AQUACULTURE INFORMATION PACKAGE

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TABLE OF CONTENTS

INTRODUCTION

SECTION 1 - MARKET AND PRICE INFORMATION

SECTION 2 - WATER QUALITY ISSUES IN AQUACULTURE

SECTION 3 - CULTURE INFORMATION

SECTION 7 - STATE/REGIONAL/UNIVERSITY/EXTENSION AQUACULTURE OFFICES

SECTION 8 - STATE AQUACULTURE PERMIT REQUIREMENTS

AQUACULTURE INFORMATION PACKAGE

INTRODUCTION

This package of information is intended to provide background information to developers of geothermal aquaculture projects. The material is divided into eight sections and includes information on market and price information for typical species, aquaculture water quality issues, typical species culture information, pond heat loss calculations, an aquaculture glossary, regional and university aquaculture offices and state aquaculture permit requirements.

Section 1 - Market and Price Information contains information on the current status of the catfish and tilapia markets in the U.S. For the catfish market, information is provided on both national and state production, pond acreage, type of production and end market served. Tilapia data presented in the section includes national and regional production figures, current price data and a brief summary of the international import volume.

Section 2 - Water Quality Issues in Aquaculture contains an introduction to the major water quality issues for aquaculture in general and explains the importance of major water quality parameters.

Section 3 - Culture Information presents information on breeding, management, feeding and harvest of typical tilapia and catfish sub-species, and prawns.

Section 4 - Pond and Raceway Heat Loss Calculations provides an introduction to the methods used in calculations of heat losses from aquaculture facilities. Procedures for calculating the geothermal flow requirements for a project are provided.

Section 5 - Aquaculture Bibliography provides a list of useful aquaculture references in the areas of general aquaculture, economics, culture systems and individual species.

Section 6 - Aquaculture Glossary define typical terms used in the aquaculture industry.

Section 7 - State/Regional/University/Extension Aquaculture Offices provides contact information for a variety of technical experts who may be of use to the aquaculture developer.

Section 8 - State Aquaculture Permit Requirements summarizes the permits which may be required for the operation of a commercial aquaculture facility in the states of, Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, South Dakota, Utah, and Washington.

SECTION 1 - MARKET AND PRICE INFORMATION

Section 1
MARKET AND PRICE INFORMATION

INTRODUCTION

The Economic Research Service, U.S. Department of Agriculture (Washington DC 20036-5831) publishes a biannual report entitled **Aquaculture Outlook**. The following information was taken from the March 1998 version of that reference.

Over the past 10 years the average per capita fish and seafood consumption has remained relatively flat, at around 15 pounds per year, roughly 2 to 3 pounds less than turkey consumption. During this time period, the source of seafood products has been shifting away from wild harvest and towards aquaculture. With about 20 percent of U.S. fish and seafood consumption now being farm-raised, aquaculture is becoming a recognized segment of the livestock complex, larger than veal, mutton and lamb combined. In 1997, U.S. annual production of processed catfish products was approximately 1 pound per capita, imports of farm-raised shrimp was likely over 1 pound per capita, and the combination of farm-raised salmon, trout, tilapia, crawfish, and other aquaculture products probably added another pound.

A number of major trends in 1998 are expected to effect the domestic aquaculture industry. First, there should be large supplies of competing meats, especially pork and chicken, available. Second, prices for catfish, the largest segment of the domestic aquaculture industry, are expected to increase as available supplies tighten. Third, with the devaluation of their currencies versus the dollar, the United States market should become more attractive to Asian seafood imports.

CATFISH MARKET AND PRICE INFORMATION

The following information was taken from the following publications **Aquaculture Outlook,** March 1998, and **Catfish Production**, February 1998.

Based on grower inventories reported for January 1, catfish sales by growers to processors in 1998 are forecast to expand to 535-545 million pounds, up 2-4 percent, after increasing 11 percent in 1997. Most of that growth is expected to come in the first and fourth quarters. In the second and third quarters, supplies are expected to tighten, due to a 20-percent decrease in inventories for stockers, and prices paid to farmers should strengthen. Falling farm prices in 1997 resulted in growers cutting back on inventories. The much smaller increase in production expected in 1998, combined with a strong domestic economy, is expected to put some upward pressure on both farm and processor prices, especially in the middle of the year. Sales to processors in January 1998 were 47 million pounds, up 10 percent, despite lower food-size inventories at the start of the year. Sales are expected to run about 5 percent above a year earlier through the first quarter, normally the strongest sales period.

With a forecast of continued economic growth in the domestic economy in 1998, strong demand is anticipated from the restaurant and food service sectors. In 1995, the national Marine

Fisheries Service estimated that restaurant and food service sales accounted for over two-thirds of all seafood sales. A strong demand picture combined with only slightly higher catfish production is expected to strengthen farm prices somewhat in 1998. After 3 years of farm prices running between 77 to 79 cents a pound, prices dropped to 71.2 cents in 1997, down 8 percent from a year earlier. Grower prices ended 1997 at 69 cents a pound, but in 1998 they are expected to strengthen in the second and third quarters as supplies of market size fish decline. Table 1 shows the total round weight (whole fish) processed and the price paid to producers from 1983 to 1997.

Table 1. Total Round Weight Processed and Price Paid to Producers, 1983 - 1997

Year	Total Round Weight Processed	Total Price Paid to Producers
	1,000 Pounds	Cents/Pound
1983	137,250	61.1
1984	154,255	69.3
1985	191,616	72.5
1986	213,756	66.8
1987	280,496	61.7
1988	295,109	76.4
1989	341,900	71.5
1990	360,435	75.8
1991	390,870	63.1
1992	457,367	59.8
1993	459,013	70.9
1994	439,269	78.4
1995	446,886	78.6
1996	472,123	77.3
1997	524,949	71.2

Growers reported starting 1998 with about eight percent lower inventories of food-size fish, and processors' inventories are also down slightly from the same time the previous year. However, the expected lower prices for pork and chicken products in first-half 1998 may tend to blunt any strengthening in catfish prices. Prices for hogs are expected to average over a third lower in the first-half of 1998 compared with a year earlier, and wholesale chicken prices are expected to decline about 7 percent.

There is also the possibility of lower prices for imported seafood items from Asia such as tilapia and shrimp products. The currencies of Thailand and Indonesia, both major seafood exporters of the United States, have fallen considerably versus the dollar since third-quarter 1997.

The total number of operations on January 1, 1998 in the 15 selected states was 1,224, down seven percent from the January 1, 1997 total of 1,319, as shown in Table 2. The number of operations in the top producing states (AL, AR, LA, and MS), also, decreased seven percent from January 1, 1997.

Catfish growers in the 15 selected states had sales of 422 million dollars during 1997. These sales were down one percent from the 1996 total of 425 million dollars. Sales of all foodsize fish

Table 2. By State, Number of Operations and Water Surface Acres, Used for Production, 1997-98 and Total Sales, 1996-97

State	Number of operations on Jan 1		Water Surface Acres Used for Production During Jan 1 - Jun 30		Total Sales	
	1997[1]	1998	1997[1]	1998	1996	1997
	Number		Acres		1,000 Dollars	
AL	245	235	21,000	21,800	52,795	53,740
AR	180	165	28,500	27,000	52,214	50,480
CA	50	64	2,400	2,300	6,873	8,225
FL	12	14	100	150	148	352
KY	20	18	280	140	517	905
LA	108	101	14,300	13,500	27,838	30,783
MS	360	331	102,000	100,000	274,559	265,934
MO	65	60	2,400	1,900	1,746	2,022
NC	60	53	1,400	1,300	2,466	2,194
OK	35	25	550	450	376	385
SC	25	20	1,200	1,100	3,223	2,833
TN	19	19	290	280	284	327
TX	74	57	1,900	2,000	936	2,244
Other States	66	62	1,140	1,090	1,408	1,319
TOTAL	1319	1224	177,460	173,010	425,383	421,743

1. Revised

totaled 402 million dollars, down fractionally from last year's total of 403 million dollars. Sales of fingerlings and fry totaled 15.4 million dollars, compares with 16.1 million dollars in sales during 1996. Sales of stockers totaled 4.03 million dollars, down 16 percent from the 4.81 million dollars in sales during 1996. Sales of broodfish previously used for breeding totaled 476 thousand dollars, compared with 383 thousand during 1996.

Growers reported that as of January 1, 1998, they anticipate 173,010 acres of ponds will be in use during the first-half 1998. This total is down three percent (3,500 acres) from the previous year (Table 2), which saw a large increase in acreage. Growers also noted that they plan on renovating or constructing about 8,300 acres of ponds. Of the total acres, 6,560 are to be renovated during the period of January 1, 1998 to June 30, 1998. An additional 1,790 acres are under construction or expected to be constructed and in use by July 1, 1998. This estimate is only about a third of what it was for the first half of 1997, reflecting falling farm level catfish prices in 1997. Most of the acreage decrease was in the four largest producing states, Mississippi, Arkansas, Alabama, and Louisiana. The number of growers in these states was also down and the trend towards smaller numbers of larger farms is expected to continue as growers look for economics of size in larger operations. Growers are looking towards spreading the costs of specialized equipment over larger overall production to lower their average production costs.

