.06	0.10	0.03	0.04	0.06
pH	7.6	7.5	7.0	7.6	7.5	7.0
Hardness	47.	45.	51.	35.0	32.0	37.0
Chloride	12.4	9.5	11.5	9.68	7.04	8.64

2.5 times greater than those of the surface samples primarily due to the lack of oxygen at the lower depths necessary for nitrification.

Selected sampling of the mid-depths of Pond C and Pond W indicated that the water quality here was higher than either the surface or bottom layers. Organic parameter concentrations and total solids were approximately 5% lower at mid-depth than at the surface. A more vigorous growth of algae in the surface layer near the sunlight would probably explain why the middle layer of water was of higher quality. Suspended solids levels were approximately 12% lower, and settleable solids were 1.5% lower in the middle layer than near the surface. Ammonia nitrogen and pH were exceptions, since ammonia levels increased and pH decreased from surface to bottom.

POND HARVEST AND WASTE QUANTITIES

Harvest

The harvest weight of fish, feeding rate and feed conversion for Ponds C and B are shown in Table 6.

Table 6. POND HARVEST DATA

Pond	Harvest Weight Lb. Fish Per Acre	Lb. Fish Per Ac-Ft.	Average Feeding Rate (% of Body Wt. Per Day)	Feed Conversion (Lb. Feed/Lb. Grain)
B	150	42	0.91	1.60
C	2250	600	2.11	2.00

Pond B was drained for harvest on January 2, 1974 through an eight-inch drain pipe and by a tractor-driven irrigation pump. The pond was drained completely except for two one-acre catch basins which collected the fish and contained about 18 inches of water. Only 1,500 pounds of fish were harvested each weighing about 32 ounces and only 2,400 pounds of feed were fed during the growing season. Since this did not represent a normal harvest (due to the earlier fish kill) no water quality measurements were made during drawdown.

Pond W was originally scheduled for harvest in the fall of 1973 but a prolonged dry spell forced cancellation of pond drawdown because of the economics of complete refilling from the well. The fish remain unharvested as of this writing. At the end of the sampling period approximately 15 tons of feed had been fed through demand feeders. An estimated nine tons of fish remained in the pond at this time. No drawdown water quality data was available for Pond W.

Pond C was harvested on October 3, 1973. Approximately 9,000 pounds of fish averaging 28 ounces each were harvested from the pond by drawing the pond down and seining. Drawdown was accomplished through a drain pipe discharging water from the pond at a depth of one foot above the bottom. Two weeks prior to the harvest of Pond C the three smaller ponds in series above Pond C were harvested. Harvest of these ponds was accomplished by lowering the water level in Pond C ; and then draining each small pond into the succeeding pond and finally into Pond C. The three smaller ponds yielded a total of 10,000 pounds of fish. The complete drawdown and harvest time for the system was less than three weeks.

Waste Quantities

Water quality and total pollutional loading for the entire system were evaluated (Table 7) in the following manner: water quality samples were collected from the bottom of Pond C prior to the initial drawdown (for accomodating the drainage of the three smaller ponds above). The parameter concentrations for these samples were then determined (column one Table 7). After harvest of the three smaller ponds the final drawdown of Pond C (for its harvest) was carried out. Water samples were collected prior to this drawdown, during this drawdown, during seining and immediately after fish harvest. The composition of these samples is also presented in Table 7. The total pounds of parameter discharged from the system (column nine) was obtained by summing the poundage in the initial drawdown volume and each of the

Table 7. WATER QUALITY DURING HARVEST DRAWDOWN FOR POND SYSTEM C

Parameter	Concentrations (mg/l)								Total lbs Parameter Discharged from Pond System	lbs of Parameter Per 100 lbs of fish Discharged
	Drawdown of 3 small ponds	Initial Drawdown				Drawdown During Seining		Drawdown After Seining		
Feet of Drawdown		1.0	2.0	3.0	4.0	4.1	4.2	4.3		
Ac-ft of Discharge	7.5	3.8	3.4	3.0	2.6	0.24	0.235	0.23	21.00	
BOD	7.2	9.6	8.4	10.4	10.4	12.8	11.2	8.6	502.	2.64
COD	32.	48.	51.	41.	58.	72.	60.	52.	2481.	13.0
TKN	14.50	9.33	11.92	8.58	10.25	12.58	10.67	8.25	665.	3.50
NH_3-N	0.84	1.21	0.84	0.93	1.12	1.49	1.21	0.19	54.7	0.288
$NO_3 + NO_2 - N$	0.07	0.29	0.25	0.23	0.39	0.47	0.33	0.13	12.0	0.0632
TS	128.	130.	135.	161.	215.	245.	208.	146.	8415.	44.2
TDS	92.	82.	111.	103.	108.	117.	117.	93.	5560.	29.2
TVS	88.	81.	94.	82.	98.	133.	118.	83.	5075.	26.7
TSS	36.	48.	24.	58.	107.	128.	91.	53.	2855.	15.0
Sett. S.	28.	13.	19.	32.	86.	123.	71.	50.	1906.	10.0
Total P	0.55	0.12	0.21	0.11	0.28	0.45	0.27	0.28	17.9	0.0942
Ortho - PO_4	0.10	0.04	0.01	0.06	0.05	0.19	0.04	0.16	3.64	0.0192
pH	7.3	6.8	6.9	6.6	6.3	6.1	6.2	6.2	6.9	6.9
Hardness	40.	70.	60.	90.	90.	70.	85.	55.	3597.	18.9
Chloride	15.0	15.0	15.0	25.0	15.0	15.0	15.0	12.0	936.	4.93

final drawdown increments. The pounds of parameter discharged per 100 pounds of fish (column 10) was based on the total fish production for the entire system (19,000 pounds).

During the final drawdown of Pond C the organic parameter concentrations of the bottom discharge increased by 37% over the levels present in the pond prior to drawdown. This increase could be attributed to flushing of bottom deposits through the drainpipe. Total solids increased by 10%, suspended solids by 28%, and settleable solids by 8%. Ammonia levels decreased by 14% during drawdown possibly due to partial aeration at the discharge outlet of the drainpipe. During drawdown the only parameter to exceed the mean concentration level recorded during the growing season was nitrate nitrogen.

The dragging of the seine across the pond floor plus the turbulence of men wading and excited fish caused considerable agitation of bottom sediment and waste deposits during seining. Discharge during seining caused the BOD to increase by 12%, COD by 23.9% total Kjeldahl nitrogen by 4.8%, and total solids by 26.4% over those values recorded during the initial drawdown. Other parameters showed smaller increases. Approximately two hours after the third and final seining, most discharge parameter levels were less than half their peak values.

Oftentimes it is difficult to be at a particular pond during preharvest drawdown and to spend the time and obtain the necessary samples during the entire drawdown period. Consequently just prior to the final harvest drawdown for Pond C water quality samples were taken from the bottom, mid-depth and surface. In Table 8 the waste quantities calculated from these concentrations and the mean concentration are compared with those based on drawdown concentrations. The waste discharge quantities calculated from mean (depth) concentrations in the pond prior to drawdown compare closely with those measured in the discharge water.

The effect of depth-of-removal on the total waste discharged during harvest drawdown can be ascertained from the data in Table 9.

Table 8. POND C PARAMETER CONCENTRATIONS AT DIFFERENT SAMPLING DEPTHS

Parameter	lbs. Parameter Per 100 lbs. Fish				
	Concentration Prior to Drawdown				Drawdown Discharge Concentration
	Surface	Middepth	Bottom	Mean	
BOD_5	2.83	2.58	2.96	2.79	2.64
COD	11.90	10.60	12.60	11.70	13.10
TKN	2.90	2.67	3.30	2.96	3.50
NH_3 - N	0.15	0.360	0.600	0.370	0.290
NO_3 + NO_2 - N	0.039	0.035	0.035	0.037	0.063
TS	42.5	41.2	48.3	44.0	44.3
TDS	38.6	34.1	23.5	32.1	29.3
TVS	24.2	23.5	28.0	25.2	26.7
TFS	18.3	17.7	20.3	18.8	17.6
TSS	3.90	7.10	24.8	11.9	15.0
Sett. S.	1.00	4.50	21.3	8.90	10.0
Total P	0.019	0.019	0.032	0.024	0.094
Ortho - PO_4	0.003	0.010	0.013	0.009	0.019
pH	8.2	7.5	7.0	7.6	6.9
Hardness	20.90	22.50	27.40	23.60	18.90
Chloride	4.83	4.83	4.03	4.56	4.93

Table 9. WASTE DISCHARGE POTENTIAL OF MID-DEPTH VS. BOTTOM DISCHARGE FROM POND C

Parameter	Total lbs. Parameter in Upper Half of Pond	Total lbs. Parameter in Lower Half of Pond
BOD_5	175.	178.
COD	730.	749.
TKN	179.	194.
$NH_3 - N$	13.6	32.4
$NO_3 + NO_2 - N$	2.39	2.24
TS	2667.	2890.
TDS	2361.	1742.
TVS	1517.	1666.
TFS	1150.	1223.
TSS	306.	1146.
Sett. S.	129.	945.
Total P	1.22	1.73
Ortho - PO_4	0.33	0.74
Hardness	1356.	1618.
Chloride	306.	274.

The average depth of Pond C is five feet. If we assume that draining the pond to the mid-depth level is sufficient for seining we can compare the total waste discharges for the drain outlet at mid-depth and at the bottom. This was done by developing a stage-storage curve for the ponds. Bottom, mid-depth and surface concentrations were weighted according to the volume representation indicated from the stage-storage curve. The results from this analysis are presented in Table 9. The reduction in pollutional loading to a receiving stream by mid-depth drainage is not large. This reduction would amount to 1.7% for BOD, 2.6% for COD, 8.4% for total Kjeldahl nitrogen and 8.4% for total solids as an example.

RACEWAY WATER QUALITY DURING GROWING SEASON

Diurnal Variations in Effluent Composition

Grab sampling can present certain limitations in that diurnal and hydrologic fluctuations in effluent composition are not always accounted for. However, grab sampling does make it possible to test many more systems in a shorter time span than would be possible employing composite (time-wise) sampling.

Grab samples were collected at six-hour intervals over a 24-hour period for three sampling dates at Raceway TR and one at Raceway ED. Table 10 presents the mean diurnal variations of the sample concentrations and the overall 24-hour mean values. Most organic parameter concentrations peaked in the afternoon and evening hours probably due to the fish and feeding activities during the day. The solids concentrations tended to be highest following the morning and afternoon feeding periods. Ammonia peaked during the early morning hours before daylight.

The mean values when compared with the interpolated (linear) values between 12 noon and 2 PM were in close agreement. Consequently all raceway water quality sampling was done by grab sampling during this time period.

Table 10. RACEWAY ED[a] & TR[b] - MEAN DIURNAL VARIATIONS IN EFFLUENT CONCENTRATIONS

Parameter	Concentrations (mg/1)				
	5 AM	11 AM	5 PM	11 PM	Mean
BOD_5	6.3	4.3	6.7	7.3	6.2
COD	36.	35.	40.	39.	37.
TKN	9.19	7.85	11.87	10.44	9.84
$NH_3 - N$	0.95	0.65	0.67	0.87	0.78
$NO_3 + NO_2 - N$	0.28	0.27	0.19	0.21	0.24
TS	169.	179.	188.	178.	179.
TDS	114.	124.	102.	113.	113.
TVS	66.	76.	90.	96.	83.
TFS	66.	103.	86.	82.	84.
TSS	55.	55.	86.	64.	65.
Sett. S.	31.	42.	66.	47.	47.
Total P	1.01	0.87	1.07	0.75	0.93
Ortho - PO_4	0.11	0.13	0.12	0.12	0.12
pH	7.1	7.1	7.3	7.4	7.2
Hardness	57.	56.	51.	56.	55.
Chloride	14.4	12.5	13.1	14.4	13.6

(a) One sampling date

(b) Three sampling dates

Water Quality

The raceway effluent parameter concentrations are presented in Figures 14 through 24. The data is presented in terms of pounds of parameter per 100 pounds of fish per day as a function of the fish density in pounds fish per acre-foot of water in the total system. The volume of water in the total system was used rather than that of the individual raceway units. In a closed-loop recirculating system the metabolic and feed wastes are retained within the entire system. Fish densities represent the estimated standing weight of fish in the raceway units on each sampling date. A regression analysis was used to obtain a best-fit curve to the plotted values. This was done not for prediction purposes but only to show trends. Correlation coefficients ranged from 0.05 to 0.47 with a mean of 0.18.

The parameter concentrations expressed as pounds per 100 pounds fish per day generally showed a slight tendency to increase as fish density increased. These trends emphasize the point that, even though larger fish produce less waste per pound than smaller fish, the system reservoirs and oxidation ponds do not have the capacity to effectively assimilate all of the waste products from intensive fish production resulting in a net buildup of certain parameters within the system during the growing season. The closed-loop system of Raceway TR yielded consistently higher parameter concentrations than did the semi-closed-loop systems of Raceways EG, EF, and ED. The lower concentrations in system E was the result of periodic wasting of water to a nearby stream. Ammonia nitrogen was an exception to the above trends showing a slight decrease in concentration as fish density increased.

Influent and Effluent Composition

Table 11 presents the mean parameter concentrations and differences for the influent and the effluent from Raceways EG, EF, ED, and TR during the growing season.

