Model Aquaculture Recirculation System (MARS)

ENGINEERING AND OPERATIONS MANUAL

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I. Introduction to Recirculating Systems

A recirculation system is an enclosed system where the only water replacement is the water lost to evaporation and cleaning. Recirculation systems in aquaculture have stirred a great deal of interest in the aquaculture community in the United States and other parts of the world. Given enough resources, there is little doubt that most species of fish grown in ponds, floating net pens, or raceways could be reared in commercial scale recirculating systems. Unfortunately, the economics of growing commonly cultured species in recirculation systems is not favorable when compared to other types of aquaculture systems. Recirculating systems have generally been expensive to build and operate; increasing the cost of producing fish. So why the interest in recirculation systems?

There are five major advantages in using recirculating aquaculture systems: low water requirements, low land requirements, the ability to control water temperature, the ability to control water quality and independence from the adverse weather conditions (Tetzlaff and Heidinger, 1990). In addition, they have great value as an educational lab. The aquaculturist has the ability to measure and control most of the variables which make up the environment of the recirculating system. This makes the recirculating system a good tool in teaching knowledge and skills in agriculture, biology, and related sciences.

Low Water Requirements

A properly designed and operating recirculating system requires a minimum daily input of water, usually less than 5-10% of the total system volume. This permits the construction of aquaculture facilities in areas where ground water is limited and even allows the construction of facilities in urban areas using dechlorinated municipal water. The production facility could then be located close to its potential markets. Traditional aquaculture production in ponds utilizes large quantities of water. Approximately one million gallons of water per acre are required to fill a pond and an equivalent volume is required to makeup for evaporation and seepage during the year. Assuming and annual pond yield of 5000 ponds per acre per year, means approximately 400 gallons of water are required per pound of production. Through water treatment and reuse, recirculating systems utilize less than 10% of the water required by ponds to produce a similar yield.

Low Land Requirements

Fish in recirculating systems must be reared in tanks or raceways at very high densities to make the production system cost effective. For example, a recirculating system is often designed to hold about 0.5 pounds of fish per gallon of tank volume. In contrast, the carrying capacity of a traditional aquaculture pond is generally considered to be 5000 - 7000 pounds of fish per acre or 0.005 - 0.007 pounds of fish per gallon of water! Thus recirculating systems can be located almost anywhere.

Control of Water Temperature

The low water requirements of a recirculating system opens up the possibility of economically controlling the water temperature. This permits the water temperature to be maintained at the optimum level to maximizing production and allowing rapid turnover of the product. Control of the temperature also allows the aquaculturist to produce species which could not normally be raised in a given geographic area (shrimp in Chicago or Trout in Hawaii).

Control of Water Quality

With recirculating systems, the aquaculturist has the opportunity to directly control water quality. Water quality parameters such as dissolved oxygen can be maintained at optimum levels, improving the growth rate and reducing stress and minimize the potential for diseases. In addition, the fish are isolated from potential environmental contaminants, thus guaranteeing the highest quality product for the market.

Independence from Weather

By rearing fish in indoor recirculating systems, the aquaculturist is no longer limited by weather conditions. A sudden cold spell can wipe out a year's production by killing larval fish or disrupting the normal spawning of broodfish. In late summer and winter, pond aquaculturists can loose their entire crop due to low oxygen levels or flooding. Having the fish indoors also permits the harvest of fish when bad weather would stop pond operations.

All aquaculture production systems must provide a suitable environment to promote the growth of the aquatic crop. Critical environmental parameters include the concentrations of dissolved oxygen, un-ionized ammonia nitrogen, nitrite nitrogen, and carbon dioxide in the water. Other important parameters include nitrate concentration, pH, and alkalinity levels within the system. To produce fish in a cost effective manner, production systems must capable of maintaining proper levels of these water quality variables during periods of rapid fish growth. To provide for such growth, fish are fed high protein pelleted diets at rates ranging from 1.5% to 15% of their body weight per day depending upon their size and species (15% for juveniles, 1.5% for grow out). Feeding rate, feed composition, fish metabolic rate, and quantity of wasted feed have a major detrimental impact on tank water quality. As pelleted feeds are introduced into the culture system, they are either consumed by the fish or left to decompose in the system. The by-products of fish metabolism, include carbon dioxide, ammonia nitrogen, and fecal solids. If uneaten feed and metabolic by-products are left in the system, they will generate additional carbon dioxide and ammonia nitrogen, reduce the oxygen content of the water and have a direct detrimental impact on the health of the cultured product.

In aquaculture ponds, proper environmental conditions are maintained by balancing the inputs of feed with the natural assimilative capacity of the pond. The pond's natural biological productivity (algae, higher plants, zooplankton and bacteria) serve as a biological filter that processes the wastes. As pond production intensifies and feed rates increase, supplemental aeration and some water exchange are required to maintain good water quality. The carrying capacity of ponds with supplemental aeration is generally considered to be 5000 - 7000 pounds of fish per acre (0.005 - 0.007 pounds of fish per gallon of pond water).

In tanks, production intensity must be very high to make the production system cost effective. As a result, the natural biological filtration capacity of the system is exceeded and the producer must rely upon the flow of water through the tanks to wash out the by-products of fish metabolism and wasted feed. Additionally, the oxygen concentration within the tank must be maintained through artificial aeration either with atmospheric oxygen (air) or pure gaseous oxygen injection.

The rate of water exchange required to maintain good water quality in tanks is best described using an example. Assume that a 5000 gallon production tank is to be maintained at a culture density of 0.5 pounds of fish per gallon of tank volume. If the 2,500 pounds of fish are fed a 32% protein feed at a rate of 1.5% of their body weight per day, then 37.5 lbs of feed would produce approximately 1.1 pounds of ammonia nitrogen per day (approximately 3% of the feed becomes ammonia nitrogen). Additionally, if the ammonia nitrogen concentration in the tank is to be maintained at 1.0 mg/l. then a mass balance calculation on ammonia nitrogen indicates that the required flow rate of new water through the tank would be approximately 5,600 gallons per hour (93 gpm) to maintain the desired ammonia nitrogen concentration. Even at this high flow rate, the system would also require aeration to supplement the oxygen added by the new water. A production system that uses water only once is referred to as a flow-through system.

Recirculating Systems in Educational Settings

Recirculating systems are ideal for educational labs. Students can learn to control and maintain the system to provide a favorable environment for the culture of fish or other aquaculture plants and animals. In the process of doing this, they can gain many competencies in agriculture, biology, physics, chemistry, mathematics, and agriculture. The purpose of the recirculating system should be education, not commercial production.

II. System Design

Recirculation systems are most often employed where sufficient water is not available to "wash" fish wastes out of the production tank. By recirculating water through a water treatment system that "removes" ammonia and other waste products, the same effect as a flow-through configuration is achieved.

A key to successful recirculating production systems is the use of cost effective water treatment systems. All recirculating production systems utilize processes to remove solid wastes, oxidize ammonia and nitrite-nitrogen, and aerate and/or oxygenate the water (see Figure 1). The following is a brief description of the individual water treatment processes that must be addressed when utilizing recirculation systems in aquaculture.

WASTE SOLIDS

The major components of feeds used in aquaculture production consist of protein, carbohydrates, fat, ash and water. The portion of feed not utilized by the fish is excreted as an organic waste (fecal solids). These fecal solids, along with uneaten feed, are broken down by bacteria in the system, consuming oxygen and generating ammonia-nitrogen. To minimize their impact on water quality, waste solids need to be removed from the system as quickly as possible. Waste solids can be classified into four categories: settleable, suspended, floatable, and dissolved solids. In recirculating systems, the first two are of primary concern, while the other two can become problems in systems with very little water exchange.

Settleable Solids Control

Settleable solids are generally the easiest of the four categories to deal with and should be removed from the water in the tank as rapidly as possible. Settleable solids are those that will settle out of water within one hour under still conditions. Settleable solids can either be allowed to settle within round culture tanks (where they accumulate on the bottom in the center), or they can be kept in suspension with continuous agitation and removed with a properly designed sedimentation tank (clarifier) or filter. The sedimentation process can be enhanced through the addition of steeply inclined tubes (tube settlers) within the sedimentation tank to reduce flow turbulence and promote uniform flow distribution.

Suspended Solids Control

From a fish producers point of view, the difference between suspended solids and settleable solids is a practical one. Suspended solids will not settle out of the water column under still conditions within one hour and would not be expected to be removed by conventional settling. Suspended solids are not always dealt with adequately in a recirculating production system. If not removed, suspended solids can significantly limit the amount of fish that can be grown in the system and can interfere with and irritate the gills of fish. The most popular treatment method for removing suspended solids generally involves some form of mechanical filtration. The two types of mechanical filtration most commonly used are screen filtration or granular media filtration (sand or pelleted media).

Floatable and Dissolved Solids Control

Fine suspended solids (less than 30 microns) have been shown to contribute more than 50% of the total suspended solids in a recirculating system. These solids increase the oxygen demand of the system and have been shown to cause gill irritation and damage in finfish. Additionally, dissolved organic solids (proteins) can contribute significantly to the oxygen demand of the total system.

Fine and dissolved solids cannot be easily removed by sedimentation or mechanical filtration technology. Foam fractionation (also referred to as protein skimming) has been widely used to remove these solids in recirculating tank systems. Foam fractionation, as employed in aquaculture, is described as a process of introducing air bubbles at the bottom of a closed column of water that creates foam at the air/water interface. As the bubbles rise through the water column, fine suspended solid particles attach to the bubbles surface, creating the foam at the top of the column. The foam build-up is then channeled out of the fractionation unit to a waste collection tank. Solids concentration in the waste tank can be five times higher than in the culture tank. The efficiency of a foam fractionation system is dependent on the properties of the water in the system (salt concentration, temperature, pH, etc.), but can significantly reduce water turbidity and oxygen demand in the culture tank.

NITROGEN

Total ammonia-nitrogen (TAN) consists of two fractions, un-ionized ammonia (NH_3) and ionized ammonia (NH_4^+) and is the by-product of protein metabolism. TAN is excreted from the gills of fish as they assimilate feed and is produced when bacteria decompose organic waste solids within the aquaculture system. The unionized form of ammonia-nitrogen is extremely toxic to fish. The fraction of TAN in the un-ionized form is dependent upon the pH and temperature of the water. At a pH of 7.0, most of the TAN is in the ionized form, while at a pH of 8.0 the majority is in the un-ionized form. While the lethal concentration of ammonia-nitrogen for many species has been established, the sublethal effects of ammonia-nitrogen have not been well defined. Reduction in growth rates may be the most important sublethal effect. In general the concentration of unionized ammonia-nitrogen in tanks should not exceed 0.05 mg/1.

Nitrite-nitrogen (NO_2^-) is a product of the oxidation of ammonia-nitrogen. Nitrifying bacteria (Nitosomonas) in the production system utilize ammonia-nitrogen as an energy source for growth and produce nitrite-nitrogen as a by-product. These bacteria are the basis for biological filtration. The nitrifying bacteria grow on the surface of the biofilter substrate and to some extent on all production system components including pipes, valves, tank walls, etc. While nitrite-nitrogen is not as toxic as ammonia-nitrogen, it is harmful to aquatic species and must be removed from the system. Concentrations of nitrite-nitrogen should not exceed 0.5 mg/l for long periods of time. Fortunately, Nitrobacter bacteria which are also present in most biological filters utilize nitrite-nitrogen as an energy source and produce nitrate as a by-product.

Nitrates are not generally of great concern to aquaculturist. Studies have shown that aquatic species can tolerate extremely high (greater than 100 mg/l) of nitrate-nitrogen in production systems. Nitrate-nitrogen concentrations do not generally reach such high levels in recirculating systems. Nitrate-nitrogen is either flushed from a system during system maintenance operations (such as settled solids removal or filter backwashing) or denitrification occurs within a treatment system component such as a settling tank. Denitrification is mainly due to the metabolism of nitrate-nitrogen by anaerobic bacteria producing nitrogen gas that is released to the atmosphere during aeration processes.

