Recirculating Tank Aquaculture for High Schools

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In a perfect world. . .

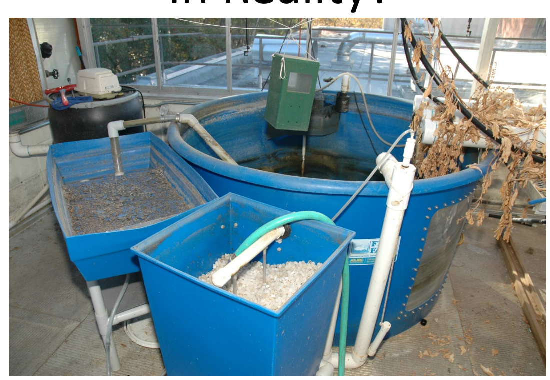
Fingerlings

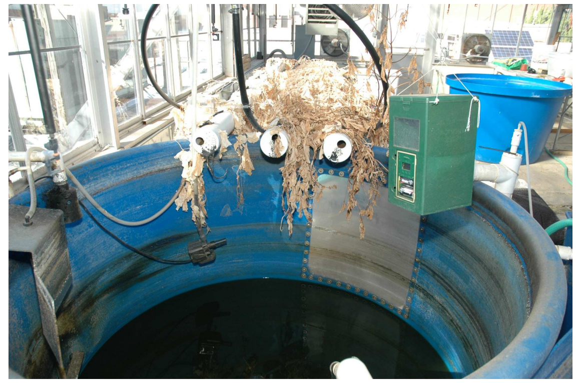
Midland Valley H.S.- South Carolina

in conjunction with Aquaponics

Sherando H.S.- Virginia

In Reality?

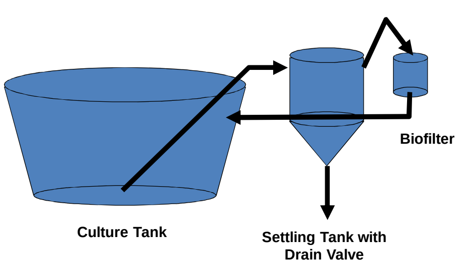




Survival of the Fittest

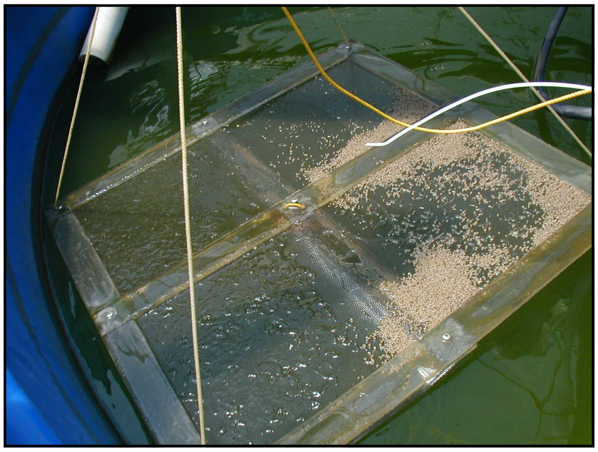
Basic Water Treatment

Typical Recirculating Configuration



Feeding Requirements

- Fish are typically fed a commercially available pelleted feed (floating or sinking)
- Feed rates are prescribed as a function of body weight
  - Market size fish consume about 1.5% of their body weight per day
  - Juvenile fish consume as much as 15% of their body weight per day



Feed Utilization

- Feed is either consumed by the fish or left to decompose in the water column
- At proper rates, all feed will be consumed by the fish
  - A portion of the nitrogen in the feed (typically about 25%) is used for fish growth
  - The remainder of the nitrogen is excreted by the fish as ammonia and urea

- At excessive rates, some feed is left to decompose in water column
  - Microbes and zooplankton will consume uneaten feed
- Oxygen demand is a function of feed application rate

