Date of Report: September 4, 1997

LCMR Research Work Program 1993

I. Project Title: Alternative Aquaculture Methods

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A. Legal Citation: M.L. 93 Chpt. 172, Sect. 14, Subd. 3(f).

Total Biennial LCMR Budget: $230,000.
Balance: 9,900.

Appropriation Language: This appropriation is from the future resources fund to the commissioner of agriculture to develop and evaluate alternative methods of raising fish, focusing on water conservation through waste removal and collection involving recirculating aquaculture systems. Grant requests to supplement this appropriation must be submitted to the U.S. department of agriculture and the national sea grant program and the results reported to the Legislative Commission on Minnesota Resources.

The project is extended to December 31, 1995; on that date the appropriations cancel and no further payment is authorized, Minnesota Laws 1995, Chap. 220, Sec. 19, Subd. 19.

B. LMIC Compatible Data Language: N/A

C. Status of Match Requirement: N/A, except submission of grant requests to U.S.D.A. and Sea Grant. A grant request "An Ecosystem Approach to Integrated Cage Aquaculture in Minnesota Mine Pit Lakes" has been submitted to U. S. Department of Agriculture in cooperation with the Bemidji State University as of April 18, 1994. The proposal to USDA was not funded. Efforts to apply for Sea Grant funding were not successful because Sea Grant requires a Principal Investigator be affiliated with a research institution. A joint effort between the University of Minnesota, Department of Fisheries Wildlife and the Minnesota Department of Agriculture was successful in seeking North Central Regional Aquaculture Center funding, also USDA funds, in the amount of $27,000 commencing September, 1996.

II. **Project Summary**:

Aquaculture is a potentially large contributor to Minnesota's economy. Traditional methodology of aquaculture production involves a large volume of water and fish waste is usually discharged into the environment, though in a diluted form. Recirculating aquaculture systems, on the other hand, recycles water by employing a biofilter. The development of recirculating aquaculture technology will 1) conserve water needed to raise large quantity of fish; 2) reduce the amount of fish waste discharged into the environment through waste collection and removal. The key to the success of employing this technology is a functional biological filter. The goal of this study is to assess technical viability of different biological filters in recirculating fish culture systems and the economic feasibility of using these systems.

Three recirculating systems utilizing different biofilters will be designed, constructed and analyzed in this study. These three biofilters have been selected as the most promising for commercial application. Tilapia will be raised in each of the systems at designed and maximum loading capacity. Capital and variable costs of raising fish will be monitored on an individual tank system basis. Results will be demonstrated to the aquaculture industry for an update of state of the art technology and for references on technology transfer for potential commercial application in the state. The entire project will be carried out in the recently completed

Fisheries/Aquaculture Lab on the St. Paul Campus in conjunction with the Department of Fisheries and Wildlife of the University of Minnesota.

III. Statement of Objectives:

A. Construction/assembly of recirculating systems.

B. Comparison of different systems.

C. Demonstration of fish production in recirculating systems.

IV. Research Objectives:

A. Title of Objective: Set-up of recirculating systems.

A.1. Activity: Design and purchase of components for recirculating systems.

A.1.a.: Context within the project: Despite certain designs and prototypes are available on the market and exist in literature, some design is needed to evaluate the technical and economical feasibility of the technology as outlined in this project.

A.1.b. Methods: Three recirculating aquaculture systems containing different biofilters, will be constructed on the newly established Fisheries/Aquaculture Lab on the University St. Paul Campus for comparison of technical and economical feasibility. Six 3,000 gallon tanks will be used for fish culture tanks. Water from each fish tank will be pumped into a filter tank.

Three biofilters will be constructed in different filter tanks; fluidized bed filter, a trickle down filter and a micro filament filter. Filter capacity will be designed to sustain production of 1.5 lb. of fish per gallon of water per year, or as much as state of the art technology allows, assuming the systems are operated continuously year round.

Solid removal will be accompanied by employing screen filters. Gas transfer and solid removal will be designed in an equitable fashion to maintain a similar impact on water quality in each system. Automatic feeders will be installed on all fish tanks.

A commercial scale design and accompanying economic projection will be developed based on the laboratory testing results. This design can then be used as a starting point for fish farmers and perspective fish farmers in the pursuit of developing their own-aquaculture recirculating systems.

A.1.c. Materials: Research of presently operational recirculating systems will be needed to develop accurate design parameters. Materials needed may include standard design tools such as calculators, rulers, pencils and CAD (computer aided design) program.

A.1.d. Budget: $6,000. balance: $0

A.1.e. Timeline:

	7/93	1/94	6/94	1/95	6/95	12/95
Literature review	***					
Design development	***					
Scale-up design					****	****

A.2. Activity: Assembly/construction/installation and testing of recirculating systems.

A.2.a: Context within the project: Assembly/construction is the realization of the design plan. As the technology is still in research phase, construction of systems in accordance with the design plan will not be an easy task. Ingenuity will be needed to make the plan fit the practice. Lack of design comprehension where theoretical information is insufficient will be complemented by trial and error.

A.2.b. Methods: Recirculating aquaculture systems, according to the plan, will be assembled/constructed in the Fisheries/Aquaculture Laboratory at the Department of Fisheries and Wildlife of the University of Minnesota on St. Paul Campus, a recently completed LCMR project. The system will be supplied with aerated well water for initial water supply and for daily make-up water. Equipment such as tanks, biological filters, screen filters, pipes, pumps, etc. will be purchased on the market for the construction. A certain amount of self-manufacturing may be required to complete the installation of the systems.

Once the systems are assembled, they will be tested to ensure the systems are running mechanically sound. Nitrifying bacteria will be inoculated into the systems. Fish loading density will be gradually increased throughout the testing period to augment a healthy bacteria growth on the filter media.

Oversights or breakdowns resulting from immaturity of the technology will be fixed or adjusted during testing period. Improvements on the design may also be made at this time. Equity among different systems will be taken into consideration whenever changes are being made.

Waste water from the recirculating systems will be discharged into St. Paul sanitary sewer system. Pollutant content of nitrogen, phosphorus and solids will be monitored before discharge.

A.2.c. Materials: A variety of materials are needed to accomplish this objective. Materials needed to construct fish culture systems will include fish tanks, screen filters, biological filters, PVC piping, water and air pumps, plastic tubing, air stones, etc. An attempt will be made for supply vendors to donate some of these materials since the project has a demonstration aspect.

Pure oxygen may be needed to ensure that sufficient oxygen is supplied to the fish and in order for the fish tanks to run at a maximum capacity. A solids removal device may be installed to keep water relatively free of solids.

Typical construction tools will also be needed for assembly of systems and transportation of materials. Other materials may include water quality analysis devices such as an oxygen meter, Hach testing kits etc.

A.2.d. Budget: $80,000. Balance for this activity is approximately $0.

A.2.e. Timeline:

	7/93	1/94	6/94	1/95	6/95
Purchase of materials	* * ***				
Assembly/construction		******			
Testing and adjustment		****			

A.3. Status: The design of the systems is completed. A portion of the project, $95,000, is subcontracted to the University in order to utilize the technical expertise and laboratory facilities of the University. Ying Ji of the Minnesota Department of Agriculture and Jay Maher of the University of Minnesota took an investigative trip of the East Coast to gather recent advances of recirculating aquaculture technology. As a result, screen technology has been brought to Glacial Hills fish farm near Starbuck, MN and almost a half dozen of other farms in Minnesota using recirculating aquaculture systems.

A two day workshop of the project advisors consisting of university professors, fish farmer and the department was convened last July during which primary design of the systems was laid out. It was the consensus of the Advisory Group that rotating biological filter systems are less than up to date technology and may not be suited for cold water fish operations. Fluidized bed filter systems are better suited for the evaluation of the technology. There is a current operation of fluidized bed systems in Albert Lea, MN. Therefore, the three systems being evaluated are: trickle filter system, submerged thin film system and fluidized bed system.

In order to evaluate the systems at a near commercial scale, system capacity was changed from 800 gallons to 3,000 gallons. Search for supplies and readjustment of design to material limitations have been under going since fall of 1993.

Commercial size recirculating aquaculture systems are normally between 5,000 and 10,000 gallons. In order to evaluate the technology, 3,000 gallon systems are more comparable to commercial scale operations. This change will make the evaluation much more valid in terms of actual industrial application and for the amount of fish being produced by the project which could be used as an indirect indicator of applicability of the technology. However, the trade off of the change is that the cost of purchasing and constructing the systems and time needed for procuring and manufacturing of the materials at a larger scale is much extended which may result in a delayed start of system's operation.

When the size of the systems being compared was upgraded to 3,000 gallons, the cost of cooling water in the summer to sustain an optimum temperature for trout became prohibitive. Therefore, trout is to be replaced with a warm water fish, tilapia.

The focal point of the experiment is not fish, but the systems within which the fish are raised. Testing is performed on comparisons of different systems. Trout or tilapia is only an experimental material. Trout is a more familiar fish to Minnesota. However, tilapia is gaining recognition as an aquaculture product. Tilapia was Fish of the Year for 1993, according to Seafood Leader, a leading seafood industry trade magazine, because it ranked number one in terms of number of people who tried it as a new fish in 1993. Tilapia production in the United States is trailing closely to salmon production. Industry experts predict that within a year or two, domestic tilapia production (not including imports) will exceed that of trout to become number three fish in farmed fish products. There is tremendous interest among Minnesota farmers to raise tilapia as a commercial business, such as exhibited at the Eighth Annual Minnesota Aquaculture Conference. North Dakota has a multi-million dollar operation, "Fish 'N Dakota", whose sole product is tilapia.

Six 3,000 gallon fish culture tanks, fluidized sand filter system and submerged thin film filter have been purchased, assembled/installed on the St. Paul Campus of the University. The systems have gone through initial test run and approximately 15,000 fish have been introduced into the systems. Numerous groups have toured the facility and were very enthused by the complexity and the amount of aquaculture principles and technology incorporated in the project.

Scale-up design is accomplished through the economic analysis of systems. The technical setup of the expanded commercial systems are similar to 3,000 gallon systems.

A.4. Final Status: Description of Systems Setup

The recirculating aquaculture systems were designed with the criterion of sustaining a maximum feeding rate of 15 pounds (6.8 kg) of feed per day without pure oxygen addition and 30 pounds (13.6 kg) of feed per day with pure oxygen addition. Each system was replicated twice. Components contained in each system included a 3000 gallon (11.4 m^3) culture tank; a Hydrotech screen filter for solids removal; a 2000 watt immersion heater; ten air diffusers for aeration and gas stripping; and an automatic feeder. In each tank the water flowed by gravity to the screen filters to avoid further disintegration of waste materials by the action of a pump. Water flow to the biofilters was such that an amount approximately equal to the total volume of the culture tank passed through the filter each hour.

Trickling filter system.

The trickling filters were designed by Dr. Thomas Losordo, a faculty member of the Departments of Zoology and Agricultural and Biological Engineering, North Carolina State University. Dr. Losordo has considerable experience in the design and operation of recirculating aquaculture systems and served as an advisor to the project.

The media used in the trickling filters was extruded polypropylene which was formed into blocks of hexagonal tubes (Nida-Core Corp., Hoboken, NJ). The blocks were approximately 4 inches (10.2 cm) square by 30 inches (76.2 cm) in length. The tubes were approximately 0.3125 inches (8 mm) in diameter. Eighty-nine full sized blocks were glued and cut to fit inside a 48-inch (1.22 m) diameter polyethylene tank. Two stacks of the material were used in each filter tank to give a total media height of 60 inches (1.52 m). Surface area of the blocks was calculated as 128 ft^2/ft^3 (411 m^2/m^3). The total amount of media installed in each filter was 49.5 ft^3 (1.4 m^3). Total surface area available on the media was estimated to be 6340 ft^2 (589 m^2).

Water exited the fish culture tank and flowed by gravity through the Hydrotech screen filter. As it left the screen filter it flowed directly to a 1/2 hp centrifugal pump and a 60 gallon (227 L) reservoir (Figure 1). The reservoir acted as a buffer for the pump to prevent it from drawing air as the water flow slowed due to clogging of the screen filter. The water was then pumped to the top of the trickling filter and distributed over the top of the media by a rotating spray bar. The spray bar was driven by the jet action of the water exiting the spray bar in opposite directions on each half of the bar. The rotating spray bar gave a pulsed flow of water in the tubes. Air was pulled down the tube with each pulse of water, aiding gas exchange in the biofilter. A small blower was used to push air in the opposite direction to the flow of water to further aid the removal of carbon dioxide and the addition of oxygen in the filter. Water collected in the bottom of the filter and flowed by gravity back to the culture tank.

Fluidized bed sand filter system

The fluidized bed sand filters were designed by Dr. Dallas Weaver, (Scientific Hatcheries, Huntington Beach, CA) and marketed by Aquaneering, (San Diego, CA). Similar systems are in place at the Freshwater Institute, Shepherdstown, WV, and in a private facility near Albert Lea, MN.

The sand filter consisted of a fiberglass tank 84 inches (2.13 m) high and 42 inches (1.07 m) in diameter. The inside bottom of the tank was lined with concrete bricks to prevent erosion of the walls by the fluidized sand. Each filter was filled with 2000 pounds (907.2 kg) of fine silica sand (Unimin 5010, see Table 1 for sieve analysis, Unimin Corp., Ottawa, MN).

The water flow in the fluidized bed system was similar to that of the trickling filter, using the Hydrotech screen filter and reservoir with a 1/2 hp centrifugal pump (Figure 2). The water was pumped to a manifold on the top of the sand filter tank. This manifold supplied water to seven probes made of 1.5-inch (3.81 cm) PVC pipe which extended to the bottom of the tank. The probes were capped at the bottom and had orifices drilled to allow the water to exit. As the water flowed through the sand, the sand bed expanded and became fluidized. The fine sand used in these filters had an estimated specific surface area of 3050 ft^2/ft^3 (approximately 1 ha/m^3)(Weaver, 1991). Two thousand pounds (907.2 kg) of sand provided an estimated 61000 ft^2 (5667 m^2) of surface area.

Submerged thin film filter system

The submerged thin film filters used in the evaluation were based on the filters used in systems of Glacial Hills Inc., St. Louis Park, MN.

Table 1. Sieve analysis for sand types used in fluidized bed filters. Values are typical mean percentages retained on individual sieves (data provided by Unimin Corp.)

Mesh (ASTM E-11)	Unimin 5010	Unimin 5020
20	0	0
30	0	0
35	0	0
40	0.1	2.7
50	12.9	20.6
70	28.2	36.5
100	34.4	26.3
140	19.0	11.4
200	4.8	2.5
270	0.5	0
Pan	0.1	0

As in the other systems, the water from the culture tank flowed by gravity through the Hydrotech screen filter for particulate removal. After exiting the screen filter the water went directly to airlift tubes and was pumped into the biofilter (Figure 3). No reservoir was needed as the airlift pumping action essentially self-regulated output in accordance with the amount of water available. The biofilter was housed in a polyethylene tank 53 inches (1.35 m) in diameter and 64 inches (1.63 m) in height. Normal water level in the tank was 60 inches (1.52 m), giving a water volume of approximately 570 gallons (2.16 m^3). Water was introduced at the bottom of the filter tank and flowed upward through the media and out an overflow on the side of the tank. After leaving the biofilter the water was airlifted back into the culture tank.

The media in the biofilter consisted of strips of thin plastic film wrapped top to bottom around frames of 0.5 inch (1.27 cm) PVC pipe. The film was a two-ply material with a portion of each edge folded in toward the center. The unevenly-folded strands were 1 inch (2.54 cm) in width, or 1.5 inches (3.81 cm) in width when unfolded. There were 17 racks, each of which was 61 inches (1.55 m) high and from 30 to 48 inches (0.76 to 1.22 m) in width to conform to the inside of the tank. During assembly the strips were wrapped tightly around the frames and then loosened to allow the strips to move slightly with the water flow. If this movement were to open the folds and separate the plies of each strip, the total surface area available per filter would be approximately 9600 ft^2 (891.8 m^2). If the strips remained unfolded and unseparated, which was largely the case in this study, the total surface area available was estimated to be approximately 3200 ft^2 (297.3 m^2).