Nitrogen Control

Control of the concentration of un-ionized ammonia nitrogen (NH_3) in the culture tank is the primary objective of recirculating treatment system design. Ammonia-nitrogen must be "removed" from the culture tank at a rate equal to the rate of production to maintain a safe concentration. While there are a number of technologies available for removing ammonia-nitrogen from the water including air stripping, ion exchange, and biological filtration, biological filtration is the most widely used. In biological filtration (also sometimes called biofiltration), a substrate with a large surface area is provided for nitrifying bacteria attachment and growth. Gravel, sand, plastic beads, plastic rings and plastic plates are commonly used biofiltration substrates. The configuration of the substrate and the manner in which it comes into contact with wastewater defines the water treatment characteristics of the biological filtration unit.

Recirculating production technology is most often utilized because sufficient water is not available on site to "wash" fish wastes out of production tanks. In most cases, a flow-through requirement of nearly 100 gpm to maintain one production tank would severely limit production capacity. By recirculating tank water through a water treatment system that "removes" ammonia and other waste products, the same effect is achieved as with a flow-through configuration. The efficiency with which the treatment system removes ammonia from the system, the ammonia production rate, and the desired concentration of ammonia nitrogen within the tank will determine the recirculating flow rate. Using the example outlined above, if a treatment system, then the flow rate from the tank would need to be twice the flow required if fresh water were used to flush the tank (93 gpm/0.5=186 gpm).

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III. Prototype Small System: Model Aquaculture Recirculation System (MARS)

The design of a recirculating aquaculture system for use in an educational setting must take into account a number of requirements unique to this application. Of primary importance is the recognition that the system may not be operated by experienced personnel. With this in mind, the system should be designed to be "forgiving" of operator error. To realize this in a design, each system component should be over-designed for its function. This does not mean that the system needs to be complicated or automated. On the contrary, the students are involved in the curriculum to gain experience in aquaculture, thus the manual operation and care of the system is desirable.

In many cases, the system will need to operate as a "stand alone" unit with little support available from the existing physical plant. Additionally, the system should operate in a classroom or laboratory setting with a minimum of room modification and distractions (ie. it should operate quietly).

With these requirements in mind, the recirculating system described here was designed as a model for getting educational programs "off the ground" with a minimum of trial and error. We hope that as you build and operate the system, you will be both creative and innovative in its design and operation. Please share these innovations with us and your colleagues so that we may improve our systems.

OVERALL SYSTEM LAYOUT

The Model Aquaculture Recirculating System (MARS) was designed to handle the feed requirements for up to 200 pounds of fish in any number or configuration of culture tanks. The waste treatment system and other life support components take into account all of the considerations described in previous sections and as shown schematically in Figure 1. The MARS unit has four major components, a solids removal basin, a nitrification basin, and two fish culture tanks (see Figure 2). In addition, the system has a low pressure air pump and delivery system, a 1/5 hp submersible water pump and delivery line, a wastewater drainage line, and an alarm system. In all, the MARS unit (as displayed) takes up 130 square feet of floor space and cost approximately $2,800 to build.

The Solids Removal Basin

Wastewater from the bottom of the fish culture tanks is delivered by gravity through a 1-1/2" PVC pipe to one end of the Solids Removal Basin. The basin measures 36" wide by 48" long by 42" high and has a sloped bottom (approx. 24^{o} angle) from the back to the front of the basin (see Figure 3). Upon entering the solids removal basin, the solids laden water encounter a "top" baffle and is forced to travel up through a tube assisted settling area constructed of two blocks (1' x 1' x 3') of commercially available settling media (Part #LS42A, Aquatic Ecosystems, Inc.). As the water passes up through the settling media, heavy solids such as uneaten feeds and fecal matter settle to the basin bottom or on the media itself. The sloped bottom of the basin causes the solids to collect in the front of the solids removal basin where they can be siphoned from the system. The clarified water then overflows into two troughs (fashioned by cutting a top section off of a 1 1/2" PVC pipe) and flows through a dividing wall in the tank to two vertical filters. The water first flows through a coarse polyester fiber filter (Part #PF-2, Aquatic Ecosystems, Inc.) placed perpendicular to the flow. The water then finally passes through a fine polyester fiber (Part #PF-1, Aquatic Ecosystems, Inc.), where the remaining fine suspended solids are trapped. The polyester fiber filter material in both vertical filters is given rigidity by sandwiching the filter material between two sheets of plastic mesh (Part #N1170, Aquatic Ecosystems, Inc.). The filters are held in the vertical position by tracks along the sides of the basin fabricated from 1" x 1" wood stock or by using commercially available fiberglass U-channel. The water then exits the solids removal basin through a bulkhead fitting on the end of the basin and is delivered by gravity to the Nitrification Basin.

Nitrification Basin

The Nitrification Basin receives clarified water that still contains high levels of ammonia nitrogen. The function of this basin is to reduce the level of the ammonia and nitrite-nitrogen prior to returning the water to the fish culture tanks. The dimensions and construction details of this basin are identical to the solids removal basin, except it doesn't require baffles. The sloped bottom, while not required, assists in concentrating biological solids that are shed from the biological filter. A rotating biological filter (RBC) was selected as the primary nitrifying filter for the system. A Floating RBC design, developed by the Rodale Aquaculture Project was selected because of its simplicity of construction and operation. The RBC can be powered by either water or air. In this design, a small (2 gpm) flow-stream of water from the submersible pump was used as the primary source of rotational power due to the limited air volume output of the air pump selected. While the RBC unit was purchased fully assembled (Part #FFRBC, Aquatic Ecosystems Inc.), the construction details for the unit are included in Appendix A of this module. The treated water is pumped from the nitrification basin (17-21 gpm) by a 1/5 hp submersible pump (Model #2300, Simer Pump Co.) via a 1 1/2" diameter PVC delivery line to the fish culture tanks.

Water Delivery Lines and Hydraulic Gradients

Water flows from the fish culture tanks to the treatment basins by gravity. When the submersible pump in the nitrification basin is off, the water in both the tanks and treatment basins reach a "static level". It is important that the top of the treatment basins be equal to or higher than the maximum "static" water level within the system. The inside diameter of the wastewater drainage lines should be between 1 1/2" and 2". Using larger diameter pipe may result in the settling of waste solids within the lines, while smaller diameter pipe will result in a reduced flow rate to the treatment basins, causing the water levels to fall below an operational minimum (where the RBC hits the bottom of the basin). The "dynamic water" level (the water level with the pump running) in the fish culture tanks should be 4" to 6" higher than the treatment basins.

It is important to note the construction details of the drainage lines within the model system. All right angle turns are made with "tee" fittings with end plug clean-outs instead of 90^{o} elbows. This was done to ease the cleaning of the pipes within the drainage system. The pipes should be cleaned whenever the dynamic water level difference (head loss) between the fish culture tanks and basins becomes greater than 8-9". For cleaning procedures, see the maintenance section to follow.

Fish Culture Tanks

The fish culture tanks within the system can be of any configuration and number within reason. In order to insure adequate dissolved oxygen levels, the density of fish in each tank should not exceed 1/4 pound of fish per gallon of water. This MARS unit is configured using two 440 gallon polyethylene tanks (Part #TP440, Aquatic Ecosystems, Inc.) having a diameter of 5' and an overall depth of 36". The tanks are elevated by one layer of concrete blocks and rest on a 1/2" plywood base to bring their tops even with the top of the basins. Drains at the bottoms of the tanks are 1 1/2" diameter bulkhead fittings located in the center. No stand-pipes are required in this system. However, the center drains should be screened to prevent blockages in the drains with fish or other large objects.

Recirculated water is provided to each tank via a 1 1/2" diameter PVC delivery line from the nitrification basin. The flow-rate in each tank is regulated with a 1" ball valve.

Temperature Control System

The water temperature of the system will depend upon the requirements of the species being cultured. For most warmwater species, a temperature range of 75-80° F is ideal. Keep in mind that in aquatic biological systems, the higher the water temperature, the faster disaster can strike! If the air temperature of the room in which the system is housed is within this range, then no additional heat source is required. However, if the room temperature is below the desired operational temperature, simple aquarium heaters will suffice as a controllable heat source.

The model recirculating system is equipped with three 300 watt aquarium heaters located within the solids removal basin. Each heater (Model #VT300, aquatic Ecosystem, Inc.) in the system has an adjustable thermostat. The thermostat is set at the lowest water temperature you would desire the system to be maintained at. If the room air temperature is below 70° F, your system may require more heaters to maintain an appropriate temperature.

In culturing coldwater species, a water temperature of 70° F or less is desirable. Unless the room can be maintained at 65° F or less, a water cooling unit will be required. Water cooling units are generally expensive and will significantly increase the cost of your system ($1000 - $1600).

Aeration System

Aeration is provided via eight 3" long airstones (Part #AS-3, Aquatic Ecosystems) in each tank. The airstone diffusers are located at a depth of 24" below the surface of the water. Air is supplied from a linear air pump (Part #L29, Aquatic Ecosystems, Inc.) mounted above the water level (to prevent back siphoning when turned off) near the basins. A Linear air pump was selected (vs. a regenerative blower) due to the quiet operating characteristics of this unit. While the entire system could be operated with a larger regenerative air blower and air-life pumps, the submersible pump and linear air blower were selected to provide quiet operation for classroom (lab) use. The air delivery line is 1" diameter PVC pipe and fittings with 1/4" diameter flexible clear tubing (Part #TV-40, Aquatic Ecosystems, Inc.) connecting the PVC pipe air delivery system (via tubing adapters, Part #62014, Aquatic Ecosystems, Inc.) with the airstone diffusers.

Fine and Dissolved Solids Removal

Fine solids and dissolved solids are removed with a simple airlift type of foam fractionator (Part #FMS-4, Aquatic Ecosystems, Inc.). The foam fractionator is mounted within one of the fish tanks and discharges solids laden foam to an external container. Because the water to both fish tanks is mixed in the treatment basins, one foam fractionator should serve to control the buildup of fine and dissolved solids within the entire MARS unit.

Feed Delivery System

Feed should be delivered to the tanks evenly over a period of time to minimize "spikes" in ammonia-nitrogen or depletions in the dissolved oxygen content. Fortunately this process is easily accomplished using automatic feeders (belt feeders) that were developed for the fingerling production industry. Each tank in this MARS unit has a spring driven 12 hour belt feeder (Part #912555, Zeigler Bros., Inc.) suspended 12" - 18" over the water. The appropriate amount of feed (see section on fish production management) for the day is spread evenly over each belt to be delivered during the working day.

Alarm System

Due to the intensive nature of recirculating systems, and the number of hours that the system will be unattended on evenings and weekends, use of a simple alarm system is strongly recommended. The MARS unit was developed, has a simple alarm system that incorporates an automated telephone dialer (Part #A-1, Aquatic Ecosystems, Inc.). The system monitors the air delivery line pressure (Part #B601, Aquatic Ecosystems, Inc.), water level in the fish culture tanks (Part #2P313, W.W. Grainger, Inc.), water temperature in the overall system (Part #A-3, Aquatic Ecosystems, Inc.), and flow status in the water delivery system (Part #6940-015, Ryan Herco, Inc.). In the case of low air pressure, low water level, high or low water temperature, or no recycled water flow, the telephone dialer will dial and deliver an alarm message to four predetermined telephone numbers. The alarm message must be acknowledged by the recipient by a phone call back to the telephone dialer within 30 seconds of the call or the automatic dialer will call the next number in its memory. This process continues until the alarm is acknowledged.

While the inclusion of an alarm in the system is not absolutely necessary, the security and peace of mind knowing that the system is "on guard" 24 hours a day, 7 days a week is well worth the $400 dollars required to implement the system.

CONSTRUCTION DETAILS

The major work entailed in implementing this model aquaculture recirculating system was the fabrication of the wastewater treatment basins. Plywood and fiberglass was chosen as the materials for this model to facilitate the fabrication of these units in a high school wood shop. In fact, the models prototype basins at North Carolina State University were put together by the FFA class at Fuquay - Varina High School in North Carolina. It should be noted that the work required to build the basins can be reduced if prefabricated tanks of similar dimension can be located. While sloping bottoms are desirable for the basins, flat bottoms basins can be substituted. Flat bottom tanks used as settling basins require more effort in the cleaning of the settled solids. Remember, the basin material must be non-toxic to fish; no galvanized steel or copper pipes!