During the period of July 1, 1997 through December 31, 1997, 3,343 acres were taken out of production. As of January 1, 1998, 6,177 acres were being used for broodfish production, 138,700 acres were being used for foodsize production and 21,960 acres were being used for fingerling production (Table 3).

Table 3. Intended Utilization of Water Surface Acres During Jan - Jun 30, 1998

State	Intended Utilization During January 1 - June 30		
	For Broodfish	For Foodsize	For Fingerlings
AL	590	18400	1900
AR	750	21200	4200
CA	90	1900	270
FL	30	35	70
KY	5	110	N/A
LA	360	11700	1400
MS	3800	80400	12400
MO	60	880	530
NC	50	1000	170
OK	50	240	95
SC	60	840	200
TN	25	225	30
TX	180	1200	430
Other States	127	570	265
TOTAL	6177	138700	21960

Total sales by catfish farmers in 1997 fell one percent to $422 million. Revenues from sales of food-size fish, stockers, and fingerlings were all lower. The poundage of food-size fish increased strongly (up seven percent from 1996), but the poundage of stocker and fingerlings sales were both down. Farmers reported total sales of food-size fish were a record 563 million pounds, but the higher poundage was offset by the eight-percent decrease in prices, from 77 to 71 cents per pound as shown in Table 4. Grower sales of food-size fish to processors accounted for 525 million pounds, so the remaining 38 million pounds were sold through other channels, such as directly to consumers or restaurants, or to brokers or wholesalers. The lower poundage of stockers and fingerlings sales helped to hold up their prices. Average unit prices for both size classes showed no change between 1996 and 1997.

With lower inventories in most size classes reported for the beginning of 1998 and a strong domestic economy, prices for food-size fish are expected to move slowly upward. If this happens then the prices for stockers and fingerlings should also show some upward strength. However, for food-size fish the impact of lower supplies may not be felt until the second quarter. Another factor that could put additional upward price pressure on smaller fish would be if corn and soybean prices move lower and these declines result in reduced feed costs. If feed prices decline, growers may increase feeding rates to attempt to get their smaller fish to market size sooner.

Grower-held inventories at the start of 1998, in terms of numbers of fish, were down for large and medium food-size fish, but up fractionally for small food-size fish. The smaller inventories of food-size fish are expected to reduce the supplies of fish over the first several months of 1998 and to exert some upward pressure on prices. Processors may be growing more sensitive to changes in supplies as their monthly ending inventories have been becoming a smaller percentage of their monthly processing volume.

Table 4. Weight and Average Value of Sales of All Foodsize by Sale, 1996-97

	Pounds Sold		Avg. Value per Pound	
State	**1996**	**1997**	**1996**	**1997**
AL	72,692	77,416	0.71	0.68
AR	57,680	65,000	0.76	0.7
CA	3,750	4,452	1.76	1.77
FL	14	N/A	0.43	N/A
KY	495	672	1.02	1.3
LA	38,000	45,000	0.71	0.67
MS	344,480	360,000	0.77	0.71
MO	1,388	1,504	0.74	0.76
NC	2,802	2,524	0.79	0.75
OK	215	224	0.93	0.86
SC	2,898	2,646	0.94	1.01
TN	123	235	1.81	1.21
TX	689	2,062	0.99	0.94
Other States	1,050	834	1.13	1.27
TOTAL	526,276	562,569	0.77	0.71

In the first quarter of 1997, farm sales to processors were 136 million pounds with an average farm price of 73 cents a pound. In 1998, the first quarter volume is expected to be higher and prices, while likely to show some strength for late 1997 levels, are expected to average lower, around 70 to 71 cents a pound.

At the beginning of 1998, growers reported that the number of fish in inventory in the stocker class, those fish weighing from 0.06 to 0.75 pound, were down 19 percent, but the number of fingerlings, fish below 0.06 pound, were 18 percent higher than the previous year. While many of the stockers will likely achieve market size during first-half 1998, most of the fingerlings will not be ready for market until the latter part of the year. If processor demand remains strong during the second and third quarters, there could be periods of reduced supplies of food-size fish before the fingerlings in inventory at the start of the year achieve market weight.

Aside from fingerlings, the only area where catfish growers indicated that their inventories increased was for broodfish stocks. The number of broodfish rose two percent to 1.19 million fish. However, the estimated weight of these broodfish was up less than one percent from 1997. The total egg production is a function of body weight, so the two percent increase in the number of broodstock in inventory is probably less significant than the very small decrease in the overall body mass of broodfish. This implies that 1998 production of fingerlings and stockers is expected to be roughly the same as in 1997.

Processor sales rose in 1997 for the third consecutive year. After increasing five percent in 1996, sales were up an additional 10 percent to 262 million pounds in 1997. The increase in processor sales was enough to offset a four percent decrease in overall processor prices. This was the second year in a row that overall processor prices have declined. Gross processor revenues in 1997 increased by just over $30 million to $591 million. This suggests that the demand for catfish over the last several years has been relatively elastic, at least at wholesale levels. Processor prices were lower throughout 1997, compared with a year earlier, and were the weakest during the summer months when sales volumes were posting their strongest gains. In 1998, gross processor revenues are again expected to increase as a small increase in sales volumes combines with slightly higher prices.

Processor sales had very few weak spots in 1997. The only category where sales declined was for frozen whole fish, but this category only accounted for five percent of processor sales. Sales of both fresh and frozen product were at record levels, posting double-digit increases in 1997. Much of the growth in catfish sales in the coming years is expected to come from fillets and other prepared products. First, many chain restaurants and food services now use portion-controlled products ready to cook. Second, with increasing time pressure, many U.S. consumers are also looking for fully prepared products. In 1998, processor sales are expected to expand, but prices are expected to be under competitive pressure from other seafood products and meat products.

Direct sales to processors accounted for 94 percent of the total sales of foodsize fish as shown in Table 5. Eighty-two percent of the stocker sales were to other producers.

Table 5. Foodsize Percent Sold by Outlet Type by State, 1997

State	Livehauls	Fee/Rec Fishing	Process	Retail Rest.& Food Store	Other Outlets
AL	0	2	93	1	4
AR	3	0	97	0	0
CA	14	3	0	65	18
FL	0	0	30	0	70
KY	0	73	0	1	26
LA	0	0	99	0	1
MS	0	0	98	0	2
MO	58	18	3	3	18
NC	0	0	96	1	3
OK	18	8	43	0	31
SC	4	2	92	1	1
TN	N/A	11	N/A	16	49
TX	1	9	39	39	12
Other States	3	49	8	17	23
TOTAL	1	1	94	2	2

TILAPIA MARKET AND PRICE INFORMATION

The American Tilapia Association (ATA, 1901 North Fort Meyer Drive, Ste. 700, Arlington, VA) publishes an annual report entitled **Tilapia Situation and Outlook Report**. The following information is summarized from the 1996 version of that reference.

Tilapia production in the U.S. in 1996 is estimated at 16,000,000 lbs up 300% in the period 1992 to 1996. Most of this production occurs in the western states led by California with a production of 6,200,000 lbs in 1996. In terms of growth, however, the largest increase was achieved in the north central region of the country where production moved from 1,850,000 lbs in 1995 to 2,600,000 lbs in 1996. Projected national production in 1997 is 17,000,000 lbs for a 6% gain over the 1996 figure.

Sixty percent of the national production is in the form of intensive culture. Many farms, particularly in California, Idaho and Oregon, are using geothermal water to control temperatures in their facilities. Table 6 presents the regional distribution of tilapia production in the continental U.S. for 1996.

Table 6. Continental U.S. Tilapia Production (in 1000 lbs live weight)

Region	1994	1995	1996	1997
North Central	1,400	1,850	2,600	2,675
Northeast	450	985	995	920
South	3,125	400	3,750	3,725
West	7,705	7,900	8,470	9,230
Total	12,980	15,075	15,965	16,935

Prices for tilapia have historically been higher ($0.25 to $0.50 per lb) in the western U.S. A substantial increase in production capacity in the past few years, however, has reduced prices to a level comparable to the east coast. Most of the production is sold into the live market in cities with large Asian populations such as Los Angeles, San Francisco and Seattle. Table 7 provides a summary of prices for 1996.

Table 7. Average Tilapia Prices per lb - 1996

	FOB Farm	Wholesale	Retail
Live	1.25 - 2.20	1.60 - 2.40	2.99 - 5.99
Whole Fresh	1.05 - 1.60	1.20 - 2.00	1.99 - 3.49
Frozen Fillet		2.50 - 3.00	3.49 - 4.99
Fresh Fillet		3.35 - 3.75	3.99 - 6.99
Large Producer	3.40 - 3.75	3.60 - 4.00	4.00 - 6.00
Medium Producer	3.60 - 4.00	3.80 - 4.20	4.50 - 6.00
Small Niche	4.00 - 5.00		5.00 - 8.00

REFERENCES

Economic Research Service, March 1998. “Aquaculture Outlook” URL: http://usda.mannlib.cornell.edu/reports/erssor/livestock/ldp-aqs/1998/aquaculture_outlook_03.05.98

National Agricultural Statistics Service, Feb. 1998. “Catfish Production” URL: http://usda.mannlib.cornell.edu/reports/nassr/other/pcf-bbc/1998/catfish_production_02.03.98

American Tilapia Association, 1996. “Tilapia Situation and Outlook Report,” ATA, 1901 North Fort Meyer Dr., Ste 700, Arlington, VA.