<u>Hydrotech Screen Filters for solid removal</u>

Each system used a Hydrotech Model 501 screen filter for removal of particulates. The screen filters were manufactured in Sweden by Hydrotech and marketed in the United States by Zeigler Aquaculture (Gardners, PA). The filter consisted of a drum covered with a 60 micron mesh screen which trapped particles as the water passed through the filter. As the screen clogged with particulates, the level of the water entering the filter rose and a sensor triggered a wash cycle. In the wash cycle, the drum was rotated and a high pressure pump (100 psi) sprayed well water through nozzles located above the screen with considerable force. The spray washed the particulate material into a trough inside the filter which was connected to a waste drain.

Figure 1. Trickling Filter System Layout.

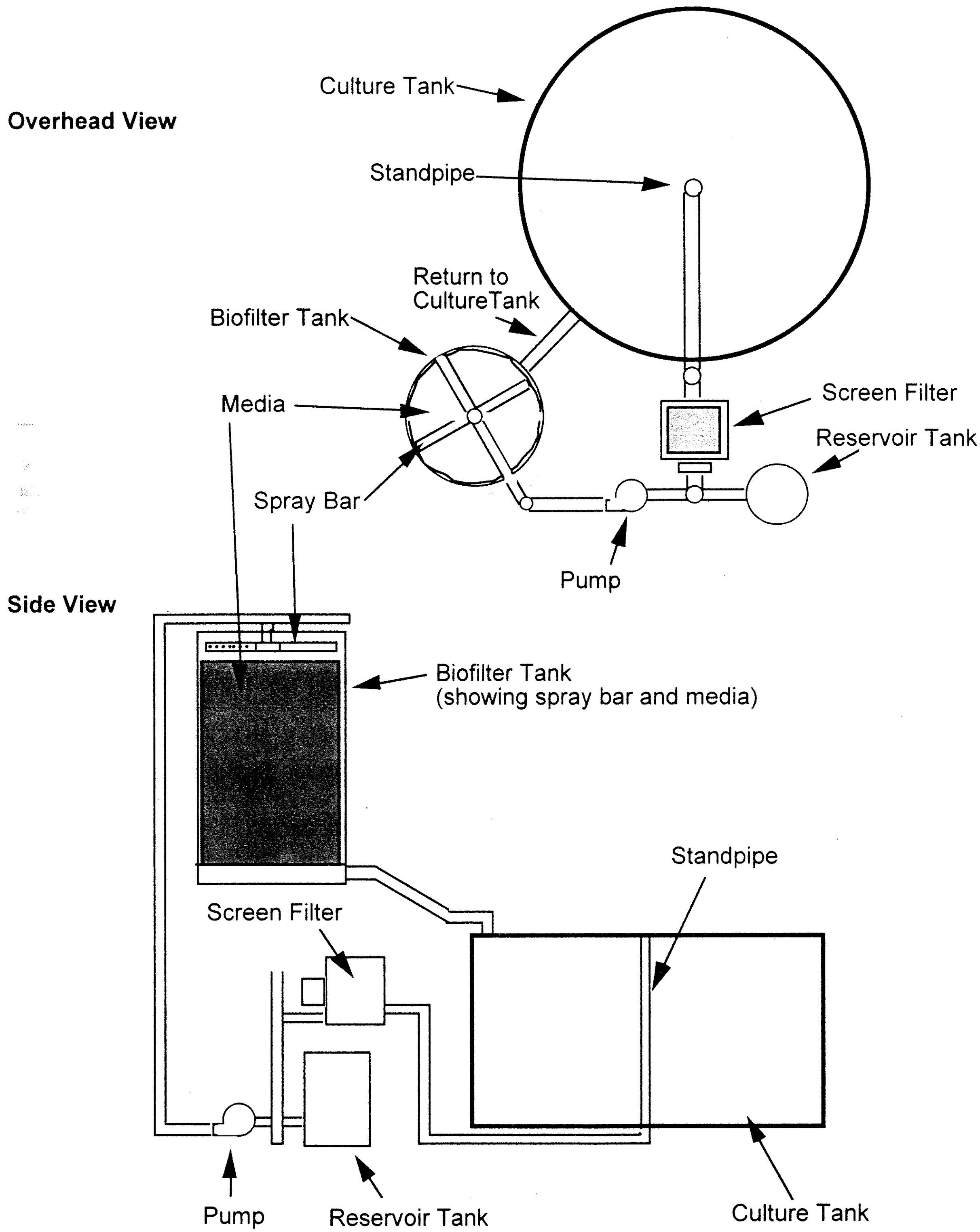


Figure 2. Fluidized Bed Filter System Layout.

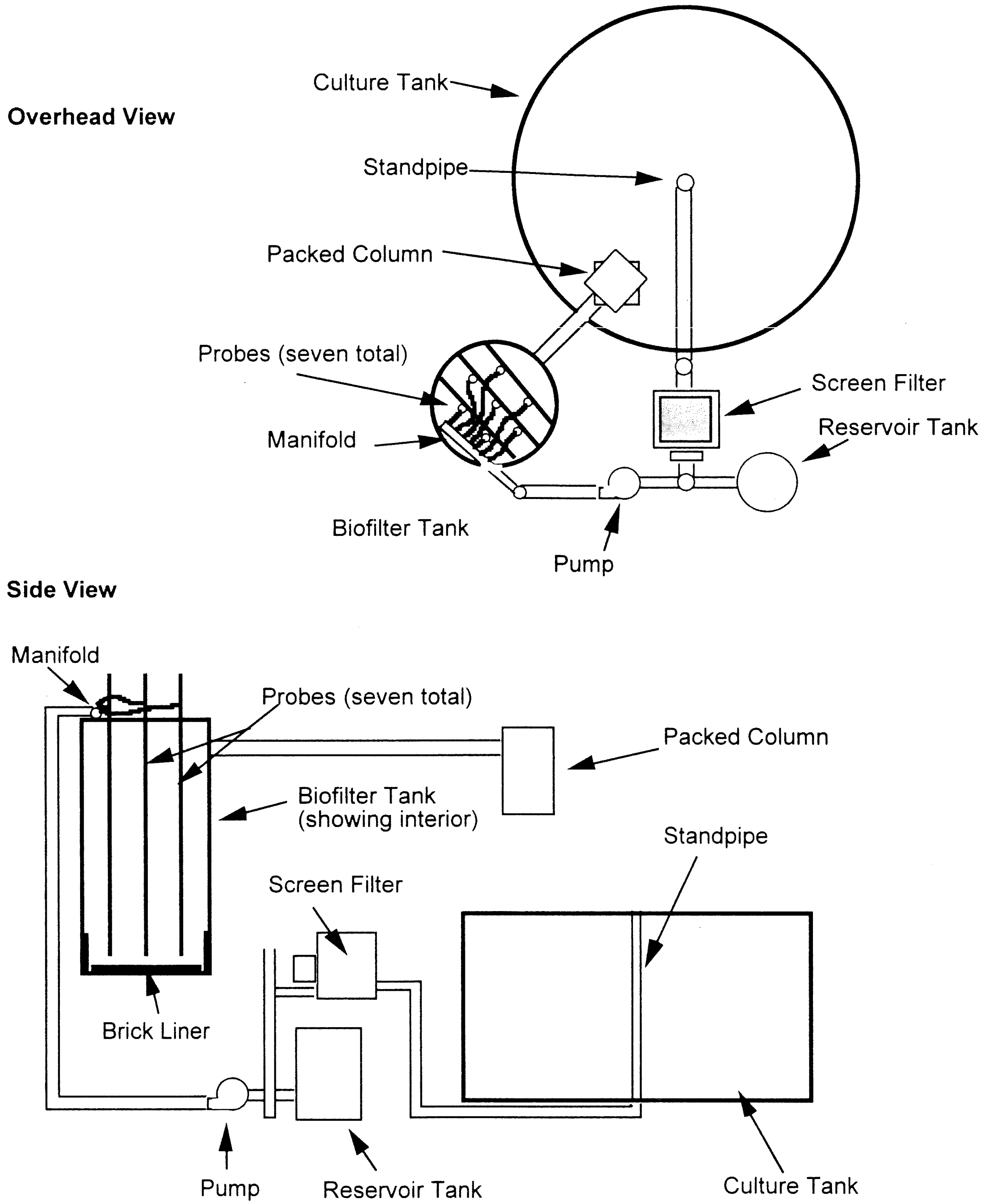
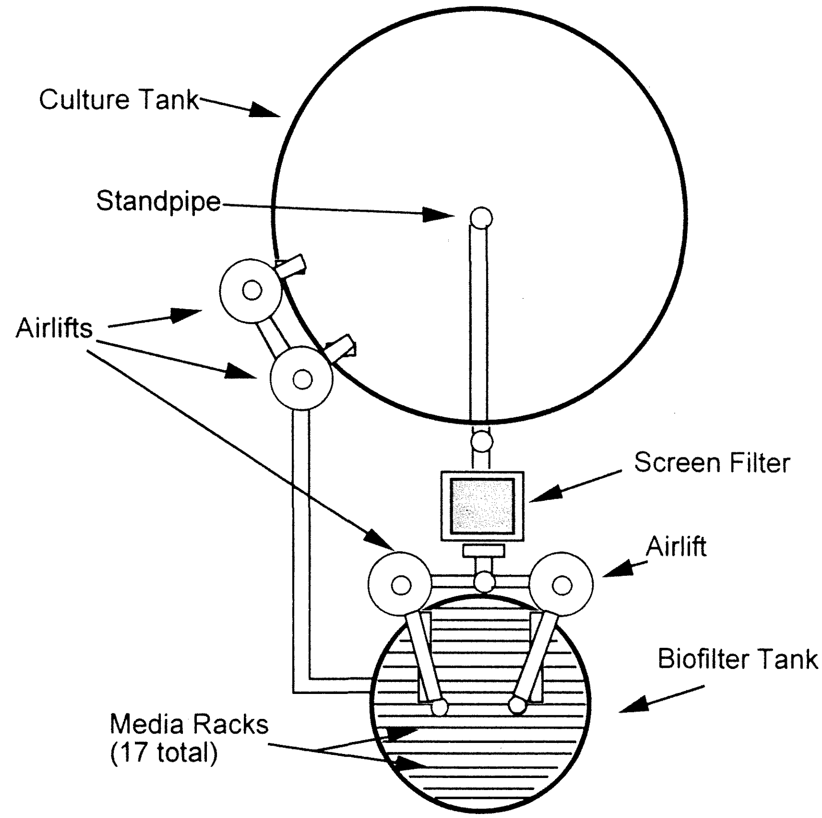
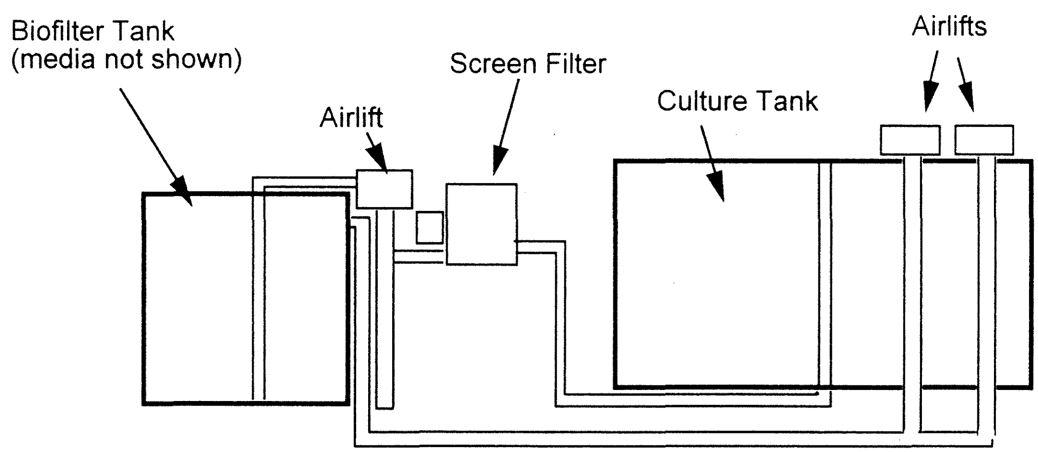


Figure 3. Submerged Thin Film Filter System Layout.

Overhead View



Side View



Start-up of the systems

On December 5, 1994, an estimated 15,000 tilapia *(Oreochromis nilotica)* fry were obtained from the Min-Kota Fisheries production facility in Philip, South Dakota. The fry were first held in floating nets in one of the fish culture tanks to facilitate raising them to a larger, more manageable size.

On February 11, 1995, the tilapia fingerlings were distributed among the six fish culture tanks. A total of 1750 fish were randomly assigned to each of the tanks. The average fish weight was 8.3 g. Fish continued to be held in floating cages constructed of 0.25 inch (6 mm) plastic mesh to aggregate them for feeding. Cages were cylindrical in shape, 4 ft (1.23 m) in diameter and 4 ft (1.23 m) deep.

Within one week of introducing fish into the systems, problems with equipment malfunctions began to appear. Overloads or ground faults in the gear motors driving the Hydrotech screen filters often tripped circuit breakers supplying power to the systems. Because the screen filters were below the water level in the culture tank to enable gravity flow, a system failure in the components outside the tank could cause the loss of up to 1200 gallons (4.54 m^3) of water from the system through the waste drain on the screen filter. These failures often occurred at night, resulting in a large loss of water from the system before staff could correct the problem. Correction of the screen filter malfunctions and other problems became an ongoing process of trial and error lasting several months.

Although the manufacturer and distributor of the screen filters were willing and helpful in solving the problems, time lost in trial and error solutions and dealing with an overseas manufacturer resulted in the use of unfiltered water for as long as 1 month. All screen filter motors required modification to conform to our electric service (208 volt AC) and conditions of use. The modified motors functioned reliably on the filters. The other problems associated with the screen filters were caused by failures in the high pressure wash system. Two high pressure hoses and all six of the PVC spray bar assemblies failed. Failure of a high pressure hose would result in loss of water from the culture system when the screens subsequently clogged and the water flow would back up into the waste trough. All of the high pressure hoses were then replaced with hoses of a higher rating. Failures of the spray bar assemblies, typically a split fitting, resulted in the addition of large amounts of cold wash water to the culture tanks. The spray bar assemblies were replaced with five Schedule 80 PVC versions assembled on site and one stainless steel spray bar provided by the distributor. The stainless steel spray bar continues to function reliably. Some of the Schedule 80 versions of the PVC spray bars have failed over time, but with far less frequency than the original lighter weight PVC versions. These failures have been limited to small stress or fatigue cracks and have not resulted in the large additions of wash water experienced with the original equipment.

Another equipment related problem experienced during the project was the loss of sand from the fluidized bed biofilter. Despite operation within design guidelines, sand was continually washed from the filter into the culture tank. Conversations with the system designer suggested two possible causes: 1) the sand grains were too small, enabling them to be lifted out of the filter at the design flow, or 2) air entrained in the pump caused bubbles which floated the sand particles out of the filter. In an attempt to correct the problem, a slightly coarser grade of sand (Unimin 5020, see Table 1) was used for further additions to the filter and the screen filters were lowered to reduce the amount of air entrained by the pump.

As a result of the differential effects of the mechanical problems, any actual differences in system performance could have been confounded. Therefore, during the week from July 14 - 21, 1995, fish were redistributed randomly among the tanks and the experiment was started anew at this time. All fish were removed from the six experimental tanks, counted into lots and weighed. The lots were then randomly assigned to six temporary holding tanks. After all fish were removed, the experimental tanks and filters were cleaned to return them to as even a baseline condition as possible. The fish were then returned to the experimental tanks. Approximately 1565 fish (average weight 191.0 grams) were placed in each tank.