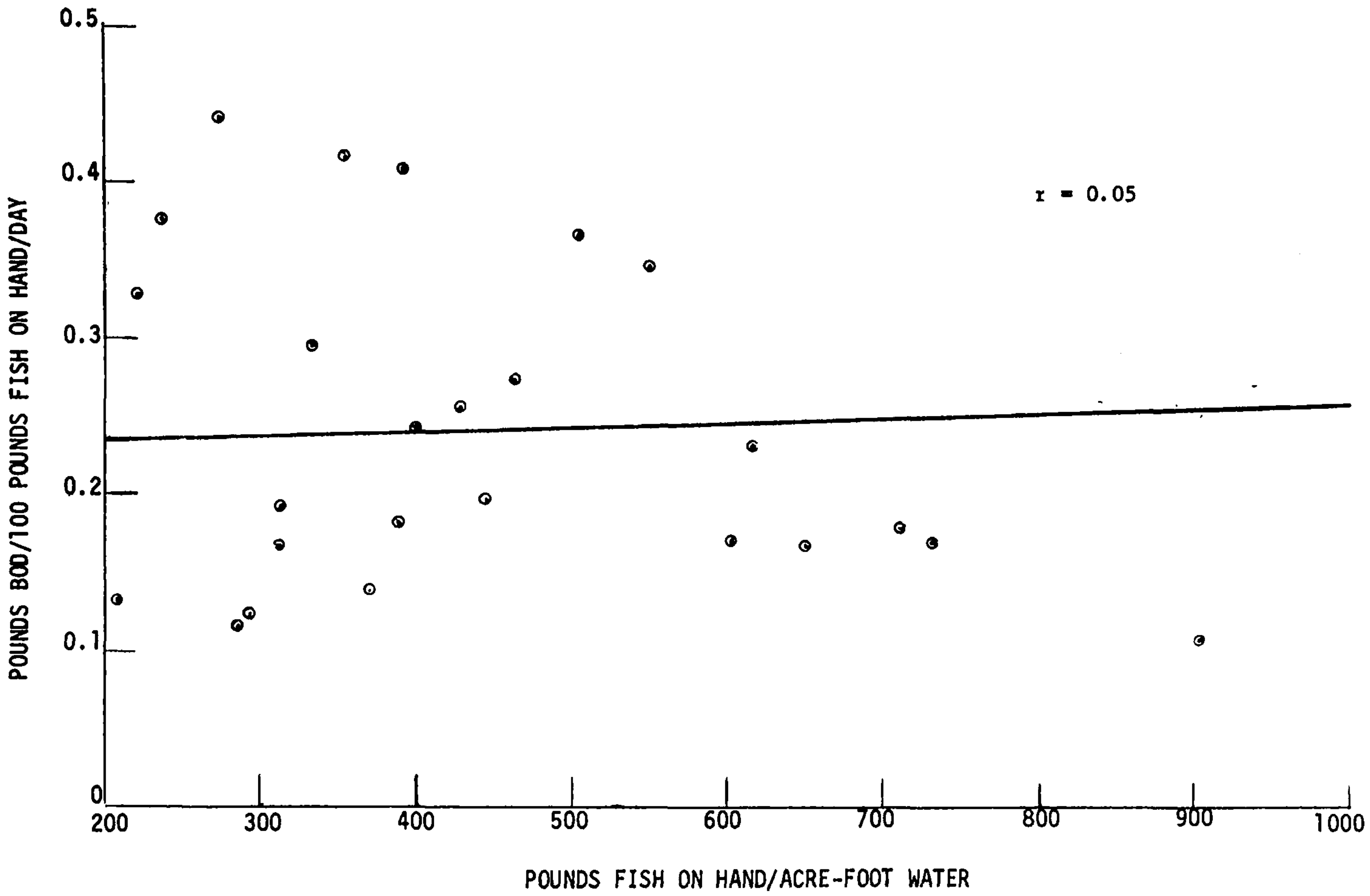


Figure 14. BOD concentration of raceway effluent as a function of standing fish density

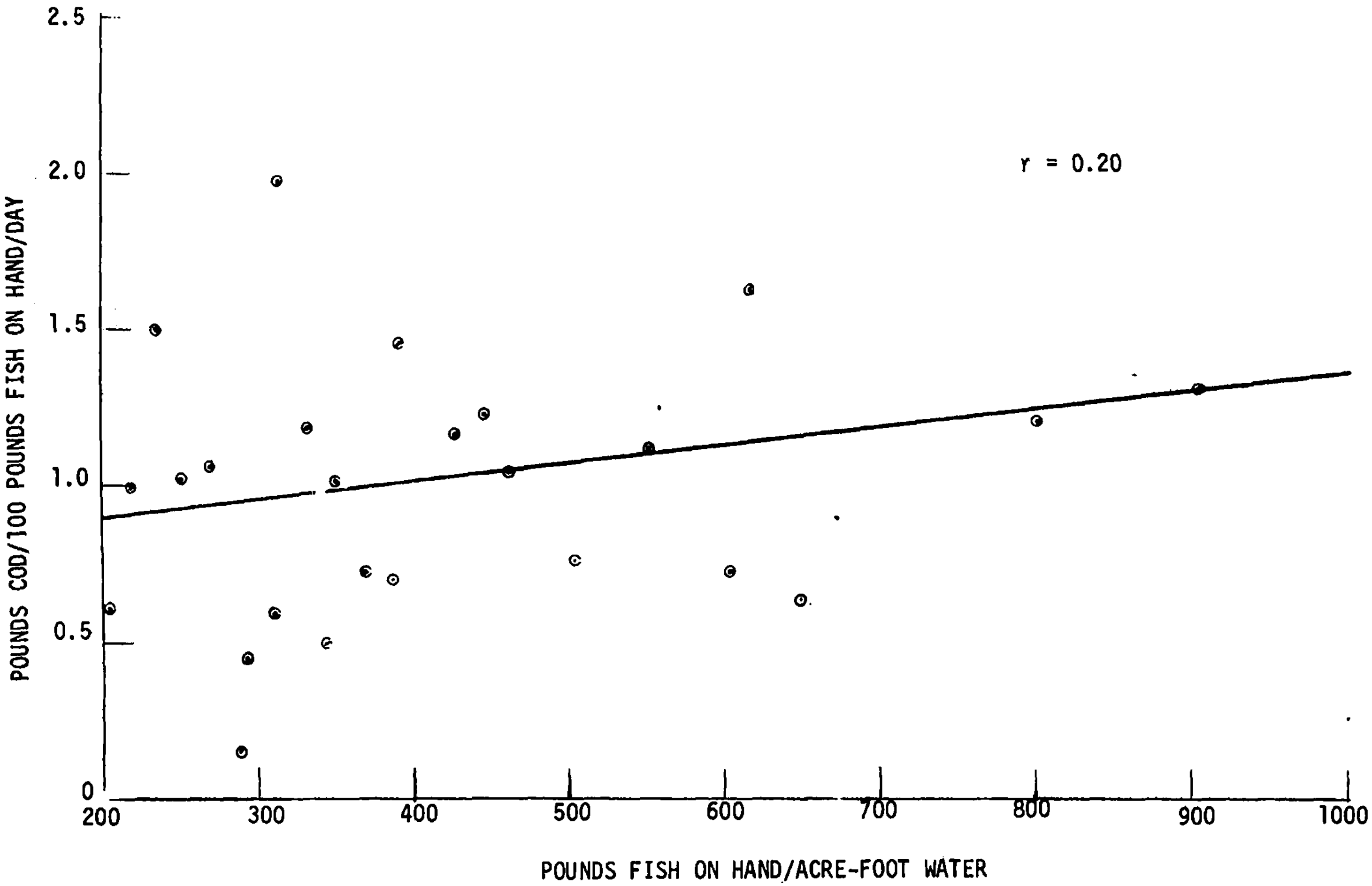


Figure 15. COD concentration of raceway effluent as a function of standing fish density

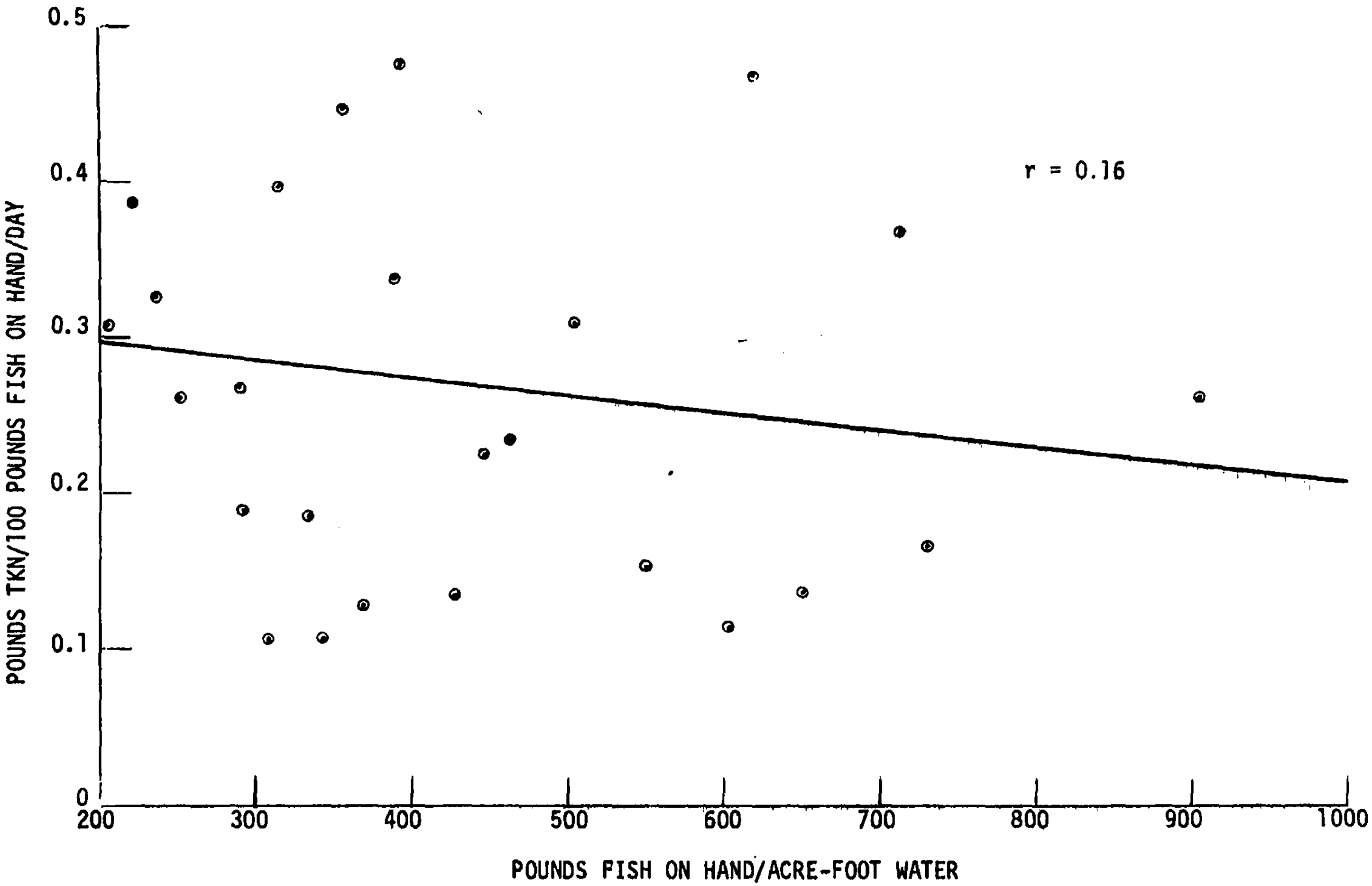


Figure 16. Total Kjeldahl nitrogen concentration of raceway effluent as a function of standing fish density

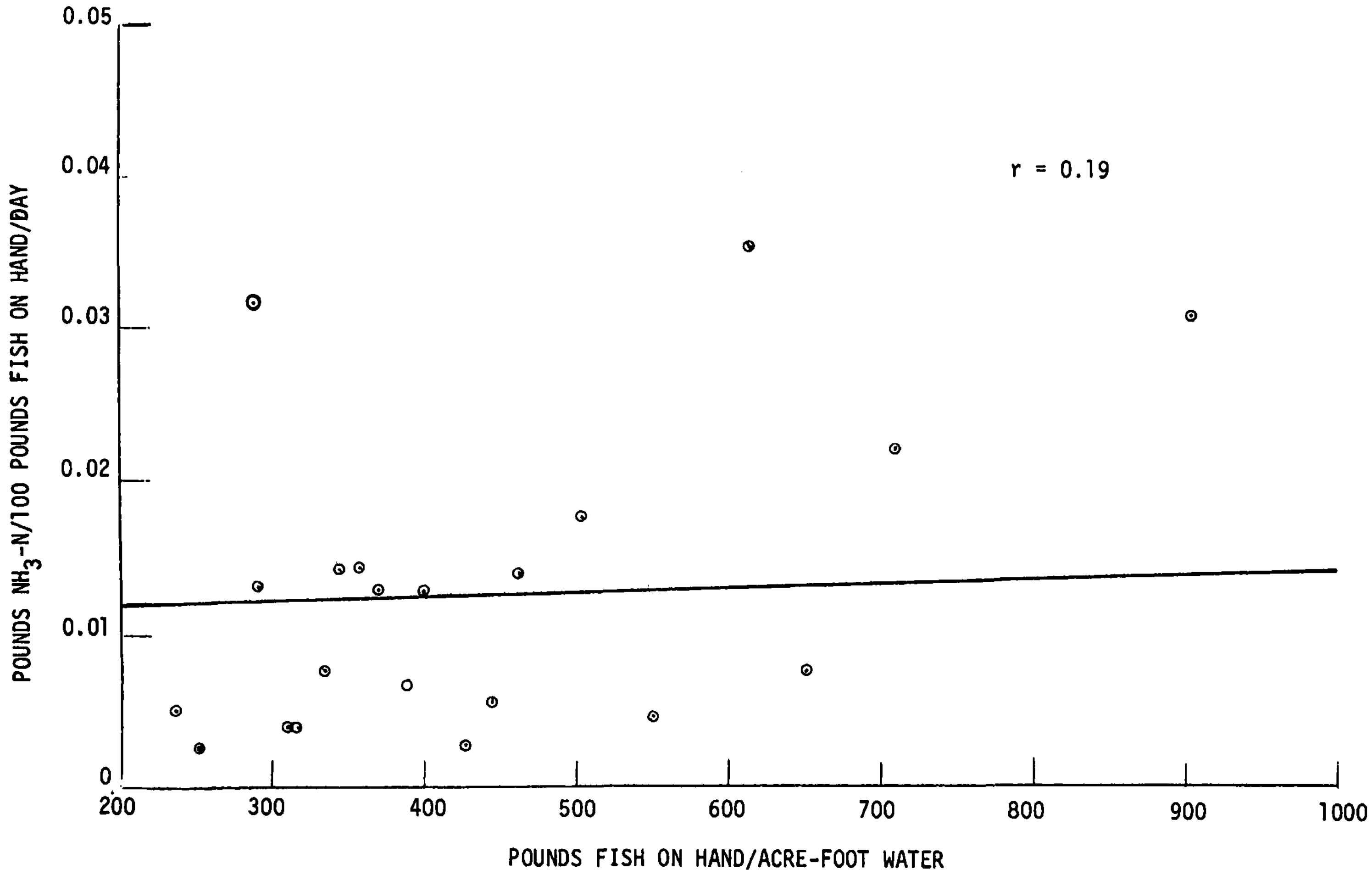


Figure 17. Ammonia nitrogen concentration of raceway effluent as a function of standing fish density