Basin Construction Details

The basic treatment basin construction details are described in plan form in Figures 4 and 5. The basins were fabricated from good quality (A/B grade) 3/4" thick exterior grade plywood. The plywood sheets were cut into panels according to the layout in Figure 5. The wood panels were glued (with a water-proof wood glue) and screwed together. The sloped bottom of each basin were supported by four evenly spaced 2" x 2" stringers. Each inside seam and corner were sanded and rounded with a silicone sealer and fiberglass tape was applied to give the seams strength and make them water proof. The entire inside of each basin was given a coat of epoxy primer (Part #PT-17, Aquatic Ecosystems Inc.) and a second finish coat of epoxy paint (Part #PT-7, Aquatic Ecosystems Inc.). The exterior of both basins were coated with a colored "exterior" wood paint. To reduce side bulging of the tank walls caused by the water pressure, a wood girdle was fabricated from four pieces of 2 x 4 and four bolts and placed mid-way up the tank sides (see figure 4). Holes in the ends of both basins are cut to fit a 1 1/2" bulkhead fitting. The holes should be located 20" (on center) from the bottom of the basins.

The solids removal basin must be fitted with two additional baffles. A short "top" baffle and a full baffle need to be installed as noted in Figures 3 and 4 and sealed (silicone alone will do). Two sets of tracks to hold the vertical polyester screen filters must also be fabricated from 1" x 1" wood stock or U-channel structural fiberglass can be used (1 1/4" x 1/4", Hulls Unlimited-East, Inc.)

Basin Support and Drain Set-Up

The tanks that were used in the model system were 36" high. To raise the tank tops level with the treatment basins and to facilitate bottom drain construction, the tanks were placed on 1/2" thick plywood set on common cement blocks (cinder blocks). The block placement and drain system components are outlined in Figure 6.

SYSTEM BUDGET

A budget for building the model system is found in Table 1. The reader should note that the budget does not include any labor cost for this project. It is assumed that the students will provide the labor in developing this system. The reader should also note that the costs listed are list prices. In many cases, a discount can be obtained for many of the items. The model was built from premium materials which, in many cases, can be downgraded without a degradation of operational characteristics or reliability. An example can be found in the plywood used to build the treatment basins. While the model used A/B exterior grade ($37 each), a lower exterior grade such as A/C or CDX ($15 - $20 each) could be substituted. Another example can be found in the cost of PVC pipe fittings. We have used the "list" catalogue price where in most cases state agencies and private contractors can buy PVC pipe and fittings at up to 70% off of these prices. Suffice it to say, your system should cost less than the models price tag of $2,878. See Appendix B for a list of aquaculture equipment suppliers.

Table 1.
Budget for the Model Aquaculture Recirculating System

Quantity	Unit	Item Description	Unit Cost	Cost
2	each	Fish tanks; 6' dia. w/shirt	$ 255.00	$510.00
2	each	Water treatment basins		441.00
24	each	Cinder blocks	.80	19.20
4	sheets	1/2" A/C plywood	11.50	46.00
2	yards	Fine polyester filter material	10.50	21.00
2	yards	Coarse polyester filter materials	14.00	28.00
6	feet	Tube settler material	10.20	61.20
1	each	Submersible pump	59.00	59.00
1	each	Rotating biological contactor	399.00	399.00
1	each	Linear air blower	266.00	266.00
20	each	Air stones	2.40	48.00
1	each	Automatic telephone dialer	287.00	287.00
1	each	Mercury float switch	20.26	20.26
1	each	Air pressure switch	28.00	28.00
1	each	Flow switch	39.00	39.00
1	each	Foam fractionator	32.80	32.80
2	each	Automatic feeders	171.00	342.00
1	100' coil	Vinyl tubing	14.50	14.50
3	each	Electric heaters, 300 watts	19.85	59.55
Misc.		PVC pipes, fittings, etc.		157.34
		Total Cost		$10,735.05

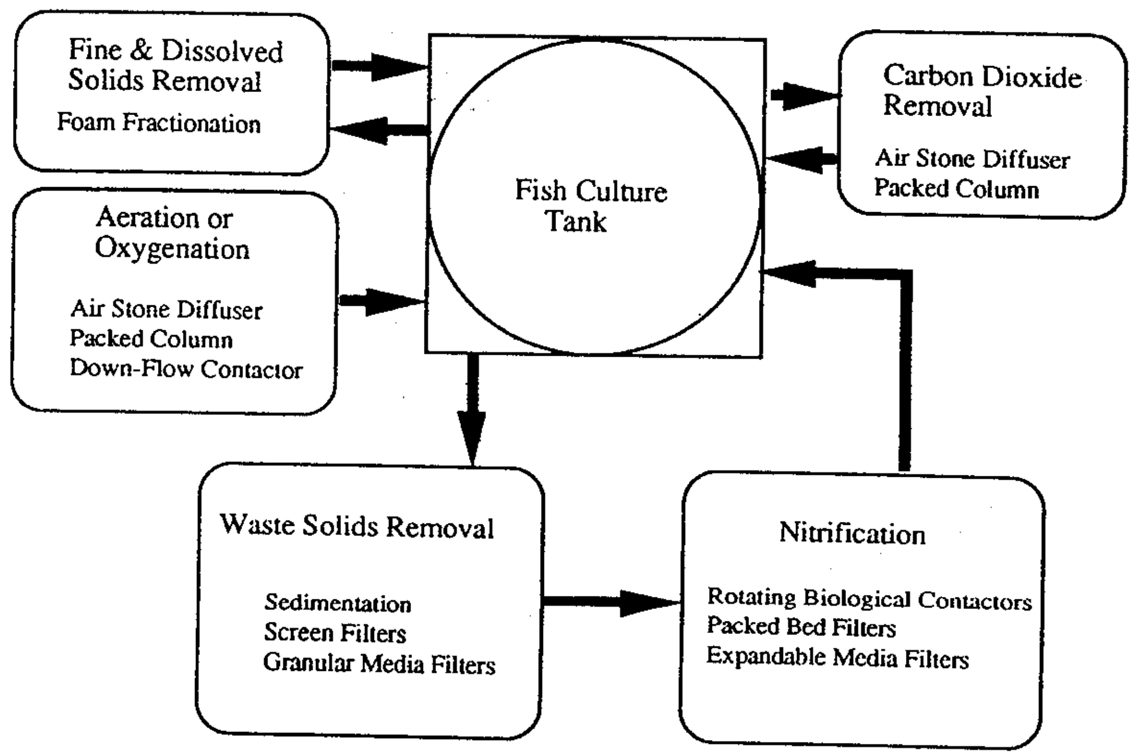


Figure 1. Required unit processes and typical components used in recirculating aquaculture production systems