B. Title of Objective: Comparison of different systems.

B.1. Activity: Comparison of fish production in different systems.

B.1.a: Context within the project: This activity is attempted to compare the capacity at which fish are produced and to evaluate different systems for performance fish production, and also to provide a foundation for the next two activities.

B.1.b. Methods: Two types of comparisons will be made. First, tilapia fingerlings will be stocked at an appropriate density and raised to near design density of 0.25 lb/gal within 3-4 months during which time biological filter is fully cultivated. The targeted design capacity of the systems expressed in terms of pounds of feed handled per day will 15 lbs/3,000 gallon tank without pure oxygen addition and 30 lbs/tank with pure oxygen addition. Once the system is running at near design capacity with pure oxygen, first comparison of all systems will be made for about 2 months to evaluate their performance at design capacity. The fish will be fed automatically at a ration after Piper et al. 1971. Fish growth will be measured every two weeks. Excess fish beyond design capacity resulting from growth will be thinned out during measurement. A technician will be hired with responsibility for all fish production and other technical data collection. Statistical analysis will be "analysis of variance".

After 2 months of testing at or near design capacity, the second comparison begins. The second comparison differs from the first in that loading capacity will be increased, by fish growth, in each system every month until it reaches maximum capacity.

A cooperative agreement with a fish farmer was attempted but not completed for provision of entrepreneurial care of fish for maximum efficiency of production. However, negotiation was successful for Minn-Kota Fisheries, a Granite Falls, MN based fish farm company to sponsor the fingerlings and take a partial co-ownership with the University of Minnesota.

B.1.c. Materials: Materials to be used in this activity consist of fish, fish feed, measuring devices and fish nets, etc. Equipment and instruments common to fisheries laboratories may be shared from other projects currently conducted in the lab.

B.1.d. Budget: $76,000. Balance: $0.

B.1.e. Timeline:

	7/93	1/94	6/94	1/95	6/95	12/95
Production at design capacity		********		*********		
Production beyond design capacity			**********		******	
Analysis of production data			***********************			

B.1.F Special Status: As stated in B.3, the project was delayed for a good portion of fiscal year 1994 due to the delayed completion of renovation of Fisheries and Aquaculture Laboratory at the University of Minnesota and due to the underestimation of amount of work it took to assemble 3,000 gallon systems, although much more applicable to real industry situations, compared to 800 gallon systems as was originally proposed. We will be pushing the timetable too much to finish this activity by June 30, 1995. Instead we request to extend it to October, 1995.

Late 1995, all systems, led by fluidized bed systems, became oxygen limited. A Pure oxygen device was installed with all systems. The selection of pure oxygen addition device was limited due to the electric supply of the laboratory. After supplying all existing power consuming devices such as pumps and screen filters, the leftover capacity of the power supply was approximately 4 amps. A concerted effort was made to widely solicit pure oxygen addition devices with the power consumption limit.

Beginning in January of 1996, installation of pure oxygen injection devices manufactured by a local company began. The injectors were designed to be placed directly in the culture tank. The device consisted of a propeller pump which moved tank water past a set of two modules. The modules had a cast plastic head which formed a manifold for numerous thin membrane tubules. Oxygen was introduced into the tubules and would diffuse out through the membrane. The shearing action of the water flow over the tubule would remove the bubbles at a very small size. Small bubbles rise slowly in the water column and allow more time for the oxygen to be absorbed into the water. Through production of bubbles of minimal size and direct dissolution into the culture water, it was hoped that oxygen transfer efficiency would be high.

The devices tested had severe leakage problems where the tubules were inserted into the cast head of the module. The leaks prevented the devices from working as designed. Increased oxygen flow to the device resulted in large, less efficiently absorbed bubbles being formed.

Lab personnel worked with the manufacturer on various methods to seal the leaks but were unsuccessful in providing a permanent solution. Attempts to continue the evaluation with the use of pure oxygen have been abandoned until a suitable oxygen transfer device can be employed.

B.2. Activity: Comparison of water quality.

B.2.a.: Context within the project: Water quality is the key to design and operation of recirculating aquaculture systems. As fish are fed in the systems, fish feces and other waste products of fish metabolism either get removed through solid removal or move onto the biofilter.

Water quality will indicate how successful the system is running and predict if a problem is developing. The impact of a system on fish production is applied through water quality. Fish rely on good water to obtain their oxygen, to discharge metabolic wastes such as ammonia and to sustain an overall healthy environment.

B.2.b. Methods: Three critical points of water quality will be emphasized: incoming and outgoing points of the fish culture tank and the outlet of the filter tank. The outlet of filter tank is important because it indicates the effectiveness of biological filtration, specifically the ability to strip ammonia out of the water. Outflow of the fish culture tank is also the inflow of filter tank which indicates the loading rate of metabolic waste onto the filters. The inflow of the fish culture tank represents the water quality of fish culture after the water is reconditioned.

Temperature, pH and dissolved oxygen will be measured daily, or continually for certain periods of time. Total ammonia-nitrogen concentration, nitrite-nitrogen and nitrate-nitrogen concentrations, turbidity, total suspended solids and total solids will be monitored at various points in each system.

Dissolved oxygen will be measured by an oxygen meter. Total ammonia nitrogen will be measured by a photo spectrometric method. Nitrite and nitrate-nitrogen concentrations will be determined by Hach water chemical analysis. Turbidity, total solids and total suspended solids will be measured by standard methods (APHA, 1990)

B.2.c. Materials: Materials involved in this activity will be water sampling bottles and tubes, water chemistry kits and spectrophotometer and its accessories. An oxygen meter, a pH meter, and recording charts will also be needed.

B.2.d. Budget: $48,000. Balance: $0.

B.2.e. Timeline:

	7/93 1/94 6/94 1/95 6/95 12/95
Sample collection	*************************
Sample Analysis	**** *** **************
Data analysis	**********************

B.2.F Special Status: Same as B.1.F.

B.3. Activity: Comparison of economic feasibility.

B.3.a.: Context within the project: A comparison of different systems is not complete without a comparison of economics. The focus of this comparison, however, is on the cost differences due to employing different biofilters, even though a cost assessment on other components of the systems will also be performed. Effort will not be made specifically on comparing cost effectiveness of different options of components of the systems other than biofilters.

B.3.b. Methods: There are two categories of cost associated with fish production: fixed cost and variable cost. Data collection sheets for collection of these costs will be designed prior to beginning of fish culture.

All fixed costs will be kept separate for each tank system. Tanks, piping, filters, solids removal equipment, oxygen supply equipment and other fixed costs necessary for fish production will be collected during assembly of the systems and when modifications are made. Variable cost data that are distinctively separate from one system to another will also be collected throughout the duration of fish production. Fish feed cost will be calculated based on feed consumed by each tank of fish. Costs that all systems share, e.g. heating, will be estimated on a system basis. Metering devices may be installed if necessary.

Energy cost of cooling water used to rear the fish, if necessary, may be assessed in each of the systems tested. The energy cost of heating the water in the winter is not feasible since this project will be carried out in a university building which is already heated in winter. All cost models will be extrapolated to commercial production size based on the cost data collected and the economic analysis.

B.3.c. Materials: Materials needed for this activity will be computer, spreadsheet software, recording charts and other analytical tools.

B.3.d. Budget: $14,000. Balance: $7,400.

B.3.e. Timeline:

	7/93 1/94 6/94 1/95 6/95 12/95
Data collection design	***** ***
Cost data collection	**********************************
Cost analysis	*************************
Expansion model building	*****************

B.3.f. Special Status: Because of the delay of the project for above mentioned two reasons, this activity will not be completed before June 30, 1995. Taking into consideration of above requested extension, complete economic analysis may not begin until October of 1995. We would like to request an extension of completing this activity by December, 1995.

Economic analysis has been completed. The economic model was expanded to 6 10,000 gallon systems based on the systems carrying capacity as tested in laboratory for each of the three systems tested.

B.4. Status: Approximately 15,000 fish fingerlings were introduced into the systems for the comparison of fish production capacity in different systems in December, 1994. Water quality testing and monitoring systems have been setup. The fish are being fed a formulated diet manufactured by Silver Cup of Utah, a well known fish feed supplier in the industry.

Mr. Richard Fagen of the Min-kota Fisheries of Granite Falls, MN is the private collaborator who supplied the fish as an in-kind contribution to the project. Min-kota Fisheries, as a private entity who has to make fish growing management decisions for its own operation will also be involve in the project in terms how best for the project to benefit real farm operations. In return for Min-kota's contributions, Min-kota retains ownership of the fish throughout the experiment.

On the average the fish has reached a size of 1/3 to 1/2 lb and almost all the systems have reached system limitations without pure oxygen addition, especially the fluidized bed systems. Oxygen addition devices are being put in place to test the systems capabilities when oxygen supply is sufficient. This should be the last equipment installation for the project. Another problem that persists in the fluidized bed system is that it continued to bleed sand out of the fluidized bed. A coarser sand than what was initially designed for has been purchased in an attempt to remedy the problem.

Problems: The project is behind schedule because of two reasons. 1) The delayed availability of the facility where this project is being conducted due to the delay of completion of the University Fisheries and Aquaculture laboratory renovation. 2) It took much longer to construct 3,000 gallon systems compared to 800 gallon tanks. However, the results from 3,000 gallon systems will be much more relevant for industry development. We would like to request an extension till December 1995 for completion of the project as a remedy to the problem.

B.4. Final Status:

B.4.a. Comparison of Fish Production. The fish were fed a 3.5 mm floating tilapia feed (32% protein, Nelson and Sons, Inc., Murray, UT). Feeding rate was increased gradually until the afternoon dissolved oxygen levels became limiting in several of the tanks. Attempts to economically supply the systems with pure oxygen were unsuccessful due to failure of the oxygenation equipment.

After consulting with industry and other researchers, we determined that the endpoint for our experiment (without pure oxygen addition) would be the feeding level at which the tank dissolved oxygen concentration fell below 2.5 mg/l for more than 30 minutes. Feed levels were increased in each tank until this limit was reached. When a tank reached the limit, the feeding rate for that tank was decreased slightly. The systems were then stabilized, holding at that maximum feeding level for approximately 2 weeks.

The procedure for increasing the feeding level was as follows: With a pure oxygen backup system in place to prevent catastrophic fish loss, the feeding rate was increased in all tanks by approximately 0.55 pounds (250 g) per day. Feedings were spread over an 8-hour day. At the first feeding of the day, each tank received 3.3 pounds (1500 g) of feed. The remainder of the feed for the day was split into six or seven increments. If uneaten feed was observed in a tank at the time of the next feeding, the tank was skipped for that interval.

Figure 4 gives a graphical representation of the amount of feed fed to each tank. The amount of feed given to each tank rose steadily and then began to fluctuate around the probable true maximum for each system.

Tank 3 (a fluidized bed system) reached the endpoint first. Fish were removed from that tank, counted and weighed on December 22, 1995. The other five tanks reached the designated endpoint nearly simultaneously, and fish were weighed December 27 -29, 1995. Results are given in Table 2. Fish growth was poor in all of the systems. This was partially due to the leveling off of the feeding rate due to oxygen limitations. As the fish increased in size, the fixed feeding rate became a maintenance ration, limiting growth. Other contributing factors to poor growth, present in some or all of the tanks included: low dissolved oxygen levels; less than optimal temperatures for tilapia growth; elevated ammonia and nitrite levels; and low pH (see water quality section). Feed conversion ratios were also poor due to the same reasons and as a result of the biomass lost from mortality.

Table 2. Growth of tilapia raised in three different recirculating systems for 5.5 months. Feed conversion ratio and percent survival are cumulative for the period.

Tank Number	Number of Fish	Total Weight lbs (kg)	Avg Weight lbs (g)	FCR[d]	Percent Survival
1[a]	1201	1170 (530)	0.97 (441)	3.04	75.4
2[a]	1384	1266 (574)	0.91 (415)	2.48	89.8
3[b]	1316	1239 (562)	0.94 (427)	2.56	82.6
4[b]	1354	1246 (565)	0.92 (417)	2.58	89.0
5[c]	1439	1338 (607)	0.93 (422)	2.21	91.9
6[c]	1301	1307 (593)	1.01 (456)	2.38	81.9

[a] Trickling filter system

[b] Fluidized bed filter system

[c] Submerged thin film filter system

[d] FCR = Feed Conversion Ratio = Total Weight of Feed / Weight Gain

B.4.b. Comparison of Water Quality.

Ammonia can be toxic to fish in recirculating aquaculture systems. The major source of ammonia in these systems is excretion by fish as a byproduct of protein metabolism. Another source is the breakdown of uneaten food and wastes in the culture tank. Ammonia exists in two forms in equilibrium in water, as ionized ammonium ions (NH_4^+) and un-ionized ammonia (NH_3). Un-ionized ammonia is the more toxic form. The equilibrium is temperature and pH dependent. As the pH drops, more of the ammonia is in the relatively non-toxic ionized form. For example, at a temperature of 27°C and a pH of 6.5, only 0.21% of the total ammonia-nitrogen present is in the toxic un-ionized form.

Total ammonia-nitrogen concentrations reached fairly high levels in all of the systems at various times throughout the study (Figure 5). The toxic effect of the ammonia was mediated by relatively low pH in the tanks. Un-ionized ammonia concentrations in the tanks generally stayed below levels which would cause chronic toxicity problems in tilapia (Figure 6). Tilapia are more tolerant of elevated levels of ammonia than more sensitive species such as salmonids. Some tilapia have been shown to acclimate to higher levels of ammonia after chronic exposure to low levels (Redner and Stickney, 1979). Levels of un-ionized ammonia which may adversely affect growth in tilapia range from 0.24 mg/l to 0.5 mg/l (Daud, et al, 1988; Balarin and Haller 1982). We have chosen 0.25 mg/l un-ionized ammonia as the level of concern for this discussion. At this level, the health and growth of the fish may be impacted. As shown in Figure 6, the submerged thin film systems approached and exceeded this level more frequently than the other systems. However, due to fluctuations in pH, the trickling filter and fluidized bed systems did experience higher levels of un-ionized ammonia than shown in the graphs (calculated maximums approximately 0.15 mg/l un-ionized ammonia).

Nitrite is produced by nitrifying bacteria as they oxidize ammonia. In turn, other bacteria oxidize the nitrite to nitrate. Nitrate is relatively non-toxic to fish and can be kept at safe levels with regular water changes. Nitrate levels in this study remained below 80 mg/l in all tanks throughout the study.

Figure 4. Feeding rates (grams/day) for tilapia in recirculating aquaculture systems with three different biofilters for over 5.5 months. Individual data points represent replicated tank system.