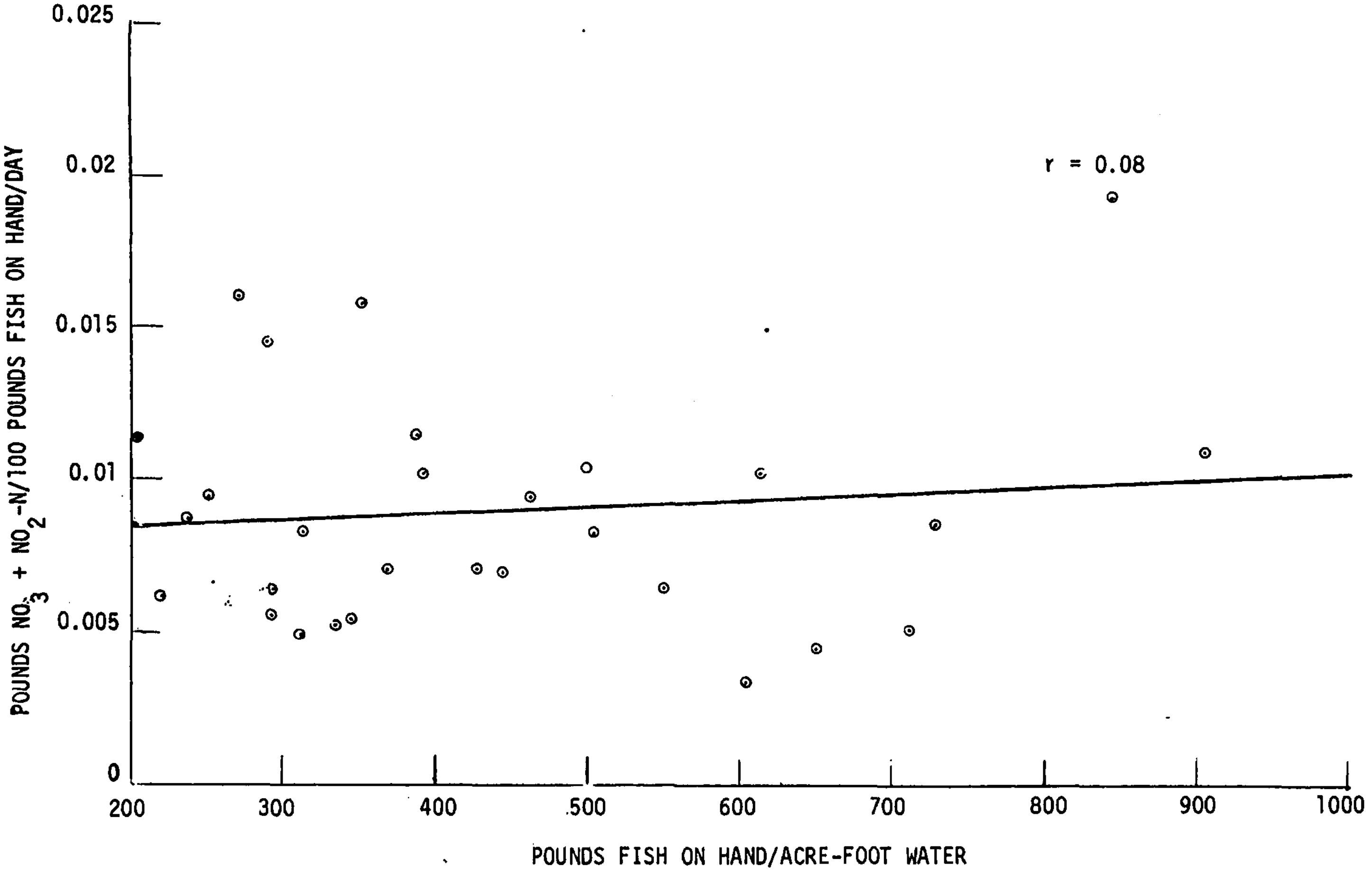


Figure 18. Nitrate + nitrite-nitrogen concentration of raceway effluent as a function of standing fish density

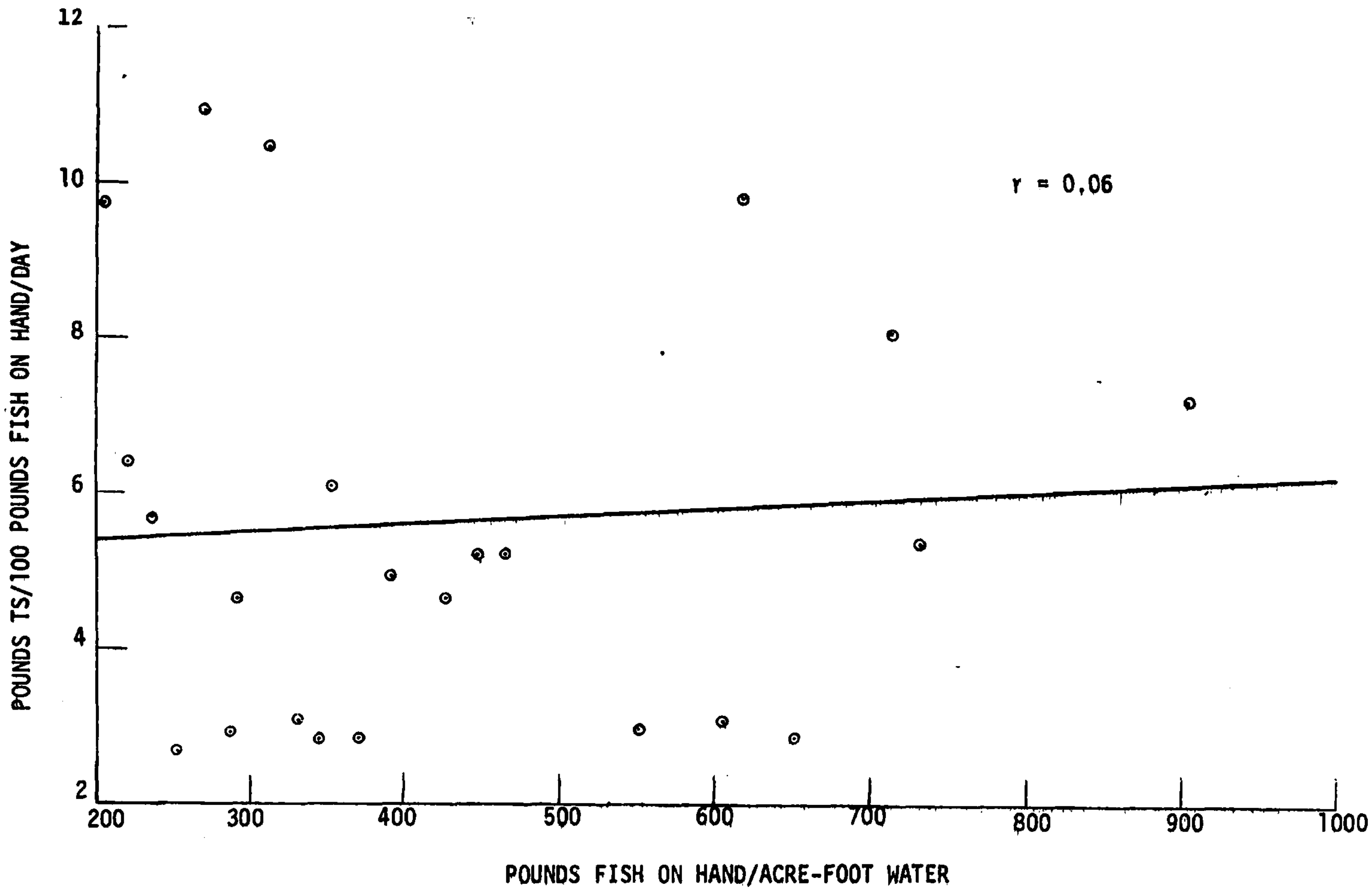


Figure 19. Total solids concentration of raceway effluent as a function of standing fish density

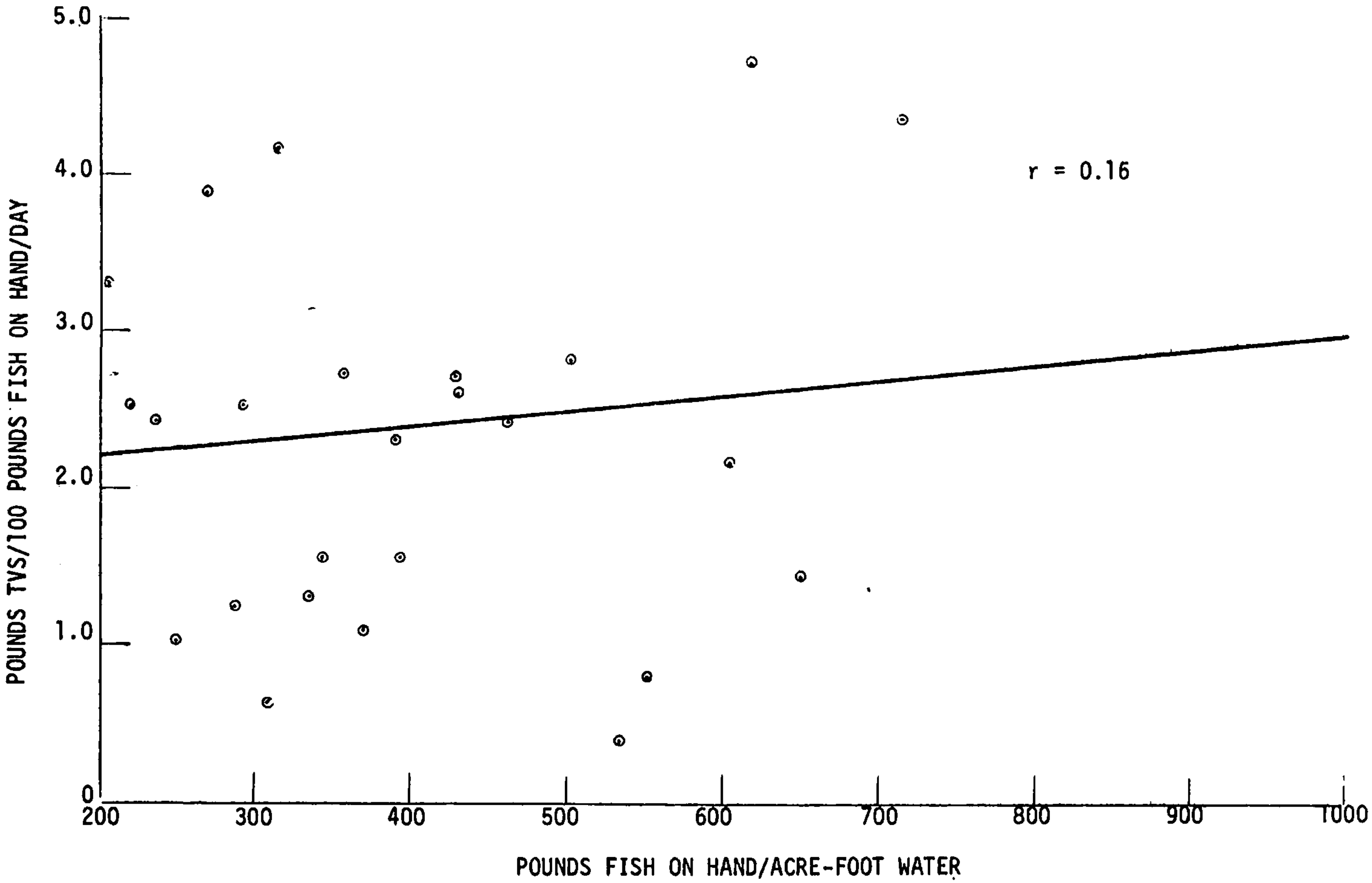


Figure 20. Total volatile solids concentration of raceway effluent as a function of standing fish density

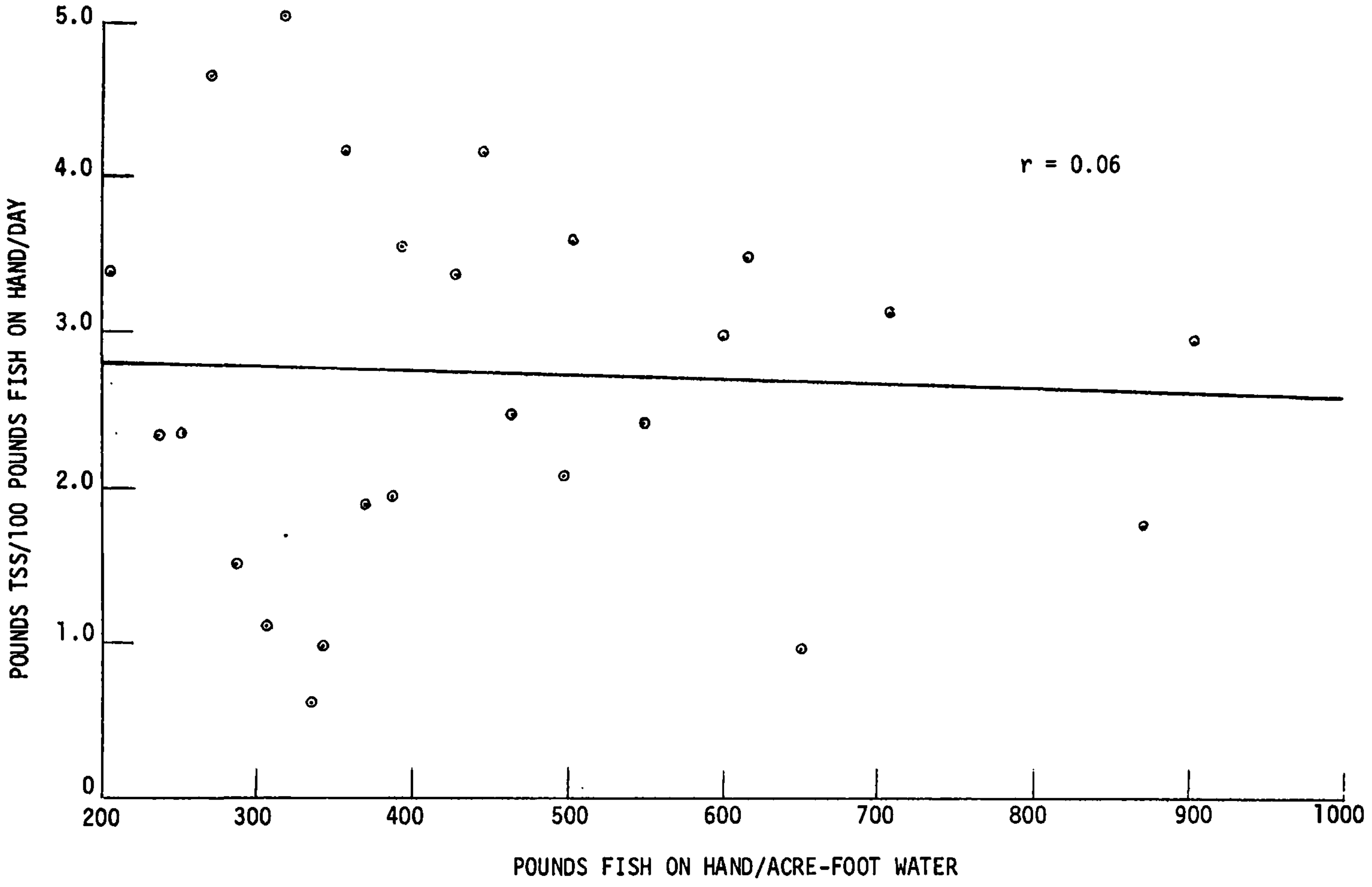


Figure 21. Total suspended solids concentration of raceway effluent as a function of standing fish density