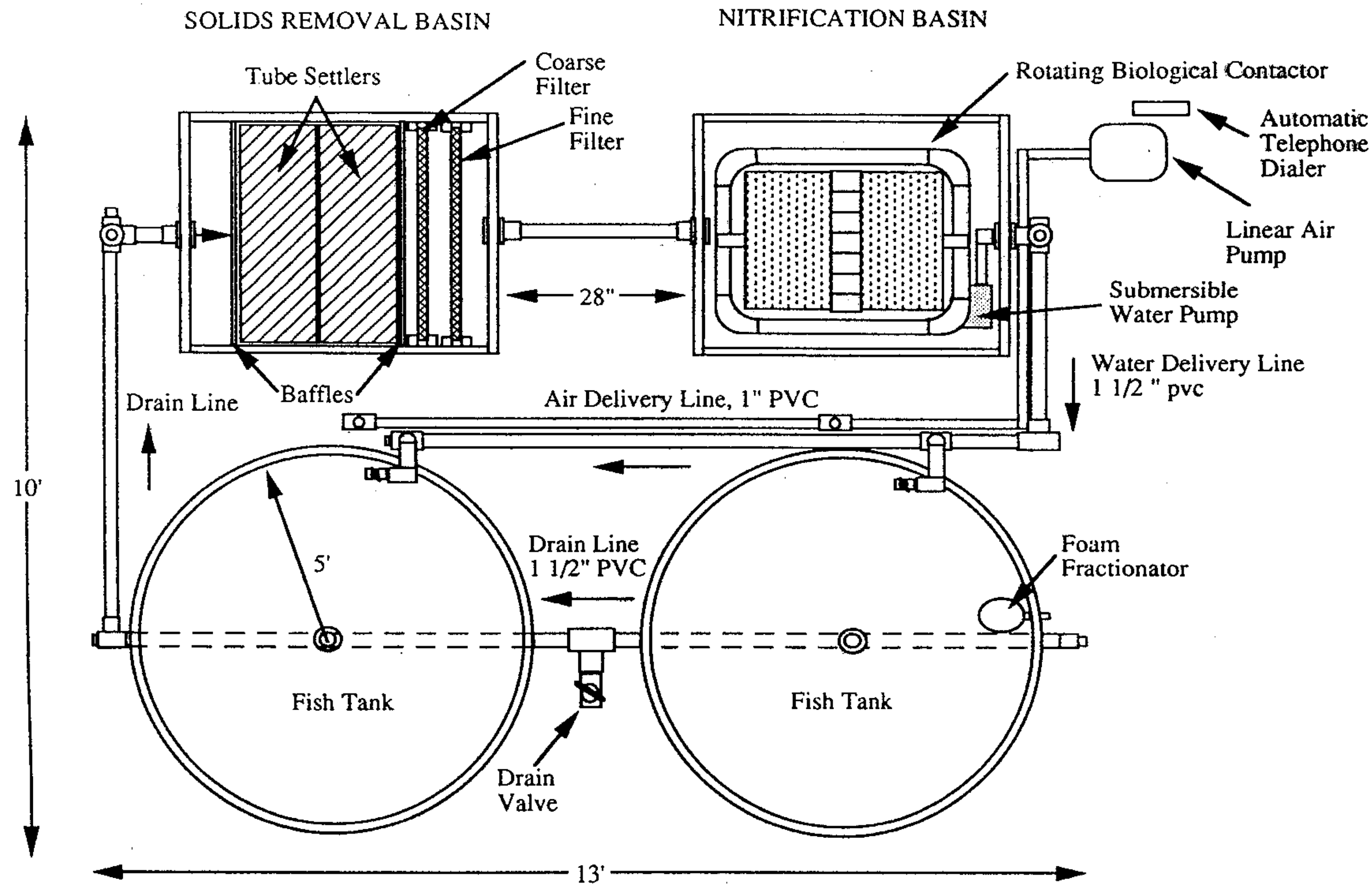


Figure 2. Overall Layout of the Model Aquaculture Recirculating System

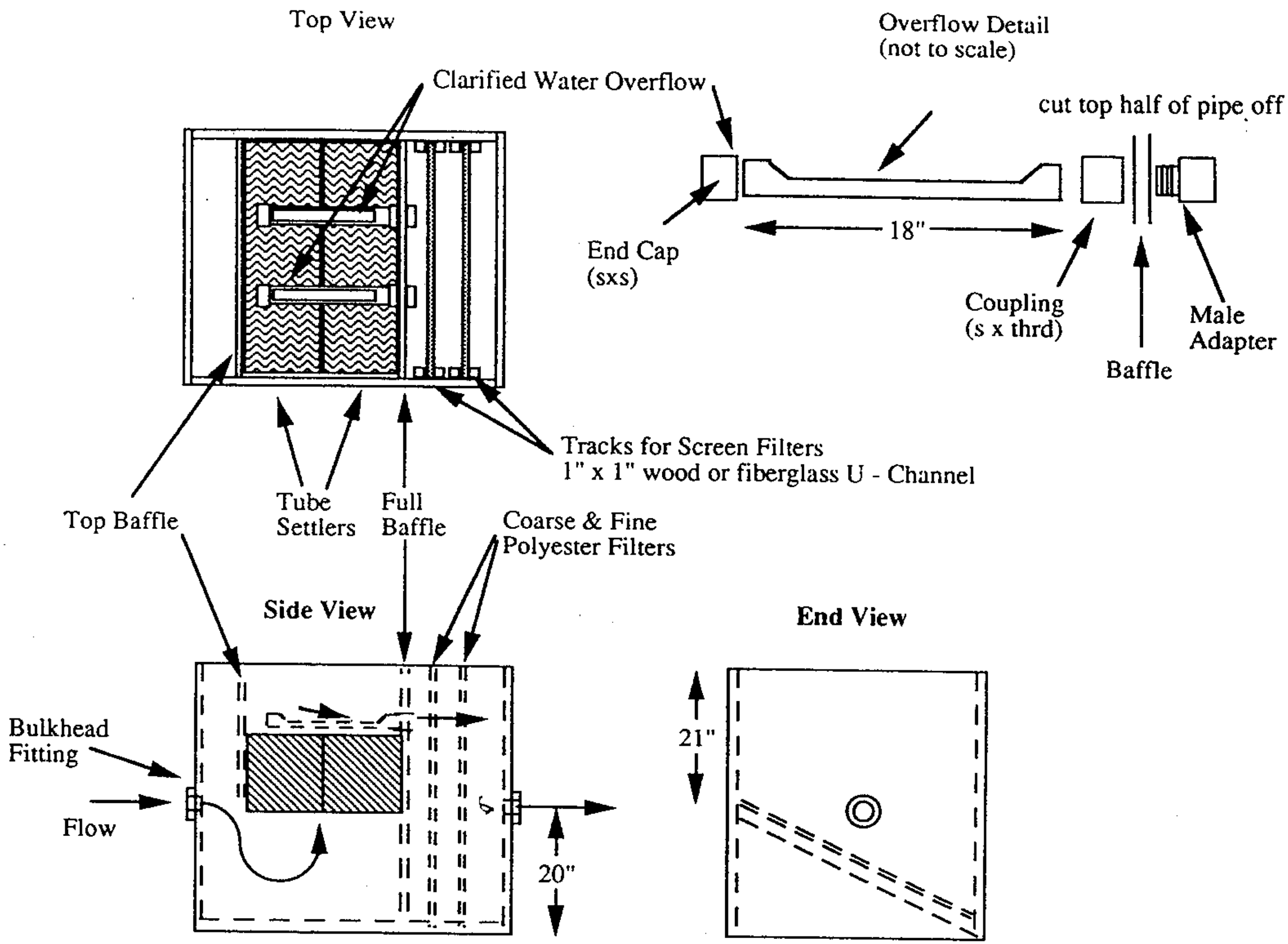
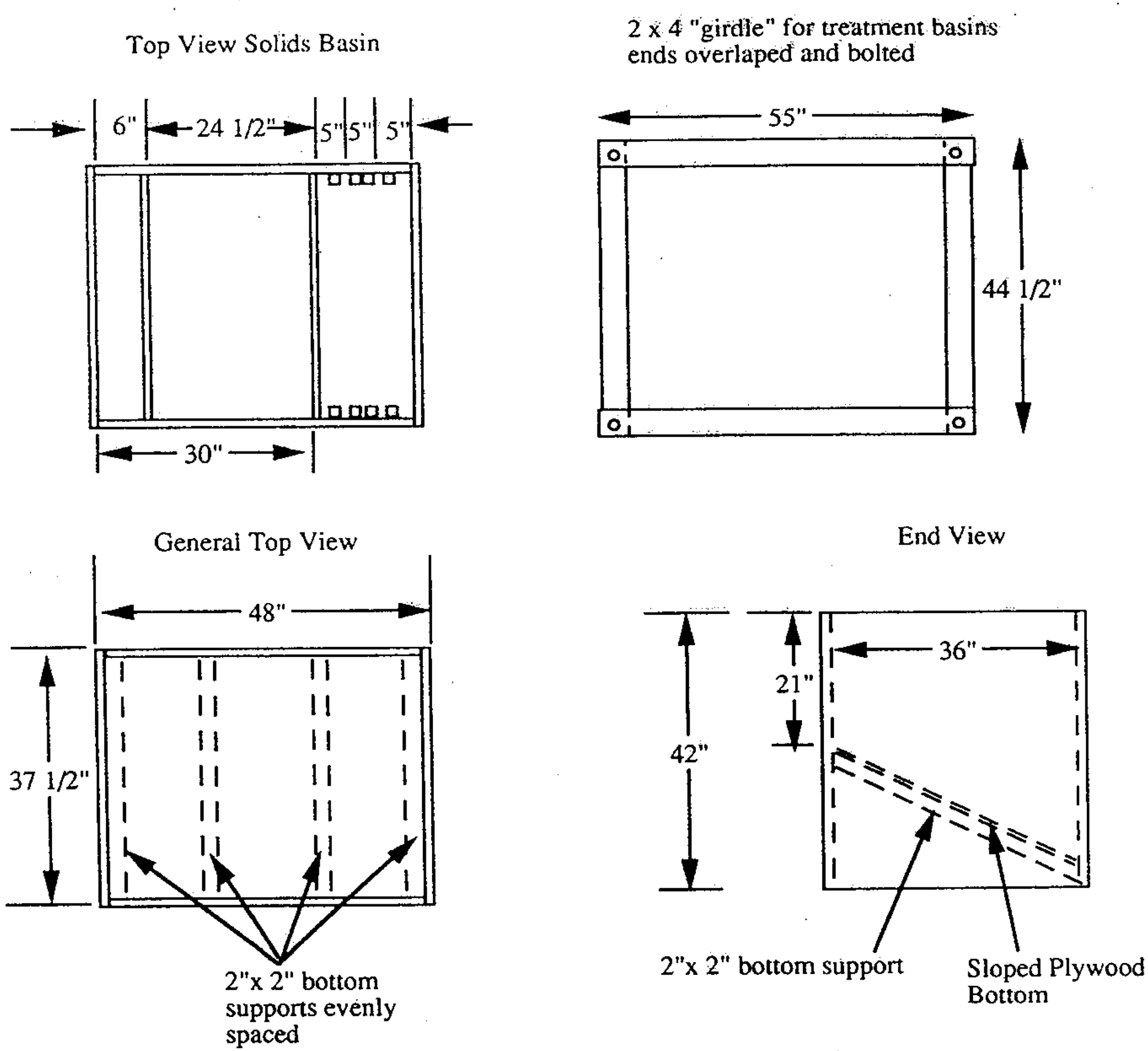


Figure 3. Solids Removal Basin Flow Details



Construction Materials

3/4"AB Plywood
4 - 2 x 4's
4" Fiberglass Tape
Fiber Glass Resin
Brass Wood Screws
Water Proof Epoxy
Paint
Exterior Paint or Stain

Figure 4. Basic Treatment Basin Construction Details

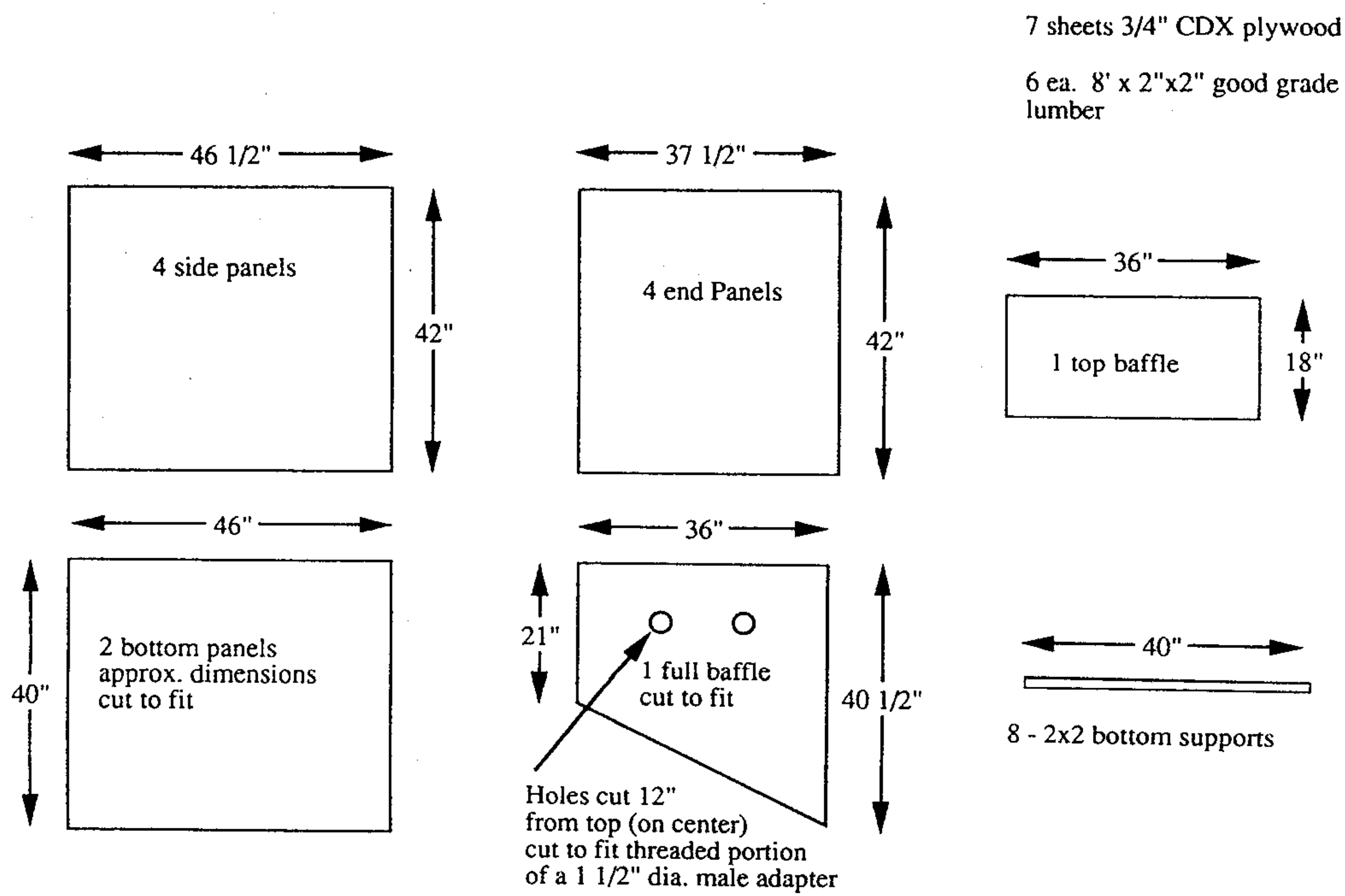
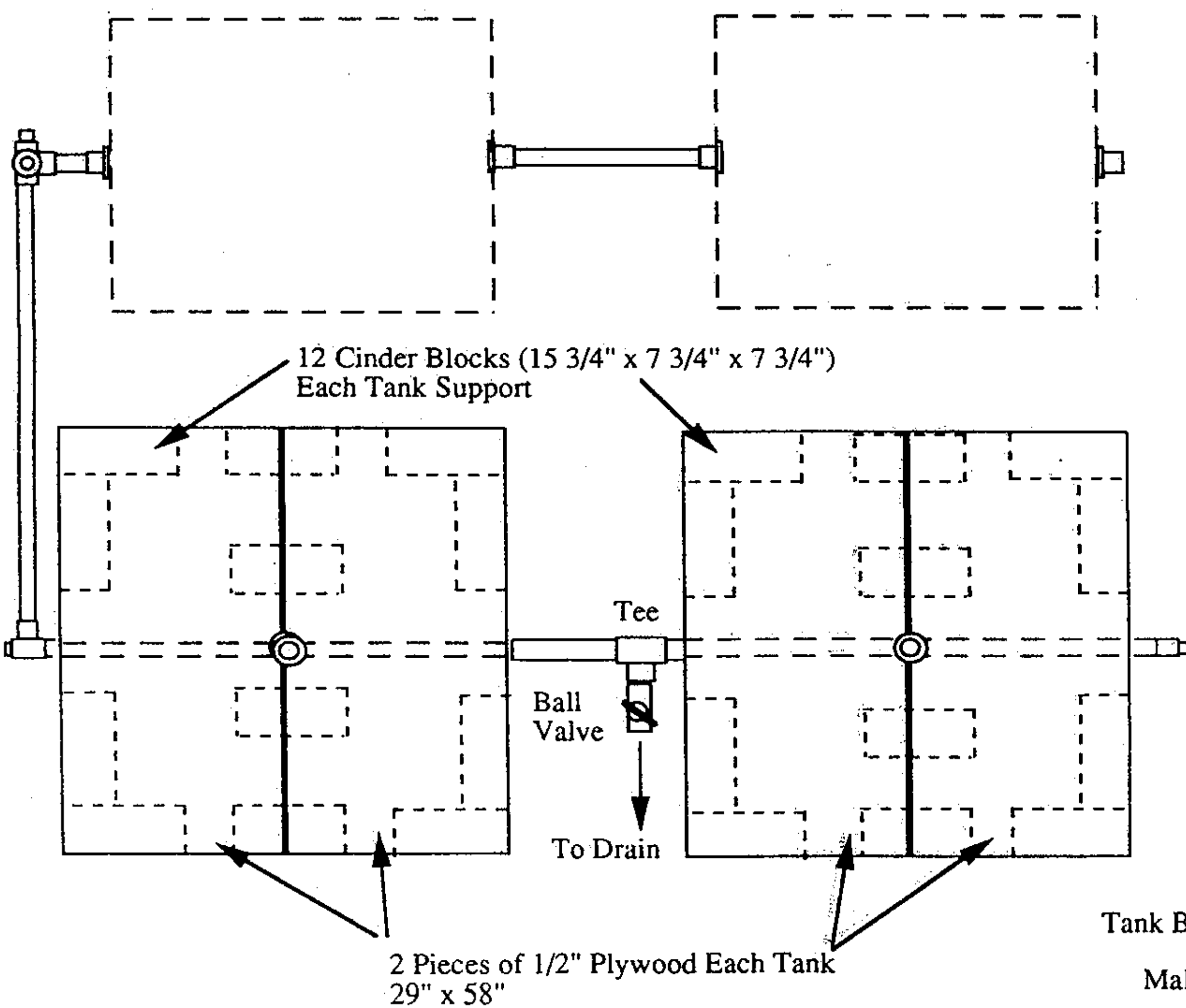