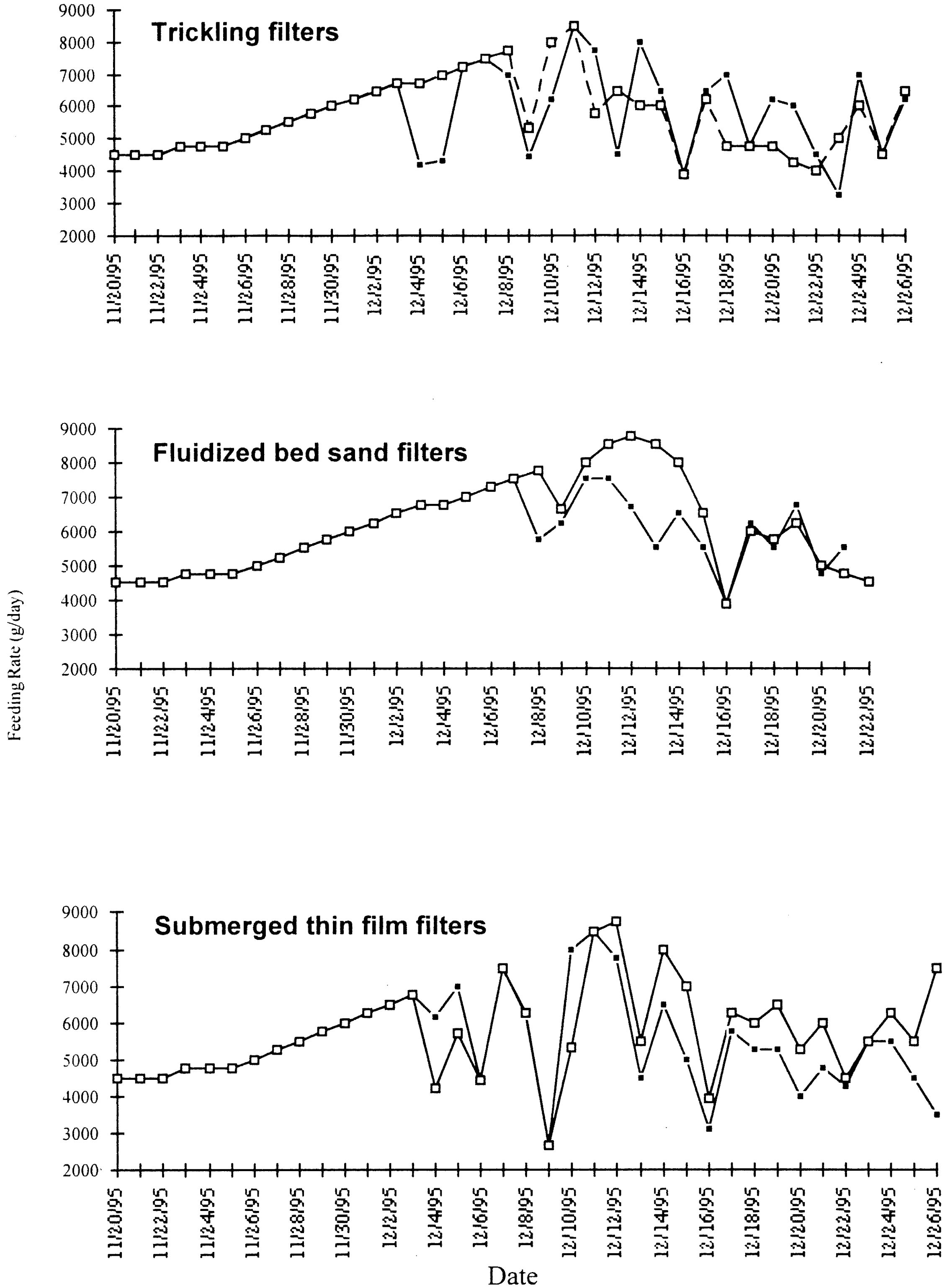


Figure 5. Weekly total ammonia-nitrogen levels (mg/l NH3-N) in three different tilapia recirculating culture systems. Individual data points represent replicated tank systems.

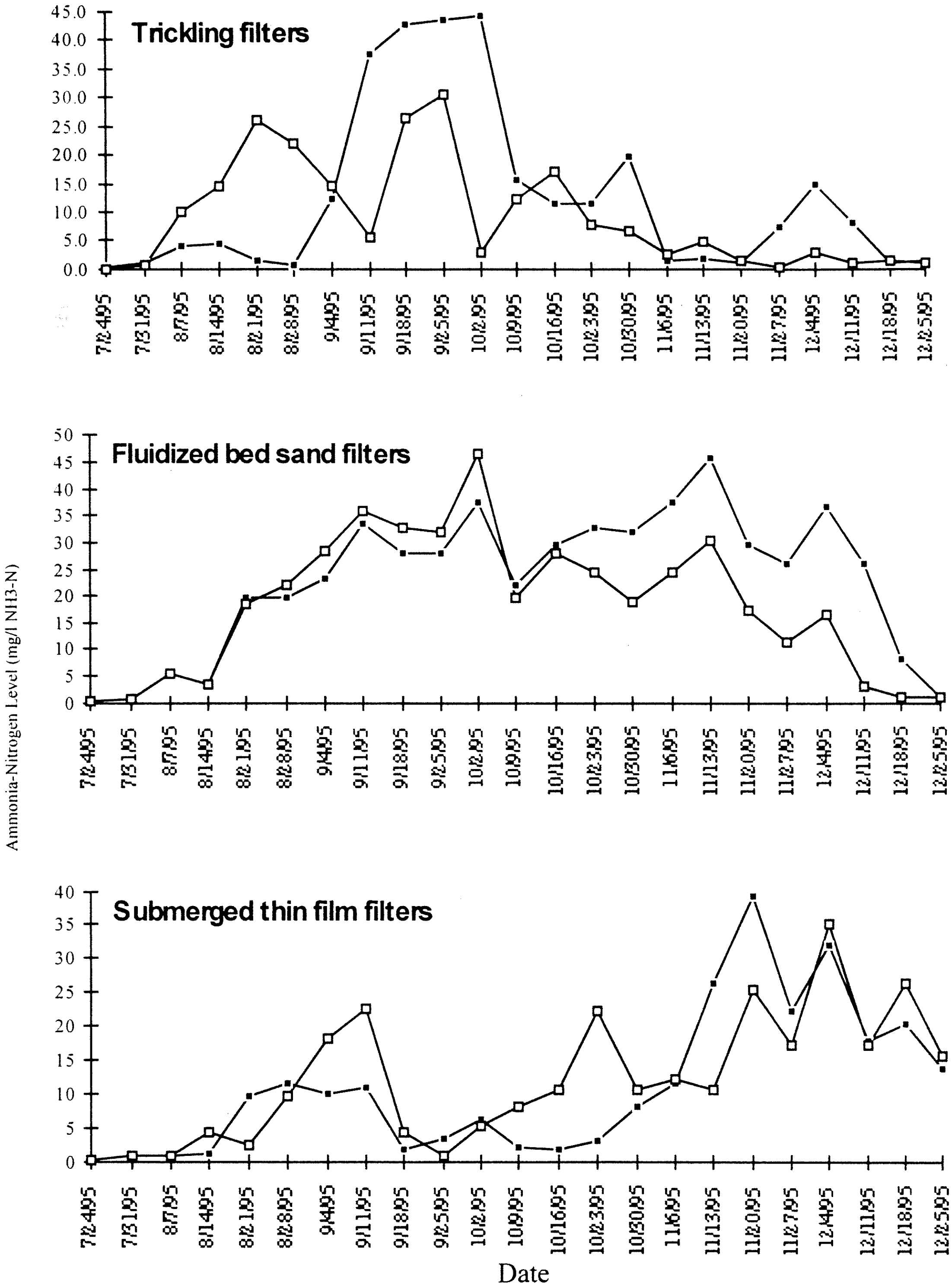
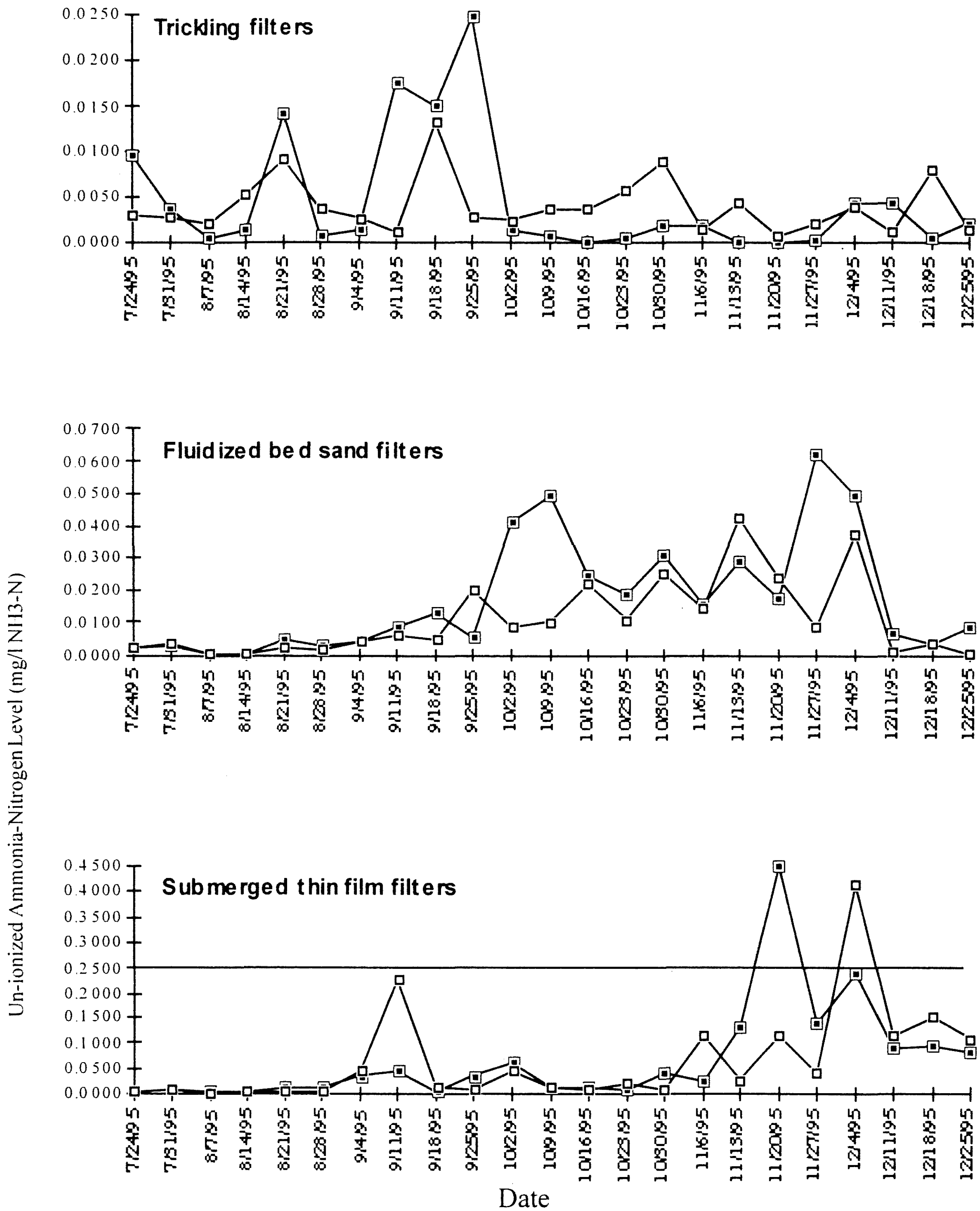


Figure 6. Weekly un-ionized ammonia-nitrogen levels (mg/l NH3-N) in three recirculating tilapia culture tank systems. Data points represent replicate tanks of the systems. Level of concern denoted by straight line.



Nitrite is far more toxic than nitrate to fish. It can cause anemia in fish, impairing their ability to use oxygen. All tanks had nitrite spikes at various times throughout the study (Figure 7). The most severe problems occurred in the submerged thin film tanks where some mortality was observed in connection with elevated levels of nitrite.

Low levels of dissolved oxygen impair fish growth and limit nitrification. Dissolved oxygen levels in the tanks were frequently below the optimum for good growth of tilapia (Figure 8). However, oxygen levels measured at the effluent of the submerged biofilters (fluidized bed and thin film) were not observed to be less than 2 mg/l and thus should not have been limiting to nitrification (Wheaton et al. 1994).

The low pH levels experienced in most of the tanks were a result of the nitrification process (Figure 9). The values listed represent the daily minimum pH as measured before addition of make-up water. When ammonia is oxidized, hydrogen ions are released to the water. As the hydrogen ions use up the alkalinity, or buffering capacity of the water, the pH declines. The rate of alkalinity destruction is therefore related to the amount of feed added to the tank. For most of the study, we attempted to maintain pH levels with the daily addition of relatively high alkalinity (225 mg/l as $CaCO_3$) well water. At lower feeding levels, this was sufficient to maintain the buffering capacity of the water and had the added benefit of removing wastes from the system. As the feeding rate was increased, sodium bicarbonate was used as an alkalinity supplement.

Tank temperatures over the course of the study are given in Figure 10. Temperatures were maintained slightly below the 30°C temperature level which is considered optimum for growth of tilapia. Additions of cold wash water from the drum filters were partially responsible for the lower temperatures. The 2,000 watt immersion heaters were undersized due to limitations in electrical service and were unable to maintain the desired 86°F (30°C) temperatures.

B.4.c. Comparison of Biofilter Performances.

Ammonia removal in the three biofilter types varied greatly. Efficiency was measured as the difference between the influent and effluent concentrations expressed as percent removal of ammonia. Measured values ranged between 0.0 and 98% removal per pass. All filter types exhibited a large range in ammonia removal efficiency during the study period. Daily variations were also common, with two to three-fold differences in measurements taken from morning and evening samples possible.

Trickling filters

The trickling filters had the lowest measured pH levels of the three systems. This reduction in pH, characteristic of the nitrification, process resulted in decreased ammonia removal efficiencies in the biofilter. The nitrification process has an optimal pH range of 6 to 9, though nitrifiers can adapt to pH values outside this range if given enough time (Wheaton, et al. 1994). Individual biofilters or populations of nitrifiers have a narrower pH range reflecting the conditions to which they have adapted. The trickling filter systems experienced large daily fluctuations in pH before sodium bicarbonate began to be added as an alkalinity supplement. These fluctuations resulted in ammonia removal efficiencies of less than 10% per filter pass during periods of low pH. At these low removal rates, total ammonia nitrogen accumulated in the system. When the pH was increased to levels above 6 after the addition of make-up water or sodium bicarbonate, the ammonia removal efficiency rose into the range of 30 to 60 % (total observed range - 0.0 to 98%). After the alkalinity began to be managed with sodium bicarbonate, the trickling filter systems maintained acceptably low levels of total ammonia nitrogen and nitrite while being fed near the design capacity of 15 pounds of feed per day (6.8 kg/day).

The only maintenance required for the trickling filter during the study period was the replacement of the washer in the rotating spray bar assembly. The spray bar was fabricated entirely of PVC pipe and fittings.

Figure 7. Weekly nitrite levels (mg/l NO2) in three different tilapia recirculating culture tanks. Replicate tanks shown in individual data points (note scale differences). Level of concern denoted by dashed line.