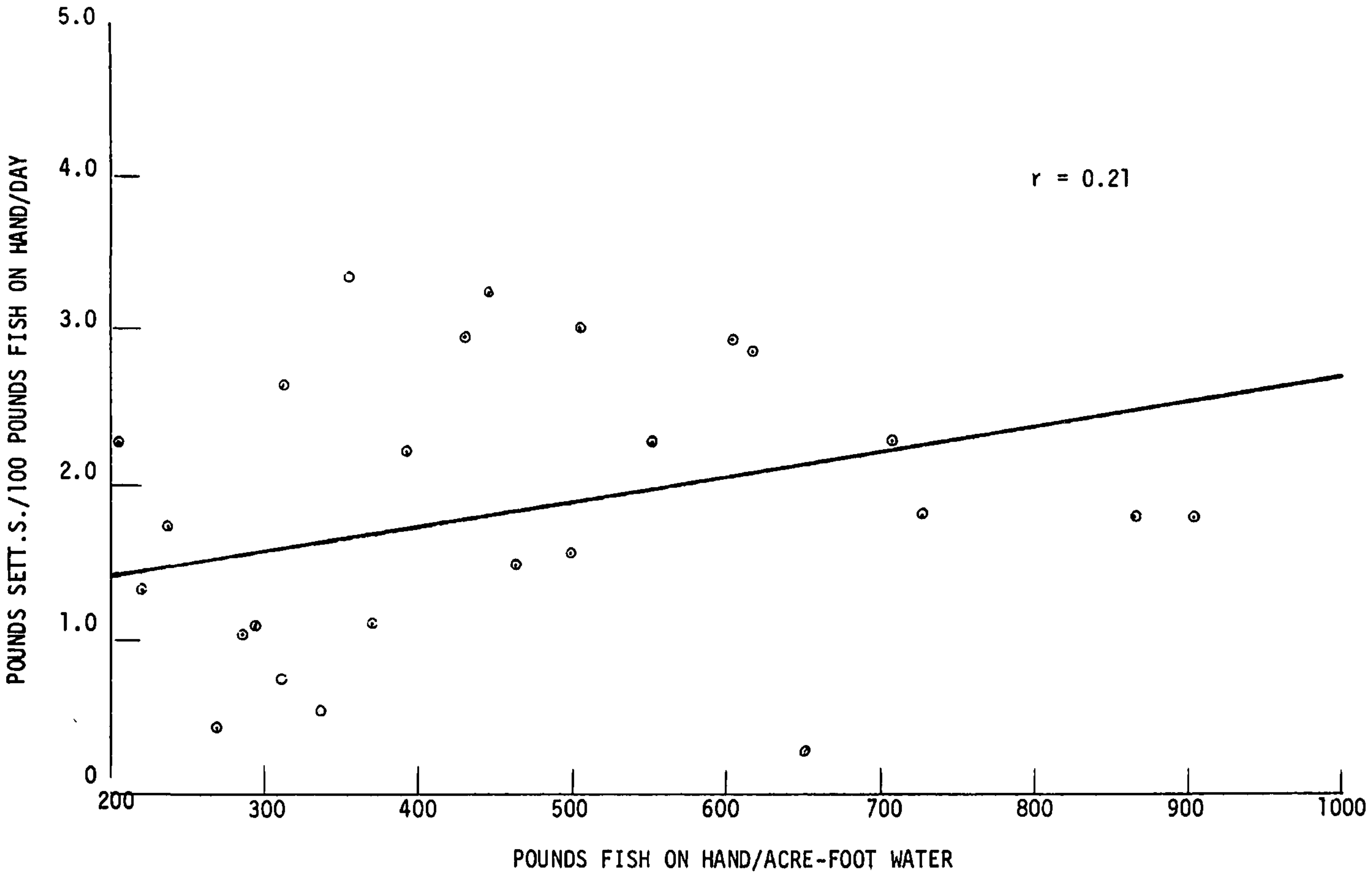


Figure 22. Settleable solids concentration of raceway effluent as a function of standing fish density

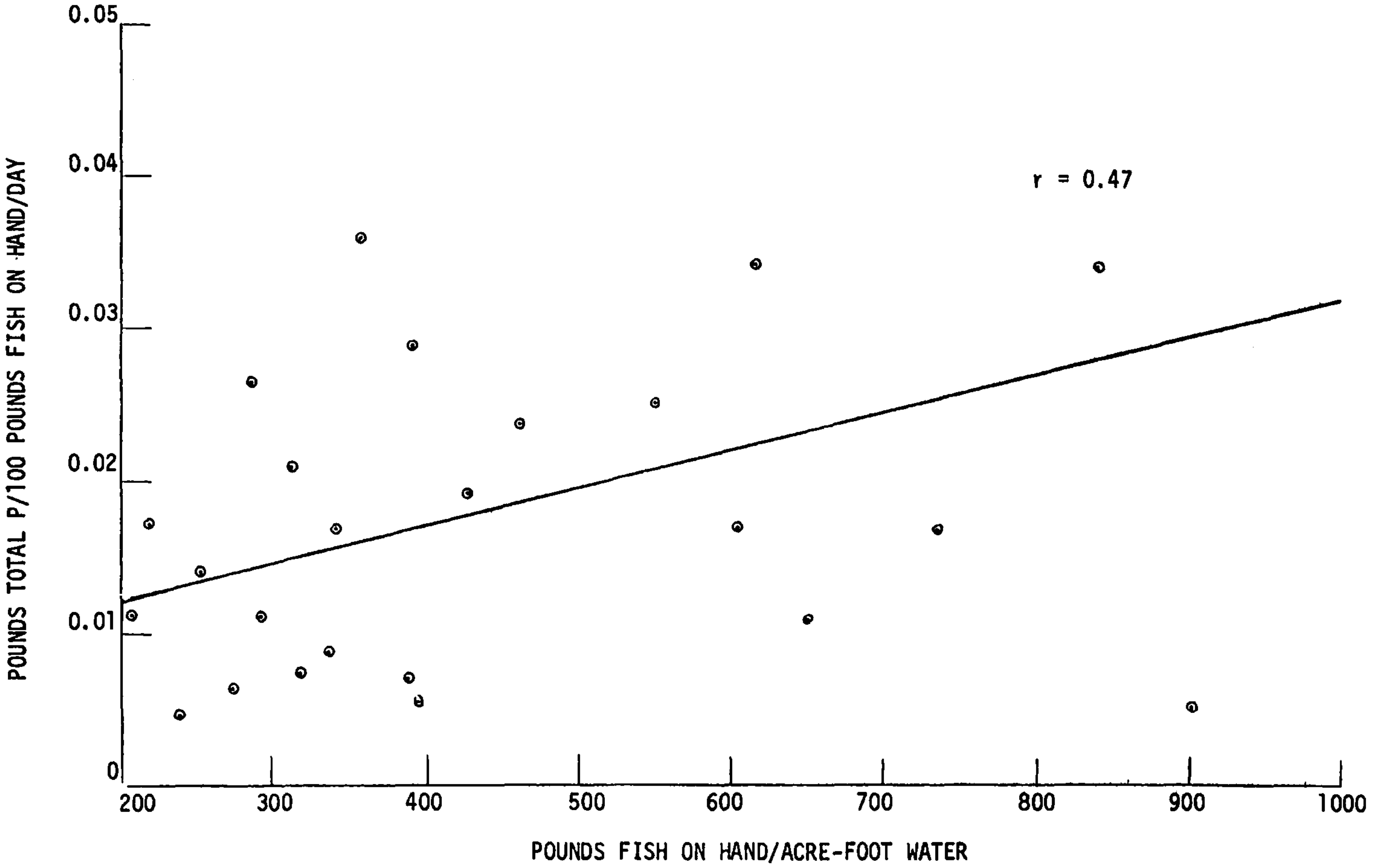


Figure 23. Total phosphate concentration of raceway effluent as a function of standing fish density

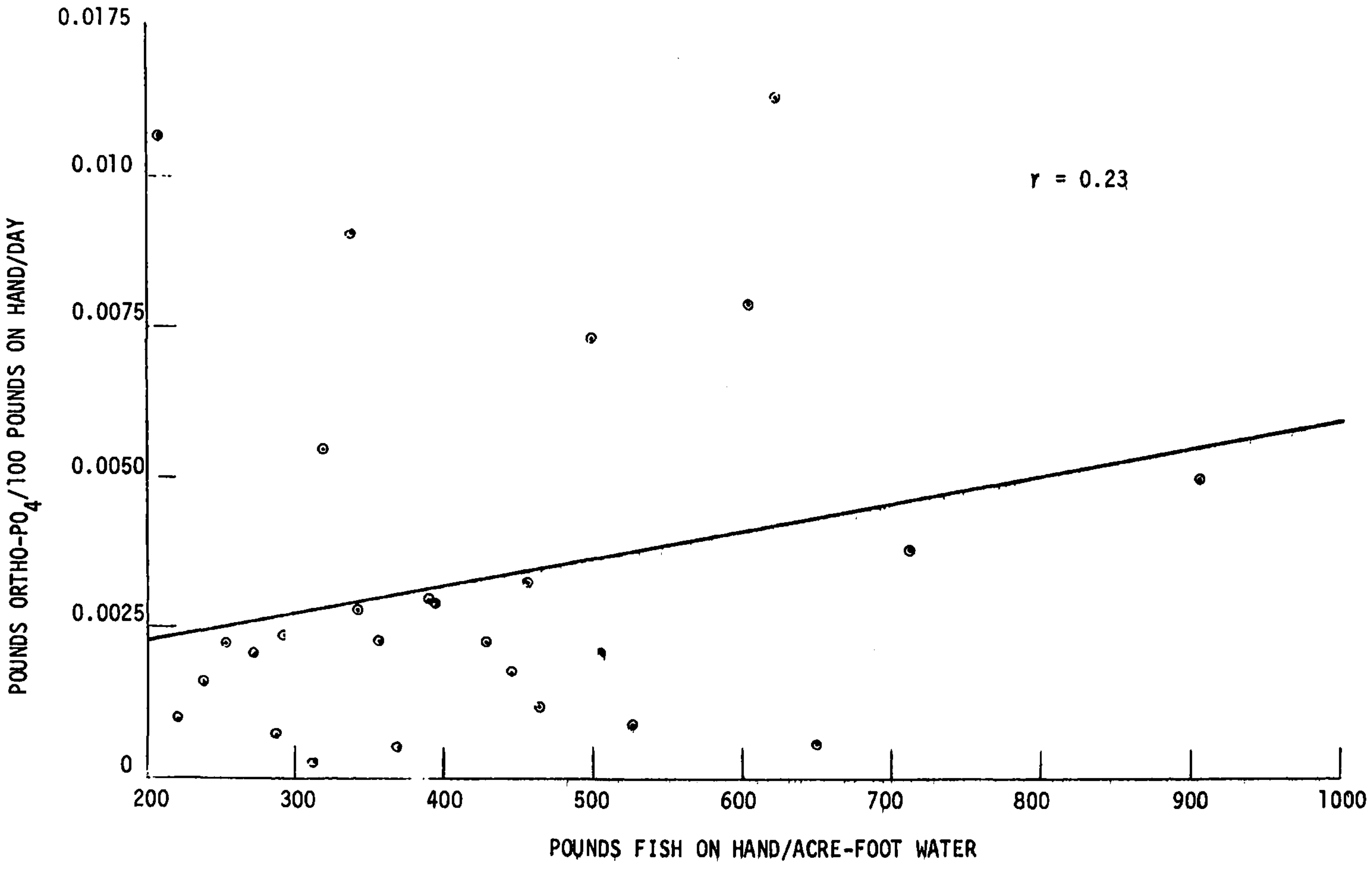


Figure 24. Orthophosphate concentration of raceway effluent as a function of standing fish density

Table 11. RACEWAYS EG, EF, ED, AND TR MEAN INFLUENT AND EFFLUENT CONCENTRATIONS[a]

Parameter	Concentration (mg/l)			lbs Parameter/100 lbs Fish/Day			lbs Parameter/lb Feed/Day		
	Influent	Effluent	E-I	Influent	Effluent	E-I	Influent	Effluent	E-I
BOD_5	6.2	6.9	0.7	0.20	0.26	0.06	0.14	0.18	0.04
COD	23.8	32.0	8.2	0.86	1.25	0.39	0.61	0.88	0.27
TKN	6.71	8.29	1.58	0.238	0.354	0.116	0.163	0.249	0.086
NH_3 - N	0.345[b]	0.518	0.173	0.012	0.022	0.010	0.009	0.016	0.007
NO_3 + NO_2 - N	0.225	0.283	0.058	0.008	0.010	0.002	0.005	0.007	0.002
TS	139.	163.	24.	5.18	6.56	1.38	3.60	4.65	1.05
TDS	83.	91.	8.	3.09	3.31	0.22	2.18	2.37	0.19
TVS	65.	74.	9.	2.46	3.06	0.60	1.74	2.19	0.45
TFS	74.	89.	15.	2.72	3.50	0.78	1.86	2.46	0.06
TSS	56.	72.	16.	2.09	3.25	1.16	1.42	2.28	0.86
Sett. S.	34.	50.	16.	1.34	1.97	0.63	0.92	1.39	0.47
Total P	0.570	0.600	0.030	0.019	0.022	0.003	0.013	0.015	0.002
Ortho - PO_4	0.103	0.103	0.	0.003	0.005	0.002	0.002	0.004	0.002
pH	7.5	7.3	-	7.6	7.4	-	7.6	7.4	-
Hardness	33.8	33.3	-	1.40	1.37	-	1.04	1.02	-
Chloride	6.90	8.30	-	0.39	0.39	-	0.28	0.27	-

(a) Mean values from eight sampling dates for System E and five for System TR.

(b) Values are shown with three digits to the right of decimal for calculation purposes.

The mean water temperature of the raceway effluents during the sampling period was 81°F. The dissolved oxygen levels of the raceway effluents averaged 6.9 mg/l and ranged from 5.5 to 7.5 mg/l. The BOD/COD ratio of 0.20 was approximately the same as that computed for the ponds. Approximately 47% of the total solids were volatile, 51% were suspended, and 30% settled out in one hour. The decrease in volatile solids when compared to pond concentrations was probably due to sediment and inorganic matter being stirred-up by fish in the raceway units. A ratio of 0.054 pounds total Kjeldahl nitrogen per pound total solids was again less than that obtained in stillwater ponds. Approximately 93.8% of the nitrogen was organic, and 6.2% was in the form of ammonia (about the same percentages as found in ponds). The nitrate plus nitrite nitrogen ratio was 0.0015 pounds per pound total solids considerably higher than that of ponds. The increase in nitrates could be coupled with increased nitrification of ammonia by aerobic bacteria. The raceway effluent contained 0.0034 pounds total phosphate per pound total solids of which 23% were in the form of orthophosphate. Again the total phosphate percentage was considerably higher than in ponds because of the sweeping of sediment and suspended matter by the flowing water. Phosphate ions become affixed to sediment and are relatively insoluble thereafter.

Comparing differences between influent and effluent concentrations shows that overall the organics in the water increased by 32%. Total solids increased by 27% while suspended solids increased 62% and settleable solids by 47%. Frequently the total solids concentrations of the influent to Raceways EG, EF, and ED were slightly higher than the effluent concentrations. This was attributed to the sweeping of sediment from the floor of the supply reservoir by bottom water intake structures. Suspended particles could be readily observed in the raceway effluents. Ammonia levels increased by 83% as water flowed through the fish production units, however, the highest concentration recorded (1.96 mg/l) was still less than levels at which total ammonia becomes toxic to catfish. The pH showed a slight decrease from 7.6 to 7.4.

Settling Basin Analysis

A trapezoidal-shaped settling basin model was designed and tested for the removal of suspended wastes in recirculation raceway systems by Chesness et al. (1974). In the recirculating, warm-water catfish production system at Raceway TR, filterable solids have been averaging 39% of the total solids. The removal of these solids by gravity settling could result in a significant improvement in water quality.

If the settling basin proved effective, the most practical adaptation would be to use (with modifications for cleaning) the last unit or portion of the raceway as a basin. A 1/12 scale model of a 54-foot long raceway unit was selected with a flow velocity 1/144 that of the prototype. A slatted baffle arrangement produced uniform, streamline flow through the basin. The effluent was discharged uniformly from the surface of the settling zone by means of a weir. Field evaluations were made by diverting effluent from the last unit of Raceway TR through the model.

A settling column analysis was performed for each field test on a single composite water sample made up from the model inlet grab samples. Grab samples were taken periodically of the basin effluent, and at the end of each flow test the sediment collected in the basin was recovered. COD and residue analyses (total, volatile, and suspended solids) were performed on the samples. In the third and final field test the basin model length was increased to simulate a full length (100-foot) raceway unit.