SECTION 2 - WATER QUALITY ISSUES IN AQUACULTURE

Section 2
WATER QUALITY ISSUE IN AQUACULTURE

INTRODUCTION

The information contained in this section was summarized from the **Northeastern Regional Aquaculture Center Fact Sheet No. 170-1993 "An Introduction to Water Chemistry in Freshwater Aquaculture"**, 1993.

Some of the water quality factors that can affect growth of an aquaculture species are 1) temperature, 2) dissolved oxygen, 3) nitrogenous wastes, 4) pH, 5) alkalinity, 6) hardness, 7) carbon dioxide, 8) salinity, 9) chlorine, and 10) hydrogen sulfide. Careful measurement and management of some/all of these factors is important for fish survival. A brief explanation of each factor and how to test for each one is listed below.

TEMPERATURE

Temperature has an influence on all biological and chemical process in an aquaculture operation. Each species has its own optimum temperature where it grows best. Growth rate is reduced when the temperature is above or below the optimum point and mortality can occur at extreme conditions.

DISSOLVED OXYGEN

The minimal safe level of dissolved oxygen is dependent on the temperature and to a certain extent the species. Throughout a 24 hour period the dissolved oxygen level of a pond can change dramatically. The lowest levels of dissolved oxygen generally occur just before dawn and the highest levels occur in the late afternoon. Warm water fish can tolerate lower levels of dissolved oxygen better than cold water fish. The level should be maintained above 3.0 ppm or 5.0 ppm for warm water and cold water fish respectively.

NITROGENOUS WASTES

Most fish excrete ammonia as their principle nitrogenous waste. The temperature and pH causes the proportion of total ammonia-nitrogen (TAN) (ionized & un-ionized) to vary. The amount of TAN in the toxic un-ionized form increases with increasing pH and temperature. Ammonia is removed by bacteria that initially converts it into nitrite and subsequently into nitrate. High levels of nitrite causes "Brown Blood" disease and is toxic to fish. When concentrations are 0.5 ppm or higher it can reduce growth and adversely affect the fish. Fish can tolerate nitrate to several hundred ppm.

pH

Fish grow best when the pH of water is between 6 - 9. Mortalities can occur at levels below 4.5 and higher than 10. The lowest levels of pH are usually associated with the lowest levels of dissolved oxygen. High pH usually coincides with the high levels of dissolved oxygen.

ALKALINITY

Alkalinity is the buffering capacity of water or its ability to absorb acids and/or bases and is expressed as ppm calcium carbonate. Alkalinity is a measurement of carbonate and bicarbonate ions dissolved in the water. The pH shift due to photosynthetic activity is reduced in ponds with higher alkalinity. A suitable range is 20 to 300 ppm.

HARDNESS

While alkalinity measures carbonate and bicarbonates ions (negative), hardness measures the positive ions (calcium and magnesium). To some species, hardness of the water can be important. The hardness should be above 50 ppm.

CARBON DIOXIDE

Usually carbon dioxide problems can occur when using groundwater, high density fish transport and recirculating systems. Some solutions to keep carbon dioxide within acceptable levels are aeration, oxygenation, or buffering the water.

SALINITY

Salinity is the total concentration of all ions in the water. Salinity influences the concentration of un-ionized ammonia. Fish species exhibit a range in salinity tolerance. During the planning stage salinity should be checked to see if the water is appropriate for the culture of the species planned.

CHLORINE

Typically municipal water supplies are treated with chlorine at 1.0 ppm. If municipal water is used, the residual chlorine must be removed. Even levels of chlorine as high as 0.02 ppm are stressful to fish.

HYDROGEN SULFIDE

Hydrogen sulfide can be released when ponds with oxygen-poor bottoms are seined or disturbed. Hydrogen sulfide has a rotten egg smell and can be extremely toxic to fish. Hydrogen sulfide can also be present in groundwater.

How often should water quality be monitored? That question depends on several parameters. Is it going to be a high or low intensity culture? Is there going to be a high density of fish grown? The higher the intensity and more dense the culture, the more frequently the parameters should be checked. Table 1 contains the test procedures and preferred ranges for the water quality factors listed above.

REFERENCE

Buttner, Joseph K.; Soderberg, Richard W.; and Terlizzi, Daniel E. 1993. "An Introduction to Water Chemistry in Freshwater Aquaculture," Northeastern Regional Aquaculture Center Fact Sheet No. 170-1993. Northeastern Regional Aquaculture Center, University of Massachusetts, Darmouth, North Darmouth, Massachuesetts.

Table 1. Water Quality Factors, Commonly Used Monitoring Procedures, and Preferred Ranges for Fish Culture

Water Quality Factor	Test Procedure	Preferred Ranges for Fish Culture
Temperature	Thermometer, Telethermister	species dependent
Dissolved Oxygen	Titrimetric (Modified Winkler) Polarographic meter, Calorimetric kits	>4-5 ppm for most species
Total Ammonia-Nitrogen (ionized and un-ionized)	Calorimetric kits (Nesslerization or Salicylate), Ion specific probes	NH_3<0.02
Nitrite	Calorimetric kits (Diazotization) Ion Specific probes	<1ppm; 0.1 ppm in soft water
pH	Calorimetric kits, Electronic meter	6-8
Alkalinity	Titrimetric with pH meter Titrimetric with chemical indicator	50-300 ppm calcium carbonate
Hardness	Titrimetric kit	>50 ppm, preferably >100 ppm calcium carbonate
Carbon dioxide	Titrimetric	<10 ppm
Salinity	Conductivity meter, Reflactometer Titrimetric	species dependent typically <0.5 - 1.0 ppt (For freshwater fish)
Chlorine	Calorimetric kit	<0.02 ppm
Hydrogen Sulfide	Calorimetric kit	No detectable level

SECTION 3 - CULTURE INFORMATION

Section 3
CULTURE INFORMATION

TILAPIA

This information was summarized from the following publications **Southern Regional Aquaculture Center Publication No. 280, "Pond Culture of Tilapia"**, 1989, **Southern Regional Aquaculture Center Publication No. 282, "Tank Culture of Tilapia"**, 1989 and **"Introduction to Tilapia Culture"**, 1996, Auburn University.

Before you start a tilapia operation you must first determine which species, if any, can be legally cultured in your state. Tilapia are disease-resistant, reproduce easily, eat a wide variety of foods and tolerate poor water quality with low dissolved oxygen levels. An increasingly important criteria for selecting a species in the northern latitudes is cold tolerance. Tilapia nilotica, T. aurea, and hybrids between these species or strains are the most appropriate species of tilapia for tank culture in the US. T. aurea grow at the slowest rate, but this species has the greatest cold tolerance. This may allow it to have the highest growth rate in temperate regions at temperatures below optimum.

The optimum temperature range for growth of tilapia is between 77 to 86^{0}F depending on the species. The low temperature tolerance is also species related and ranges from 46 to 55^{0}F. At temperatures lower than optimum, growth can be significantly diminished and if temperatures are too low death can occur.

Tilapia grow well at high densities in the confinement of tanks when good water quality is maintained. Tanks allow the fish culutrist to easily manage stocks and to exert a relatively high degree of environmental control over water quality parameters that can be adjusted for maximum production.

Geographic range for culturing tilapia in tanks is dependent on water temperature. The optimum range is 82 to 86^{0}F. Death can occur below 50^{0}F. Flow-through systems are only practical for year-round culture in temperate regions if geothermal water is available. Indoor recirculating systems are more appropriate for year-round culture, for the buildings can be insulated which will conserve heat and the heated water is saved through recycling.

Flow-Through Systems

The most durable tank materials are concrete and fiberglass and they should be non-toxic and non-corrosive. The most common tank shapes are circular and rectangle with the rectangle ones being long and narrow. Circular tanks are the most popular, for they usually tend to be self-cleaning. Rectangular tanks come in various dimensions and size and for proper operation the length to width to depth ratio should be 30:3:1 for a good flow pattern.

Another important aspect of tank culture is the drain design. For effective removal of waste a center drain is best for circular tanks. The rate of water exchange can determine the aeration requirements. Aeration may not be required if the water is exchanged rapidly (1 to 4 times per hour). To support the oxygen requirement of 100 pounds of tilapia a flow rate of 6 to 12 gallons/minute is needed. Flow-through systems should be setup to take advantage of gravity fed water supplies. Aeration requirements can be estimated by using the aerator ratings and oxygen (O^2) consumption rates of tilapia, which consume 4.5 grams O^2/100 pounds of fish/hour while resting and several times more oxygen while they are feeding and active.

Recirculating Systems

In recirculating systems 90 to 99 percent of the water is recycled. The main components for a recirculating system are a clarifier (settling tank) and a biofilter. The clarifier is used to remove solid waste and the biofilter is used to remove toxic waste products (ammonia and nitrite) produced by the fish.

There are many effective biofilters designs, but they all operate on the same principle of providing a large surface area for the attachment of vitrifying bacteria that transforms ammonia into nitrite, which in turn is converted to nitrate. The biofilter can be sized by balancing the ammonia production rates with the ammonia removal rates. The required surface area of a biofilter can be obtained by dividing the total ammonia production for the maximum standing crop by the ammonia removal rate. The volume of the filter can be determined by dividing the required biofilter surface area by the specific surface area (ft^2/ft^3) of the media.