Figure 5. Treatment Basin Plywood Panels



Drain Construction Materials

4 - 1 1/2" SxS Bulkhead fittings
2 - 1 1/2" SxThrd Bulkhead fittings
6 - 1 1/2" SxS Tee's
1 - 1 1/2" SxS Ball Valve
3 - 1 1/2" SxThrd Couplings
3 - 1 1/2" Thrd. Plugs
2 - 1 1/2" Male Adapters

Fish Tank Support Materials

48 Cinder Blocks
4 4'x8' sheets of 1/2" plywood

Tank Bottom Drain Detail
(not to scale)

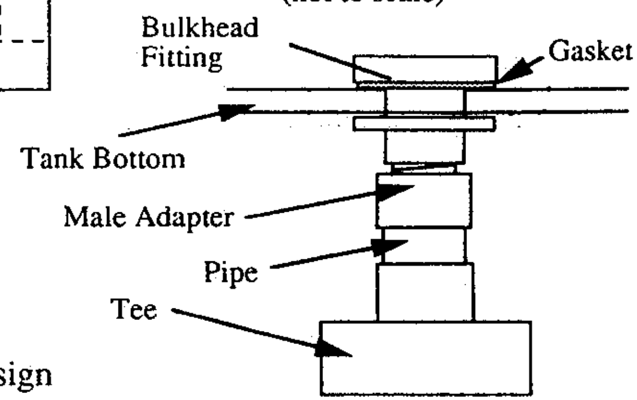


Figure 6. Fish Culture Tank Support and Drain Design

IV. Start-Up

Upon completion of the construction phase of this project, your students will be eager to fill the system with water and stock the fish. It is a good practice, however, to fill your system with water, let it sit for 4 - 7 days, then waste the water to the drain. This is to ensure that any toxins from the new epoxy paint, new polyethylene tanks or PVC pipes have leaked out.

After refilling the system, if city water is the source, it is important that you aerate the water in the system for at least 24 hours before stocking fish. This aeration process will remove excessive amounts of chlorine, if it is present. To ensure a healthy biofilter and fish, we recommend that you operate the system with elevated levels of alkalinity and chlorides in the water. Alkalinity is required for the biofilter and the chlorides tend to reduce stress in the fish. As part of your laboratory, you should have a test kit to measure both of these parameters. You should use baking soda (food grade) as a source of alkalinity and food grade salt or sea salt as a source of chlorides. We recommend that the alkalinity be raised an maintained at 150 - 200 mg/L (as C_aCO_3) and the chloride level be raised to 200 - 300 mg/L. These levels translate to 0.125 - 0.167 lbs. of baking soda and 0.275 - 0.413 lbs. of salt (NaCl) per 100 gallons of water in the system.

The operational temperature for this system will depend upon the species you intend to grow. For most warmwater species, a temperature range of 75 - 80^o F is ideal. If the room temperature is below this range, you will not need to set the thermostats on the "aquarium" heaters (see the previous section on temperature control) to the lowest temperature desired. Be sure that the temperature of the water that you are transferring your fish from is not more than 2^o F different from the temperature of your system's water.

When starting up a new system, the rotating biological filter does not initially have the ability to remove ammonia or nitrite - nitrogen from the water. During a one month start-up period you will need to nurture the bacterial populations on the filter to gain this capacity. The model system is designed to process waste from up to 3 lbs. of feed per day when it is fully operational. To start the system, you should stock each tank with only a few (preferably adult) fish. The total weight of fish in the system should not exceed 20 lbs. You should feed the fish in each tank no more than 1/8 to 1/4 lbs. of feed per day.

The ammonia-nitrogen concentration is then monitored and the feed rate adjusted downward if the un-ionized ammonia concentration exceeds 0.2 mg/L. Within two to three weeks you will see the level of ammonia-nitrogen decline with a concurrent rise in nitrite-nitrogen concentration. The nitrite-nitrogen concentration should be maintained below 15 mg/L. The chloride concentration in the water will work to counter-act the nitrite toxicity. You should maintain at least 6 mg/L of chlorides for each mg/L of nitrite concentration (ie. 15 mg/L nitrite = 90 mg/L chlorides). Within approximately 6 weeks from the time of start-up, the nitrite concentration in the water will decline with a concurrent rise in the concentration of nitrate-nitrogen in the system. Nitrates are not toxic to fish at levels below 150 mg/L. The nitrate concentration will be controlled through the removal of wastewater from the system and the addition of new water. Once the ammonia and nitrite-nitrogen concentrations are within a safe range (see the section on fish health and care), you are ready to stock your system with the fish you wish to culture. In daily operations, keep in mind that the system will not respond well to large changes in feed rate or temperature. Do not change the feed rate more than 10% per day.

ROUTINE SYSTEM MAINTENANCE

Very little routine maintenance needs to be performed on the fish tanks. The smoothed bottom, circular fish tanks chosen for use with the model system provide a self-cleaning flow that directs most of the uneaten feed and fish feces to the center drain. Once a day, the screens on the tank drains should be removed and cleaned as necessary.

Every second or third day of operation, the solids removal basin will require cleaning. This operation will require that the submersible pump be unplugged and the tube settlers removed from the basin. The accumulated solids are siphoned from the bottom of the basin. Although you may dump the wastewater into a drain, you may choose to use this highly organic wastewater as fertilizer on a garden. The tube settlers should be washed down with a hose and reinstalled in the basin. The coarse and fine polyester fiber screens should be removed and cleaned by spraying with a "high" pressure hose. Upon replacing the vertical filters you may restart the submersible pump. New water from the tap should be added to one of the fish tanks to replace the water removed in the solids siphoning operation (5 - 10 gallons). The only other water loss from the system will come from the container into which the foam fractionator discharges.

Once a week or as needed, the drain lines should be cleaned. To do this you will need to unplug the submersible pump and place a standpipe in each tank (a pipe fitting into the drain to stop the discharge of water; 3' long each) and a plug in the inflow bulkhead fittings in the solids removal basin. The water in the drainage system should be emptied into the room drain and the end plugs from the drainage system removed. A large bottle brush (1 1/2" diameter) should be attached to a long 12' stiff wire (electricians wire chase) and pulled or pushed through each straight section of the drain. This procedure will remove the slim buildup on the pipes, reducing the frictional losses. Failure to clean the drainage system will result in a lowering of the water level in the water treatment basins.

All other system components should be maintained according to the manufacturers specifications and guidelines.

V. Management of System

The management of a recirculating system can be satisfying, confusing and depressing all at the same time. Do not be upset if you experience all of the above, in fact if you do not, you probably cannot claim to be normal. When everything goes as planned and your fish do well, it can be a satisfying accomplishment. When things are not going well, it can be depressing and in between there is confusion and a feeling of isolation, but trust us when we tell you that everyone who attempts a recirculation system experiences the same feelings and no level of expertise protects you from these feelings. So please just relax, be alert but calm in your approach to managing your system.

Water Quality Monitoring:

Water quality monitoring begins with observing you fish because they will often, by their actions, tell you about many problems. When you are inexperienced, this can be a problem. What does constitute proper behavior for fish in your particular system? The way to determine this is to write down your observations of day to day fish behavior along with your daily recording of the test data on your system. So a systematic monitoring of both the water quality and fish behavior will pay dividends at a later time. Please note that water quality forms have a place for such observations.

The equipment you use is a matter of preference and budget. A kit that will allow you to test oxygen, nitrite, carbon dioxide, alkalinity, ammonia, and chlorides is essential. Most kits contain some version of the Winkler method of testing oxygen which is good but very time consuming and oxygen requires several tests per day so if budgets permit an oxygen meter is a good investment. An Imhoff cone is useful to determine the solids in your system and a good thermometer.

In considering the individual water quality parameters please keep in mind what effect they have on the cultured species and the biofilter will be altered by other aspects of water quality occurring at the same time. (Example: ammonia values that are lethal at a pH of 8 are harmless at a pH of 7.2). When testing keep in mind that you are dealing with two living systems, the species you are culturing and also the bacteria in your biofilter. Do not get too excited if one or more of your parameters seem high or low. In correcting these do so gradually as a rapid change for what you perceive to be the better may be more harmful in the long run if done too quickly. The key is to make the changes gradually giving both the biofilter and the cultured species a chance to adapt to the new conditions. The possible exception to this is low D.O., if this is very low it should be raised as quickly as possible.

Temperature

Temperature is a parameter that effects the rate at which the fish metabolize feed, the saturation point of oxygen, and the rate at which the biofilter functions. Rapid changes upset all of the above in your system. The actual system temperature will be determined by the species cultured but should not vary by more than a few degrees over the course of the day. The cultured species will probably not be seriously effected by this but keep in mind a drop of about 10^{o} F will reduce the biofilter capacity by 25 to 50%. The biofilter will adjust to new temperatures if you decide to culture a different species in the same system but it does take time. A good thermometer is all that is needed to check this parameter.

Dissolved Oxygen

Dissolved oxygen (DO) limits the amount of feed the cultured species can metabolize, the density of the species and the activities of the biofilter. We try to maintain DO at 5 ppm+. It will fall below this level occasionally but usually this causes no harm if it persists for short periods of time and other parameters are in good order. DO depressions occur mostly in the hour after feeding and the more feed used the greater the variation. Good feeding practices of spreading the daily ration over the greatest number of feedings possible will reduce these depressions. (Example: 3 lb/day could be divided into 6 feedings of 8 ozs. each). Automatic feeders will take this concept to its ultimate level of spreading food over the longest period possible. So if you are feeding by hand, DO should be checked before feeding and 30 to 45 minutes after feeding. The biofilter oxygen requirements are not as high and about 2 ppm is probably satisfactory and with the RBC, in the demonstration model, it is not a problem as the bacteria have access to atmospheric oxygen. One must also keep in mind that DO is consumed by many processes in your system other than the cultured species or biofilter, some of those are chemical, some heterotrophic bacteria and algae under low light conditions. So all oxygen is not available to your fish.

Ammonia

Ammonia is produced in the system by the metabolism of the fish and is also produced by the decomposition of the fish wastes and uneaten feed. This is one reason why solid wastes and uneaten feed should be removed as quickly and completely as possible. Ammonia is not as big a problem as was once thought, first of all the part of the biofilter that reduces ammonia is the most consistent part of the biofilter and is the first to start-up. Secondly ammonia comes in two forms NH_3 (toxic) and NH_4 (non-toxic), so in your test kit your readings will be the total of both forms. The good news about this is that at pH values near neutral the percentage of toxic ammonia is very low. At pH values of 7 to 7.5 total ammonia values of 6 ppm seem to cause few problems, especially if oxygen is in good order. It is not uncommon to see systems where ammonia levels of 20 ppm were present with the fish showing no ill effects. Aquaculturists don't recommend this level and for the most part typical systems have seemed to produce ammonia levels of 1.5 to 2.0 ppm under stable operating conditions. Ammonia produced in the system increases as the feeding rate goes up or as the protein content of the feed increases. Since as your fish grow you will be increasing the amount of feed into the system the biofilter must be given an opportunity to adjust to these increases gradually to be able to assimilate the additional ammonia this practice produces. As long as you do not exceed the amount of ammonia that your biofilter is capable of removing, it will adjust to each new level in time.