The average removal of filterable solids for the basin with a 33.9-in. long settling zone was 43.2%. When the settling zone length was increased 2.5 times to 78 in. the actual removal increased to only 57.3%.

Even though the basin removed an average of 48% of the filterable solids, this represented less than a 6% reduction in effluent COD. The reason for this was evident--only 16% of the sediment in the basin was organic. The low percentage of volatile (organic) solids in the sediment from the basin is apparently a characteristic of recirculation raceway systems used for warm-water fish culture. The higher water temperatures (75°F to 86°F) and increased sunlight intensity and duration combined with recirculation apparently result in increased biological activity and the subsequent breakdown (or dissolution) of wasteparticulates (fecal and waste feed).

RACEWAY HARVEST AND WASTE QUANTITIES

Harvest

The harvest weight of fish, feeding rate and feed conversion for Raceways EG, EF, ED and TR are presented in Table 12.

Table 12. RACEWAY HARVEST DATA

Raceway	lb/unit	lb/ft^3 in unit	lb/ac-ft(total)	Average Feeding Rate (% of body wt/day)	Feed Conversion (lb feed/ lb gain)
EG	2500	0.45	572	1.59	1.75
EF	2500	0.45	806	1.59	1.75
ED	1875	0.34	458	1.59	1.75
TR	2380	0.50	907	1.23	1.25

Harvesting of the fish began November 1, 1973 with Raceways EG and EF and continued through January 1974 with Raceway ED. Harvesting was accomplished by successively draining each unit (beginning at lower end) of a raceway and seining the fish. This method was utilized for each succeeding unit until the entire raceway was harvested. Approximately 95% of the fish that were stocked were harvested at an average weight of 20 ounces each. Raceway EG yielded 2,500 pounds of fish per unit for a total weight of 17,500 pounds. Raceway EF yielded a total weight of 25,000 pounds while Raceway ED yielded 30,000 pounds. These fish were hand-fed daily a total of 63.5 tons of catfish ration during the growing season.

Raceway TR yielded an average of 2,380 pounds per unit for a total weight of 19,050 pounds of fish averaging 17 ounces each. Approximately 10.5 tons of a commercial high protein trout ration were hand-fed twice daily during the growing season. Good management practices resulted in a 99.6 percent survival and recovery at harvest on October 18, 1973.

Waste Quantities

Raceway systems EF, EG, and ED are semi-closed recirculation systems. During the course of the growing season the total volume of water in each system was replaced four times with river water. By assuming the parameter concentrations for the raceway influent were equal to those of the oxidation pond discharge it was possible to calculate the quantities of wastes released each time the oxidation ponds were drained. Summing these values for the entire growing season results in the total waste discharge figures presented in Table 13.

WASTE LOADINGS FROM PONDS, RACEWAYS AND TANKS

By combining the results of this study with several of those reported in the literature it was possible to compare waste loadings resulting from three different types of catfish production systems. The results of this analysis are presented in Table 14. The values represent the total waste production from each culture system per 100 pounds of fish (mean weight of 1.25 lbs. each) produced during a 240-day culture period. These waste concentrations would represent the loading to a receiving stream if the ponds were completely drained for harvest, the raceway water volume was exchanged four times and the tanks were in effect indoor single pass raceways with no waste removal facilities.

Table 13. POUNDS PARAMETER DISCHARGED FROM RACEWAY SYSTEM E

Parameter	Raceway System E[a]	
	Total lbs. Parameter Discharged	lbs. Parameter Discharged Per 100 lbs. Fish
BOD_5	6,886.	1.62
COD	29,563.	6.95
TKN	9,019.	2.12
$NH_3 - N$	273.	0.064
$NO_3 + NO_2 - N$	364.	0.086
TS	171,700.	40.4
TDS	91,715.	21.5
TVS	79,475.	18.7
TFS	92,225.	21.7
TSS	79,985.	18.8
Sett. S.	44,867.	10.5
Total P	671.	0.158
Ortho - PO_4	61.2	0.014
pH	7.5	7.5
Hardness	30,287.	7.12
Chloride	12,394.	2.92

(a) 477 acre-feet discharged during growing season; 425,000 lbs. fish on hand at harvest.

Table 14. WASTE PRODUCTION FROM DIFFERENT FISH CULTURE SYSTEMS

Parameter	lbs. Parameter Per 100 lbs. Fish on Hand for 240-Day Growing Season							
	Page & Andrews Tank	Harris Tank	Tank Means	Barker *et al.*, Pond System C	Barker *et al.* Pond System	Beasley & Allen Ponds	Pond Means	Barker *et al.* Raceway System E
BOD_5	67.6	96.7	82.1	2.64	2.61	2.69	2.65	1.62
COD				13.0	23.5	20.1	18.9	6.95
TKN	48.5		48.5	3.50	1.91		2.70	2.12
NH_3 - N	14.8	4.56	9.71	0.29	0.41	0.04	0.25	0.06
NO_3 + NO_2 - N	49.0		49.0	0.06	0.06	0.52	0.21	0.09
TS	78.3		78.3	44.2	76.1	103.	74.7	40.4
TDS				29.2	41.6	86.5	52.5	21.5
TVS				26.7	38.7	53.5	39.6	19.2
TFS				17.5	37.3	50.3	35.0	22.2
TSS		136.	136.	15.0	34.4	17.3	22.2	18.8
Sett. S.				10.0	18.4		14.2	10.5
Total P	6.10		6.10	0.09	0.15	0.04	0.09	0.16
Ortho - PO_4				0.02	0.03		0.02	0.01
Hardness				18.9	61.6		40.2	7.12
Chloride				4.93	6.34		5.64	2.92

Representative data on raw waste (feed and metabolic) composition and production for catfish was extremely limited. Utilizing mean values from Page and Andrews' and Harris' works it was possible to arrive at certain raw waste production values for catfish. With this data it is possible to assess the waste assimilative capacities of the pond and semi-closed raceway systems.

The waste production from ponds represents data from eight ponds with stocking densities ranging from 1,800 to 3,000 fish/surface-acre. It is assumed that all pond waters had zero waste levels at the time of stocking. General agreement between the three sets of values is good. Perhaps the two most significant differences occur in COD and total solids values. For Pond C COD is 40% less and total solids 103% less than the respective mean values for the other ponds. The mean values given in column four should be a reasonably accurate representation of potential waste discharge loadings from pond culture systems for catfish.

The waste stabilization effect by the natural biological processes occurring in the ponds is very pronounced. BOD and TKN have been reduced by 96.8% and 94.9% respectively when compared to the mean raw waste levels reported from tank studies. Assuming a 4.5 pound oxygen demand per pound of TKN this means a total oxygen demand (on natural waterways) reduction of 95.4%.

The semi-closed Raceway System E shows the positive effects of increased physical (mixing and aeration) and biological activity on waste stabilization. When compared with the mean values for the ponds, BOD and TKN loadings are further reduced by 38.9% and 14.5% respectively.

During the stabilization process in the ponds and raceways total suspended solids are reduced by an average of 85% when compared with raw waste quantities from tanks. This is further evidence that physical settlement is not likely to effect much improvement in water quality in the culture of warm water fish in ponds or raceways.

In our discussion of waste production and possible discharge loadings to streams it is important that we reconsider our earlier assumption of zero concentration levels at the start of production. If a catfish producer must remove production wastes from the water he uses before discharging it he should not be held accountable for the initial waste loadings in the water. Consequently, additional information is needed to determine the general background or initial waste level of the water sources used for catfish production.

SECTION VIII

REFERENCES

Adrian, J. L. and E. W. McCoy. 1971. Costs and Returns of Commercial Catfish Production in Alabama. Auburn University Agricultural Experiment Station, Auburn, Alabama. Bulletin No. 421. 23 p.

Allen, K. O. 1974. Fisheries Research Biologist with U. S. Bureau of Sport Fisheries and Wildlife Fish Farming Experiment Station. Stuttgart, Arkansas. Personal Correspondence.

American Public Health Association, American Water Works Association, and Water Pollution Control Federation. 1971. Standard Methods for the Examination of Water and Wastewater. Thirteenth Edition. New York, American Public Health Association, Inc.

Andrews, J. W. 1972. Stocking Density and Water Requirements for High-Density Culture of Channel Catfish in Tanks or Raceways. Feedstuff. 44(6): 40.

Bardach, J. E., J. H. Ryther, and W. O. McLarney. 1972. Aquaculture--The Farming and Husbandry of Freshwater and Marine Organisms. New York, Wiley-Interscience. p. 159-205.

Beasley, D. B. and J. B. Allen. 1973. Engineers Study Water Quality in Commercial Catfish Ponds. Mississippi Agricultural & Forestry Experiment Station Research Highlights. 36:3.

Bonn, E. W. and B. J. Follis. 1966. Effects of Hydrogen Sulfide on Channel Catfish (Ictalurus Punctatus). In: Proceedings of the 20th Annual Conference of Southeastern Association of Game and Fish Commissioners, Webb, J. W. (ed.). Dennison, Texas Parks and Wildlife Department. p. 424-431.

Boyd, C. E. 1973. The Chemical Oxygen Demand of Waters and Biological Materials from Ponds. Transactions of the American Fisheries Society. 102(3):606-611.

Boyd, C. E. 1971. Phosphorus Dynamics in Ponds. In: Proceedings of the 25th Annual Conference of the Southeastern Association of Game and Fish Commissioners. Auburn, Auburn University International Center for Acquaculture. p. 418-426.

Boyd, C. E. 1970. Influence of Organic Matter on Some Characteristics of Aquatic Soils. Hydrobiologia (The Hague). 36(1): 17-21.

Boyd, C. E. and C. P. Goodyear. 1971. Nutritive Quality of Food in Ecological Systems. Savannah River Ecology Laboratory, Aiken, South Carolina. Report No. 69-2-256-270. U. S. Atomic Energy Commission. 15p.

Broussard, M. C., Jr., N. C. Parker, and B. A. Simco. 1973. Culture of Channel Catfish in a High Flow Recirculating System. Memphis State University. (Presented at 27th Annual Conference Southeastern Association of Game and Fish Commissioners. Hot Springs. October 14-17). 13 p.

Brown, E. E. 1971. Economics of Catfish. In: Proceedings of the Catfish Farmers of Georgia, Schuler, G. A. and J. L. Byford (eds.). Athens University of Georgia Cooperative Extension Service. p. 39-42.

Busch, C. D., J. L. Koon, and R. Allison. 1973. Aeration, Water Quality and Catfish Production. Auburn University Agricultural Engineering Department. (Presented at Annual Meeting American Society of Agricultural Engineers. Lexington. June 17-20.). 14 p.

Chapman, S. R., J. L. Chesness, and R. B. Mitchell. 1971. Design and Operation of Earthen Raceways for Channel Catfish Production. Soil

Conservation Service. (Presented at Joint Meeting of Southeast Region Soil Conservation Society of America, and Southeast Region American Society of Agricultural Engineers. Jacksonville. January 31 - February 3.) 12 p.

Chesness, J. L., J. L. Stephens, and T. K. Hill. 1972. Gravity Flow Aeration for Raceway Fish Culture Systems. University of Georgia Agricultural Experiment Station, Athens, Georgia. Research Report No. 137. 21 p.

Chesness, J. L. and J. L. Stephens. 1971. A Model Study of Gravity Flow Aerators for Catfish Raceway Systems. Transactions of the ASAE. 14(6):1167-1169, 1174.

Chu, C. L. and G. N. Greene. 1966. Experiments on the Use of a Biofilter to Remove Wastes from Fish Tanks. In: Proceedings of the 20th Annual Conference of the Southeastern Association of Game and Fish Commissioners, Webb, J. W. (ed.). Auburn, Auburn University Fisheries Laboratory. p. 446-455.

Container Culture of Catfish and Removal of Excess Nutrients from Fish Pond. 1973. Excerpts from FAO Aquaculture Bulletin. April-July Issue. p. 7-8.

Culley, D. D., Jr. 1973. Raceways; Exotic Species Most Affected by Proposed EPA Discharge Permits. The American Fish Farmer & World Aquaculture News. 4(8):9-12.

Davis, J. T. and J. S. Hughes. 1970. Channel Catfish Farming in Louisiana. Louisiana Wildlife and Fisheries Commission, Baton Rouge, Louisiana. Wildlife Education Bulletin No. 98. 48 p.

Dupree, H. K. 1972. Evaluation of an Oxidation Pool to Remove Wastes in a Closed System for Raising Fish. Southeastern Fish Cultural Laboratory, Marion, Alabama. Technical Assistance Project No. 14-16-0008-571. U. S. Department of the Interior. p. 49-62.

Environmental Protection Agency. 1971. Methods for Chemical Analysis of Water and Wastes. Washington, D. C., U. S. Government Printing Office. 312 p.

Federal Water Pollution Control Administration. 1968. Water Quality Criteria. Washington, D. C., U. S. Government Printing Office. 234 p.

Gray, D. L. 1973. The Biology of Channel Catfish Production. University of Arkansas Cooperative Extension Service, Fayetteville, Arkansas. Circular No. 535. U. S. Department of Agriculture. 16 p.

Greene, G. N. 1969. Biological Filters for Increased Fish Production. Auburn University Agricultural Experiment Station. (Prepared by Auburn University Agricultural Experiment Station. Auburn). 15 p.

Grizzell, R. A., Jr. 1967. Pond Construction and Economic Considerations in Catfish Farming. Soil Conservation Service. (Presented at 21st Southeastern Association of Game and Fish Commissioners. New Orleans. September 25-27.) 5 p.

Grizzell, R. A., Jr., O. W. Dillon, Jr., and E. G. Sullivan. 1969. Catfish Farming - A New Farm Crop. Soil Conservation Service, Washington, D. C. Farmers' Bulletin No. 2244. United States Department of Agriculture. 22 p.

Hach Chemical Company. 1969. DR-EL Methods Manual. Seventh Edition. Ames, The Iowa State University Press. 68 p.

Hall, M. D. 1972. The Fish Barn. Agricultural Engineering. 53:16.

Harris, J. C. 1972. Pollution Characteristics of Channel Catfish Culture. Unpublished Masters Thesis. The University of Texas at Austin. 94 p.

Hastings, W. H. 1972. Feeding Domestic Freshwater Fish. Agricultural Engineering. 53:16-17.

Hatcher, R. M. 1972. Catfish Farming in Tennessee. Tennessee Game & Fish Commission, Nashville, Tennessee. Report No. 5-72-5M (Second Edition). 47 p.

Hill, T. K., J. L. Chesness, and E. E. Brown. 1973. A Two-Crop Fish Production System. Transactions of the ASAE. 16(5):930-933.

Hinshaw, R. N. 1973. Pollution as a Result of Fish Cultural Activities. Utah State Division of Wildlife Resources, Salt Lake City, Utah. Environmental Protection Agency. 209 p.

Hubert, W. A. 1973. Evaluation of Intensive Catfish Culture Systems for Potential Valley Use. Tennessee Valley Authority. (Prepared by Division of Forestry, Fisheries, and Wildlife Development. Muscle Shoals. April.) 27 p.

Hubert, W. A., W. T. Morgan, and A. O. Smith. 1972. A Description of the Fish Culture Industry in the Tennessee River Valley and A Review of the Major Cause of Fish Loss - Oxygen Depletion. Tennessee Valley Authority, Norris, Tennessee. Technical Note No. B3. 21 p.