Breeding

Tanks are commonly used to breed tilapia. Fry can be captured with a dip net and transferred to a nursery unit. The fry that avoid capture will prey on subsequent spawns which will cause production to decline. When that happens the tank must be drained to remove the juvenile fish and begin a new spawning cycle. Net enclosures (hapas) are used to obtain more controlled breeding. The use of hapas means all fry can be removed at regular intervals and insure size uniformity, predation reduction, and eliminated the need to drain the tanks. Hapas are made from nylon netting with a 1/16-inch mesh.

The male and female broodfish are stocked at a ratio of two females for each male to begin breeding. This will produce a large quantity of fry. For optimum stocking density the range is from 0.5 to 1.0 fish/ft^2 . The recommended feeding rate is two percent of their body weight per day with a high quality feed. A few days after the fry begin to appear they should be removed. To accomplish the removal of fry, the broodfish should be concentrated to one side of the tank. A large-mesh dip net is used to remove the broodfish. The fry are then captured with a fine-mesh dip net and transferred to a nursery tank. Each broodfish should then have its mouth checked to remove any fry, sac fry or eggs that it may be incubating.

Production Management

During the production cycle, the stocking density should be decreased at regular intervals to reduce crowding and ensure adequate water quality. Table 1 shows the recommended stocking and feeding rates for different size groups of tilapia. Fry are fed continuously throughout the day with automatic feeders and given a complete diet of powered feed. Under ideal conditions the initial feeding rate can be as high as 20 percent of body weight. Fingerlings require continuous feeding also, but the feed size can be increased to various grades of crumbles. The feed is changed during the growout periods to floating pellets to allow for visual inspection of the feeding response. For adult fish the daily ration is divided into three to six feedings evenly spaced throughout the day. Feeding levels should be reduced if the feed is not consumed rapidly. Recommended protein levels for fry are 40 percent, fingerlings 32 to 36 percent and for larger fish 28 to 32 percent.

Table 1. Recommended Stocking and Feeding Rates for Different Size Groups of Tilapia in Tanks and Estimated Growth Rates

Stocking Rate (number/m^3)	Weight Initial	(grams) Final	Growth Rate (g/day)	Growth Period (days)	Feeding Rate (%)
8,000	0.02	0.5-1	–	30	20-15
3,200	0.5-1	5	–	30	15-10
1,600	5	20	0.5	30	10-7
1,000	20	50	1.0	30	7-4
500	50	100	1.5	30	4-3.5
200	100	250	2.5	50	3.5-1.5
100	250	450	3.0	70	1.5-1.0

1 m^3 = 35.3 ft^3, 1 g = 0.0353 oz = 0.00220 lbs.

The fry rearing stage has the highest mortality (about 20 percent) of the production cycle. This is mostly due to predation. As the fish become hardier no more than 2 percent of the fish are expected to die during the final growout. Total production levels range from three to six pounds/ft^3 of rearing space and 6 to 17 pounds/gallon/minute of flow. Flow-through systems generally obtain the highest production levels.

There are only a few species of tilapia cultured around the world today. The following summarizes five of the most popular cultured species.

Oreochromis Aureus

Oreochromis aureus are mouth brooders and the female can spawn three or more times a year with 500 to 1400 eggs produced per spawn. The optimum temperature for spawning is from 73 to 82^{0}F. The eggs will hatch within three to five days, and the female will guard them for an additional eight to 10 days after hatching. Fry will eat zooplankton and adults will eat zooplankton, phytoplankton, and graze on the bottom organisms. The adults will also eat manufactured food.

They grow well when salinities are keep below 1.6 to 2.0%. Their optimum growing temperature is between 77 to 86^{0}F and their low temperature tolerance is 46 to 48^{0}F.

Oreochromis Mossambicus

Oreochromis mossambicus are mouth brooders and the female can spawn six to 12 times a year with 350 to 800 eggs produced per spawn. The optimum temperature for spawning is between 73 to 82^{0}F. The eggs hatch after two to five days and the female guards them for an additional eight to 10 days after hatching. Fry will eat zooplankton and adults will eat zooplankton, phytoplankton, and graze on the bottom organisms. The adults will also eat manufactured food. They can spawn and grow well in full strength sea water. Their optimum growing temperature is between 77 to 86^{0}F and can not tolerate temperatures below 50 to 53^{0}F.

Oreochromis Niloticus

Oreochromis niloticus are mouth brooders and the females can spawn on an average of three times a year with 250 to 2000 eggs being produced per spawn. The optimum temperature for spawning is between 77 to 84^{0}F. The eggs hatch within three to five days from laying and the female guards them for an additional eight to 10 days after hatching. Fry will eat zooplankton and adults will eat phytoplankton, zooplankton, insects and other bottom organisms, plus manufactured food. They can grow well in salinity up to 2.0%. Their optimum growing temperature is 77 to 86^{0}F and can not tolerate temperatures below 52^{0}F.

Tilapia Rendalli

Tilapia rendalli are substrate spawners and spawning can occur at seven-week intervals with 12,000 to 20,000 eggs being produced per year. The optimum temperature for spawning is 77 to 86^{0}F and the eggs hatch within five days from laying. Fry will eat zooplankton, while the adults eat aquatic weeds, insects, algae and manufactured food. They can grow well in brackish water. Their optimum growing temperature is 82^{0}F and can’t tolerate temperatures below 55^{0}F.

Tilapia Zilli

Tilapia zilli are substrate spawners and the females can spawn about six times a year with 1,000 to 7,000 eggs produced per spawn. The optimum spawning temperature range is 72 to 79^{0}F and the eggs will hatch within three to five days. Fry will eat zooplankton, while the adults eat phytoplankton, leaves, stems rooted aquatic vegetation, and manufactured food. They can grow well in full strength sea water. Their optimum growing temperature is 82^{0}F and can’t tolerate temperatures below 48^{0}F.

CHANNEL CATFISH

This information was summarized from the following publications **North Central Regional Extension Publication No. 444 "Pond Culture of Channel Catfish in the North Central Region"**, 1993 and Southern Regional Aquaculture Center Publication No. 18 **"Channel Catfish - Life History and Biology,"** 1988.

This is the principal warm water species grown in the Southeastern US and the most popular fish currently cultured in the US. They are mostly raised in ponds ½ to 10 acres in size. In an existing pond, cage culture represents one way for those considering fish farming to try their hand at fish culture with a minimal cash investment.

When water temperatures are between 80 to 85^{0}F, optimal growth occurs. The high and low temperature limits are 45 to 95^{0}F. Channel catfish are known for their ability to withstand lower water quality conditions , but limits do exist. Table 2 shows the suggested safe limits for the water quality parameters for channel catfish.

With each 18^{o}F change in temperature there is a doubling or halving of their metabolic rate. This means that within limits, their appetite increases with increasing water temperatures or decreases with decreasing water temp. Most farm-raised catfish are harvested at a weight of 1 1/4 pounds at an age of about 18 months.

Brood Stock

Channel catfish that have been domesticated through several generations are preferred over wild stock. Brood stock should be obtained in the fall prior to or at least two months before the spawning season starts. They should have robust bodies, be free of wounds and diseases, and not

Table 2. Suggested safe limits for water quality parameters for Channel catfish

Parameters	Recommended Range
Dissolved Oxygen	4 ppm or above
Alkalinity	20 - 400 ppm
Hardness	20 - 400 ppm
Ponds	20 - 400 ppm
Hatcheries	above 10 - 20 ppm
pH	6 - 9 ppm
Un-ionized Ammonia	less than 0.05 ppm
Nitrite	
Minimum Chloride	
Nitrite Ratio	minimum 5:1
Hydrogen Sulfide	0 ppm
Carbon Dioxide	
Depend on Oxygen Level	less than 20 ppm

be larger than 6 - 8 lbs. Females weighing 3-4 lbs, will provide approximately 4,000 eggs/lb of body weight. Females over four lbs will produce approximately 3,000 eggs/lb.

During the winter months brood stock should be fed on sunny days when the air temperature is above 32^0F. Since food consumption is limited by temperature, you should feed between ½ to one percent of the ponds total fish weight 2-3 times a week. The purpose of this is to maintain their weight, not increase it.

Spawning

Brood stock should be collected from their wintering ponds at least 6-8 weeks before spawning and taken to a common facility. Catfish spawn when the water temperature is between 75 to 85^0F with 80^0F being optimum. Channel catfish are cavity spawners and will spawn only in secluded, semi-dark areas.

PRAWNS

This information was summarized from the following publications **Southern Regional Aquaculture Center Publication No. 483, "Biology and Life History of Freshwater Prawns"**, 1996 and **Southern Regional Aquaculture Center Publication No. 484, "Production of Freshwater Prawns in Pond"**, 1996.

Basic production techniques for Macrobrachium rosenbergii (Malaysian Prawn) were developed in the late 1950s in Malaysia.

In order for growth to occur, freshwater prawns, like all crustaceans, have a hard outer skeleton or shell that must be shed regularly. Due to these periodic sheddings, growth occurs in distinct increments, rather than continuously. The process of shedding the shell is called "molting," and weight and size increase occur principally soon after each molt.