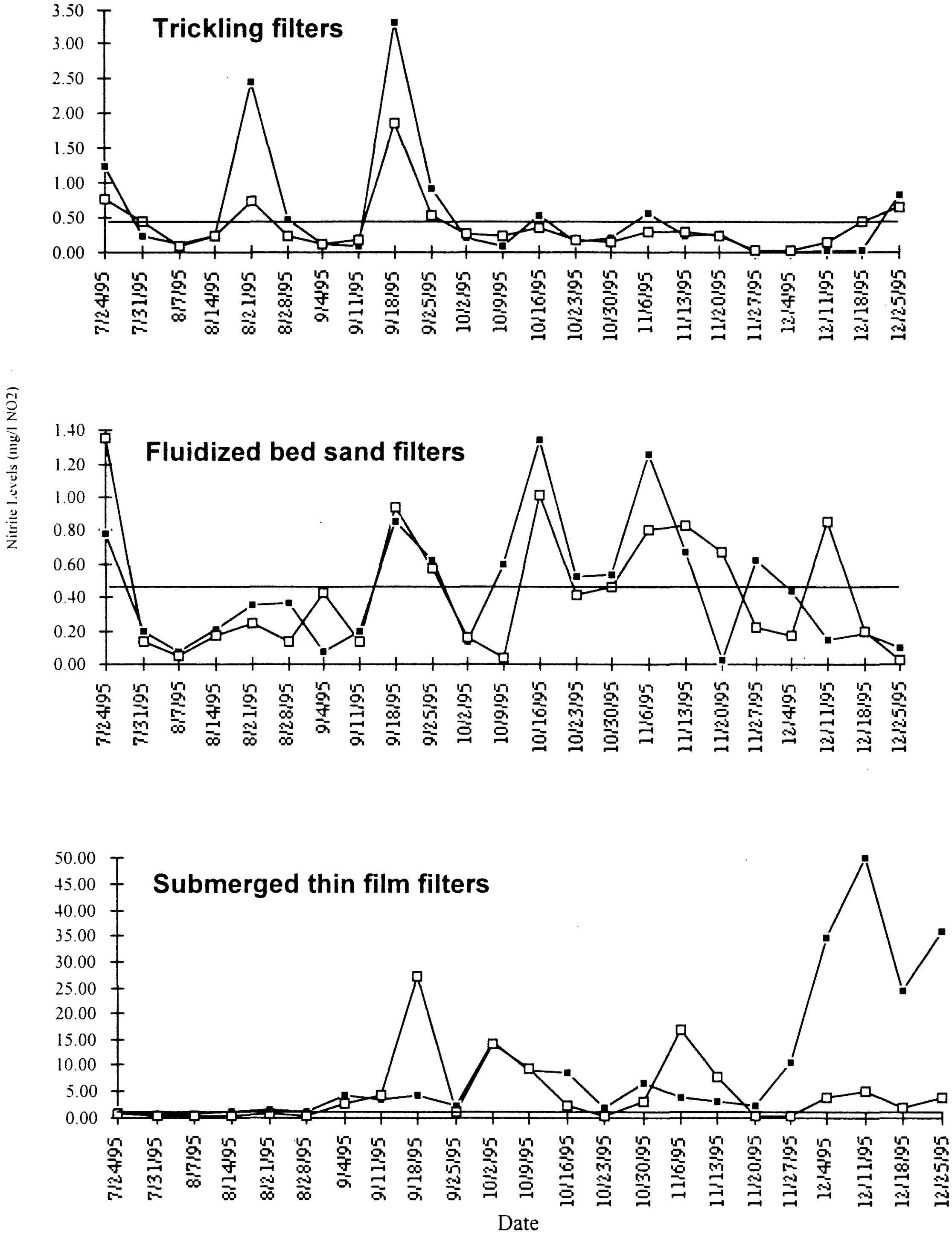


Figure 8. Weekly dissolved oxygen levels (mg/l dissolved oxygen) in three tilapia recirculating culture systems. Replicate tanks are shown in individual data points. Level of concern denoted by dashed line.

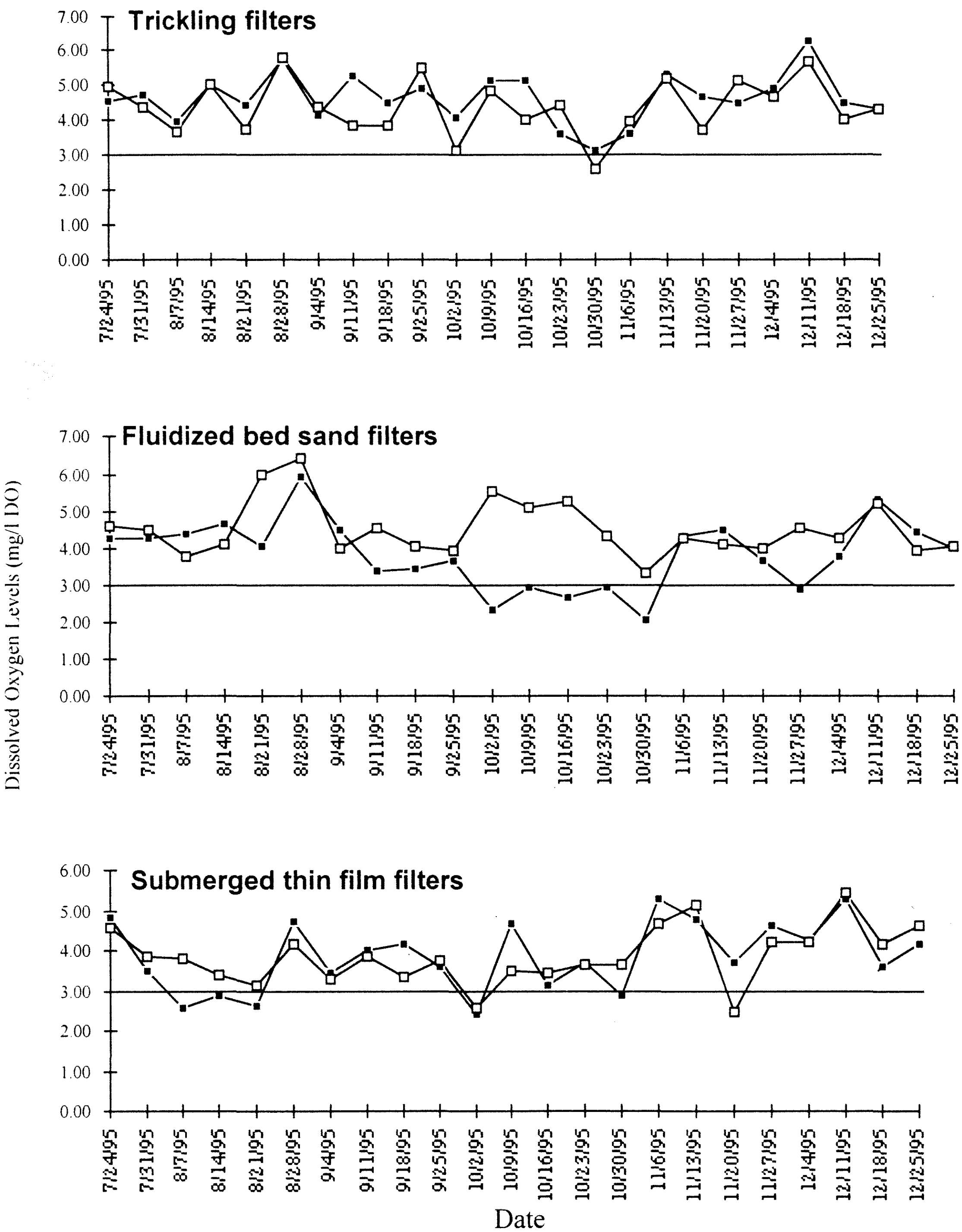


Figure 9. Weekly pH levels in three recirculating tilapia culture systems. Replicate tanks are shown as individual data points. Level of concern denoted by dashed line.

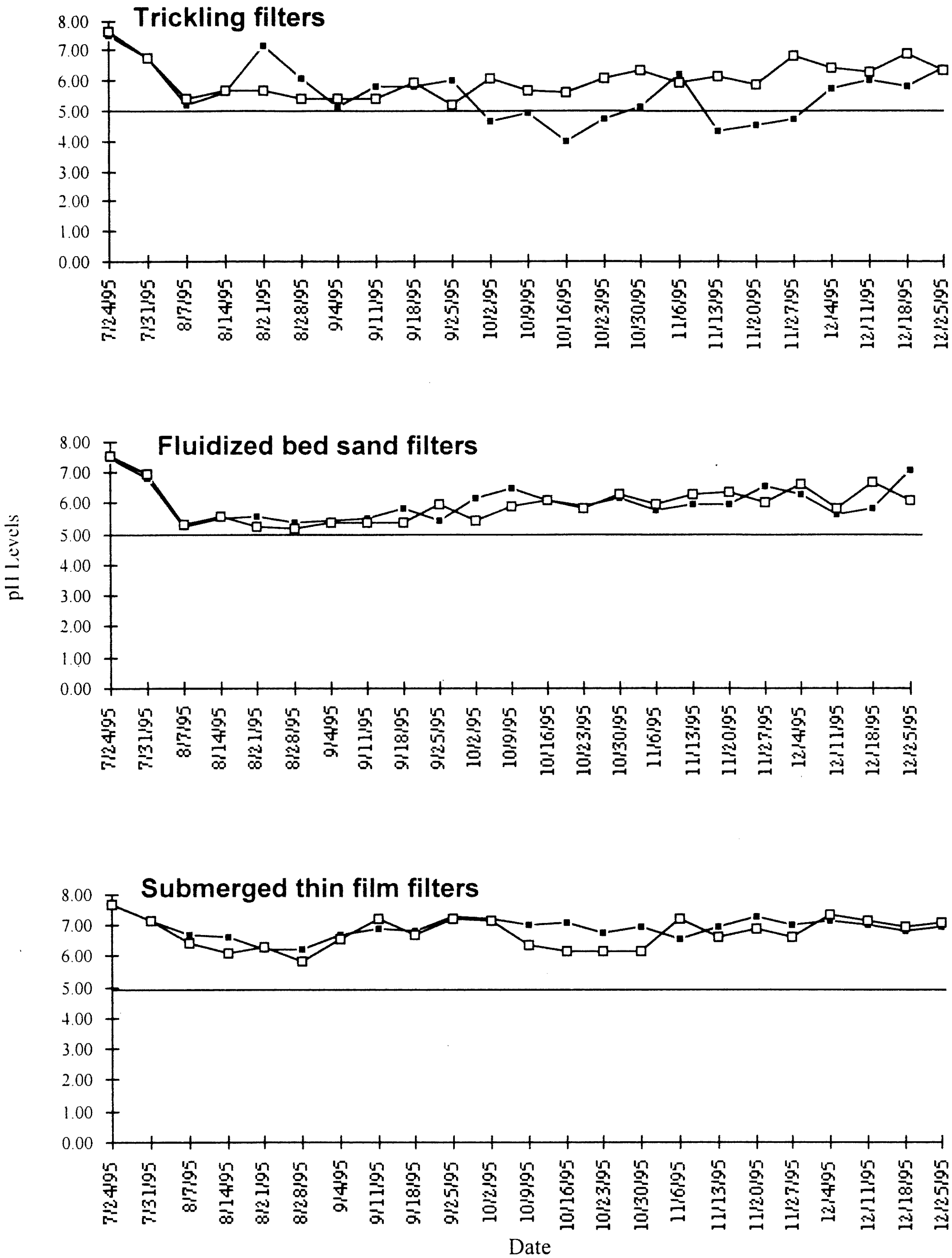
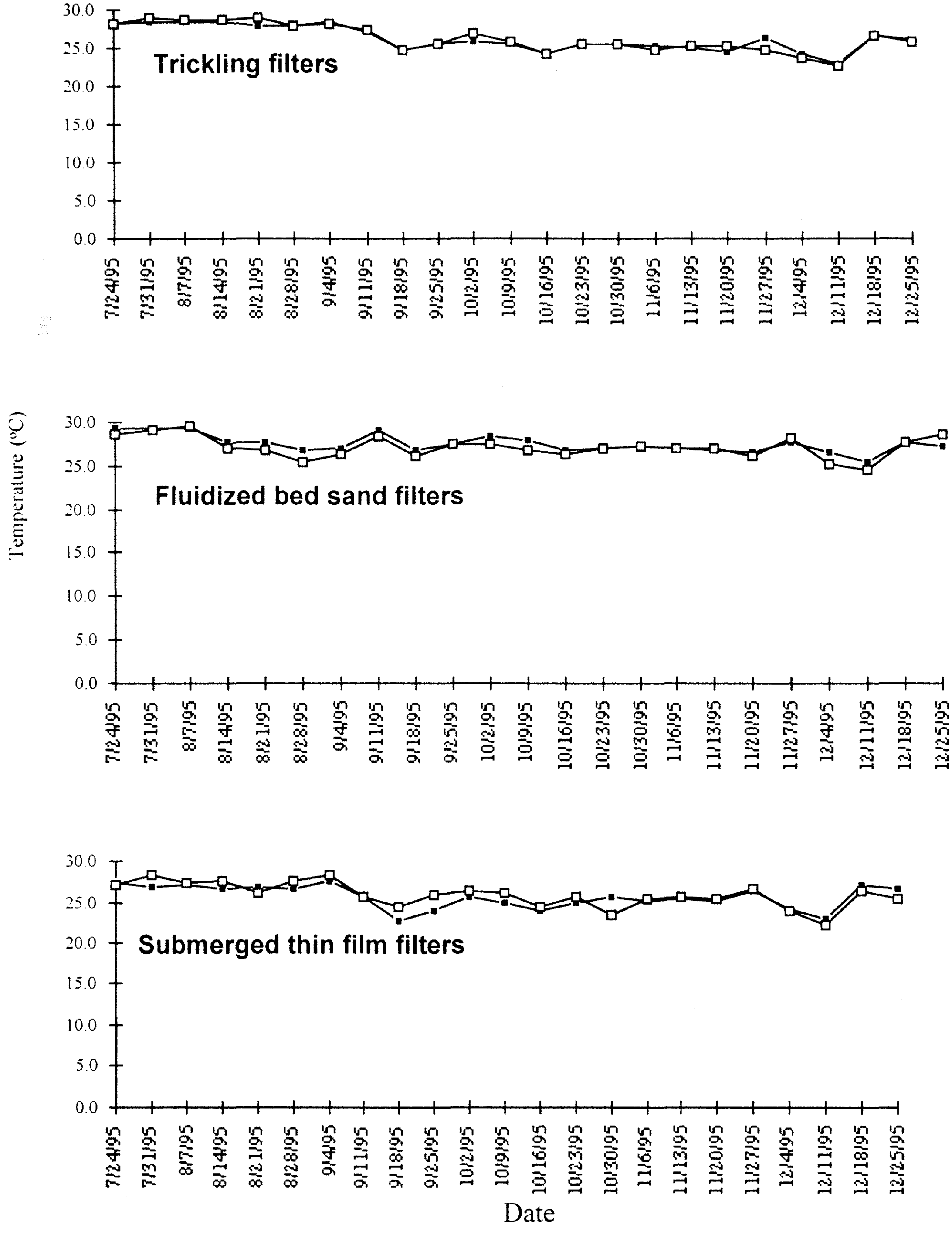


Figure 10. Weekly temperature (°C) in three recirculating tilapia culture tank systems. Replicate tanks are shown as individual data points.



A Teflon washer reduced friction between the two bearing surfaces in the assembly. The washer would erode over time and was replaced approximately once per month.

The biofilter media used in the trickling filter was selected with the hope that the vertically oriented tubes would resist clogging with waste. Trickling filters utilizing randomly packed media have been known to trap wastes in the filter (solids from the culture tank or sloughed biomass from the filter) resulting in reduced effectiveness and increased maintenance costs. Ideally, little organic material should accumulate in the biofilter and the biofilm should remain thin and active. With a vertical tube media, if any obstruction would occur in the tube, water would build up above it and flush it out. The design for the trickling filters used in this study called for a total media height of 60 inches (1.52 m), but the material was only available in 30 inch (0.76 m) lengths. Because of the need to use two layers of media in the biofilter, we suspected that some clogging of the tubes would occur due to bridging of wastes at the interface between the layers. This had occurred in a similar biofilter at North Carolina State University (Losordo, personal communication) and was solved in that situation by separating the layers. We did not observe any clogged tubes during the study period and no corrective action was needed.

One of the main advantages of the trickling filter is that because the media is simply wetted and not submerged, good gas exchange takes place in the filter itself. The oxygen demand of the nitrifying bacteria is satisfied and the filter actually provides a net increase in dissolved oxygen content of the water. Carbon dioxide can also be stripped in the filter, eliminating the need for a separate process. A possible disadvantage of trickling filters can be increased pumping costs to raise the water high enough to keep the media above culture tank water level. The media used in this study was also relatively expensive and hard to obtain, but alternative media are available.

Fluidized bed sand filter

The fluidized bed systems experienced the same difficulties with low pH levels that were discussed previously for the trickling filter systems. The fluctuating pH levels throughout the day were accompanied by reduced ammonia removal efficiencies and accumulation of total ammonia nitrogen in the system. The fluidized bed systems were capable of the same ammonia removal efficiencies as found in the trickling filter systems. After the addition of sodium bicarbonate as an alkalinity supplement, the fluidized bed systems became more stable. In the period following the experiment, the fluidized bed filters were able to maintain acceptable levels of total ammonia nitrogen and nitrite under full feeding load as well as the trickling filter systems.