Jeffrey, N. B. 1969. Some Aspects of the Ecology of Fish Ponds. In: Proceedings . . . 1969 Fish Farming Conference. College Station, Texas Agricultural Extension Service. p. 40-42.

Knepp, G. L. and G. F. Arkin. 1972. Ammonia Toxicity Levels and Nitrate Tolerance for Channel Catfish (Ictaluras Punctatus). University of Illinois. (Presented at 1972 Annual Meeting American Society of Agricultural Engineers. Hot Springs. June 27-30). 6 p.

Liao, P. B. 1970. Salmonid Hatchery Wastewater Treatment. Water & Sewage Works. December Issue. 5 p.

Liao, P. B. 1970. Pollution Potential of Salmonid Fish Hatcheries. Water & Sewage Works. August Issue. p. 291-296.

Lee, J. S. 1971. Catfish Farming . . . A Reference Unit. Mississippi State University. (Published by Mississippi State University Curriculum Coordinator Unit for Vocational Technical Education. State College.) 103 p.

Lewis, S. D. 1971. Effect of Selected Concentrations of Sodium Chloride on the Growth of Channel Catfish. In: Proceedings of the 25th Annual Conference Southeastern Association of Game and Fish Commissioners, Webb, J. W. (ed.). Carbondale, Southern Illinois Fisheries Research Laboratory. p. 459-466.

Lovell, R. T. 1973. Put Catfish Offal to Work for You. Fish Farming Industries. October - November Issue. 3 p.

Lovell, R. T. 1972. Fight Against Off Flavors Inches Ahead. Fish Farming Industries. February Issue. 3 p.

Mack, J. 1971. Catfish Farming Handbook. San Angelo, Info Books. 195 p.

McCoy, E. W. 1973. Catfish Marketing and Related Production Factors. Auburn University Agricultural Experiment Station, Auburn, Alabama. Circular No. 206. 23 p.

Montfort, W. W., Jr., K. L. Anderson, and W. J. Lorie. 1969. Production of Channel Catfish. Mississippi Cooperative Extension Service, State College, Mississippi. Publication No. 622. U. S. Department of Agriculture. 16 p.

Murphy, J. P. and R. I. Lipper. 1972. 1971 Confinement Rearing of Channel Catfish. Kansas State University, Manhattan, Kansas. KCREA Annual Report. 10 p.

Murphy, J. P. and R. I. Lipper. 1971. Confinement Fish Rearing. Kansas State University, Manhattan, Kansas. KCREA Annual Report. 8 p.

Murphy, J. P. and R. I. Lipper. 1970. BOD Production of Channel Catfish. Progressive Fish Culturalist. 32:195.

Page, J. W. and J. W. Andrews. 1973. Chemical Composition of Effluent from High Density Culture of Channel Catfish. Skidaway Institute of Oceanography. (Presented at Summer Meeting of American Society of Agricultural Engineers. Lexington. June 17-20.) 11 p.

Page, J. W. and J. W. Andrews. 1972. Efficiency of Two Types of Microbiological Filters for Removing Ammonia from Effluents of High Density Culture of Channel Catfish. Skidaway Institute of Oceanography. (Prepared by Skidaway Institute of Oceanography. Savannah. March 29.) 14 p.

Parker, N. C. and B. A. Simco. 1973. Evaluation of Recirculating Systems for the Culture of Channel Catfish. Memphis State University. (Presented at 27th Annual Conference Southeastern Association of Game and Fish Commissioners. Hot Springs. October 14-17.) 29 p.

Patterson, D. W. 1973. Observations on Aerated Ponds for Catfish Production. Soil Conservation Service. (Presented at Catfish Farmers of California Convention. Fresno. January 12-13.) 15 p.

Satomi, Y. 1966. Physiological Significance of Carbon Sources in Fertilized Fish Ponds. Bulletin of Freshwater Fisheries Research Laboratory. 15(2):99-104.

Smitherman, R. O. and T. E. Corley. 1971. Catfish Culture and the Ag Engineer. Agricultural Engineering. 53:416-417.

Speece, R. E. 1973. Trout Metabolism Characteristics and the Rational Design of Nitrification Facilities for Water Reuse in Hatcheries. Transactions of the American Fisheries Society. (2):323-334.

Steinbach, D. and W. Klussman. 1971. Channel Catfish Farming. Texas A & M University, College Station, Texas. Report No. B-1024. United States Department of Agriculture. 16 p.

Swingle, H. S. 1966. Fish Kills Caused by Phytoplankton Blooms and Their Prevention. Auburn University. (Presented at FAO World Symposium on Warm-Water Pond Fish Culture. Rome. May 18-25.) 7 p.

Swingle, W. E. and E. W. Shell. 1971. Tables for Computing Relative Condition of some Common Freshwater Fishes. Auburn University Agricultural Experiment Station, Auburn, Alabama. Circular No. 183. 55 p.

Tennessee Valley Authority. 1971. Producing & Marketing Catfish in the Tennessee Valley. In: Conference Proceedings, June 30-July 1, Williams, G. C., Chance, B. Carroll, and R. D. Rouse (eds.). Knoxville, Tennessee Valley Authority. 96 p.

Thornton, M. E. 1973. Oxygen Depletion: An Unnecessary Evil. The American Fish Farmer & World Aquaculture News. 4(9):11-13,22.

Tiemeier, O. W. and C. W. Deyoe. 1968. Production of Channel Catfish. Kansas State University, Manhattan, Kansas. Bulletin No. 508. 24 p.

Upchurch, J. E. 1971. Beneficial Uses of Heated Water. In: Conference Proceedings. . . Producing & Marketing Catfish in the Tennessee Valley, Rouse, R. D. (ed.). Knoxville, Tennessee Valley Authority. p. 84-87.

Wahlquist, H. 1972. Production of Waterhyacinths and Resulting Water Quality in Earthen Ponds. Hyacinth Control Journal. 10:9-11.

Willoughby, H., H. N. Larsen, and J. T. Bowen. 1972. The Pollutional Effects of Fish Hatcheries. American Fishes and U. S. Trout News. 17(3):1-3.

SECTION IX

GLOSSARY

SAMPLING LOCATIONS FOR WATER QUALITY DATA

EGFX - Outlet of oxidation pond serving Raceways EG and EF

EDX - Outlet of oxidation pond serving Raceway ED

TPO - Outlet of reservoir for Raceway TR at pump intake

TRT - Beneath riser aerator tower of Raceway TR

TDI - Raceway TR effluent during first fish harvest seining of last unit of raceway

TD2 - Raceway TR effluent during second fish harvest seining of last raceway unit

TD3 - Raceway TR effluent during third fish harvest seining of last raceway unit

NS - Surface of catfish pay lake near Morven, Georgia

NB - Bottom of catfish pay lake near Morven, Georgia

GKM - Middepth of Pond GK

CM - Middepth of Pond C

BM - Middepth of Pond B

WM - Middepth of Pond W

CD1 - Pond C discharge after 1 foot drawdown prior to fish harvest

CD2 - Pond C discharge after 2 feet drawdown prior to fish harvest

CD3 - Pond C discharge after 3 feet drawdown prior to fish harvest

CD4 - Pond C discharge after 4 feet drawdown and at beginning of first fish harvest seining

CD5 - Pond C discharge during first fish harvest seining

CD6 - Pond C discharge during second fish harvest seining

CD7 - Pond C discharge two hours after third and final fish harvest seining

ABBREVIATIONS FOR WATER QUALITY PARAMETERS AND OTHER VARIABLES

D.O. - Dissolved Oxygen

BOD - Five day Biochemical Oxidation Demand

COD - Chemical Oxidation Demand

TKN - Total Kjeldahl Nitrogen (as N)

NH_3-N - Ammonia Nitrogen (as N)

NO_3-N - Nitrate plus Nitrite Nitrogen (as N)

TS - Total Solids

TDS - Total Dissolved Solids

TVS - Total Volatile Solids

TFS - Total Fixed Solids

TSS - Total Suspended Solids

Sett.S - Settleable Solids

Total P - Total Phosphate

Ortho-PO_4 - Orthophosphate

Hardness-Total Water Hardness (as $CaCO_3$)

Chloride - Chloride (as Cl)

Water Temperature - Water Temperature, °F

TOC - Total Organic Carbon

Stocking Rate - Number of fish stocked per production unit (raceway) or per surface acre (pond)

Flow Rate - Gallons per minute (gpm)

Water Volume - Acre-feet at normal pool level

Fish Weight - Total pounds of fish in raceway or pond on sampling date

Amount Fed - Total pounds of feed fed on sampling date.

SECTION X

APPENDICES

The water quality parameter concentrations (mg/l) for each sample collected from the ponds and raceways during the field study are presented in Tables 15 through 35.

The parameter concentrations for surface (S suffix) and bottom (B suffix) water samples for each pond visited on a given date are presented in Tables 15 through 22. The parameter concentrations obtained from water samples taken during the harvest drawdown of Pond C are presented in Table 22.

Influent and effluent parameter concentrations for each raceway sampled in System E are shown in Tables 22 through 31.

Parameter concentration data collected from Raceway System TR are presented in Tables 32 through 35.

Table 15. WATER QUALITY DATA, PONDS, 7/18/73

Parameter	Pond							
	GKS	GKB	CS	CB	NS	NB	WS	WB
Stocking Rate		-	2000	2000	2000	2000	1800	1800
Surface Area	1.25	1.25	4	4	2	2	10	10
Water Volume	5	5	15	15	8	8	48	48
Fish Weight	-	-	5364	5364	2682	2682	8839	8839
Amount Fed	-	-	113	113	40	40	131	131
BOD	8.4	8.4	15.6	9.2	8.8	8.8	8.8	8.4
COD	29	25	84	81	49	51	29	31
Total Kjeldahl Nitrogen	8.83	8.14	17.05	17.58	12.89	13.18	7.11	6.34
Ammonia Nitrogen	0.28	0.42	0.14	0.42	0.28	0.28	0.28	0.28
Nitrate + Nitrite - N	0.07	0.08	0.16	0.15	0.17	0.21	0.09	0.07
Total Solids	193	172	208	242	126	84	38	101
Total Dissolved Solids	110	86	103	110	79	77	26	26
Total Volatile Solids	122	90	145	143	-	-	24	70
Total Fixed Solids	71	82	63	99	-	-	14	31
Total Suspended Solids	83	86	105	132	47	7	12	75
Settleable Solids	67	58	90	122	11	4	4	42
Total Phosphate	0.38	0.90	0.18	0.52	0.08	0.03	0.08	0.12
Orthophosphate	0.27	0.55	0.03	0.02	0.07	0.02	0.06	0.07
pH	7.6	7.2	8.1	7.3	7.6	7.8	7.7	7.6
Hardness	90	100	35	35	5	10	10	5
Chloride	15.0	15.0	10.0	12.5	7.5	10.0	7.5	7.5

Table 16. WATER QUALITY DATA, PONDS, 8/14/73

Parameter	Pond							
	GKS	GKB	CS	CB	BS	BB	WS	WB
Stocking Rate	-	-	2000	2000	1600	1600	1800	1800
Surface Area	1.25	1.25	4	4	10	10	10	10
Water Volume	5	5	15	15	36	36	48	48
Fish Weight	-	-	6639	6639	1293	1293	11,009	11,009
Amount Fed	-	-	140	140	11.8	11.8	163	163
BOD	4.4	4.4	6.4	12.0	8.4	7.6	11.6	11.6
COD	11	11	20	37	8	28	44	42
Total Kjeldahl Nitrogen	6.95	7.10	8.58	15.83	8.44	6.39	7.26	7.47
Ammonia Nitrogen	0.28	0.37	0	2.99	0.37	0.47	0.37	0.47
Nitrate + Nitrite - N	0.07	0.07	0.08	0.13	0.11	0.10	0.09	0.11
Total Solids	116	130	100	177	120	81	69	118
Total Dissolved Solids	74	58	18	20	97	28	19	40
Total Volatile Solids	70	65	70	118	74	55	48	83
Total Fixed Solids	46	65	30	59	46	26	21	35
Total Suspended Solids	42	72	82	157	23	53	50	78
Settleable Solids	14	23	67	56	15	43	41	62
Total Phosphate	0.16	0.22	0.13	0.38	0.08	0.13	0.18	0.16
Orthophosphate	0.09	0.03	0.05	0.35	0.02	0.07	0.04	0.09
pH	8.4	8.1	8.5	6.6	6.9	6.7	6.7	6.1
Hardness	100	100	50	50	20	20	15	15
Chloride	20.0	17.5	15.0	15.0	12.5	15.0	10.0	10.0

Table 17. WATER QUALITY DATA, PONDS, 9/4/73

Parameter	Pond							
	GKS	GKB	CS	CB	BS	BB	WS	WB
Stocking Rate	-	-	2000	2000	1600	1600	1800	1800
Surface Area	1.25	1.25	4	4	10	10	10	10
Water Volume	5	5	15	15	36	36	48	48
Fish Weight	-	-	7631	7631	1343	1343	12,696	12,696
Amount Fed	-	-	161	161	12,3	12.3	188	188
BOD	2.4	4.0	3.6	7.2	4.8	4.0	2.4	2.4
COD	25	26	21	32	30	36	24	22
Total Kjeldahl Nitrogen	7.82	7.20	9.67	14.50	7.26	7.93	6.35	5.24
Ammonia Nitrogen	0.37	1.49	0.56	0.84	0.75	0.93	0	0.37
Nitrate + Nitrite - N	0.05	0.07	0.10	0.07	0.01	0.10	0.05	0.08
Total Solids	240	194	140	128	107	96	94	135
Total Dissolved Solids	128	163	93	92	48	37	45	62
Total Volatile Solids	113	94	112	88	61	45	29	71
Total Suspended Solids	112	31	47	36	59	59	49	73
Settleable Solids	56	30	24	28	50	54	33	68
Total Phosphate	0.28	0.28	0.17	0.55	0.15	0.10	0.44	0.32
Orthophosphate	0.12	0.20	0.12	0.10	0.04	0.03	0.05	0.08
pH	8.2	7.8	7.6	7.3	6.8	6.4	7.0	6.9
Hardness	130	135	40	40	15	18	35	37
Chloride	22.5	22.5	17.5	15.0	15.0	15.0	15.0	12.5

Table 18. WATER QUALITY DATA, PONDS, 9/25/73

Parameter	Pond					
	GKS	GKM	GKB	CS	CM	CB
Stocking Rate	-	-	-	2000	2000	2000
Surface Area	1.25	1.25	1.25	4	4	4
Water Volume	5	5	5	15	15	15
Fish Weight	-	-	-	8622	8622	8622
Amount Fed	-	-	-	182	182	182
BOD	5.6	5.0	6.8	8.8	8.0	9.2
COD	17	15	25	37	33	39
Total Kjeldahl Nitrogen	5.67	5.28	7.82	9.00	8.30	10.25
Ammonia Nitrogen	0.65	0.84	0.93	0.47	1.12	1.87
Nitrite + Nitrate - N	0.08	0.07	0.09	0.12	0.11	0.11
Total Solids	194	182	216	132	128	150
Total Dissolved Solids	156	155	155	120	106	73
Total Volatile Solids	85	69	67	75	73	87
Total Fixed Solids	109	113	149	57	55	63
Total Suspended Solids	38	27	61	12	22	77
Settleable Solids	30	15	34	3	14	66
Total Phosphate	0.15	0.15	0.28	0.06	0.06	0.10
Orthophosphate	0.06	0.08	0.07	0.01	0.03	0.04
pH	8.3	8.7	8.5	8.2	7.5	7.0
Hardness	120	135	170	65	70	85
Chloride	20.0	22.5	25.0	15.0	15.0	12.5