Breeding

At six months of age females generally are reproductively mature. Females who have just completed a premating or prenuptial molt are the only ones who can mate for mating can only occur between hard-shelled males and soft-shelled females. The size of the female is directly proportional to the number of eggs produced at each spawn and as long as the water temperature exceeds 70^0F, multiple spawns per female can occur annually.

Larvae

The larvae survive best in brackish water with salinities of 9 to 19 parts per thousand (ppt) and cannot survive in freshwater beyond approximately 48 hours. The larvae will undergo 11 molts, each representing a different stage of metamorphosis. The transformation requires 15 to 40 days from newly hatched larvae to postlarvae, depending on food quality and quantity, temperature, and a variety of other water quality variables. Optimum temperatures for growth are about 82 to 88^0C.

Postlarvae

Postlarvae resemble miniature adult prawns and weigh from 6 to 9 mg (50,000 to 76,000 per pound) and are about 0.3 to 0.4 inches long. At this point their behavior will change and become principally bottom dwellers. They can tolerate a range of salinities and will migrate to freshwater upon transformation. The diet for postlarvae includes larval and adult insects, algae, mollusks, worms, fish, and feces of fish and other animals. Prawns will become cannibalistic at high densities, or under conditions of food limitations.

Adult

Adult males are larger than the females, and the sexes are easily distinguishable. The second walking legs or claws (chela) and the head region of males are larger than those of the females.

There are three types of males which are distinguished by their external characteristics. The blue-claw (BC) are distinguished by their long spiny blue claw. There is also the orange claw (OC) and the strong orange claw (SOC). The transformation sequence for the males is from OC to SOC to BC. The BC is the most successful at mating. He maintains a territory associated with a group of females ready for mating and protects them during the vulnerable period before and after molting.

Stocking of Juveniles

Juveniles is the stage between the postlarvae and adult. When transporting the juveniles to the growout pond they should be acclimated to the conditions of the pond to prevent temperature shock. Juveniles appear to be more susceptible to lower temperatures than adults and the pond water at stocking should be keep at least 68^0F. For a yield of larger prawns, lower stocking densities are essential, but will produce a lower total harvested poundage. The grow out period is dependent upon water temperature.

Feeding

Juveniles are able to obtain sufficient nutrition from the organisms present in the pond when initially stocked. When the average weight of the prawn is 5.0 g (0.18 oz) or greater, feeding should be started. The feeding rate should be based on the mean weight of the population. Table 3 is an example for a semi-intensive pond grow out.

If good water quality maintenance is practiced survival rate for the grow out season can range from 60 to 85 percent. Depending on initial stocking density a typical yield can range from 600 to 1,200 pounds per acre with individual weights from 35 to 45 g (1.2 to 1.6 oz.)

Table 3. Weight-Dependent Feeding Rates

Mean Wet Weight (g)	Daily Feeding Rate (% of Body Weight)
<5	0
5 to 15	7
15 to 25	5
>25	3

Water Quality Management

Dissolved oxygen is important, and a good monitoring program is essential to achieve maximum yields. The dissolved oxygen should be checked in the bottom one foot of the pond, since prawns are bottom dwellers. The level of dissolved oxygen should not fall below three part per million (ppm). This can be stressful to prawns and at lower levels lethal. The prevention of thermal stratification is also important, but if a pond does not exceed the recommended depth and aeration is employed properly, thermal stratification is unlikely.

The levels of un-ionized ammonia should also be checked. When levels are higher than 0.1 ppm it can be detrimental to the prawns, therefore every effort to keep levels below 0.1 ppm is recommend. Prawns have been raised in ponds with pH levels from 6.0 to 10.5 and showed no adverse affects, the recommend range is from 6.5 to 9.5.

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SECTION 4 - POND AND RACEWAY HEAT LOSS CALCULATIONS

Section 4
POND AND RACEWAY HEAT LOSS CALCULATIONS

INTRODUCTION

One of the most common areas of interest in geothermal direct use is that of aquaculture. For those involved with the initial planning of such a project, one of the first questions to be addressed relates to project size. In most geothermal applications, the maximum pond area that can be developed is restricted by the maximum heat available from the resource. It is the purpose of this chapter to present a brief introduction to the subject of heat loss from ponds (or pools) so that developers can make an informed evaluation of geothermal resources for this purpose.

TEMPERATURE REQUIREMENTS FOR SELECTED SPECIES

In order to determine the heat loss of the ponds, it is necessary to first select the temperature at which the water must be maintained. Table 1 provides a summary of appropriate temperatures for selected species. In addition, growth periods for cultures at optimum temperatures are shown in the last column.

HEAT EXCHANGE PROCESSES

A non-covered body of water, exposed to the elements, exchanges heat with the atmosphere by way of four mechanisms: (a) evaporation, (b) convection, (c) radiation, and (d) conduction. Each of these is influenced by different parameters that are discussed separately in the following paragraphs.

Evaporative Loss

Evaporation is generally the largest component of the total heat loss from the pond. Considering evaporation, the loss of volume generally comes to mind rather than the loss of heat. However, in order to boil water (and hence cause evaporation) heat must be added. The quantity of heat required to evaporate one pound of water varies with temperature and pressure, but under normal atmospheric conditions the value is approx-mately 1,000 British thermal units (Btu). When water is evaporated from the surface of the pond, the heat is taken from the remaining water. As a result, as each pound of water evaporates from the surface, approxiately 1,000 Btu

Table 1. Temperature Requirements and Growth Periods for Selected Aquaculture Species[a]

Species	Tolerable Extremes (ºF)	Optimum Growth (ºF)	Growth Period to Market Size (mos)
Oysters	32 to 97 typ	76 to 78 typ	24
Lobsters	32 to 88	72 to 75	24
Penaeid Shrimp			
Kuruma	40 to ?	77 to 87	6 to 8 typ
Pink	52 to 104	75 to 85	6 to 8
Salmon (Pacific)	40 to 77	59	6 to 12
Freshwater Prawns	75 to 90	83 to 87	6 to 12
Catfish	35 to 95	82 to 87	6
Eels	32 to 97	73 to 86	12 to 24
Tilapia	47 to 106	72 to 86	—
Carp	40 to 100	68 to 90	—
Trout	32 to 89	63	6 to 8
Yellow Perch	32 to 86	72 to 82	10
Striped Bass	? to 86	61 to 66	6 to 8

a. Behrends, 1978

are lost with escaping vapor. Losses can occur by evaporation even when the water temperature is at or below the surrounding air temperature.

The rate at which evaporation occurs is a function of air velocity and the pressure difference between the pond water and the water vapor in the air (vapor pressure difference). As the temperature of the pond water is increased or the relative humidity of the air is decreased, evaporation rate increases. The equation that describes the rate of evaporation is (ASHRAE, 1995).

$$Wp = (0.097 + 0.038v) \times (Pw - Pa) \times A$$

where

Wp = rate of evaporation (lbm/h)
A = pond surface area (ft^2)
v = air velocity, (mph)
Pw = saturation vapor pressure of the pond water (psia)
Pa = saturation pressure at the air dew point (psia)

For enclosed ponds or indoor swimming pools, this equation can be reduced to (ASHRAE, 1995).

$$Wp = 0.204 \cdot \times A \times (Pw - Pa)$$

where

Wp = rate of evaporation (lbm/h)
A = pond area (ft^2)
Pw = saturation pressure of the pond water (psia)
Pa = saturation pressure at air dew point (psia)

Following are some common values for Pw and Pa:

For Pw: @ 60°F water, Pw = 0.256 psia
@ 70°F water, Pw = 0.363 psia
@ 80°F water, Pw = 0.507 psia
@ 90°F water, Pw = 0.698 psia

For Pa: For outdoor locations with a design dry bulb air temperature below 30°F, Pa can be taken as 0.074 psia.

For indoor locations with a design of approximately 75°F and 50% relative humidity, Pa can be taken as 0.211 psia.

For example, assume a pond with a surface area of 500 ft^2 (10 ft x 50 ft) located outside in an area with design temperature of 15°F. Wind velocity is 5 mph and pond water is to be 80°F.

$$Wp = (0.097 + (0.038 \times 5)) \times (.507 - .074) \times 500$$
$$= 62.1 \text{ lb/hr}$$

To obtain the heat loss (q_{EV}) in Btu/h, simply multiply the lbm/h loss by the value of 1,050 Btu/lbm.

$$q_{EV} = 62.1 \text{ lb/h} \times 1{,}050 \text{ Btu/lb}$$
$$q_{EV} = 65{,}200 \text{ Btu/h}$$

This is the peak or design heat loss. It is important to note that the example values given above are for the design (worst) case. At higher outdoor air temperatures and different relative humidities, this value would be less. As mentioned earlier, the rate of evaporation loss is influenced by the vapor pressure difference between the pond water and the water vapor in the air. Reduced water temperature would reduce the vapor pressure differences and hence, the rate of evaporation.

Wind speed over the surface of the water has a very substantial impact upon both evaporative and convective heat losses from ponds. When calculating the design heat loss for ponds, it is not necessary to use unrealistically high wind speeds. In general, the coldest outdoor temperatures are not accompanied by high wind speed conditions.