The fluidized bed systems required more maintenance than the trickling filter systems. The probes which form the inlet to the biofilter had to be checked daily for clogging. The sand level in the filter tank also had to be monitored regularly. Sand was continually carried out of the biofilter tank with the effluent water and accumulated in the culture tank. Possible reasons for the loss of the sand were discussed earlier. As the ammonia and organic load increased on the filter, sand was also washed out of the filter as increased biofilm thickness on the sand grains resulted in increased buoyancy. The sand used in the filters had an effective size of approximately 160 microns. Significant biofilm growth on individual grains, or clumping of grains, would quickly increase the effective diameter and make the particles more likely to be carried out of the filter. The filter configuration and sand sizes used in this study are often used in the ornamental fish industry. Typical loading in these applications would consist of high transient levels of ammonia with low levels of organics (large numbers of fish with little feeding). Nitrifying bacteria produce much less cell mass or biofilm in the process of oxidizing ammonia than is produced by heterotrophic bacteria oxidizing organic matter. In a production aquaculture situation, the size of the sand grains should be increased to prevent sand loss under higher organic loads. Larger sand grains would have less available surface area and would require a greater flow rate to fluidize the filter bed. Given the relatively low cost of the sand and the large amounts of surface area available on even much larger grain sizes, the pumping requirements of the larger sand sizes would be the biggest concern.

The main advantage of fluidized bed sand filters is that the media is inexpensive and has a large amount of available surface area per volume. A relatively low cost filter could be constructed which would be compact and retain the ability to remove the ammonia produced in a heavily fed production system. A disadvantage of fluidized beds is that all of the oxygen needed for the nitrification process must be present in the influent water. The water must also pass through a separate process to re-oxygenate and strip carbon dioxide after leaving the biofilter.

Submerged thin film filters

The submerged thin film filters performed as well as the trickling and fluidized bed filters at the beginning of the study period. As the feeding rate was increased and the study progressed, their performance dropped off. The ammonia removal efficiency then remained below 10% for much of the time, allowing total ammonia nitrogen levels to increase. The submerged thin film filters also exhibited some of the same problems with low pH in the early stages. The decrease in pH was never as pronounced as in the other filter types and the pH stayed well within the optimal range for most of the study period. This was due to other problems which inhibited the nitrification process in the submerged thin film filters. With reduced nitrification, fewer hydrogen ions were released and thus pH remained more stable.

The biofilters in these systems may have been limited by available surface area. As mentioned earlier, the available surface area of the strands making up the filter media would be greatly reduced if the two plies did not unfold and separate. In our configuration, most of the plies did not separate. The strands also had a tendency to bunch up and overlap, further reducing surface area available for the nitrifying bacteria. In some of the full size commercial installations of these systems that we became aware of after the end of the experimental period, aeration is used to a greater extent than we used in the biofilter tanks. In these larger systems, the amount of air added created a turbulence comparable to that of a rapid boil. At this level of mixing, it is possible that the strands would separate more readily and the available surface area would be greater.

The main problem observed with the submerged thin film filters as they were operated in our study was that they acted as a solids trap. The slow moving water in the filter tank allowed solids to settle out on the strands of filter media. Particles which were able to pass through the screen filter would settle on the media in the filter tank. There they would be broken down by heterotrophic bacteria, adding to the oxygen demand of the filter and releasing ammonia through mineralization of proteinaceous material. At times, the filter effluent was higher in ammonia than the influent water. Periodically draining the filter tank and washing down the filter media would help restore performance. It is possible that operating the filter with excessive aeration as done in the large scale systems could reduce this problem as well. Solids would not be allowed to settle on the strands and would pass out of the filter tank. The turbulence could also help ensure that the biofilm layer on the media would remain thin and active and not as prone to sloughing.

The submerged thin film filters required the most maintenance time of the three systems. However, the majority of this time was spent cleaning the filter tank and the airlift pumps. In the commercial size systems, the depth of the tanks allows for a different airlift configuration which does not need the same maintenance. The greater depth of the commercial tanks allows sufficient submergence to enable a single airlift tube with non-diffused air injection to move enough water to operate the tank. In our systems the depth was limited and multiple smaller diameter airlifts were needed to move the required amount of water. Cleaning and adjusting these airlifts was a large part of the time require for system maintenance. As discussed earlier, the practice of excessively aerating the biofilter tank may also eliminate much of the need for cleaning the biofilters.

Advantages of the submerged thin film filter include relatively low media costs and the ability to operate at a low differential in head between the biofilter and culture tank. This can result in decreased pumping costs, depending on the method chosen for pumping. Airlift pumps are not an efficient means of lifting water, but part of the lack in efficiency is compensated by the dual benefits of pumping and gas exchange.

Excessive aeration in the biofilter could overcome the disadvantages of solids collection and poor gas exchange in the submerged thin film filter.

B.4.d. Comparison of Economic Feasibility

Capital costs are summarized in Table 3. Variable cost data were collected on labor, energy consumption, feed expense and other inputs and presented through the following assumptions or as otherwise noted.

The economic evaluation only included data based on a 156 day period from July 24, 1995 to December 26, 1995. Before that period, time was spent on fine tuning the mechanical components of the systems and cultivation of bacteria in the biofilters for processing of fish waste.

Based on these data, the actual operation in the laboratory was analyzed and commercial scale projections were made to project income statements, supporting depreciation schedules, and break-even production and prices. The expanded commercial scale projection should be used only as a guide or a template for comparison. Actual system results may be different due to changing market conditions, site selection, and individual production techniques.

The analysis and projection were performed for each of the three systems. From the data and results of the laboratory analysis, model adjustments that were made in the scale-up projection included building costs, additional capital equipment and changing labor usage. A comparison of the two scenarios reveal some key differences between the three recirculating systems. These results are highlighted in the financial statement discussion.

Relevant information such as sales prices, fixed and variable costs, and production information are included in the List of Assumptions as shown below.

<u>List of Assumptions</u>

1) Analysis is based on Aquaculture Laboratory two 3000 gallon tanks per recirculating system, or six tanks total for the scenario. In the Commercial Scale-up Projection model six 10,000 gallon tanks for each system are used.

2) Tilapia are stocked at a rate of 1500 fingerlings per tank in the Lab. In the Commercial Projection, maximum stocking capacity is set at 0.25 lb of fish per gallon of water; an average stocking rate at 0.21 lb per gallon is used and the feeding rate is assumed at 2% body weight per day which approximate the final maximum production capacity in the laboratory.

3) Tilapia are sold for $1.40 per pound (lb). Assuming feed conversion rate of 1.5:1, a production of 4784 lbs of fish is estimated to be sold per month in six 10,000 gallon tank systems.

4) The Lab fingerling cost is $0.69 per fish at 8 inches in size or 0.41 lb (181 grams) on July 24, 1995 and $0.25 for 3-inch fish in the Commercial Projection.

5) Tilapia are fed five times per day for both the 156 day growing period in the Lab and in Commercial Projection. Feed cost is 24.5 cents per lb.

6) The cost of Buildings and Capital Equipment requirements are amortized and Depreciation/Amortization is shown as operating expenses. The 2000 ft^2 Aquaculture Lab facility rent is estimated at $10/$ft^2$. New commercial construction is projected at $15/$ft^2$ for a 6300 ft^2 building.

Table 3. Capital Cost of Recirculating Aquaculture Systems

Common Costs to All Systems

Components	Cost
Culture tank	1424.00
Screen filter	4261.00
Immersion heater and control	230.00
Airstones (10 @ 9.00 ea)	90.00
Piping and valves	300.00
Automatic feeder	399.50
Aeration (1/6 of blower cost)	112.67
Subtotal	6817.17

Additional costs of trickling filter system

Components	Cost
Biofilter tank	450.00
Biofilter media (49.5 ft^3 @ 19.00/ft^3)	940.50
Pump	550.00
Subtotal for trickling filter	1940.50
Subtotal for costs common to each system	6817.17
Total for trickling filter system	8757.67

Additional costs of fluidized bed system

Components	Cost
Biofilter package cost (does not include media)	3022.10
Biofilter media (filter sand)	75.00
Subtotal for fluidized bed system	3097.10
Subtotal for costs common to each system	6817.17
Total for fluidized bed system	9914.27

Additional costs of submerged thin film system

Components	Cost
Biofilter cost	995.00
Blower	498.00
Airlift pumps (piping and airstones)	150.00
Subtotal for submerged thin film system	1643.00
Subtotal for costs common to each system	6817.17
Total for submerged thin film system	8460.17

7) Labor Expenses are shown as three types of tasks with various activities:

Daily Tasks
- Feeding
- Cleaning standpipes and screens
- Water changes
- Water quality monitoring

Recurring Periodic Tasks
- Clean screen filters
- Clean Airstones
- Weigh Fish

System Maintenance
- Replace parts
- Check and clean probes, airstones and airlifts
- Clean and pack media

The wage rate is $8.17/hr. Time logs were kept in the Aquaculture Lab. In the Full Production model less time is spent monitoring and weighing to reflect a typical commercial operation.

8) System Utilities are calculated for key equipment by kilowatt (kW) equivalent usage. The utility rate is $0.060/kW. There is a total of 3744 hours (24 hours x 156 days) for the Aquaculture Lab and a total of 8760 hours (24 hours x 365 days) for the Commercial Production model. Table 4 and 5 show the rate of kW usage per hour for system equipment and length of time used.

9) Water and Sewage cost is estimated at $1.85 per 1000 gallons.

10) The Aquaculture Lab building utilities for the 5-month period are estimated at $200 per system or $600 total. Commercial Production model is projected at $250 per month.

11) The Aquaculture Lab building telephone for the 156 day period is estimated at $50 per system or $150 total. Commercial Production model is projected at $600 per month.

12) The Aquaculture Lab building rent for the 5 month period is estimated at $200 per system or $600 total. Commercial Production model is projected to build a 6300 sq. ft. facility at a cost of $15/sq.ft.

13) Equipment purchases included in the Commercial Projection are Test Kit for $200 with $600 of reagents replaced annually and a $76 Top Load Scale.

14) Chemical cost is quicklime at $0.17 per lb applied at 0.014/lb per lb of feed.

15) Marketing and Travel cost are zero for the Aquaculture Lab because of a special marketing arrangement for the grown tilapia. For the Commercial Production model marketing and Travel are estimated at $0.02/lb of fish production.

16) License fees are zero for the Aquaculture Lab and $55 for the Commercial Production operation.

17) Commercial Production Insurance is projected at $0.01/lb. of fish production

18) No Loan or Interest Expense are shown for the Aquaculture Lab. Building and equipment loans of $94,600 and $50,000 respectively, are projected for Commercial Production. The building loan is amortized at 9.0% over 30 years. The equipment loan is amortized at 10.5% over 10 years.

Table 4. Utility consumption of major components of different recirculating aquaculture systems as evaluated in the Aquaculture Laboratory.

Equipment	Hourly kW Rate	Length of Use
Lab Trickling Filter		
1/2 hp centrifugal pump	0.703	Continuous
2 kW immersion heater	1.960	Continuous
Hydrotech screen filter	1.080	79 minutes/day
Main lab blower	0.390	Continuous
Lab Fluidized Bed		
1/2 hp centrifugal pump	0.894	Continuous
2 kW immersion heater	1.960	Continuous
Hydrotech screen filter	1.080	79 minutes/day
Main lab blower	0.390	Continuous
Lab Submerged Thin Film		
1 hp blower (2)	0.794	Continuous
2 kW immersion heater	1.960	Continuous
Hydrotech screen filter	1.080	79 minutes/day
Main lab blower	0.390	Continuous

Table 5. Utility consumption of major components of different recirculating aquaculture systems as projected in a scale up Commercial Production System.

Projected Trickling Filter

Equipment	Hourly kW Rate	Length of Use
1 hp centrifugal pump	1.000	Continuous
2 hp submersible pumps (3)	3.500	Continuous
Hydrotech screen filter	2.000	4.8 hours/day
2.5 hp blowers (3)	2.400	Continuous

Equipment	Hourly Therm Rate	Length of Use
Natural gas water heater, Controls and circulating pump	4.29	Continuous

Projected Fluidized Bed

Equipment	Hourly kW Rate	Length of Use
1 hp centrifugal pump	1.000	Continuous
2 hp submersible pumps (3)	3.500	Continuous
Hydrotech screen filter	2.000	4.8 hours/day
2.5 hp blowers (3)	2.400	Continuous

Equipment	Hourly Therm Rate	Length of Use
Natural gas water heater, Controls and circulating pump	4.29	Continuous

Projected Submerged Thin Film

Equipment	Hourly kW Rate	Length of Use
Rotary lobe blower	5.000	Continuous
2.5 hp blowers (3)	2.400	Continuous
Hydrotech screen filter	2.000	4.8 hours/day

Equipment	Hourly Therm Rate	Length of Use
Natural gas water heater, Controls and circulating pump	4.29	Continuous

19) Property taxes are only estimated as $1200 for the Commercial Production scenario.

20) Straight-line depreciation method is used in all depreciation estimates for building and equipment. In only the Aquaculture Lab scenario shared or common equipment depreciation is split equally between the three systems.

Income Statements

Aquaculture Laboratory Analysis

Table 6 is the income (profit or loss) statement for the three recirculating aquaculture systems in the Aquaculture Laboratory. The first point to be made about the income statement is profitability. None of the Aquaculture Lab systems are profitable. This is because the two tank systems are not taking advantage of economies of scale which lowers the per-tank cost of utilities and labor. But rank ordering each system by net income reveals that the Tricking Filter has the smallest loss (-$5480) with the Submerged Thin Film second (-$5679) and finally the Fluidized Bed (-$5790). But there is much more knowledge that can be gained from Table 6 than just bottom-line profitability.

Tilapia production ranged from 1,743 to 1,946 lbs. between the systems. Fish production was not maximized in the Aquaculture Lab scenario, therefore these results (and profitability) could have been improved. Also, due to unforeseen delays in the project, Purchased Stock fingerlings size was 8 inches and reported value was 69 cents each. These are expensive fingerlings and normally this cost would be much lower.

Upon closer examination of Labor Expenses, System Maintenance is one key difference between the systems. The Trickling Filter system was very inexpensive ($69 for 5 months) to maintain. However, the Submerged Thin Film system needed $539 of labor maintenance over 5 months and the Fluidized Bed required $400 of labor over 5 months.

Another important comparison can be seen in System Utilities. The cost of running pumps and blowers varied between the systems. Again, the Trickling Filter system was the cheapest to operate with a total System Utilities cost of $699 over 5 months. The Submerged Thin Film was the second cheapest system at $719 over 5 months, while the Fluidized Bed was the most costly with $742 over the 5-month period. These differences would expand if the costs were annualized.

Depreciation/Amortization is another cost category that should be noted. Due to higher lab equipment requirements, the Fluidized Bed system had the highest Depreciation Expense of $300. The Trickling Filter had the second highest equipment needs and had a $285 Depreciation Expense. Finally the Submerged Thin Film was the lowest lab equipment cost system with $275 of Depreciation cost.

Commercial Production Projection

Table 7 is the income statement for the three projected recirculating Commercial Production systems. All of the commercial systems were profitable. The six-tank systems take advantage of economies of scale which lowers the per-tank cost of utilities and labor. Rank ordering each system by net income reveals that the Fluidized Bed had the highest profits ($1,946) with the Trickling Filter second ($1,813) and finally the Submerged Thin Film ($107).

Tilapia production is 57,408 lbs annually for all systems This is based on 0.25 lb stocking density and selling 4,784 lbs monthly. Purchased Stock fingerling size has changed to 3 inches and reported value is 25 cents each. These are less expensive fingerlings than the 69 cent Aquaculture Lab fingerlings and reflect a typical stocking cost.