Table 19. WATER QUALITY DATA, PONDS, 9/25/73

Parameter	Pond					
	BS	BM	BB	WS	WM	WB
Stocking Rate	1600	1600	1600	1800	1800	1800
Surface Area	10	10	10	10	10	10
Water Volume	36	36	36	48	48	48
Fish Weight	1393	1393	1393	14,384	14,384	14,384
Amount Fed	12.7	12.7	12.7	213	213	213
BOD	2.8	2.4	6.0	1.0	1.0	1.0
COD	20	19	37	22	23	39
Total Kjeldahl Nitrogen	5.34	4.72	7.42	7.58	6.52	8.18
Ammonia Nitrogen	0.65	0.75	0.93	0.75	1.21	1.59
Nitrite + Nitrate - N	0.02	0.03	0.12	0.09	0.09	0.14
Total Solids	91	87	101	83	76	91
Total Dissolved Solids	48	62	63	62	60	35
Total Volatile Solids	69	62	72	56	55	65
Total Fixed Solids	22	25	29	27	21	26
Total Suspended Solids	43	25	38	21	16	56
Settleable Solids	31	13	33	17	13	35
Total Phosphate	0.25	0.10	0.14	0.13	0.18	0.38
Orthophosphate	0.05	0.02	0.01	0	0	0
pH	7.1	7.2	6.8	6.6	7.1	7.0
Hardness	50	40	40	60	60	70
Chloride	15.0	15.0	10.0	10.0	7.50	10.0

Table 20. WATER QUALITY DATA, PONDS, 10/18/73

Parameter	Pond								
	GKS	GKM	GKB	BS	BM	BB	WS	WM	WB
Stocking Rate	-	-	-	1600	1600	1600	1800	1800	1800
Surface Area	1.25	1.25	1.25	10	10	10	10	10	10
Water Volume	5	5	5	36	36	36	48	48	48
Fish Weight	-	-	-	1448	1448	1448	16,232	16,232	16,232
Amount Fed	-	-	-	13.2	13.2	13.2	240	240	240
BOD	7.6	4.8	6.8	3.2	2.4	5.6	4.8	4.0	6.4
COD	34	27	53	21	14	32	31	25	40
Total Kjeldahl Nitrogen	10.08	7.03	7.53	7.20	6.35	7.87	7.00	5.74	8.83
Ammonia Nitrogen	1.03	1.03	1.21	1.40	1.40	1.68	0.84	0.93	1.12
Nitrate + Nitrite - N	0.10	0.10	0.11	0.02	0.04	0.14	0.11	0.10	0.12
Total Solids	178	158	194	123	122	153	110	99	136
Total Dissolved Solids	135	134	121	54	86	60	85	83	72
Total Volatile Solids	108	77	92	67	47	69	92	76	87
Total Fixed Solids	70	81	102	56	75	84	18	23	49
Total Suspended Solids	43	24	73	69	36	93	25	16	64
Settleable Solids	27	19	65	68	22	37	13	8	43
Total Phosphate	0.15	0.11	0.16	0.23	0.10	0.11	0.20	0.19	0.34
Orthophosphate	0.08	0.08	0.14	0.03	0	0.06	0.05	0.05	0.08
pH	7.9	8.0	7.7	7.5	7.2	6.5	7.7	7.6	7.0
Hardness	120	105	110	30	35	60	75	70	80
Chloride	12.5	15.0	17.5	15.0	15.0	10.0	10.0	5.0	7.5

Table 21. WATER QUALITY DATA, PONDS, 11/9/73

Parameter	Pond								
	GKS	GKM	GKB	BS	BM	BB	WS	WM	WB
Stocking Rate	-	-	-	1600	1600	1600	1800	1800	1800
Surface Area	1.25	1.25	1.25	10	10	10	10	10	10
Water Volume	5	5	5	36	36	36	48	48	48
Fish Weight	-	-	-	1500	1500	1500	18,000	18,000	18,000
Amount Fed	-	-	-	13.7	13.7	13.7	266	266	266
BOD	4.3	3.0	5.8	4.4	2.8	7.2	2.8	2.4	4.4
COD	32	27	32	33	29	41	30	29	35
Total Kjeldahl Nitrogen	4.46	2.98	2.75	2.76	2.46	5.27	2.47	2.40	2.79
Ammonia Nitrogen	0.37	0.75	1.03	0.47	0.65	0.84	0.37	0.65	0.75
Nitrate + Nitrite - N	0.37	0.23	0.25	0.19	0.18	0.53	0.05	0.05	0.13
Total Solids	244	210	210	130	122	139	101	98	109
Total Dissolved Solids	179	169	151	69	70	62	66	74	79
Total Volatile Solids	129	92	62	73	65	52	59	51	48
Total Fixed Solids	115	118	148	57	57	87	42	47	61
Total Suspended Solids	65	41	59	61	52	77	35	24	60
Settleable Solids	36	20	41	46	17	56	21	17	30
Total Phosphate	0.31	0.22	0.39	0.23	0.09	0.16	0.20	0.16	0.21
Orthophosphate	0.04	0.04	0.08	0.02	0.02	0.03	0.01	0	0.01
pH	8.9	8.6	7.8	7.7	7.3	6.6	7.8	7.5	6.7
Hardness	150	145	180	30	30	45	80	80	90
Chloride	17.5	15.0	20.0	15.0	15.0	15.0	10.0	5.0	7.5

Table 22. WATER QUALITY DATA, POND HARVEST, 10/3/73

Parameter	Pond								
	CS	CB	CD1	CD2	CD3	CD4	CD5	CD6	CD7
Stocking Rate	2000	2000	2000	2000	2000	2000	2000	2000	2000
Surface Area	4	4	4	4	4	4	4	4	4
Water Volune	15	15	15	15	15	15	15	15	15
Fish Weight	9000	9000	9000	9000	9000	9000	9000	9000	9000
Amount Fed	189	189	189	189	189	189	189	189	189
BOD	8.8	9.2	9.6	8.4	10.4	10.4	12.8	11.2	8.6
COD	37	39	48	51	41	58	72	60	52
Total Kjeldahl Nitrogen	9.00	10.25	9.33	11.92	8.58	10.25	12.58	10.67	8.25
Ammonia Nitrogen	0.47	1.87	1.21	0.84	0.93	1.12	1.49	1.21	0.19
Nitrate + Nitrite - N	0.12	0.11	0.29	0.25	0.23	0.39	0.47	0.33	0.13
Total Solids	132	150	130	135	161	215	245	208	146
Total Dissolved Solids	120	73	82	111	103	108	117	117	93
Total Volatile Solids	75	87	81	94	82	98	133	118	83
Total Fixed Solids	57	63	49	41	79	117	112	90	63
Total Suspended	12	77	48	24	58	107	128	91	53
Settleable Solids	3	66	13	19	32	86	123	71	50
Total Phosphate	0.06	0.10	0.12	0.21	0.11	0.28	0.45	0.27	0.28
Orthophosphate	0.01	0.04	0.04	0.01	0.06	0.05	0.19	0.04	0.16
pH	8.2	7.0	6.8	6.9	6.6	6.3	6.1	6.2	6.2
Hardness	65	85	70	60	90	90	70	85	55
Chloride	15.0	12.5	15.0	15.0	25.0	15.0	15.0	15.0	12.0

Table 23. WATER QUALITY DATA, RACEWAYS, 6/13/73

Parameter	Raceway					
	EG1	EG8	EF1	EF11	ED1	ED17
Stocking Rate	2000	2000	2000	2000	1500	1500
No. of Units	7	7	10	10	16	16
Flow Rate	350	350	350	350	350	350
Fish Weight	6338	6338	9054	9054	10,864	10,864
Amount Fed	101	101	144	144	172	172
Dissolved Oxygen	7.9	8.1	8.2	7.2	8.4	7.9
BOD	1.4	2.0	1.9	2.6	1.7	2.7
COD	5	9	7	10	8	18
Total Kjeldahl Nitrogen	3.46	4.65	4.87	4.08	6.64	9.56
Ammonia Nitrogen	0.09	0.09	0.28	0.28	0.19	0.37
Nitrite + Nitrate - N	0.12	0.17	0.11	0.12	0.55	0.83
Total Solids	129	117	147	100	126	168
Total Dissolved Solids	78	72	87	85	78	72
Total Volatile Solids	48	50	32	55	68	78
Total Fixed Solids	81	67	115	45	58	90
Total Suspended Solids	45	51	23	60	48	96
Settleable Solids	14	34	15	23	13	71
Total Phosphate	0.31	0.17	0.42	0.24	0.13	0.43
Orthophosphate	0.20	0.16	0.06	0.05	0.01	0.03
pH	7.3	7.2	7.4	7.2	7.2	7.2
Hardness	20	15	10	10	20	20
Chloride	10.0	10.0	5.0	7.5	10.0	7.5
Water Temperature	82	82	83	82	85	85

Table 24. WATER QUALITY DATA, RACEWAYS, 6/25/73

Parameter	Raceway					
	EGI	EG8	EF1	EF11	ED1	ED17
Stocking Rate	2000.	2000.	2000.	2000.	1500.	1500.
No. of Units	7.	7.	10.	10.	16.	16.
Flow Rate	350.	350.	350.	350.	350.	350.
Fish Weight	7288.	7288.	10411.	10411.	12493.	12493.
Amount Fed	116.	116.	165.	165.	198.	198.
Dissolved Oxygen	6.8	7.0	7.3	6.7	7.9	6.7
BOD	6.3	6.5	6.5	7.3	5.7	6.1
COD	20.	26.	26.	31.	36.	48.
Total Kjeldahl Nitrogen	4.94	5.63	5.48	4.57	9.30	12.41
Ammonia Nitrogen	0.09	0.09	0.19	0.19	0.19	0.47
Nitrite + Nitrate - N	0.11	0.15	0.09	0.13	0.19	0.26
Total Solids	78.	98.	98.	75.	108.	202.
Total Dissolved Solids	28.	57.	67.	60.	80.	106.
Total Volatile Solids	37.	42.	26.	33.	68.	82.
Total Fixed Solids	41.	56.	72.	42.	40.	120.
Total Suspended Solids	50.	41.	31.	15.	28.	96.
Settleable Solids	46.	30.	13.	14.	22.	48.
Total Phosphate	0.13	0.08	0.14	0.22	0.12	0.17
Orthophosphate	0.07	0.06	0.04	0.22	0.08	0.05
pH	7.4	8.1	8.3	8.2	8.3	8.6
Hardness	20.	15.	15.	20.	15.	15.
Chloride	10.0	10.0	5.0	10.0	7.5	10.0
Water Temperature	85.	83.	86.	82.	85.	84.

Table 25. WATER QUALITY DATA, RACEWAYS, 7/9/73

Parameter	Raceway					
	EG1	EG8	EF1	EF11	ED1	ED17
Stocking Rate	2000.	2000.	2000.	2000.	1500.	1500.
No. of Units	7.	7.	10.	10.	16.	16.
Flow Rate	350.	350.	350.	350.	350.	350.
Fish Weight	8396.	8396.	11994.	11994.	14393.	14393.
Amount Fed	133.	133.	190.	190.	228.	228.
Dissolved Oxygen	8.9	8.1	8.4	8.1	8.5	8.9
BOD	5.2	8.8	4.8	5.2	3.2	11.2
COD	21.0	21.	10.	20.	32.	34.
Total Kjeldahl Nitrogen	7.12	15.86	10.54	9.66	9.90	13.20
Ammonia Nitrogen	0.14	1.12	0.98	1.22	0.30	0.56
Nitrite + Nitrate - N	0.27	0.32	0.27	0.33	0.14	0.21
Total Solids	180.	218.	153.	176.	168.	219.
Total Dissolved Solids	127.	125.	105.	120.	84.	117.
Total Volatile Solids	71.	78.	41.	66.	109.	86.
Total Fixed Solids	109.	140.	112.	110.	67.	133.
Total Suspended Solids	53.	93.	48.	56.	84.	102.
Settleable Solids	19.	9.	22.	10.	51.	46.
Total Phosphate	0.13	0.13	0.32	0.20	0.08	0.61
Orthophosphate	0.05	0.03	0.20	0.08	0.05	0.03
pH	7.8	7.8	7.8	7.8	7.9	7.8
Hardness	15.	20.	18.	17.	15.	17.
Chloride	10.0	10.0	7.5	10.0	7.5	10.0
Water Temperature	84.	84.	85.	83.	82.	82.

Table 26. WATER QUALITY DATA, RACEWAYS, 7/25/73

Parameter	Raceway					
	EG1	EG8	EF1	EF11	ED1	ED17
Stocking Rate	2000	2000	2000	2000	1500	1500
No. of Units	7	7	10	10	16	16
Flow Rate	350	350	350	350	350	350
Fish Weight	9662	9662	13,804	13,894	16,564	16,564
Amount Fed	153	153	219	219	263	263
Dissolved Oxygen	8.4	7.4	8.4	6.3	7.6	7.6
BOD	5.2	4.4	7.2	6.4	3.6	8.8
COD	34	44	36	40	24	40
Total Kjeldahl Nitrogen	7.78	9.16	9.23	7.42	7.28	10.28
Ammonia Nitrogen	0.19	0.09	0.37	0.19	0.09	0.09
Nitrate + Nitrite - N	0.15	0.19	0.27	0.23	0.21	0.37
Total Solids	154	240	149	171	123	104
Total Dissolved Solids	77	121	44	34	30	11
Total Volatile Solids	69	96	55	100	70	41
Total Fixed Solids	85	144	94	71	53	63
Total Suspended Solids	77	119	105	137	93	93
Settleable Solids	67	61	94	106	30	20
Total Phosphate	0.83	0.17	0.26	0.18	0.04	0.55
Orthophosphate	0.45	0.12	0.08	0.06	0.02	0.07
pH	7.3	7.3	7.3	7.2	7.3	7.3
Hardness	20	25	30	20	20	15
Chloride	7.5	10.0	10.0	7.5	10.0	10.0
Water Temperature	84	83	84	85	86	85

Table 27. WATER QUALITY DATA, RACEWAYS, 8/9/73

Parameter	Raceway					
	EG1	EG8	EF1	EF11	Ed1	ED17
Stocking Rate	2000	2000	2000	2000	1500	1500
No. of Units	7	7	10	10	16	16
Flow Rate	350	350	350	350	350	350
Fish Weight	10,929	10,929	15,613	15,613	18,736	18,736
Amount Fed	173	173	248	248	297	297
Dissolved Oxygen	6.8	5.4	6.4	5.3	5.4	4.0
BOD	3.6	10.8	5.6	13.6	4.8	5.2
COD	14	26	19	28	5	7
Total Kjeldahl Nitrogen	7.35	11.67	9.37	11.54	8.06	11.92
Ammonia Nitrogen	0.19	0.37	0.28	0.65	0.65	1.40
Nitrite + Nitrate - N	0.32	0.41	0.34	0.31	0.48	0.65
Total Solids	158	158	147	179	121	131
Total Dissolved Solids	112	50	80	46	53	64
Total Volatile Solids	68	71	44	106	61	57
Total Fixed Solids	90	87	103	73	60	74
Total Suspended Solids	46	108	67	133	68	67
Settleable Solids	38	87	45	112	10	46
Total Phosphate	0.99	0.93	0.78	0.94	0.96	1.18
Orthophosphate	0.07	0.06	0.02	0.08	0.07	0.03
pH	7.5	6.7	7.3	6.8	7.5	7.1
Hardness	20	20	15	25	20	20
Chloride	10.0	10.0	7.5	12.5	10.0	10.0
Water Temperature	82	82	83	82	81	82