In addition, sustained high wind conditions are generally not experienced for extended periods of time. This, coupled with the high thermal mass of the water, allows the pond or pool to sustain brief high wind periods without significant water temperature drop.

Mean wind speeds which appear in Chapter 1 of the Department of Defense publication *Engineering Weather Data* (AFM 88-29)(1978) are appropriate values for these calculations.

Pond surface area can be influenced by surface disturbances due to waves or the use of splash-type aeration devices. The calculation presented above are based upon a calm water surface. If surface disturbances exist, the pond surface area ("A" in the above equation) should be increased to reflect the departure from the calm water condition.

Convective Loss

The next major mechanism of loss from the pond surface is that of convection. This is the mode associated with the heat loss caused by cold air passing over the pond surface. The two most important influences on the magnitude of convective heat loss are wind velocity and temperature difference between the pond surface and the air. This is evidenced in (Wolf, 1983):

$$q_{CV} = (0.198v) \times A \times (Tw - Ta)$$

where
q_{CV} = convection heat loss (Btu/h)
v = air velocity (mph)
A = pond area (ft^2)
Tw = water temperature (°F)
Ta = air temperature (°F)

The shape of the pond and the direction of the prevailing wind influences the magnitude of the convective heat loss. The method used here is appropriate for pond dimensions of up to approximately 100 ft . For very large ponds, convective losses would be up to 25% less than the figure which result from this method.

For an indoor pool, this equation would be (Lauer, undated):

$$q_{CV} = 0.38\ (Tw - Ta)^{0.25} \times A \times (Tw - Ta)$$

Using the example from above (15°F design temperature, 80°F water and 5 mph wind), the following convective heat loss can be calculated:

$$q_{CV} = (0.198 \times 5\ ft/s) \times 500\ ft^2 \times\ (80^o - 15^o)$$

$$q_{CV} = 32{,}200\ Btu/h$$

Radiant Loss

Radiant heat loss, the third largest component of the total heat loss is dependent primarily on the temperature difference between the pond surface temperature and the surrounding air temperature. Under normal circumstances, radiant heat exchange is assumed to occur between solid bodies with little or no gain to the air in between the bodies. However, because of the evaporative losses near the pond surface, the air tends to contain a large quantity of water vapor. When this is the case, the pond surface radiates to the water vapor in the air, which is assumed to be at the temperature of the air itself. The equation describing this process is (Stoever, 1941):

$$q_{RD} = 0.174 \times 10^{-8} \cdot\times 0.93\ [(460 + Tw)^4 - (460 + Ta)^4] \times A$$

where
q_{RD} = radiant heat loss (Btu/h)
Tw = pond water temperature (°F)
Ta = air temperature (°F)
A = pond surface area (ft^2)

Again referring to the above example (15°F design temperature, 80°F pond temperature), the following radiant heat loss is calculated:

$$q_{RD} = 0.174 \times 10^{-8} \times 0.93\ [(460 + 80^oF)^4 - (460 + 15)^4] \times 500$$

$$q_{RD} = 27{,}600\ Btu/h$$

Conductive Loss

The final mode of heat loss is that of conduction. This is the loss associated with the walls of the pond. Of the four losses, conduction is by far the smallest and in many calculations is simply omitted. The following method (ASHRAE, 1985) is valid for a pond depth of 3 to 5 ft.

$$q_{cd} = \{[(L + W)\cdot 2] + (L \cdot W \cdot 0.02)\}[(Tw - (Ta + 15)]$$

where
q_{CD} = conductive heat loss (Btu/h)
L = length of pond (ft)
W = width of pond (ft)
Tw = design water temperature (°F)
Ta = design outside air temperature (°F)

This calculation assumes the use of lined pond construction. That is, there is no significant leakage of water from the walls or floor of the pond.

Using the previous example, the following conductive heat loss is calculated:

$$q_{CD} = \{[(10 + 50) \times 2] + (10 \times 50 \times 0.02)\}\ [80 - (15 + 15)]$$

$$q_{CD} = 6{,}500\ Btu/h$$

Table 2 summarizes the results of the calculations performed for the example 500 ft^2 pond.

Table 2. Summary of Example Heat Loss

Heat Loss Method	Loss (Btu/h)	Amount (%)
Evaporation	65,200	50
Convection	32,200	24
Radiation	27,600	21
Conduction	6,500	5
TOTAL	131,500	100

These losses are the peak or maximum heat loss. At any given time during the year, other than the design case, the heat loss would be less than this value. The annual heating requirement cannot be determined from simply multiplying the peak heating requirement by 8760 h/y. Because of the need for consideration of varying temperature, wind, humidity, and solar heat gain, methods for calculating the annual heating requirement are beyond the scope of this chapter.

SURFACE COVER

Heat losses from the pond surface are most heavily influenced by wind velocity and the temperature difference between the pond and the surrounding air. Any method that can be employed to reduce these values can substantially reduce heating requirements.

For outdoor pools, a floating cover is an excellent example. The use of a 0.5 in. floating foam cover (on the pool surface) would reduce the peak heat loss for the example pool to the values shown in Table 3.

Table 3. Summary of Example Heat Loss Using Pool Cover

Heat Loss Method	Loss (Btu/h)	Amount (%)
Evaporation	0	0
Convection	5,200	35
Radiation	3,200	22
Conduction	6,500	43
TOTAL	14,900	100

This peak load is only approximately 11% of the originally calculated heat loss. This is, in large measure, a result of the elimination of evaporation loss that is provided by a floating type cover. Unfortunately, a floating cover is generally not considered practical for commercial aquaculture applications.

POND ENCLOSURE

A pond enclosure is another (though much more expensive) option for reducing heat loss. The advantages provided by an enclosure depend to a large extent upon the construction techniques employed (covering material, degree of enclosure, presence, or absence of ventilation. The variety of construction methods and materials available are too numerous to cover here. The basic advantages of an enclosure are: (a) reduced air velocity, (b) reduced temperature difference between the pond and surrounding air, and (c) reduced vapor pressure difference between the pond water and air (increased relative humidity). These effects reduce the losses associated with evaporation, convection and radiation.

Assuming an enclosure is placed over our example pond, reducing air velocity to the 10 to 30 ft/min range, increasing humidity to 90% and air temperature to 48^{o}F (half way between outside air and pond water temperature), pond heat loss would be reduced to the values shown in Table 4.

Table 4. Summary of Example Heat Loss Using Pond Enclosure

Heat Loss Method	Loss (Btu/h)	Amount (%)
Evaporation	35,200	47
Convection	14,500	19
Radiation	18,200	25
Conduction	6,500	9
TOTAL	74,400	100

This value amounts to 57% of the original example.

It is often erroneously believed that the use of a pond enclosure will allow the air within to become saturated and thus, eliminate evaporative loss from the pond surface. This is not the case in most applications. For greenhouse-type enclosures (the most common), the inside surface temperature of the roof and walls is well below the dew point of the air during the winter. This results in substantial condensation occurring on these surfaces. As a result, moisture is continuously removed from the air allowing more to be absorbed (through evaporation) from the pond surface.

For conventional constructed buildings, ventilation air is normally supplied to reduce humidity in the space to a point which will protect the structure from moisture damage. Under these conditions of course, evaporation continues to occur and an additional heating load is imposed by the requirement to heat the ventilation air. This topic is covered in detail in Chapter 4 of the *1995 ASHRAE Handbook of Applications*.

THERMAL MASS

One final method for reducing peak heating requirements for pond or pool heating lies in the use of the large thermal mass supplied by the water itself. Water is an excellent heat storage medium. Assuming the example pond is 5 ft deep and 500 ft^{2} in area, the total volume contained would be 2,500 ft^3. At 7.49 gal/ft^3, this results in 18,725 gal or 156,000 lbm of water at 8.33 lbm/gal. Be-cause 1 lb of water gives up one Btu for each degree it is cooled, this means that our example pond that contains 156,000 lbm of water could provide 156,000 Btu of offset heating requirements if it were allowed to cool 1°F. This stored heating capacity can be used to reduce the peak heating requirement on the heating system. Using the originally calculated peak heating requirement of 131,500 Btu/h, an example of thermal storage use follows. Assume that the peak heating requirement occurs over an 8-hour period after which, because of air temperature increase and solar gain, the heating load is reduced. Further, assume that the heating system is designed to supply only 80% of the peak requirement. What will happen to the pond temperature?

First, calculate the total heat required for the 8-hr period.

8 h x 131,500 Btu/h = 1,052,000 Btu

Second, calculate the heat that the system can supply based on its 80% capacity.

8 h · x (0.80 x 131,500 Btu/h) = 842,000 Btu

Then, calculate the difference to be supplied by allowing the pond water to cool.

1,052,000 Btu - 842,000 Btu = 210,400 Btu

Finally, calculate the drop in pond temperature caused by supplying the heat required.

210,400 Btu/(156,000 lbm x 1 Btu/lbm°F)
= 1.35°F.

As a result, the pond will have cooled by 1.35°F. The heating system would then bring the pond back up to the temperature during the day when higher temperatures and solar gain would reduce heating requirements.