Table 6 Aquaculture Laboratory Filter Systems
Income Statement

	Trickling Filter	Fluidized Bed	Submerged Thin Film	
Revenues				
Fish Production (LB.)	1,743	1,800	1,946	
Price Per LB.	$1.40	$1.40	$1.40	
Total Revenues	2,440	2,521	2,724	
Cost of **Goods Sold**				
Purchased Stock	2,070	2,070	2,070	
Feed	744	738	738	
Gross **Profit**	(374)	(287)	(85)	
Operating Expenses				
Labor Expenses				
Daily Tasks	2,761	2,761	2,761	
Recurring Periodic Tasks	708	708	708	
System Maintenance	61	400	539	
System Utilities				
Pump	158	201	0	
Heater	440	440	440	
Screen Filter	13	13	13	
Blower	88	88	266	
Water and Sewage	141	141	141	
Building Utilities	200	200	200	
Telephone	50	50	50	
Rent	200	200	200	
Equipment	0	0	0	
Chemicals	0	0	0	
Marketing & Travel	0	0	0	
Licenses & Fees	0	0	0	
Insurance	0	0	0	
Depreciation/Amortization	285	300	275	
Other	0	0	0	
Total **Operating Expenses**	5,106	5,503	5,594	
Operating Income	(5,480)		(5,790)	
(5,679)				
Other Expenses				
Interest Expense		0	0	0
Property Taxes		0	0	0
Net Income Before Taxes	(5,480)	**(5,790)**	**(5,679)**	

Table 7. Projected Commercial Production Systems
Income Statement

Revenues	Trickling Filter	Fluidized Bed	Submrged Thin Film
Fish Production	57,408	57,408	57,408
Price Per LB.	$1.40	$1.40	$1.40
Total Revenues	80,371	80,371	80,371
Cost of Goods Sold			
Purchased Stock	11,482	11,482	11,482
Feed	21,097	21,097	21,097
Gross Profit	47,792	47,792	47,792
Operating Expenses			
Labor Expenses			
Daily Tasks	3,489	3,489	3,489
Recurring Periodic Tasks	1,013	1,013	1,013
System Maintenance	147	1,389	2,614
System Utilities			
Pump	2,365	2,365	0
Heater	1,879	1,879	1,879
Screen Filter	210	210	210
Blower	158	158	2,786
Water and Sewage	3,150	3,150	3,150
Building Utilities	3,000	3,000	3,000
Telephone	600	600	600
Rent	0	0	0
Equipment	876	876	876
Chemicals	2,049	2,049	2,049
Marketing & Travel	1,148	1,148	1,148
Licenses & Fees	55	55	55
Insurance	574	574	574
Depreciation/Amortization	14,965	13,590	13,941
Other	0	0	0
Total Operating Expenses	35,679	35,545	37,385
Operating Income	12,113	12,246	10,407
Other Expenses			
Interest Expense	9,100	9,100	9,100
Property Taxes	1,200	1,200	1,200
Net Income Before Taxes	1,813	1,946	107

Under Labor Expenses, System Maintenance was again one key difference between the systems. The Submerged Thin Film system was the most costly to maintain ($2,614 for 12 months). However, the Trickling Filter system needed only $147 of labor maintenance over 12 months and the Fluidized Bed required $1,389 of labor maintenance annually.

The cost of running pumps and blowers would vary between the systems. The Submerged Thin Film system was the most expensive to operate with a total System Utilities cost of $4,875 over 12 months. The Fluidized Bed and Trickling Filter had the same System Utilities Expense of $4,612 annually.

Due to lowest equipment requirements in the commercial scenario, the Fluidized Bed showed the lowest Depreciation Expense of $13,590. But the Trickling Filter had the highest equipment needs, so it showed a $14,965 Depreciation Expense. The Submerged Thin Film system was between the other systems at $13,941 for Depreciation cost.

Break-even Yields and Prices

Tables 8-10 and Tables 11-13 are break-even evaluations for the Aquaculture Lab and projected Commercial Production, respectively . The costs used are the same as those shown on the income statement but are broken down into fixed and variable costs. Fixed costs include equipment, licenses and fees, property taxes, and depreciation. All other costs are considered variable.

The analysis looks at both break-even yields and break-even prices. The break-even yield is the pounds of production needed to cover either the variable or total costs when sold for $1.40 per pound. The break-even price is the market sales price required to cover variable and total costs at the production quantity shown on the total revenue line.

Aquaculture Laboratory Analysis

Due to relatively low tilapia production and only a two tank system, economies of scale were not seen so the break-even prices and break-even yields were extremely high. But just as in the income statement evaluation, comparisons between the systems is valuable.

The break-even yield ranged from 5,310 lbs for the Trickling Filter system to cover just variable costs to 6,001 lbs in the Submerged Thin Film system to cover all costs. The Variable Costs calculations reveal why the differences were found. The Trickling Filter system had the lowest variable cost of $7,434 and the Submerged Thin Film had the highest at $7,926.

The break-even price ranged from a low of $4.07 per lb in the Submerged Thin Film system to cover just variable costs to $4.62 per lb to cover all costs in the Fluidized Bed system. This result appears to be inconsistent with previous results. But it can be explained by the fact that fish production determines the break-even price. The relatively high production allowed the Submerged Thin Film system to overcome its variable cost disadvantage to have the lowest break-even price. If tilapia production were maximized, these break-even findings would change. However, since the market price was $1.40 per pound, the $4.07 break-even price still indicated this was an unprofitable situation. One observation should be made that in the Aquaculture Laboratory situation, only in the last week of the 5-month period, the systems were operating near their carrying capacity. The rest of time there was considerable waste of system space that was not fully utilized for maximum production due to various constraints of the laboratory setup.

Projected Commercial Production

Tables 11, 12 and 13 are break-even evaluations for the Projected Commercial Production. These figures show that the six 10,000 gallon tanks scenarios were relatively close to the break-even yields and prices. The Submerged Thin Film was virtually at the break-even points based on the current $1..40 market price for tilapia.

Table 8. Aquaculture Laboratory Break-Even Analysis
Trickling Filter System

Two 3000 gallon tanks stocked at 1500 fingerlings per tank		
Total Gallons	6000	
Total LBS of harvested fish is	1743	

	UNIT	TOTAL VALUE OR COST	VALUE OR COST PER LB.	VALUE OR COST PER GAL	VALUE OR COST PER TANK
Revenues					
Net Sales	LBS	$2,440	$1.40	$0.41	$1,220
Total Revenues	$2,440	$1.40	$0.41	$1,220	
VARIABLE COSTS					
Purchased Stock		$2,070	$1.19	$0.35	$1,035
Feed	LBS	$744	$0.43	$0.12	$372
Labor Expenses					
Daily Tasks	HRS	$2,761	$1.58	$0.46	$1,381
Recurring Periodic Tasks	HRS	$708	$0.41	$0.12	$354
System Maintenance	HRS	$61	$0.03	$0.01	$31
System Utilities					
Pump	TANK	$158	$0.09	$0.03	$79
Heater	TANK	$440	$0.25	$0.07	$220
Screen Filter	TANK	$13	$0.01	$0.00	$7
Blower	TANK	$88	$0.05	$0.01	$44
Water and Sewage	TANK	$141	$0.08	$0.02	$71
Building Utilities	TANK	$200	$0.11	$0.03	$100
Telephone	TANK	$50	$0.03	$0.01	$25
Chemicals	GAL	$0	$0.00	$0.00	$0
Marketing & Travel	TANK	$0	$0.00	$0.00	$0
Insurance	SYSTEM	$0	$0.00	$0.00	$0
Other	TANK	$0	$0.00	$0.00	$0
TOTAL VARIABLE COSTS		$7,434	$4.27	$1.24	$3,717
FIXED COSTS					
Rent		200	$0.11	$0.03	$100
Equipment		0	$0.00	$0.00	$0
Licenses & Fees		0	$0.00	$0.00	$0
Interest Expense		0	$0.00	$0.00	$0
Property Taxes		0	$0.00	$0.00	$0
Depreciation/Amortization		285	$0.16	$0.05	$143
TOTAL FIXED COSTS		$485	$0.28	$0.08	$243
TOTAL COSTS		$7,919	$4.54	$1.32	$3,960
Returns After Costs		($5,479)	($3.14)	($0.91)	($2,740)

Break-even Yield - Var. Costs	5310(lbs.)	Break-even Price - Var Costs	$4.27
Break-even Yield - All Costs	5656(lbs.)	Break-even Price - All Costs	$4.54

Table 9. Aquaculture Laboratory Break-Even Analysis
Fluidized Bed Filter System

Two 3000 gallon tanks stocked at 1500 fingerlings per tank
Total Gallons 6000
Total LBS of harvested fish is 1800

	UNIT	TOTAL VALUE OR COST	VALUE OR COST PER LB.	VALUE OR COST PER GAL	VALUE OR COST PER TANK
Revenues					
Net Sales	LBS	$2,521	$1.40	$0.42	$1,261
Total Revenues		$2,521	$1.40	$0.42	$1,261
VARIABLE COSTS					
Purchased Stock		$2,070	$1.15	$0.35	$1,035
Feed	LBS	$738	$0.41	$0.12	$369
Labor Expenses					
Daily Tasks	HRS	$2,761	$1.53	$0.46	$1,381
Recurring Periodic Tasks	HRS	$708	$0.39	$0.12	$354
System Maintenance	HRS	$400	$0.22	$0.07	$200
System Utilities					
Pump	TANK	$201	$0.11	$0.03	$101
Heater	TANK	$440	$0.24	$0.07	$220
Screen Filter	TANK	$13	$0.01	$0.00	$7
Blower	TANK	$88	$0.05	$0.01	$44
Water and Sewage	TANK	$141	$0.08	$0.02	$71
Building Utilities	TANK	$200	$0.11	$0.03	$100
Telephone	TANK	$50	$0.03	$0.01	$25
Chemicals	GAL	$0	$0.00	$0.00	$0
Marketing & Travel	TANK	$0	$0.00	$0.00	$0
Insurance	SYSTEM	$0	$0.00	$0.00	$0
Other	TANK	$0	$0.00	$0.00	$0
TOTAL VARIABLE COSTS		$7,810	$4.34	$1.30	$3,905
FIXED COSTS					
Rent		200	$0.11	$0.03	$100
Equipment		0	$0.00	$0.00	$0
Licenses & Fees		0	$0.00	$0.00	$0
Interest Expense		0	$0.00	$0.00	$0
Property Taxes		0	$0.00	$0.00	$0
Depreciation/Amortization		300	$0.17	$0.05	$150
TOTAL FIXED COSTS		$500	$0.28	$0.08	$250
TOTAL COSTS		$8,310	$4.62	$1.39	$4,155
Returns After Costs		($5,789)	($3.22)	($0.96)	($2,895)

Break-even Yield - Var. Costs	5579 lbs.)	Break-even Price - Var Costs	$4.34
Break-even Yield - All Costs	5936 (lbs.)	Break-even Price - All Costs	$4.62

Table 10. Aquaculture Laboratory Break-Even Analysis
Submerged Thin Film System

Two 3000 gallon tanks stocked at 1500 fingerlings per tank
Total Gallons 6000
Total LBS of harvested fish is 1946

	UNIT	TOTAL VALUE OR COST	VALUE OR COST PER LB.	VALUE OR COST PER GAL	VALUE OR COST PER TANK
Revenues					
Net Sales	LBS	$2,724	$1.40	$0.45	$1,362
Total Revenues		$2,724	$1.40	$0.45	$1,362
VARIABLE COSTS					
Purchased Stock		$2,070	$1.06	$0.35	$1,035
Feed	LBS	$738	$0.38	$0.12	$369
Labor Expenses					
Daily Tasks	HRS	$2,761	$1.42	$0.46	$1,381
Recurring Periodic Tasks	HRS	$708	$0.36	$0.12	$354
System Maintenance	HRS	$539	$0.28	$0.09	$270
System Utilities					
Pump	TANK	$0	$0.00	$0.00	$0
Heater	TANK	$440	$0.23	$0.07	$220
Screen Filter	TANK	$13	$0.01	$0.00	$7
Blower	TANK	$266	$0.14	$0.04	$133
Water and Sewage	TANK	$141	$0.07	$0.02	$71
Building Utilities	TANK	$200	$0.10	$0.03	$100
Telephone	TANK	$50	$0.03	$0.01	$25
Chemicals	GAL	$0	$0.00	$0.00	$0
Marketing & Travel	TANK	$0	$0.00	$0.00	$0
Insurance	SYSTEM	$0	$0.00	$0.00	$0
Other	TANK	0	0.00	$0.00	$0
TOTAL VARIABLE COSTS		7,926	$4.07	$1.32	$3,963
FIXED COSTS					
Rent		00	$0.10	$0.03	$100
Equipment			$0.00	$0.00	$0
Licenses & Fees			$0.00	$0.00	$0
Interest Expense			$0.00	$0.00	$0
Property Taxes			$0.00	$0.00	$0
Depreciation/Amortization		75	$0.14	$0.05	$138
TOTAL FIXED COSTS		75	$0.24	$0.08	$238
TOTAL COSTS		8,401	$4.32	$1.40	$4,201
Returns After Costs		($5,677)	($2.92)	($0.95)	($2,839)

Break-even Yield - Var. Costs	5661(lbs.)	Break-even Price - Var Costs	4.07
Break-even Yield - All Costs	6001(lbs.)	Break-even Price - All Costs	4.32

Table 11. Projected Commercial Production Break-Even Analysis
Trickling Filter System

Six 10,000 gallon tanks stocked at 5500 fingerlings per tank

Total Gallons	60000
Total LBS of harvested fish is	57408

	UNIT	TOTAL VALUE OR COST	VALUE OR COST PER LB.	VALUE OR COST PER GAL	VALUE OR COST PER TANK
Revenues					
Net Sales	LBS	$80,371	$1.40	$1.34	$40,186
Total Revenues	$80,371	$1.40	$1.34	$40,186	
VARIABLE COSTS					
Purchased Stock	$11,482	$0.20	$0.19	$5,741	
Feed	LBS	$21,097	$0.37	$0.35	$10,549
Labor Expenses					
Daily Tasks	HRS	$3,489	$0.06	$0.06	$1,745
Recurring Periodic Tasks	HRS	$1,013	$0.02	$0.02	$507
System Maintenance	HRS	$147	$0.00	$0.00	$74
System Utilities					
Pump	TANK	$2,365	$0.04	$0.04	$1,183
Heater	TANK	$1,879	$0.03	$0.03	$940
Screen Filter	TANK	$210	$0.00	$0.00	$105
Blower	TANK	$158	$0.00	$0.00	$79
Water and Sewage	TANK	$3,150	$0.05	$0.05	$1,575
Building Utilities	TANK	$3,000	$0.05	$0.05	$1,500
Telephone	TANK	$600	$0.01	$0.01	$300
Chemicals	GAL	$2,049	$0.04	$0.03	$1,025
Marketing & Travel	TANK	$1,148	$0.02	$0.02	$574
Insurance	SYSTEM	$574	$0.01	$0.01	$287
Other	TANK	$0	$0.00	$0.00	$0
TOTAL VARIABLE COSTS	$52,361	$0.91	$0.87	$26,181	
FIXED COSTS					
Rent		$0	$0.00	$0.00	$0
Equipment		$876	$0.02	$0.01	$438
Licenses & Fees		$55	$0.00	$0.00	$28
Interest Expense		$9,100	$0.16	$0.15	$4,550
Property Taxes		$1,200	$0.02	$0.02	$600
Depreciation/Amortization		$14,965	$0.26	$0.25	$7,483
TOTAL FIXED COSTS		$26,196	$0.46	$0.44	$13,098
TOTAL COSTS		$78,557	$1.37	$1.31	$39,279
Returns After Costs		$1,814	$0.03	$0.03	$907

Break-even Yield - Var. Costs	37401(lbs.)	Break-even Price - Var Costs	$0.91
Break-even Yield - All Costs	56112(lbs.)	Break-even Price - All Costs	$1.37

Table 12. Projected Commercial Production Break-Even Anaysis
Fluidized Bed Filter System

Six 10,000 gallon tanks stocked at 5500 fingerlings per tank
Total Gallons 60000
Total LBS of harvested fish is 57408