Nitrite

Nitrite is the product of the biofilter resulting from the breakdown of ammonia. Converting nitrite to nitrate seems to be the least dependable part of the nitrification process. It seems to be easily upset by rapid changes of nearly any kind, also these bacteria seem to be easily dislodged, so swings in nitrite levels are fairly common. Nitrites are toxic because they inhibit the hemoglobin of the fish from absorbing oxygen from the water, therefore even though oxygen tests indicate that D.O. is in good supply, if the fish are exposed to high nitrite levels they are still oxygen starved resulting in poor growth and poor general health. Fortunately, nitrite toxicity can be counteracted by the addition of chlorides (NaCl) at the rate of 6 ppm chloride for each 1 ppm of nitrite (example: if nitrite values are 3 ppm - maintaining 18 ppm+ of chlorides controls the problem). It may be good practice to routinely maintain chlorides at 100 to 150 ppm in your system at all times. It not only reduces the threat of nitrite toxicity, but also relieves stress, reduces fungus infections and reduces the energy required by the fish to perform active transport of materials across cell membranes. In testing chlorides if you use a Hach test kit your supply of titration material will be quickly exhausted if you test levels of 150 ppm chlorides very often - so dilute with distilled water before testing - with the Hach kit the measuring tube for chloride has a volume of 6 ml, they also supply a dropper that measures .5 ml. So simply place .5 ml from your system in the measuring tube, fill the tube to the top with distilled water and test as directions indicate. When finished multiply by 12 and get a total result. This reduces the amount of test materials required to measure relatively high chlorides. Variations of this same method can be used for ammonia and nitrites that test higher than the scales in the same kit allow you to read. Just remember to multiply by the rate of dilution to obtain a final reading.

Alkalinity

Alkalinity is another of the factors that is interrelated with others such pH, CO_2 and ammonia nitrification. In a functioning biofilter the bacteria remove carbonates from the water to produce bacterial mass. The energy to do this comes from nitrification, therefore, as the amount of ammonia removed by the biofilter increases the amount of alkalinity in the system will decrease, the process also produces acids which further reduce the alkalinity of the system. If the proper alkalinity is not maintained in the system, the pH will drop due to the lack of buffering and the bacteria in the filter stop functioning due to lack of carbonates. We maintain from 75 to 120 ppm in the system by adding sodium bicarbonate on a daily basis. Testing will indicate amounts to be added, this is not as complicated as it may seem for under a routine of adding the same amount of feed each day produces nearly the same demand on the alkalinity each day. In fact about 7 grams of alkalinity is consumed by the biofilter to handle 1 gram of ammonia. You can predict your alkalinity demand from your feeding regiment.

pH

pH has already been mentioned in relation to ammonia toxicity and CO_2 concentrations as well. In our system we attempt to maintain pH levels from 7 to 7.5. This is accomplished by adding sodium bicarbonate and aerating to reduce CO_2. If nothing were done to prevent it, the system would eventually become acid. pH should not be adjusted more than .5 units per day. It would save money to use agricultural sodium bicarbonate simply be aware it is not 100% pure when calculating amounts to be added.

CO_2

CO_2 is mostly controlled by aeration of the water and in some cases by algae. CO_2 higher than 2 ppm will cause the pH to be more acid. A simple test will tell you if CO_2 is high, place several drops of universal indicator in a small flask and observe the color - shake the flask vigorously. If the color changes toward the alkaline side it would indicate the CO_2 is high and most probably the O_2 is low. If the change is to the acid side the indication is that CO_2 is very low and the water well aerated. CO_2 values can be lowered by the addition of more air stones in your culture tanks. CO_2 can also be tested by using a CO_2 kit.

Nitrate

Nitrate, the final product of the biofilter, does not seem to cause many problems to the fish and is mostly managed by the daily replacement of water which is removed when cleaning settling tanks and evaporation. If from 5 to 10% of the total water is replaced daily, it will help control nitrate levels. Nitrates may also be reduced by a denitrification process which simply involves moving some of the water from the system into an empty tank - stir the water to mix completely and then allow to sit for several days. Do not aerate as you want the tank to become anaerobic. After sitting several days decant off the clear water at the top, discard the settled material and the decanted water may be returned to the system as the nitrate has been converted to atmospheric nitrogen and simply goes off into the air.

Foam

Foam in your culture tank is actually a blessing disguised as rather nasty looking blobs of light tan to brown froth floating on the water. It may be unsightly, but it affords an opportunity to remove some proteins and very fine particulates that otherwise will remain in your water in spite of your best efforts to filter or settle it. Foam is the result of fine particles and proteins sticking to the outside of air bubbles and remaining above the surface of the water due to the surface tension of the water. Foaming occurs when air is driven into the water such as when water is being sprayed into the tank, near paddle-type aerators, or most commonly, above air stones. Foam will apparently come and go to some extent, this is due mostly to the fact that feed contains fats and oils which break the surface tension allowing the bubbles to break and return to the tank. So very often when the fish have not been fed for a few hours, such as overnight, an operator is greeted in the morning by foam that may extend a foot or more above the tanks. A simple method of removing foam is to use a wet-dry vacuum cleaner when large amounts occur. A better method is to employ a foam fractionator to constantly remove foam when it occurs (see diagram of foam fractionator). It will deposit the foam, along with its waste load, in a bucket or down a drain. This has a dramatic, positive, affect on water quality. A little trick to make your tanks foam-free for a short period of time, like during a tour or an open house, is to have on hand a little high fat fish feed such as salmon starter or Purina's Trout Chow (TM) and simply throw a small amount into each tank a few minutes before your group arrives for their visit. The foam will disappear, as by magic, for a short period of time. This is, of course, only a cosmetic improvement and as a matter of practice the development of foam should be encouraged and viewed as a result of good management.

Sunlight

Sunlight is not a water quality parameter but it can effect the water quality so we might make note of a few of these effects. If the system is located near a window or in a greenhouse, some provision must be made to reduce the light because it will cause excessive algae growth which in turn may cause large variations in pH, DO, CO_2, Nitrate toxicity, ammonia toxicity and biofilter fouling. Most sources indicate that biofilters are adversely affected by light and total darkness may be the best. Excess algae also may lead to off flavors in the fish when harvest time rolls around.

Managing The Biofilter

Managing a biofilter is related to all of the water quality tests you run, any of which tell you what your filter needs and how well it is doing. An aquaculturist will often explain that keeping the biofilter happy is my most important job in recirculation as a matter of fact if he/she were given a choice between having the biofilter die today or having all the fish die today, his/her choice is to have the fish die. If your biofilter dies, your fish will all die in a few days anyway and it will take weeks to recondition the filter and start again. If the biofilter is good and the fish die, you just buy more fish and you are back in business. Our goal is to make our biofilter function as efficiently and as stable as possible, while the practice of growing fish, increasing feed, harvesting fish and adding material to the water reduces efficiency and makes the filter less stable. If this sounds counterproductive, it is, thus the constant advice of making changes in your system very gradually helps your biofilter do its job. If your biofilter is functioning well be aware that sudden removal of a large portion of your fish and thus their wastes may upset your filter as badly as rapidly increasing the feed rate. A healthy biofilter has a very thin growth of orange-brown colored bacteria on the surface of the biofilter material. Thick clumps of a brown slimy material is likely to be heterotrophic bacteria and not nitrifying bacteria these may lead to clogging of the filter and also pipes and should be discouraged by keeping the particles of uneaten feed and wastes out of your system as much as possible. Water quality tests must be looked at in two ways. What does it mean to my cultured species and what does it mean to my biofilter?

If it appears to you that biofilters are new and magical devices, they are not, for the same bacteria have been biofiltering organic material in our lakes, rivers, and oceans for billions of year. If you are upset when your biofilter is not functioning well, take heart from the ugly fact that for all of our technology and money we have spent, we as a species are not managing our natural biofilters very well either, thus we still use the words water pollution all too often. Organic material added to water is not pollution, organic material add to water too rapidly or in quantities beyond the capacity of the biofilter, natural or in your system, is pollution. Keep this in mind when managing your biofilter.

Summary

In review of the parameters discussed the watch word is make changes as gradual as possible except dissolved O_2 must be raised to comfortable levels as quickly as possible. When fish show extreme distress and many parameters are not good the safest course of action to buy time is to replace as much water as possible. In fact the best safety net you can have is to have a supply of standby water tempered to temperature and adjusted to proper pH in an equal volume to the water in the system for such emergencies. Also, one needs to be aware that many of the discussed factors are interrelated and changing one may have somewhat of a domino effect on others. Please bare in mind that fish sometimes just die and that a single or several dead fish may indicate nothing more than poor handling or an incidental death. However, a pattern of dead fish require investigation. One thing many aquaculturists have found is that persons who have had more experience with systems are quite willing to share information and help where possible, so maintain a card file or list of experienced operators you can call when you need it, it is a comfort to have even if you don't use it.

Fish Production Management

Species for Culture

Many species are suitable for recirculating aquaculture but Tilapia are very tough fish and will survive when other species may die. So,if possible, they should be used as beginning species. However, hybrid striped bass do well as do pure striped bass, largemouth bass trained on artificial feed, minnows, sunfish and ornamentals such as koi, goldfish and guppies. Catfish contrary to popular opinion do not seem to do well in recirculation systems unless from a disease free source which are difficult to obtain. Rainbow trout do extremely well if temperatures can be maintained just below 70° F, keep in mind with lower temperatures a larger biofilter may be needed to offset the lower activity of the bacteria due to temperature.

Obtaining Fish

Obtaining good stock can be a problem, for help check with others using the species you desire. Universities and research stations maintained by state or federal organizations, other high schools or a list of suppliers in the commercial sector can be found in the Aquaculture Magazine buyers guide, also your state conservation department may be able to supply a list of commercial hatcheries as they need licenses to sell and propagate fish.

Transporting Fish

Once you have located your desired fish, if possible have them delivered but if you must do this yourself the simplest method is to use a 12 volt aeration device called a minnow-saver coupled with almost any container capable of handling 50 gallons of water. (An insulated container is nice but not absolutely necessary to be successful). With this unit about 100 to 120 lbs. of fish may be transported safely. The most important consideration is the water you use to transport them. If the fish are from a flow through system, use clean water from the source of the flow through system. If the fish are from a recirculation system, the fish may be stressed by absolutely clean water due to differences in the character of the water caused by recirculation. Mix some closed system water and clean water from the same source as their system gets its water about 50/50. In both cases add about 1 lb. of pure salt, it reduces stress and seems to calm them. You should also make arrangements in advance to have the fish taken off feed for several days as this is vital to successful transport.

Stocking Fish in Your System

After you arrive at your facility, check the pH and temperature in both your system and your transport tank if it is only a couple degrees and less than .5 units of pH a few buckets of water exchange between the system and the transport tank should suffice (discard water from transport tank). If more than a few degrees allow about 30 minutes for every two degrees by exchanging more water, continue to exchange until the temperatures match. pH will usually follow. Follow the same procedure if pH is more than .5 units different. Before the fish are placed in your system, the exact number of fish should be determined by actual count and the total weight determined by scales. This will be needed to determine feeding schedules and other management practices later. All this takes time but is well worth it in producing a good start.

Feed Storage

Feed is usually just left in the paper bag it comes in and stored in a dry, vermin free environment. Feed should also be stored at room temperature or less. When handling feed in bags, bare in mind that rough handling causes the feed pellets to grind together increasing the fines in the feed which later need to be removed before the feed can be used. No more feed should be purchased than can be used in 60 days. Some components in feed, even when stored properly, break-down in time. Since we are talking about feed storage in a school setting, other methods should be considered, perhaps storing in plastic or metal containers, such as trash cans, may reduce the odor of the feed in the room and reduce the potential vermin attraction. If feed should start to mold: discard that batch immediately. Do not feed it to the fish.