An alternate way of looking at this is in terms of the selection of the ambient temperature to be used in the calculation of the pond losses. Use of the mean-duty temperature in-stead of the minimum-duty temperature would allow the design to incorporate the effect of the pond thermal mass on the heat loss. Use of an air temperature higher than the mean-duty value could be employed in very clear climates where solar heat gain can be assumed to contribute to pond heating during the day.

The degree to which thermal storage can be incorporated into the heating system design is a complex issue of environmental factors, pond characteristics, and the species being raised. Some species, such as prawns, are particularly sensitive to temperature fluctuations (Johnson, 1978).

FLOW REQUIREMENTS

The rate of flow required to meet the peak heating demand of a particular pond is a function of the temperature difference between the pond water and the resource temperature. The following equation can be used to determine the flow (Q) requirement and is written:

$$Q = q_{tot}/[500 \times (Tr - Tw)]$$

where
Q = resource flow requirement (gpm)
q_{tot} = total calculated pond heat loss
$= q_{EV} + q_{CV} + q_{RD} + q_{CD}$
Tw = pond temperature (°F)
Tr = resource temperature (°F)
500 = constant (Btu/h gpm °F)

Assuming that our example pond is to be heated with a resource temperature of 100°F:

Q = 105,120 Btu/h/[500 x (100°F - 80°F)]
Q = 10.5 gpm

Again, the point is made that this is the peak requirement. The required flow at any other time would be a value <10.5 gpm. This approach is valid for aquaculture projects and resource temperatures up to levels that would prove harmful if supplied directly to the pond. Above this temperature (which varies according to species), the heating water would have to be mixed with cooler water to reduce its temperature. Two methods are possible for mixing. If a sufficient supply of cold water is available, the hot water could be mixed with the cold water before introduction in the pond. A second approach, which would apply in the absence of cold water, would be to recirculate pond water for mixing purposes. The recirculation could be combined with an aeration scheme to increase its beneficial effect. In both cases, the quantity of cold or recirculated water could be determined by the following formula:

$$Q_c = \frac{Q_h\,(T_h - T_m)}{(T_m - T_c)}$$

where

Q_c = required cold flow rate (gpm)
Q_h = hot water flow rate (gpm)
T_h = temperature of hot water (°F)
T_c = temperature of cold water (°F)
T_m = temperature of desired mixed water (°F)

The above methods are presented to provide interested individuals with an introduction to the subject of heat losses from ponds. The equations provided are simplifications of very complex relationships and should be employed only for initial calculations. In addition, losses that can occur from various aeration schemes and other activities have not been addressed. It is strongly recommended that a competent engineer be enlisted for final design purposes.

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Section 5
AQUACULTURE BIBLIOGRAPHY

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SECTION 6 - AQUACULTURE GLOSSARY

Section 6
AQUACULTURE GLOSSARY

Aquaculture - The production and sale of farm-raised aquatic plants and animals

Bacteria - Microscopic animal life, some kinds of which are responsible for the decay of dead materials and wastes.

Biofilter **-** Component of recirculating systems consisting of a large surface area upon which bacteria grow. These live on fish waste products, breaking them down into forms much less harmful to fish.

Brackish Water - a mixture of fresh and salt water.

Broodfish - Fish kept for egg production, including males. Broodfish produce the fertilized eggs which go to hatcheries.

Dissolved Oxygen - Oxygen dissolved poorly in water and is often in short supply for aquatic animals. Warm water holds even less oxygen than cold water.

Extensive Culture - outdoor, low density culture usually involving large ponds and/or flow-through raceways.

Fertilizer - a substance added to water to increase the production of natural fish food organisms.

Fingerlings - Young fish from one inch in length up to one year of age. This stage comes after the fry stage. Fish weighing 60 pounds per 1,000 fish and less.

Fry - young fish from the time of hatching up to 1 inch in length. Fish weighing 60 pounds per 1,000 fish and less.

Grow-Out Pond/Facility - a pond or other facility used to grow aquatic animals to marketable size.

Integrated Aquaculture - aquaculture systems integrated with livestock and/or crop production. For example, using animal manures to fertilize a pond to enhance fish production and water from the pond to irrigate a garden.

Intensive Culture - indoor, high density culture usually involving recirculation of water and biofilters.

Large Foodsize - Fish weighing over three pounds.

Large Stockers - Fish weighing over 180 pounds to 750 pounds per 1,000 fish.

Levee Ponds - Standing water impoundments built by excavating the pond area to a shallow depth and using the soil obtained to build a perimeter of levees or dykes.

Male Hormone - a substance that, when fed to Tilapia fry, induces undifferentiated tissue to develop into male gonads (testes).

Manual Sexing - examining a fish to determine its sex.

Manufactured Food - commercially processed food for fish or livestock.

Medium Foodsize - Fish weighing over one and one-half pounds to
three pounds.

Mixed-Sex Culture - culture of males and females in the same grow-out facility.

Monosex Culture - culture of all-male fish for market.

Mouth-Brooder - a fish that hatches its eggs in its mouth.

Off-flavor - Aquatic animals can absorb and take on bad flavors from the water in which they live. These musty, muddy or otherwise undesirable flavors usually come from substances put out by certain species of microscopic plants (phytoplankton).

Partial Harvesting - periodic harvesting of a portion of the fish from a culture facility during a culture cycle.

Phytoplankton - The plant component of plankton.

Plankton - the various, mostly microscopic, aquatic organisms (plants and animals) that serve as food for larger aquatic animals and fish.

Poly Culture - simultaneous culture of two or more aquatic species with different food habits.

Predacious Fish - a fish species that eats other fish as food.

Raceways - Long channels through which large amounts of new water flow continuously and are then discarded. Usually built of concrete, these can also be earthen channels or long tanks of other materials.

Recirculating Systems - Tank systems which rely on biofilters to break down harmful fish waste products so water can be reused.

Seine - A long net used to capture fish.

Small Foodsize - Fish weighing over three-fourths pound to one and one-half pounds.

Small Stockers - fish weighing over 60 pounds to 180 pounds per 1,000 fish.

Spawning - the act of depositing eggs and producing young.

Substrate Spawner - a fish that lays its eggs on some form of substrate or surface where they will hatch.

Turnover - Mixing of top and bottom water that can lead to fish kills, especially in watershed ponds. During the summer a cold bottom layer of water lacking in oxygen develops. In fall, the bottom and top layers can suddenly mix or "turnover".

Watershed Ponds - Impoundments built by damming ravines or small valleys. Runoff from the surrounding watershed fills the ponds.

Water Quality - The degree of suitability of water for growing fish and other aquatic organisms. Water high in dissolved oxygen and low in animal wastes such as ammonia is generally considered to be high quality. Other factors also come into play such as alkalinity, chlorides and harmful substances such as iron and hydrogen sulfide.

Zooplankton - an animal component of plankton.

SECTION 7 - STATE/REGIONAL/UNIVERSITY/EXTENSION AQUACULTURE OFFICES

Section 7
STATE/REGIONAL/UNIVERSITY/EXTENSION AQUACULTURE OFFICES

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(907) 274-9691

Arizona
Environmental Research Lab
University of Arizona
2601 East Airport Drive
Tucson, AZ 85706-6985
(520) 741-1990

Arizona Cooperative Extension
University of Arizona
301 Forbes Bldg.
Tucson, AZ 85721
(602) 621-5308

California
Dept. Of Animal Science
University of California-Davis
Davis, CA 95616
(916) 752-7689

U.C. Cooperative Extension
Sea Grant Marine Advisory Prog.
2 Commercial Street, Suite 4
Eureka, CA 95501
(707) 527-2621

UC-Cooperative Extension Sea Grant
2604 Ventura Avenue
Room 100P
Santa Rosa, CA 95403-2894
(707) 527-2621

UC Sea Grant Extension Program
Area Marine Advisor
PO Box 440
Moss Landing, CA 95039
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Fishery & Wildlife Biology
Colorado State University
239 Wager Building
Fort Collins, CO 80523
(303) 491-5091

Cooperative Extension
Colorado State University
1 Administration Building
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(303) 491-6208

Idaho
Aquaculture Research Institute
University of Idaho
Moscow, ID 83843
(208) 885-5830

Twin Falls County Extension
University of Idaho
246 Third Ave. East
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(208) 734-9645

Montana
Conservation Education Division
Montana Dept. Of fish Wildlife and Parks
Helena, MT 59620
(406) 444-4038

Fisheries Div
Montana Dept of Fish, Wildlife and Parks
1420 E. Sixth Avenue
Helena, MT 59620
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Department of Biology
Montana State University
Bozeman, MT 59717-0001
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College of Agriculture/Extension Service
Montana State University
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(406) 994-3681

Nevada
Nevada Cooperative Extension
2345 Red Rock Street, Suite 330
Las Vegas, NV 89102-3157
(702) 251-7531

Nevada Dept. Of Wildlife
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Reno, NV 89520
(702) 688-1500

New Mexico
Cooperative Extension Service
New Mexico State University
Box 30003, Dept 3AE
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Dept. Of Game and Fish
PO Box 25112
Sante Fe, NM 87503
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Oregon State University
250 - 36th Street
Astoria, OR 97103
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Extension Office
2204 4th St.
Tillamook, OR 97141
(503) 842-3433