	UNIT	TOTAL VALUE OR COST	VALUE OR COST PER LB.	VALUE OR COST PER GAL	VALUE OR COST PER TANK
Revenues					
Net Sales	LBS	$80,371	$1.40	$1.34	$40,186
Total Revenues		$80,371	$1.40	$1.34	$40,186
VARIABLE COSTS					
Purchased Stock		$11,482	$0.20	$0.19	$5,741
Feed	LBS	$21,097	$0.37	$0.35	$10,549
Labor Expenses					
Daily Tasks	HRS	$3,489	$0.06	$0.06	$1,745
Recurring Periodic Tasks	HRS	$1,013	$0.02	$0.02	$507
System Maintenance	HRS	$1,389	$0.02	$0.02	$695
System Utilities					
Pump	TANK	$2,365	$0.04	$0.04	$1,183
Heater	TANK	$1,879	$0.03	$0.03	$940
Screen Filter	TANK	$210	$0.00	$0.00	$105
Blower	TANK	$158	$0.00	$0.00	$79
Water and Sewage	TANK	$3,150	$0.05	$0.05	$1,575
Building Utilities	TANK	$3,000	$0.05	$0.05	$1,500
Telephone	TANK	$600	$0.01	$0.01	$300
Chemicals	GAL	$2,049	$0.04	$0.03	$1,025
Marketing & Travel	TANK	$1,148	$0.02	$0.02	$574
Insurance	SYSTEM	$574	$0.01	$0.01	$287
Other	TANK	$0	$0.00	$0.00	$0
TOTAL VARIABLE COSTS		$53,603	$0.93	$0.89	$26,802
FIXED COSTS					
Rent		$0	$0.00	$0.00	$0
Equipment		$876	$0.02	$0.01	$438
Licenses & Fees		$55	$0.00	$0.00	$28
Interest Expense		$9,100	$0.16	$0.15	$4,550
Property Taxes		$1,200	$0.02	$0.02	$600
Depreciation/Amortization		$13,590	$0.24	$0.23	$6,795
TOTAL FIXED COSTS		$24,821	$0.43	$0.41	$12,411
TOTAL COSTS		$78,424	$1.37	$1.31	$39,212
Returns After Costs		$1,947	$0.03	$0.03	$974

Break-even Yield - Var. Costs	38288(lbs.)	Break-even Price - Var Costs	$0.93
Break-even Yield - All Costs	56017(lbs.)	Break-even Price - All Costs	$1.37

Table 13. Projected Commercial Production Break-Even Analysis
Submerged Thin Film Filter System

Six 10,000 gallon tanks stocked at 5500 fingerlings per tank
Total Gallons 60000
Total LBS of harvested fish is 57408

	UNIT	TOTAL VALUE OR COST	VALUE OR COST PER LB.	VALUE OR COST PER GAL	VALUE OR COST PER TANK
Revenues					
Net Sales	LBS	$80,371	$1.40	$1.34	$40,186
Total Revenues		$80,371	$1.40	$1.34	$40,186
VARIABLE COSTS					
Purchased Stock		$11,482	$0.20	$0.19	$5,741
Feed	LBS	$21,097	$0.37	$0.35	$10,549
Labor Expenses					
Daily Tasks	HRS	$3,489	$0.06	$0.06	$1,745
Recurring Periodic Tasks	HRS	$1,013	$0.02	$0.02	$507
System Maintenance	HRS	$2,614	$0.05	$0.04	$1,307
System Utilities					
Pump	TANK	$0	$0.00	$0.00	$0
Heater	TANK	$1,879	$0.03	$0.03	$940
Screen Filter	TANK	$210	$0.00	$0.00	$105
Blower	TANK	$2,786	$0.05	$0.05	$1,393
Water and Sewage	TANK	$3,150	$0.05	$0.05	$1,575
Building Utilities	TANK	$3,000	$0.05	$0.05	$1,500
Telephone	TANK	$600	$0.01	$0.01	$300
Chemicals	GAL	$2,049	$0.04	$0.03	$1,025
Marketing & Travel	TANK	$1,148	$0.02	$0.02	$574
Insurance	SYSTEM	$574	$0.01	$0.01	$287
Other	TANK	$0	$0.00	$0.00	$0
TOTAL VARIABLE COSTS		$55,091	$0.96	$0.92	$27,546
FIXED COSTS					
Rent		$0	$0.00	$0.00	$0
Equipment		$876	$0.02	$0.01	$438
Licenses & Fees		$55	$0.00	$0.00	$28
Interest Expense		$9,100	$0.16	$0.15	$4,550
Property Taxes		$1,200	$0.02	$0.02	$600
Depreciation/Amortization		$13,941	$0.24	$0.23	$6,971
TOTAL FIXED COSTS		$25,172	$0.44	$0.42	$12,586
TOTAL COSTS		$80,263	$1.40	$1.34	$40,132
Returns After Costs		$108	$0.00	$0.00	$54

Break-even Yield - Var. Costs	39351(lbs.)	Break-even Price - Var Costs	$0.96
Break-even Yield - All Costs	57331(lbs.)	Break-even Price - All Costs	$1.40

The break-even yield ranged from 37,401 lbs for the Trickling Filter system to cover just variable costs to 57,331 lbs in the Submerged Thin Film system to cover all costs. The Variable Costs calculations again revealed why the differences were found. The Trickling Filter system had the lowest variable cost of $52,361 and the Submerged Thin Film had the highest at $55,091.

The break-even price ranges from a low of $0.91 per lb in the Trickling Filter system to cover just variable costs to $1.40 per lb to cover all costs in the Submerged Thin Film system. These findings are consistent with previous results of the Aquaculture Lab..

The break-even prices indicated that both the Trickling Filter and Fluidized Bed systems could withstand a small market price drop and at least break-even. However, the Submerged Thin Film system is already at its break-even price so it would become an unprofitable operation if there were a market price decline.

By examining the break-even yields, the same evaluation as under the break-even prices can be made. Both the Trickling Filter and Fluidized Bed systems could withstand a small drop in estimated production of fish and still break-even. But the Submerged Thin Film system is already at its break-even yield so it would become an unprofitable operation if the projected tilapia production goal is not met.

Conclusions of the Economic Analysis

The economic evaluation results indicate that a tilapia culture operation has a few important factors that determine its profitability and break-even prices and yields. Labor expense, system utilities cost and different equipment requirements are the key determinants.

The Trickling Filter system had the lowest operating and variable costs and the lowest break-even yield, but relatively high capital equipment requirements . The Submerged Thin Film system had the highest variable cost and break-even yield, but less capital equipment needs. The Fluidized Bed system results generally fell between the other two systems..

The scale of operation in number of tanks is critical to take advantage of economies of scale and generate sufficient revenue to cover costs. Costs such as labor and utilities are lower per tank the larger the tilapia operation. But not all costs per tank decline with tank expansion. Feed and fingerling costs are very important factors that are not subject to economies of scale, although some saving may be realized through purchasing larger quantities at a given time.

C. Title of Objective: Demonstration of fish culture in recirculating systems. This objective will be carried out in conjunction with, or contingent upon a project funded under M.L. 93 Chpt. 172, Sect. 14, Subd.3(g), Minnesota Aquaculture Development Grant Program, for a farm site demonstration and description of recirculating aquaculture systems.

C.1. Activity: Manual development.

C.1.a: Context within the project: While the primary goal of the project is to assess the feasibility of recirculating aquaculture systems, it is also important to present the technology to interested farmers. People who are interested in recirculating aquaculture systems often have to start from ground zero because of a lack of practical guiding materials or an unwillingness of private entrepreneurs to share information with each other. It will be very useful to describe systems set-up and the day to day operational procedures in layman's language so that this project may also become the starting point for new users of the technology.

C.1.b. Methods: Materials needed for the construction of the fish culture systems will be listed in the manual. Procedures of how the system can be put together will be described in detail. Photographs may be used to aide description. Stocking density, feeding rate, and daily maintenance procedures will also be described in the manual. A summary of this study and data analysis will be reported in the manual. The results may be published in the "Minnesota Aquaculture Report" which the Department of Agriculture publishes.

C.1.c. Materials: Materials needed to accomplish this objective include word processing capabilities, camera for documentation and printing.

C.1.d. Budget: $4,000. Balance: $2,500

C.1.e. Timeline:

	7/93	1/94	6/94	1/95	6/95	12/95
Documentation		***				
Manual writing		******************			***********	
Report writing				******************		
Layout design and printing					****	******

C.2. Activity: On-site demonstration.

C.2.a: Context within the project: In addition to demonstrating the project in written form, on-site demonstration will be effective in illustrating recirculating aquaculture technology. Seeing is believing.

C.2.b. Methods: After the systems are set up and proven to be running smoothly, notices will be given to the fish farming community that a facility is available for inspection. Periodically demonstration gatherings will be coordinated to discuss project progress and further problems. Experts on recirculating technology may also be featured at these demonstration gatherings. Meanwhile, primary demonstration will be accomplished on a farm-site which will be carried out under funding from M.L. 93 Chpt. 172, Sect. 14, Subd.3(g).

C.2.c. Materials: Transportation vehicles, postage, printing and conference facilities may be needed for this activity.

C.2.d. Budget: $2,000, balance: $0

C.2.e. Timeline:

	7/93	1/94	6/94	1/95	6/95	12/95
Outreach/publicity		*****		****	***	***
On-site demonstration/meeting facilitation				***	*****	******

C.3. Status: There has been numerous groups that have toured the facility. One farm in particular is duplicating one of the three systems that we set up and is coming to the lab on a regular basis to copy the set-up. The Minnesota Aquaculture Commission held its fall, 94 meeting at the site and visited the project at a great detail. Over 150 people toured the facility in conjunction with the Ninth Annual Minnesota Aquaculture Conference and Trade Show and the North Central Aquaculture Conference held at Radisson South in Bloomington on February 18-19, 1995. The extension of this project to December 31, 1995 will give extended time for fish farmers and perspective fish farmers to visit and study the systems.

There have been numerous additional groups that visited the project site. As a notice was sent out on the termination of funding of the project, more people have contacted staff and the University on visiting the project. Arrangements have been made and will continue to be made to accommodate these interests.

Problems: For the same problems as stated in B.4.d., the development of the manual is incomplete as much of the input to the development to be generated by the research is not completed yet. Because of the delays, the financial resources for this objective were returned.

A general paper that contains all the content of this report, but in a easier to read form has been developed to serve as information source and a guide for farm situation of developing and operating a recirculating aquaculture farm.

V. Evaluation: This project can be evaluated by 1) whether or not recirculating aquaculture systems are constructed and fish successfully raised in them; 2) how efficient the systems are in terms of reliability and quantity of fish raised; 3) quantity of fish successfully raised in these systems and their economic efficiency; and 4) how many fish farmers this project influences.

In the long run, the project should be evaluated by its effectiveness to 1) assess recirculating aquaculture technology and its potential for application in Minnesota; 2) extend and apply this technology into practice if the technology developed is proven feasible for Minnesota.

VI. **Context within field:** Successful aquaculture requires a practical and sustainable production methodology. The reality of Minnesota aquaculture is the growing season is too short for intensive outdoor production in most of our water resources.

Indoor recirculating aquaculture systems give the advantage of raising fish in a controlled environment. In addition, it conserves heat and water since it reuses the water after clean-up by biological filtration. It is an immature technology. There are many studies of different systems, or new designs of systems (Heinsbroek, 1990, Rusten, 1989, Yang et al 1989, and Millamena et al 1991); however, few studies compare systems to each other. There is little or no effort so far to compare these systems on a economic basis. It is the intent of this study to examine the technical merits of the most promising recirculating systems presently available for aquaculture production complimented by an economic analysis of these systems.

The most crucial component of a recirculating aquaculture system is the filter where ammonia and other metabolic wastes are removed and/or detoxified. The most promising filters presently available are selected for study to determine potential for application in commercial production. The three biofilters that will be evaluated are trickle down filters for its best efficiency in waste water treatment (Miller and Libey 1984, Mathsen 1992), rotating biological contactor (RBC) for its simplicity (Miller and Libey, 1983) and a micro filament filter which has been recently developed by a Minnesota entrepreneur (Reese, personal communications).

The effort of evaluating biofilters may lead, if such technology is feasible for application to the aquaculture industry, to evaluation of other components of recirculating systems such as solids removal, the application of ozone (Paller and Lewis 1988). In addition, aquaculture may be coupled with hydroponics which promises an integrated system for multiple food product production (MacKay and Toever 1981, McMurtry et al. 1990, Rakocy and Allison 1981). However, all these further evaluation is beyond the scope of this study. The focus of this project is to test and evaluate (both biologically and economically) biofilters, the most crucial component of the recirculating systems, that are currently employed on a commercial scale.

VII. Benefits: Aquaculture is developing rapidly. It may develop with more traditional methodology of production by which the environment may be negatively impacted; or it may develop employing recirculating technologies which conserve water and heat and removes much of the fish waste before it is released. This project will direct aquaculture development interest to fully consider this newly emerging technology. The environment will benefit from less water consumption and less nutrient discharge.

By assessing this technology, its practicality can be presented so investors will not invest in a facility that does not work. This has happened in Minnesota. Investors benefit by not investing in areas that will not work. Most of all, fish farmers who would experiment with this new technology will benefit by using this project as a starting point so that they may avoid "re-inventing the wheel" individually.

This study may also benefit businesses that are getting into fish culture in a recirculating system, but lack economic data for planning purposes.

The eventual goal of this project is to establish this technology in Minnesota as a practical and economical means of large scale aquaculture production in an environmentally sound manner. In the end, the state benefits from a diversified agriculture economy and consumers benefit from a high quality food source produced under a controlled environment with a minimal impact on the environment.

VIII. Dissemination: Results from this project will be presented at to national and regional scientific meetings to peers in the field, as well as at the Minnesota Aquaculture Annual Conference in addition of dissemination efforts outline in objective C. Results and findings in written form will also be published in a peer reviewed journal.

The findings and experience gained will also be used in the department's routine consulting with fish farmers and prospective fish farmers as to what a successful recirculating aquaculture system constitutes and what pitfalls one should avoid. The Minnesota Aquaculture Commission will be abreast of the progress of the project on a regular basis and be consulted as to how the project is finally implemented.

IX. Time: N/A

X. Cooperation:

1. Dr. Ira R. Adelman
   Professor and Head, Department of Fisheries and Wildlife
   University of Minnesota

   A fish physiologist with much experience working with fish under laboratory conditions, Dr. Adelman will be an advisor in general setup (A.2.) and water quality analysis (B.2.). He may also execute data collection if an appropriate graduate student is found.

2. Dr. Michael Semmens
   Professor, Department of Civil Engineering
   University of Minnesota

   Dr. Semmen's background is in engineering of waste water treatment with a current interest in aquaculture engineering. His primary involvement on the project is to design mass transfer and solid waste removal of the recirculating systems (A.1.).

3. Dr. Charles Gantzer
   Membran Corporation
   Minneapolis, MN

   Dr. Gantzer's expertise is in biofilm. He will be primarily responsible for designing biofilters.

4. Dr. Jim Skurla
   Agriculture Economist, Center for Economic Development
   Natural Resources Research Institute, University of Minnesota

   Dr. Skurla will be taking the lead in economic analysis (B.3.).

5. Mr. Duaine Flanders
   Technical Manager, Morris Office
   Agriculture Utilization Research Institute

   Mr. Flanders role will be to assist in economic analysis and financial projection (B.3.).

6. Mr. Ken Reese

President, Glacial Hills Fish Farm

Mr. Reese has develop a micro filament filter which has shown potential for application in aquaculture. His responsibility will be to, or in assistance to, design the micro filament filter.

XI. Benefit Returns and Reporting Requirements: Patents and royalties resulting from this project, if any, are subject to laws and regulations applicable to the Future Resources Fund. Semiannual status reports will be submitted not later than Jan. 1, 1994, July 1, 1994, Jan. 1, 1995 and a final status report by June 30, 1995.

XII. References:

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