Table 28. WATER QUALITY DATA, RACEWAYS, 8/17/73

Parameter	Raceway ED17			
	5AM	11AM	5PM	11PM
Stocking Rate	1500	1500	1500	1500
No. of Units	16	16	16	16
Flow Rate	350	350	350	350
Fish Weight	19,686	19,686	19,686	19,686
Amount Fed	312	312	312	312
Dissolved Oxygen	-	-	-	-
BOD	2.0	0.8	3.6	3.6
COD	28	26	27	19
Total Kjeldahl Nitrogen	9.58	8.31	8.79	8.06
Ammonia Nitrogen	1.12	0.47	0.19	0.65
Nitrite + Nitrate - N	0.69	0.39	0.29	0.46
Total Solids	116	123	180	145
Total Dissolved Solids	60	60	47	62
Total Volatile Solids	31	26	52	65
Total Fixed Solids	85	97	128	80
Total Suspended Solids	56	63	133	83
Settleable Solids	31	22	79	58
Total Phosphate	1.07	1.10	0.81	0.54
Orthophosphate	0.02	0.03	0.03	0.05
pH	7.4	7.5	7.6	7.5
Hardness	25	25	25	20
Chloride	10.0	10.0	12.5	12.5
Water Temperature	-	-	-	-

Table 29. WATER QUALITY DATA, RACEWAYS, 8/23/73

Parameter	Raceway						Oxidation Pond	
	EG1	EG8	EF1	EF11	ED1	ED17	EGFX	EDX
Stocking Rate	2000	2000	2000	2000	1500	1500	0	0
No. of Units	7	7	10	10	16	16	-	-
Flow Rate	350	350	350	350	350	350	-	-
Surface Area	-	-	-	-	-	-	3.4	7.8
Water Volume	-	-	-	-	-	-	20.2	47.0
Fish Weight	11,958	11,958	17,083	17,083	20,500	20,500	0	0
Amount Fed	190	190	271	271	325	325	0	0
D.O.	8.5	8.5	8.3	8.3	8.0	7.2	-	-
BOD	12.4	11.6	11.2	14.0	8.4	8.0	12.0	9.6
COD	30	41	44	49	19	29	47	20
Total Kjeldahl Nitrogen	5.14	13.50	5.52	6.22	4.87	5.05	5.34	11.17
Ammonia Nitrogen	0.09	0.19	0.09	0.19	0.19	0.19	0.09	0.28
Nitrate + Nitrite - N	0.24	0.29	0.23	0.27	0.25	0.24	0.28	0.26
Total Solids	118	141	110	121	90	95	142	77
Total Dissolved Solids	22	41	62	23	13	41	29	10
Total Volatile Solids	44	45	29	33	47	32	31	35
Total Fixed Solids	74	96	81	88	43	63	111	42
Total Suspended Solids	96	100	48	98	77	54	113	67
Settleable Solids	88	63	26	93	60	38	110	60
Total Phosphate	0.87	0.82	0.88	1.02	1.35	1.02	0.63	0.91
Orthophosphate	0.06	0.08	0.07	0.04	0.02	0.01	0.02	0.02
pH	9.2	8.6	8.6	8.7	7.0	7.2	9.2	7.3
Hardness	30	20	20	20	20	25	20	25
Chloride	7.5	7.5	10.0	7.5	10.0	12.5	10.0	10.0
Water Temperature	76	75	77	76	78	78	-	-

Table 30. WATER QUALITY DATA, RACEWAYS, 9/6/73

Parameter	Raceway						Oxidation Pond	
	EG1	EG8	EF1	EF11	ED1	ED17	EGFX	EDX
Stocking Rate	2000	2000	2000	2000	1500	1500	0	0
No. of Units	7	7	10	10	16	16	-	-
Flow Rate	350	350	350	350	350	350	-	-
Surface Area	-	-	-	-	-	-	3.4	7.8
Water Volume	-	-	-	-	-	-	20.2	47.0
Fish Weight	13,067	13,067	18,667	18,667	22,400	22,400	0	0
Amount Fed	207	207	296	296	356	356	0	0
D.O.	7.2	7.2	8.1	8.1	10.3	8.1	-	-
BOD	6.4	8.0	6.0	7.6	5.2	1.2	10.0	1.2
COD	8	36	16	32	8	26	40	23
Total Kjeldahl Nitrogen	4.16	4.23	3.40	5.18	7.05	5.74	4.07	3.49
Ammonia Nitrogen	0	0.09	0.47	0.75	0.19	0.75	0.37	0.37
Nitrate + Nitrite - N	0.17	0.22	0.18	0.15	0.21	0.28	0.29	0.19
Total Solids	152	147	126	138	145	154	174	119
Total Dissolved Solids	66	42	54	105	84	102	75	79
Total Volatile Solids	82	86	43	97	73	84	76	60
Total Fixed Solids	70	61	83	41	72	70	98	59
Total Suspended Solids	86	105	72	133	61	52	99	40
Settleable Solids	59	91	66	133	24	46	34	31
Total Phosphate	0.60	0.60	1.15	0.75	1.35	0.90	1.31	0.07
Orthophosphate	0.04	0.07	0.06	0.36	0.09	0.14	0.02	0.04
pH	8.4	6.9	7,8	7.0	7.2	6.0	6.5	6.5
Hardness	30	20	20	30	20	30	40	17
Chloride	5.0	10.5	10.0	10.0	20.0	12.5	10.0	8.5
Water Temperature	84	84	84	84	83	82	-	-

Table 31. WATER QUALITY DATA, RACEWAYS, 9/19/73

Parameter	Raceway						Oxidation Pond	
	EG1	EG8	EF1	EF11	ED1	ED17	EGFX	EDX
Stocking Rate	2000	2000	2000	2000	1500	1500	-	-
No. of Units	7	7	10	10	16	16	-	-
Flow Rate	350	350	350	350	350	350	-	-
Surface Area	-	-	-	-	-	-	3.4	7.8
Water Volume	-	-	-	-	-	-	20.2	47.0
Fish Weight	14,096	14,096	20,137	20,137	24,164	24,164	0	0
Amount Fed	224	224	320	320	384	384	0	0
D.O.	8.8	8.2	8.4	8.0	9.0	7.8	-	-
BOD	5.6	9.2	6.4	8.0	6.4	8.0	8.0	6.4
COD	8	35	22	30	41	42	32	20
Total Kjeldahl Nitrogen	5.85	7.93	9.00	6.66	7.47	7.47	6.05	6.22
Ammonia Nitrogen	0.19	0.47	0.28	0.37	0.37	0.75	0.28	0.28
Nitrate + Nitrite - N	0.17	0.32	0.18	0.22	0.34	0.41	0.23	0.24
Total Solids	126	177	163	136	141	169	143	126
Total Dissolved Solids	62	94	82	90	94	61	63	91
Total Volatile Solids	51	82	54	60	60	63	51	44
Total Fixed Solids	75	95	109	76	81	106	92	82
Total Suspended Solids	64	83	81	46	47	108	80	35
Settleable Solids	13	50	70	15	17	63	61	17
Total Phosphate	0.65	0.79	0.66	0.52	0.49	0.24	0.92	0.35
Orthophosphate	0.06	0.04	0	0.03	0.03	0.03	0.02	0.08
pH	7.7	6.8	7.0	7.0	7.4	7.1	7.5	7.6
Hardness	30	31	38	40	40	30	35	30
Chloride	10.0	8.5	9.5	8.5	12.5	10.0	10.0	12.5
Water Temperature	77	76	77	77	77	77	-	-

Table 32. WATER QUALITY DATA, RACEWAYS, 8/14/73

Parameter	Raceway							
	5 AM		11 AM		5 PM		11 PM	
	TR1	TR8	TR1	TR8	TR1	TR8	TR1	TR8
Stocking Rate	2250	2250	2250	2250	2250	2250	2250	2250
No. of Units	8	8	8	8	8	8	8	8
Flow Rate	530	530	530	530	530	530	530	530
Fish Weight	12,983	12,983	12,983	12,983	12,983	12,983	12,983	12,983
Amount Fed	159	159	159	159	159	159	159	159
D.O.	-	-	-	-	-	-	-	-
BOD	7.5	3.3	5.8	4.2	4.9	5.3	4.1	6.1
COD	31	39	30	31	26	30	21	33
Total Kjeldahl Nitrogen	5.76	8.17	6.58	8.62	5.26	10.85	4.42	10.70
Ammonia Nitrogen	0	0.65	0.84	0.93	0.47	0.56	0.56	0.75
Nitrate + Nitrite - N	0.11	0.13	0.32	0.44	0.24	0.15	0.11	0.13
Total Solids	147	189	171	235	150	199	144	179
Total Dissolved Solids	116	138	118	136	121	132	117	113
Total Volatile Solids	82	133	91	93	82	79	78	82
Total Fixed Solids	65	56	80	142	68	120	66	97
Total Suspended Solids	31	51	53	99	29	67	27	66
Settleable Solids	5	28	16	94	25	54	26	61
Total Phosphate	0.64	0.62	0.62	0.92	0.87	0.66	0.44	0.60
Orthophosphate	0.11	0.17	0.28	0.32	0.26	0.24	0.07	0.20
pH	7.1	6.8	7.0	6.8	6.8	6.6	7.1	6.9
Hardness	70	80	70	80	75	70	80	70
Chloride	17.5	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Water Temperature	-	-	-	-	-	-	-	-

Table 33. WATER QUALITY DATA, RACEWAYS, 9/4/73

Parameter	Raceway							
	5 AM		11 AM		5 PM		11 PM	
	TR1	TR8	TR1	TR8	TR1	TR8	TR1	TR8
Stocking Rate	2250	2250	2250	2250	2250	2250	2250	2250
No. of Units	8	8	8	8	8	8	8	8
Flow Rate	530	530	530	530	530	530	530	530
Fish Weight	14,943	14,983	14,983	14,983	14,983	14,983	14,983	14,983
Amount Fed	183	183	183	183	183	183	183	183
D.O.	-	-	-	-	-	-	-	-
BOD	5.6	1.6	4.8	3.2	4.0	4.8	4.4	7.2
COD	16	30	4	31	15	40	17	43
Total Kjeldahl Nitrogen	5.30	7.15	4.06	5.57	5.19	11.67	5.02	10.08
Ammonia Nitrogen	0	0.28	0.47	0.56	0.65	0.65	0.47	0.56
Nitrate + Nitrite - N	0.06	0.13	0.12	0.10	0.18	0.12	0.07	0.14
Total Solids	180	191	153	171	178	192	188	202
Total Dissolved Solids	105	107	115	145	122	82	88	131
Total Volatile Solids	123	101	84	83	110	112	135	117
Total Fixed Solids	57	90	69	88	68	80	53	85
Total Suspended Solids	75	84	38	26	56	110	100	71
Settleable Solids	70	46	13	22	51	104	78	42
Total Phosphate	0.50	1.50	0.60	0.70	1.20	1.93	0.98	1.10
Orthophosphate	0.10	0.06	0.03	0.07	0.01	0.10	0.03	0.13
pH	6.8	6.6	6.5	6.5	7.5	6.9	7.0	7.4
Hardness	75	70	80	75	80	75	80	75
Chloride	20.0	20.0	17.5	15.0	17.5	17.5	17.5	20.0
Water Temperature	-	-	-	-	-	-	-	-

Table 34. WATER QUALITY DATA, RACEWAYS, 10/3/73

Parameter	Raceway	
	TR1	TR8
Stocking Rate	2250	2250
No. of Units	8	8
Flow Rate	530	530
Fish Weight	17,650	17,650
Amount Fed	216	216
Dissolved Oxygen	-	-
BOD	7.2	12.4
COD	42	75
Total Kjeldahl Nitrogen	7.12	26.41
Ammonia Nitrogen	0.84	1.96
Nitrite + Nitrate - N	0.30	0.54
Total Solids	161	524
Total Dissolved Solids	77	149
Total Volatile Solids	93	227
Total Fixed Solids	68	297
Total Suspended Solids	84	375
Settleable Solids	57	186
Total Phosphate	0.13	0.95
Orthophosphate	0	0.82
pH	7.2	7.1
Hardness	90	95
Chloride	15.0	10.5
Water Temperature	-	-

Table 35. WATER QUALITY DATA, RACEWAYS, 10/18/73

Parameter	Reservoir	Raceway				
	TPO	TRT	TR8	TD1	TD2	TD3
Stocking Rate	0	2250	2250	2250	2250	2250
No. of Units	-	8	8	8	8	8
Flow Rate	-	530	530	530	530	530
Surface Area	5	-	-	-	-	-
Water Volume	20	-	-	-	-	-
Fish Weight	-	19,050	19,050	19,050	19,050	19,050
Amount Fed	0	233	233	233	233	233
Dissolved Oxygen	-	-	-	-	-	-
BOD	3.2	1.2	3.2	7.2	4.0	10.0
COD	15	20	39	62	40	76
Total Kjeldahl Notrogen	8.00	7.92	7.82	9.58	8.44	9.67
Ammonia Nitrogen	0.65	0.47	0.93	1.77	1.31	2.52
Nitrite + Nitrate - N	0.27	0.25	0.33	0.48	0.33	0.58
Total Solids	213	177	218	292	250	292
Total Dissolved Solids	126	144	131	118	104	136
Total Volatile Solids	81	69	89	69	128	77
Total Fixed Solids	132	108	129	223	122	215
Total Suspended Solids	87	33	87	174	146	156
Settleable Solids	54	29	54	80	84	136
Total Phosphate	0.18	0.29	0.71	1.32	3.30	2.40
Orthophosphate	0.09	0.02	0.15	0.65	0.81	1.30
pH	7.6	7.1	7.4	6.9	6.2	7.3
Hardness	110	120	120	135	125	150
Chloride	10.0	15.0	12.5	15.0	10.0	10.0
Water Temperature	-	-	-	-	-	-

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16. Abstract

A literature review and field study was undertaken to determine the waste concentrations and discharge loadings occurring in the waters from catfish-culturing ponds and raceways. Water quality analyses were performed on samples taken during a 240-day growing season and at drawdown (assuming drainage at harvest).

The natural biological degradation of the raw wastes in the ponds and raceway systems resulted in BOD reductions of 96.8% and 98.0% respectively when compared to waste levels produced in indoor single pass tank systems with no waste removal facilities. Reductions in total nitrogen of 97.2% and 97.7% occurred in ponds and raceways respectively, while ammonia nitrogen was reduced by 97.4% and 99.4% respectively. Sedimentation and biodegradation resulted in an 83.6% reduction in suspended solids in ponds and an 86.2% suspended solids reduction in raceways. Total phosphate levels were reduced by 98.5% and 97.4% in ponds and raceways respectively.

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