South Dakota
Interagency Coordinator
Dept of Game, Fish & Parks
445 E. Capitol
Pierre, SD 57501
(605) 773-4196

Utah
Aquatic Section
Utah Division of Wildlife Research
1594 West North Temple, Suite 2110
PO Box 146301
Salt Lake City, UT 84114-6301
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College of Natural Resources
Dept of Fish & Wildlife
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Alaska
USFWS, Kenai Fishery Resource Office
Gary Sonnevil
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PO Box 1670
Kenai, AK 99611
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Northern Central Valley
Fish and Wildlife Office
10950 Tyler Road
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US Fish and Wildlife Service
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California
California Dept of Fish & Game
1416 Ninth St.
Sacramento, CA 95814
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Idaho
Rangen Aquaculture Research Center
2928B S 1175 E
Hagerman, ID 83332
(208) 837-6191

Oregon
Fish Division
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South Dakota
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Foss Building, 523 E Capitol
Pierre, SD 57501
(605) 773-4508

Utah
US Fish and Wildlife Service
Ouray National Fish Hatchery
266 W. 100 North
Vernal, UT 84078
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Clocktower Plaza, Suite 222
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Alaskan Shellfish Growers Assoc.
PO Box 7
Moose Pass, AK 99631
(907) 288-3667

Southern Southeast Regional
Aquaculture Association, Inc.
2721 Tongass
Ketchikan, AK 99901
(907) 225-9605

California
California Aquaculture Association
PO Box 1004
Niland, CA 92257
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Colorado
Colorado Aquaculture Assoc.
Box 27
Leadville, CO 80461
(719) 486-1075

Idaho
Idaho Aquaculture Assoc.
PO Box 28
Buhl, ID 83316
(208) 543-4898

Washington
WA Farmed Salmon Commission
PO Box 5305
Bellingham, WA 98227
(360) 671-1997

Washington Fish Growers Association
10420 173rd Ave SW
Pochester, WA 98579
(360) 273-5890

Washington Pacific Coast Oyster Growers
Assoc.
120 State Ave NE #142
Olympia, WA 98501
(360) 754-2744

State Aquaculture Coordinators

California
Gerald W. Miller
Principal Biologist
Dept. Of Food and Agriculture
1220 N. St.
Division of Plant Industry
Sacramento, CA 95814
(916) 654-0768

Idaho
Dr. Phillip Mamer
Aquaculture Coord.
Division of Animal Industries
Idaho Dept. Of Agriculture
Box 7249
Boise, ID 83707
(208) 332-8560

Montana
Darla Anderson
Montana Dept. Of Agriculture
PO Box 200201
Helena, MT 59620-0201
(406) 444-2402

Oregon
Dalton Hobbs, Int'l Trade Mgr.
Oregon Dept of Agriculture
Agric. Development and Marketing Div.
121 SW Salmon Street, Suite 240
Portland, OR 97204-2987
(503) 229-6734

Nevada
Nevada Dept. Of Agriculture
350 Capitol Hill Ave.
PO Box 11100
Reno, NV 89510
(702) 789-0180

Utah
Russell Lee, DVM
Fish Health Specialist
Utah Dept of Agriculture
350 North Redwood Rd.
PO Box 146500
Salt Lake City, UT 84114-6500
(801) 538-7029

Diagnostic Services Available

California
Fish Disease Lab
California Dept of Fish and Game
407 West Line Street
Bishop, CA 93514
(760) 872-1134

Dept of Medicine and Epidemiology
School of Veterinary Medicine
University of California
Davis, CA 95616
(916) 752-3411

Colorado
Wildlife Pharmaceuticals, Inc.
1401 Duff Drive #700
Fort Collins, CO 80524
(970) 484-6267

Idaho
Idaho Dept. Of Fish and Game
1800 Trout Rd.
Fish Health Laboratory
Eagle, ID 83616

Montana
Fish Health Center
US Fish and Wildlife Service
920 Technology Blvd., Suite G
Bozeman, MT 59718-4001
(406) 582-8656

US Fish and Wildlife Service
Fish Technology Center
4050 Bridger Canyon Road
Bozeman, MT 59715-8713

Oregon
Dept. Of Microbiology
Nash Hall 220
Oregon State University
Corvallis, OR 97331-3804
(541) 737-4753

Utah
Zoology Department
153 WIDB
Brigham Young University
Provo, UT 84602
(801) 378-2495
(801) 378-2006

Washington
Olympia Fish Health Center
3704 Griffin Lane SE, Suite 101
Olympia, WA 98501
(360) 753-9046

Troutlodge, Inc.
PO Box 1290
Sumner, WA 98390
(253) 863-0446

US Fish and Wildlife Service
MAKAH NFH
PO Box 739
Nesh Bay, WA 98357
(360) 645-2521

Wyoming
Game and Fish Laboratory
University of Wyoming
PO Box 3312
Laramie, WY 82071
(307) 766-5618

Chief of Fisheries
State of Wyoming
Wyoming Game and Fish Dept.
5400 Bishop Blvd.
Cheyenne, WY 82006
(307) 777-4559

Sea Grant Program Abbreviations and Addresses

AKU
Alaska Sea Grant College Program
University of Alaska Fairbanks
PO Box 755040
Fairbanks, AK 99775-5040
(907) 474-7086
(907) 474-6285 (fax)
www.uaf.alaska.edu/seagrant/

AZU
Dept. Of Veterinary Science
University of Arizona
Tucson, AZ 85721
(602) 621-8414

CUIMR
California Sea Grant
University of California/San Diego
9500 Gilman Drive
La Jolla, CA 92093-0232
(619) 534-444
(619) 453-2948 (fax)
www-csgc.ucsd.edu/

HAWAU
University of Hawaii
Sea Grant College Program
1000 Pope Road, MSB 200
Honolulu, HI 96822
(808) 956-7410
www.soest.hawaii.edu/SEAGRANT/

NCRI
National Costal Resources Research &
Development Inst.
528 Southwest Mill, Suite 222
PO Box 751
Portland, OR 97207
(503) 725-5725

ORESU
Oregon Sea Grant
Oregon State University
AdS 402
Corvallis, OR 97331-2134
(541) 737-2716
(541) 737-2392
seagrant.orst.edu

OREXT
Publications Orders
Agricultural Communications
Oregon State University
Ads 422
Corvallis, OR 97331-2119
(541) 737-2513
seagrant.orst.edu

SCU
Southern California Sea Grant
University of Southern California
University Park
Los Angeles, CA 90089-0373
(213) 740-1961
(213) 740-5936 (fax)
www.usc.edu/dept/seagrant/seagrant.html

WASHU
Washington Sea Grant, HG-30
University of Washington
3716 Brooklyn Avenue, N. E.
Seattle, WA 98105-6716
(206) 543-6600
(206) 685-0380 (fax)
www.wsg.washington.edu/

SECTION 8 - STATE AQUACULTURE PERMIT REQUIREMENTS

This section contains information from the publication entitled "**State/Territory Permits and Regulations Impacting the Aquaculture Industry, 1995**." The information for this section was found through the website http://ag.ansc.purdue.edu/aquanic/publicat/state/md/md.htm under the AquaNIC State Publications for Maryland. The direct link to the publication is http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm.htm

The report provides an overview of regulations and permits by individual states and territories which concern the aquaculture industry. Most of the listings are summarized with pertinent information and contact information to help in the user's investigation. This publication was intended for informational purposes. Interested parties should contact appropriate agencies directly for current information or contact the office of your state aquaculture coordinator.

Below are the links to the overview of regulations and permits by individual states which concern the aquaculture industry.

Alabama
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm1.pdf

Alaska
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm2.pdf

Arizona
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm3.pdf

Arkansas
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm4.pdf

California
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm5.pdf

Colorado
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm6.pdf

Connecticut
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm7.pdf

Delaware
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm8.pdf

Florida
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm9.pdf

Georgia
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm10.pdf

Hawaii
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm12.pdf

Idaho
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm13.pdf

Illinois
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm14.pdf

Indiana
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm15.pdf

Iowa
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm16.pdf

Kansas
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm17.pdf

Kentucky
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm18.pdf

Louisiana
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm19.pdf

Maine
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm20.pdf

Maryland
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm21.pdf

Massachusetts
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm22.pdf

Michigan
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm23.pdf

Minnesota
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm24.pdf

Mississippi
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm25.pdf

Missouri
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm26.pdf

Montana
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm27.pdf

Nebraska
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm28.pdf

Nevada
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm29.pdf

New Hampshire
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm30.pdf

New Jersey
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm31.pdf

New Mexico
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm32.pdf

New York
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm33.pdf

North Carolina
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm34.pdf

North Dakota
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm35.pdf

Ohio
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm36.pdf

Oklahoma
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm37.pdf

Oregon
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm38.pdf

Pennsylvania
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm39.pdf

Rhode Island
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm41.pdf

South Carolina
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm42.pdf

South Dakota
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm43.pdf

Tennessee
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm44.pdf

Texas
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm45.pdf

Utah
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm46.pdf

Vermont
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm47.pdf

Virginia
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm49.pdf

Washington
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm50.pdf

West Virginia
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm51.pdf

Wisconsin
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm52.pdf

Wyoming
http://ag.ansc.purdue.edu/aquanic/publicat/state/md/perm53.pdf