Feeding of Fish

Feeding should be a very controlled process if a biofilter is to function well and any hope of calculating feed conversions exists. The first step in feeding is to select the proper type and size of feed. The size of the feed depends on the size of the fish being fed. Feed manufacturers will gladly make recommendations along these lines or the persons from whom fish are obtained can properly size the feed you need. Feeding pellets too large lead to uneaten feed and poor digestion due to larger particles taking longer to break down in the fish. Feeding feed too small results in feed again being uneaten and dissolving in the water causing problems with heterotrophic bacteria, also very small feed fed to larger fish seems to cause gill problems. Proper sizing leads to less waste, more growth, fewer fish health problems, and much cleaner water. The type of feed depends on again the species, however, most feed used in recirculation systems is either made for trout or catfish. One must keep in mind that the feed is designed for open ponds or flow through systems where excessive fats cause no problems to the fish or the system. In recirculation systems high fat or high energy diets may cause foam fractionators to become ineffective by breaking the surface tension of the water making it impossible to remove very fine wastes from the system. It is recommended that you use what is currently called regular trout grower with a fat content of about 8%. The perfect feed has not been developed for recirculation systems; in fact this may be the area where the greatest potential for improvement of recirculation systems may lie.

Once the size and type is established you must deal with the amount of feed to use per day. You need to know the total weight of the fish in the system and the percent of body weight you need to feed. As a basic rule small fish are generally fed at a higher rate than larger fish, so as the fish grow the percentage of body weight being fed reduces.

For example:	20 gram fish	6%
	50 gram fish	5%
	100 gram fish	4%
	200 gram fish	3%
	300 gram fish	2%
	400 gram fish	1.5%
	500 gram fish	1%

If you have 500 fish that weigh an average of 200 gram each, the total weight is 100,000 grams. If you feed at 3% of the body weight, the amount required is 3000 grams per day. You should check the growth of the fish every two weeks by capturing a 3 to 5% sample and doing a test of their weight. After determining the average weight of the individual fish and finding the percent of body weight to be fed, multiply the new average weight by the number of fish in the system to determine total weight and then by the percent to be fed to determine the quantity to be fed. Of course, records of mortalities or other losses must be maintained to give the estimates as much accuracy as possible. A form is used to keep track of all this type of information. A feed conversion rate can be calculated by dividing the weight gained by the weight of feed used over the same period of time. Once it has been determined that for example 3000 grams of feed are going to be fed for the day, the feed can be weighed out on any type of scale you desire. Before weighing it is best to screen the feed to remove fines. This reduces uneaten feed in the system. For #4 crumbles and 3/32" pellets we use a 1' x 1' frame with window screen in the frame, for 1/8" or larger pellets we use the same size frame with 1/8" mesh hardware cloth. You will be surprised how many fines are in the feed when you do this (save the fines it makes good feed for very small fish that you may want to start later). The screening device has a metal feed pouring scoop in one corner so feed can be poured into the container to be weighed (see diagram).

The actual feeding should be divided over as many smaller feedings as possible. The reason for this has been explained in the section under dissolved oxygen. A small amount of feed may be fed first to make sure fish are active and eating. If they are not there may be a problem, do not throw a large quantity of feed at a time, for uneaten feed will cause serious problems. Floating feed has an advantage of being visible and the activities of the fish evident. It has the disadvantages of being more expensive and often contains more oil which creates a problem with foam fractionators.

Disease and Stress

If you keep your water quality in good order and don't overfeed and mishandle the fish you should not have many disease problems due to stress. Diseases are a problem that generally are a result of stress so if it is kept to a minimum disease should not be a major problem. If a disease problem does come your way, you have no way to treat it that will not adversely affect the biofilter. It may be to your advantage to get rid of the fish and start over without destroying the biofilter that you have started. If you medicate sick fish in the system, the biofilter will die and then all the fish will die. So your option is to pick them out or get rid of all of them at once. Most aquaculturists have rarely seen a disease that killed all the fish, if the water quality remained good. Relax, there is not a whole lot you can do anyhow.

Purging Fish

Purging is a process that produces a fish free of off-flavors and should be practiced on fish produced in recirculation systems. Fish should not be taken directly from your system and prepared for consumption. A 3-5 day period of time should elapse during which the fish are held in clean water without being fed. This may be in a tank with a small flow of water constantly changing the water in the tank or by holding the fish in a tank with an airstone and using the water from the purge tank everyday for make-up water in your culture system and replacing nearly all the water in the purge tank one or more times each day. If the second method is used an extra day may achieve better results. This method also has the advantage of getting double use from your water, once in the purge tank and later in the culture system. Salt should be added to the purge tank at a rate of 100 ppm and temperature changes should be gradual. Some fish taste great directly out of the system but some do not, so purging is the safest method of producing a good edible product. The taste of an off-flavor fish will certainly reduce the interest in your system for it is sometimes described as a muddy taste. Some aquaculturists like to describe it in this manner--it tastes like a small slice of basement.

Do's and Don't's

- Do monitor your water quality daily with several O_2 tests both before and 1/2 to 1 hour after feeding.
- Do keep records of feed and growth of fish.
- Do keep records of water quality to see trends.
- Do keep a small quantity of floating feed to see if your fish are active and feeding.
- Do not make rapid changes in any water quality parameter except O_2.
- Do keep records of mortalities and fish removed from the system.
- Do make increases in feed amounts gradually.
- Do not feed any moldy feed.
- Do change feed sizes as your fish grow.
- Do allow make-up water that is chlorinated to stand for several days with an air stone in it before using in the system.
- Don't get in a hurry to stock your fish before the biofilter is active.
- Do be alert to changes in your fishes appetite or general behavior.
- Don't get excited if a fish or two die.
- Do have make-up water standing by for emergencies.
- Do handle fish gently and as little as possible.
- Do use some type of netting or screen over the tanks to prevent fish from jumping out of the tanks.
- Do make feed charts for others to follow, you may not always be there.
- Do remember that decreases in feed will upset the biofilter as much as increases.
- Do remember this is a learning process and failures sometimes result in more gain than successes.
- Do shield your tanks and biofilter from excessive light because of algae and light will inhibit bacteria metabolism.

- Don't get upset if your fish don't grow perfectly even (look at your class they are the same age, are they all the same size?)

- Don't expect clear water in your system, good quality water in a recirculation system will eventually look like good onion soup without cheese and croutons.

- Do have a plan of action for power failures.

- Do generate as much help and interest from other members of your faculty as possible, you can use all the help you can get.

VI. Appendix

Species Selection and General Requirements

SPECIES	SUITABILITY	REQUIREMENTS	STOCKING	FEEDING
Channel Catfish (Ictalurus Punctatus)	Fair	Warm, freshwater, good water quality	.25 lbs per gal.	36% protein @ 3-5% weight
Rainbow Trout (Salmo gairdneri)	Fair	Cool, freshwater, clear, flowing, superior water quality	.25 lbs per gal.	45% protein @ 3-5% weight
Hybrid Stripped Bass (Morone crysops x Morone saxtilis)	Good	Warmwater, fresh or brackish, good water quality, high hardness & alkalinity	.25-.5 lbs per gal.	38% protein @ 3-5% weight
Tilapia species	Excellent	Very warm water, fresh or brackish, fair water quality	.25-.5 lbs per gal.	32% protein
Largemouth Bass (Micropterus salmoides)	Fair	Warm, freshwater, good water quality	.25 lbs per gal.	38% protein @ 3-5% weight
Baitfish (shiners, minnows)	Good	Warm, freshwater fair water quality	.5 lbs per gallon	32% protein @ 3-5% weight
Bluegill (Lepomis macrochirus)	Good			
Goldfish or Koi (Cryprinids)	Good			
Spottail Bass (Scieanops ocellatus)	Fair			
Salmon (Salmo or Oncorhynchus)	Fair			
Marine Shrimp (Penaeus)	Poor			
Crawfish Red Swamp (Procambrus clarkii)	Good/Fair			
Freshwater Prawn (Macrobrachium rosenbergii)	Poor			
Brine Shrimp (Artemia salina)	Excellent			
Oysters (Crassostrea)	Good			
Hard Clams (Mercenaria)	Good			
Marine Algae (misc. genera)	Good			

Disease/Stress Indicators

SIGN/SYMPTOM	CAUSES	TREATMENT
Lethargy	Chlorine	Aerate heavily and add dechlorinating agent ie, sodium thiosulfate
	Low D.O.	Aeration, remove any organic matter, stop feeding, check airlines
Rapid gill venting	Low D.O.	Aeration, remove any organic matter, stop feeding, check airlines
	High Nitrites	Aeration and add sodium chloride
	Gill parasites	Reduce stocking, aeration
	High ammonia	Aeration and exchange water, check pH
White spots	ICH disease	Quarantine infected fish
Boil-like sores	Bacterial disease	Quarantine infected fish
Reddened fins or abdomen	Bacterial or viral disease	Quarantine infected fish
Rubbing sides	Parasites	Quarantine infected fish
Whirling	Viral disease	Quarantine infected fish
Peculiar swimming	Viral disease or parasites	Quarantine infected fish and check water quality
Eroded fins	Bacterial disease	Quarantine infected fish
	Low pH	Add sodium bicarbonate
Cloudy water	High solids (dissolved and suspended)	Exchange water, remove any accumulated organic matter, reduce feeding
Algae	Excessive light	Exchange water, shade tank, check pH

Reporting/Monitoring Check Sheet

For the week of:

Tank/Pool #:

DAILY

Date/Remarks Initials	Temperature	D.O.	Ammonia	Nitrite	pH	Deaths	Feed
1.							
2.							
3.							
4.							
5.							
6.							
7.							

WEEKLY

Date Initials	Hardness	Alkalinity	Chloride	Salinity	Remarks

SUMMARY

Feed Totals:

Mortality Totals:

Water Exchanges:

Fish Added:

System Maintenance Check Sheet

DAILY

Feed Fish
Water Quality Tests
Check Pump Strainer
Check Airlines
Check Pressure on Sand Filter
Backwash Filter
Check Water Levels
Check Flow Rate

Water Quality Management

Parameter	Optimum	Toxic/Stress	Test	Treatment
Nitrite	Zero	above .2 ppm	Daily	Raise chloride, water exchange, don't feed

High nitrite levels are safe if there is plenty of chloride.

Un-ionized Ammonia	Zero	above .2 ppm	Daily	Water exchange, aerate, don't feed
pH	7 - 7.5	below 6 or or above 9	Daily	Add sodium bicarbonate
Dissolved Oxygen	above 5 ppm	below 3 ppm	Daily	Increase aeration, remove organic solids, don't feed

In cold water systems, D.O. should be maintained above 6 ppm. Levels below 5 ppm are stressful and may cause mortalities.

Hardness	above 100 ppm	below 50 ppm	When add water	Add calcium carbonate or calcium chloride.
Alkalinity	above 100 ppm	below 50 ppm	Weekly or when add water	Add sodium bicarbonate or calcium carbonate
Chloride	6 times nitrites	less than 3 times nitrite level	Weekly or when high nitrite	Add sodium chloride
Salinity (marine ppt)	28 - 32	above 35 ppm or below 25 ppt	When add water	Add freshwater or saltwater (salt mix)

In freshwater systems, salinity should be zero.

Temperature (warmwater)	75-85 degrees Fahrenheit	below 65 or above 90	Daily	Adjust heater/chiller, exchange water, use species tolerant of natural conditions
(coldwater)	55 - 65 degrees Fahrenheit	below 45 or above 75	Daily	Adjust heater/chiller, exchange water, use species tolerant of natural conditions

Table of Common Treatments

Problem	What Use	Rate	Comments
Low pH	Sodium Bicarbonate	1.5 lbs/10,000 gal.	Add gradually over 2-3 days
High pH	Sodium Bisulfate	.5 lbs/10,000 gal.	Caustic, dissolve in a bucket, add to water storage, add gradually over 2-3 days.
Low Alkalinity	Sodium Bicarbonate	1.5 lbs/10,000 gal. for 10 ppm increase	Raise only 10 ppm per day
Low Hardness	Calcium Carbonate	1 lb/10,000 gal. for 10 ppm increase	Can also use Calcium chloride at the same rate, raise only 10 ppm per day
High Un-ionized Ammonia	Exchange water	Replace 25% of volume with new water	Watch out for sudden increase in nitrites, adjust pH
High Nitrite	Sodium Chloride	2.5 oz/10,000 gal. for 1 ppm increase	Add gradually

The following treatments may or may not be approved for use in food fish production of a given species. Check on FDA regulations for approved therapeutics for your particular species.

External Parasites, Protozoans and Fungi	Sodium Chloride	Dip: 3% solution for 2-5 minutes Bath: 1% solution for 20-30 minutes
	Formalin	25-250 ppm for 30-60 minutes (use less if the D.O. is low or temperature is high)
	Potassium Permanganate	2-3 ppm (.5 teaspoons per 500 gallons), must aerate, let dissipate
Internal Parasites and Protozoans	Epsom Salts	3.0% of the diet for 2-3 days
Bacterial Infections (internal)	Romet	Use commercially prepared medicated feed, give 3% body weight daily for 10 days. Must stop 21 days before harvest
	Oxytetracycline (Terramycin)	Use commercially prepared medicated feed, give 3% body weight daily for 10 days. Must stop 21 days before harvest.
Bacterial Infections (External)	Sodium Chloride	Same as for parasites
	Potassium Permanganate	Same as for parasites
Viral Infections	There are no known cures for viral diseases of fish. To improve survival, a medicated feed may be used (this helps prevent secondary infections). Also lowering the water temperature often improves survival.	

The best treatment and prevention for any disease problem is maintaining good water quality.

Juniata Valley Aquaculture Project: Water Tests

Day	System	Average pH	Average Total NH_3	Alkalinity	Chloride	Average Nitrite	Temperature	Average DO	CO_2	Comments

Juniata Valley Aquaculture Project: Feed Consumption Chart

Day	Tank 1	Tank 2	Tank 3	Tank 4	Tank 5	Tank 6	Tank 7	Tank 8	Tank 9	Comments

Juniata Valley Aquaculture Project: Average Fish Weights

Date	No.	Container Weight	No. of Fish	Total Weight	Fish Weight	Average Fish Weight

Juniata Valley Aquaculture Project: Filleting Records

Fish Number	Total Weight	Fillet Weight	Dress Percentage	Comments
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
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33				

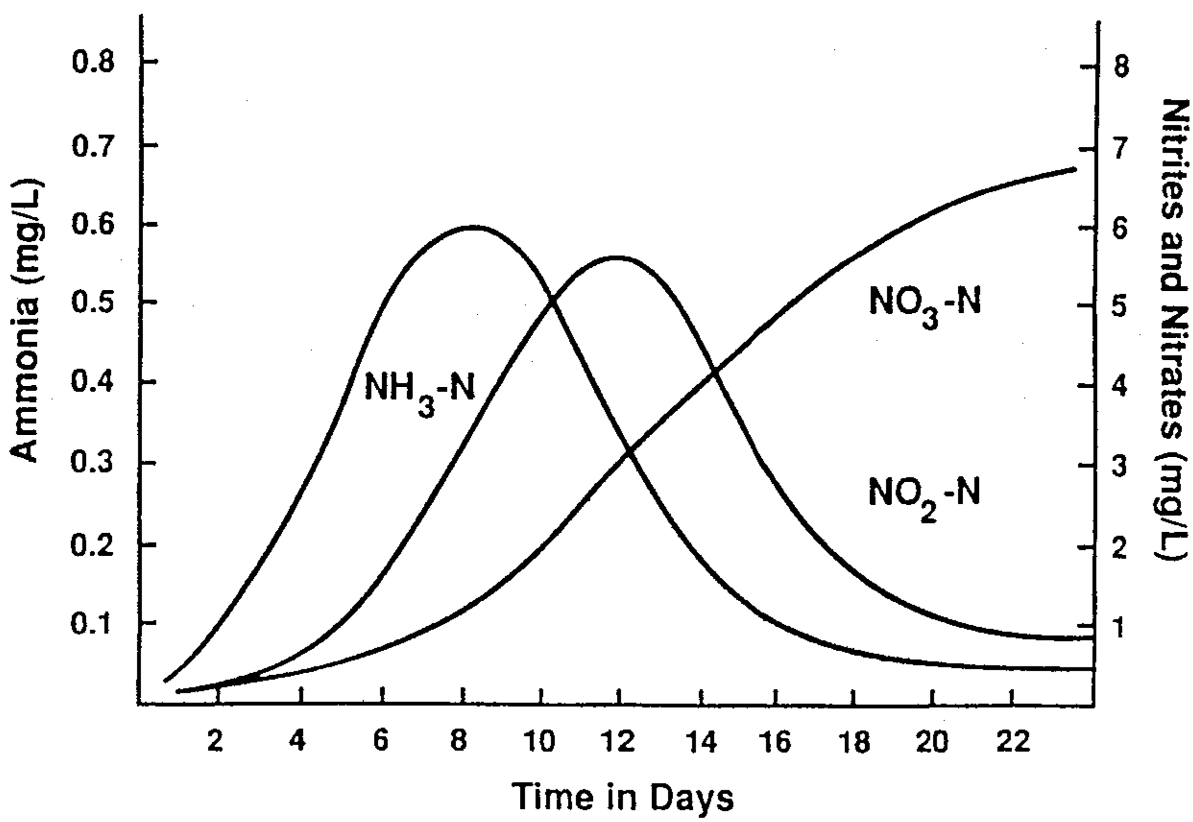


Figure 5. Typical response of nitrifying bacteria in a new culture system with 2% makeup flush.

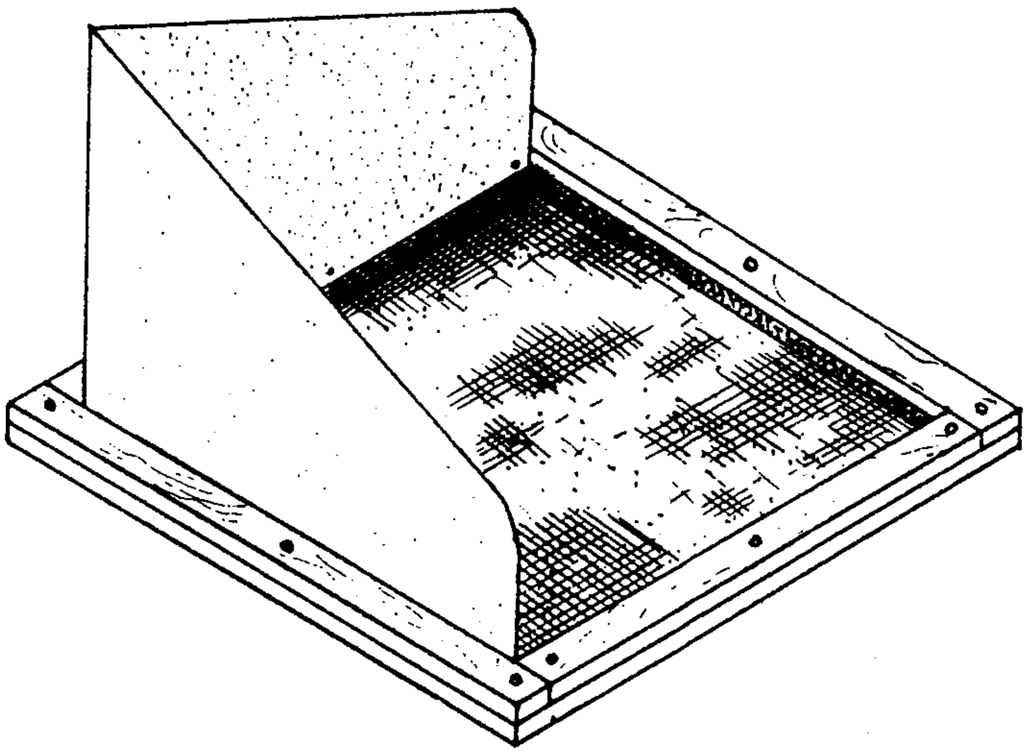
Percentage of toxic ammonia (NH_3) in a fish culture system at different pH and temperature levels.

Temperature °Fahrenheit

pH	61	64	68	72	75	79	82	86	90
7.0	0.30	0.34	0.40	0.46	0.52	0.60	0.70	0.81	0.95
7.2	0.47	0.54	0.63	0.72	0.82	0.95	1.10	1.27	1.50
7.4	0.74	0.86	0.99	1.14	1.30	1.50	1.73	2.00	2.36
7.6	1.17	1.35	1.56	1.79	2.05	2.35	2.72	3.13	3.69
7.8	1.84	2.12	2.45	2.80	3.21	3.88	4.24	4.88	5.72
8.0	2.88	3.32	3.83	4.37	4.99	5.71	6.55	7.52	8.77
8.2	4.49	5.16	5.94	6.76	7.68	8.75	10.00	11.41	13.22
8.4	6.93	7.94	9.09	10.30	11.65	13.20	14.98	16.96	19.48
8.6	10.58	12.03	13.68	15.40	17.28	19.42	21.83	24.45	27.68
8.8	15.76	17.82	20.08	22.38	24.88	27.84	30.68	33.90	37.76
9.0	22.87	25.57	28.47	31.37	34.42	37.71	41.23	44.84	49.02
9.2	31.97	35.25	38.69	42.01	45.41	48.96	52.65	58.30	60.38
9.4	42.68	46.32	50.00	53.45	58.86	60.33	63.79	67.12	70.72
9.6	54.14	57.77	61.31	64.54	67.63	70.67	73.63	76.39	79.29
9.8	65.17	68.43	71.53	74.25	76.81	79.25	81.57	83.68	85.85
10.0	74.78	77.46	79.92	82.05	84.00	85.82	87.52	89.05	90.58
10.2	82.45	84.48	86.32	87.87	89.27	90.56	91.75	92.80	93.84

Figure 2. pH/Temperature/Ammonia Relationship

Diagram of Feed Sifter



#4 crumbles, 3/32 pellets use window screening 1/8 inch to 3/32 inch pellets, use 1/8 inch mesh hardware cloth.

Reference: Maintaining Alkalinity. Add 64 g. bicarbonate (sodium bicarbonate) for each pound of feed per day
or
142 g. bicarbonate for each 1000 g. of feed per day

Appendix B. Sources of Aquaculture Equipment and Supplies

Argent Chemical Laboratories
8702 152nd Ave. NE
Redmond, WA 98052
206-885-3777
206-885-2112 (Fax)
theraputics, chemicals, supplies

Aquaculture Supply
5532 Old Saint Joe Road
Dade City, FL 33525
904-567-8540
904-567-3742 (Fax)
equipment and supplies

J. L. Eagar, Inc.
526 Nort 700 West
P.O. Box 476
North Salt Lake City, UT 84054
801-292-9017
801-295-7569 (Fax)
equipment and supplies

Fritz Chemical Co. Aqua. Div.
P.O. Drawer 17040
Dallas, TX 17040
214-285-5471
214-270-0179 (FaxZ)
800-955-1323
chemicals and equipment

W.W. Grainger, Inc.
see Yellow Pages for local
sales branches
equipment and supplies

LaMotte Co.
Route 213 N
P.O. Box 329
Chestertown, MD 21620
301-778-3100
800-334-3100
301-778-6394 (Fax)
water quality testing

Hach Company
P.O. Box 389
Loveland, CO 80539
303-669-3050
303-669-2932 (Fax)
800-227-4224
water quality testing

Hulls Unlimited-East Inc.
Deltaville, VA 23043
804-776-9711
804-776-7251 (Fax)
tanks and equipment

Memphis Net & Twine Co., Inc.
2481 Matthews Avenue
Box 8331
Memphis, TN 38108
901-458-2656
901-458-1601
800-238-6380
equipment and supplies

Ken's Hatchery and Fish Farm
P.O. Box 449
Alapha, GA 31622
912-532-5359
912-532-7220 (Fax)
equipment and supplies

Red Ewald, Inc.
P.O. Box 519
Karnes City, TX 78118
512-780-3304
512-780-4272 (Fax)
tanks

Ryan Herco Industrial Plastics
P.O. Box 588
Burbank, CA 91503
800-423-2589
818-842-4488 (Fax)
equipment and supplies

Royce Equipment Corp.
13555 Gentilly Road
New Orleans, LA 70129
504-254-8888
504-254-8855 (Fax)
testing equipment

Solar Components
P.O. Box 237
Manchester, NH 03105
603-668-8186
603-627-3110 (Fax)
tanks

YSI, Inc.
P.O. Box 279
Yellow Springs, OH 45387
513-767-7241
513-767-9353 (Fax)
water quality test equipment

Zeigler Brothers, Inc.
P.O. Box 95
Gardners, PA 17324
717-677-6181
717-677-6826 (Fax)
feeds and equipment

Aquatic Eco-Systems, Inc.
2056 Apopka Blvd.
Apopka, FL 32703
407-886-3939
407-886-6787 (Fax)
aquaculture products

Inclusion on this list does not imply endorsement by the authors or The Council nor is there any intention to exclude any suppliers for the aquaculture industry.