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Fish Metabolism Breakdown

- When the fish consume feed to grow and support their metabolism, the feed is broken down into:
  - Fecal solids
    - Ultimately converted into ammonia and CO_2
  - Urea
    - Ultimately converted into ammonia-nitrogen
  - Carbon Dioxide
    - Elevated levels toxic at low DO
  - Ammonia nitrogen
    - Elevated levels toxic, toxicity affected by pH

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Fecal Solids Classifications

- Settleable solids
  - Easy to remove with settling tank
  - Should be removed from all systems (except extensive)
- Suspended solids
  - Must be removed with mechanical filtration
  - Removal only necessary in intensive systems
- Floatable and dissolved solids
  - Must be removed via foam fractionation
  - Removal may be required in intensive systems and likely required in super-intensive systems

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Settleable Solids Removal

- Entrapment generally occurs in a quiescent settling tank
  - Removal will be a function of hydraulic retention time (HRT) in the settling tank
  - HRT calculated as volume of settling tank divided by flow rate through settling tank
  - Settling tank HRT should be at least 20 minutes
- Delivery of solids from culture tank to settling tank
  - (1) Maintain solids in suspension in culture tank via agitation…remove solids by pumping water
  - (2) Allow solids to settle in culture tank and deliver water from bottom of culture tank to settling tank

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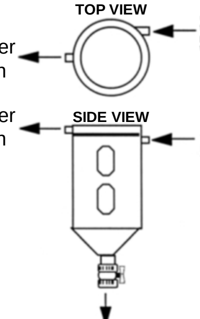
Typical Cyclone Separator Configuration for Settling Tank



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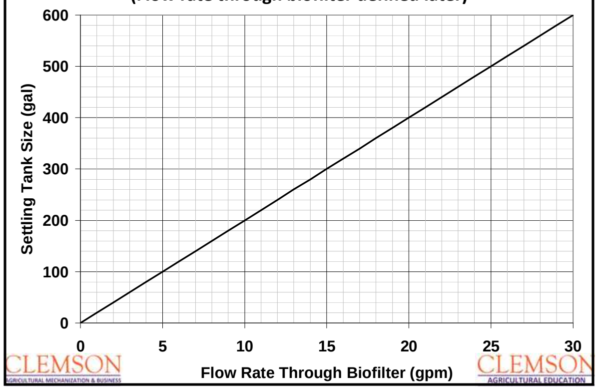
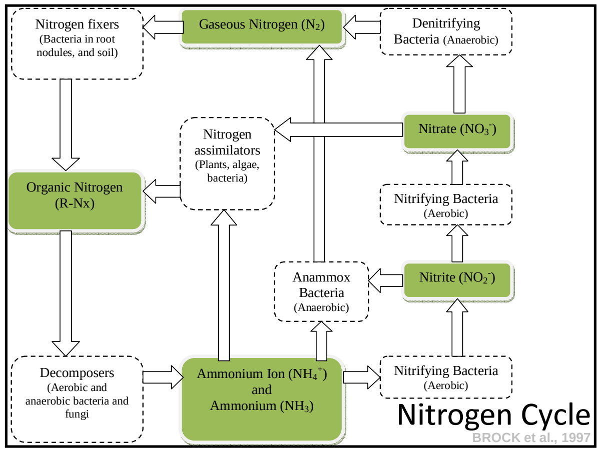
Determining Size of Settling Tank

(Flow rate through biofilter defined later)





Nitrogen Cycle

BROCK et al., 1997

Total Ammonia Nitrogen (TAN)

- Recall that ammonia forms through protein metabolism
- TAN is the sum of unionized ammonia (NH_3) and ionized ammonia (NH_4^+)
  - Unionized ammonia is extremely toxic to most fish
- The pH determines what fraction of the TAN is unionized
  - At high pH, more of the TAN is in the unionized form

$$NH_4^+ \leftrightarrow NH_3 + H^+$$

Low pH **High pH**

- Lethal concentrations of unionized ammonia are known for most cultured fish
  - Sublethal affects in most cases are unknown
  - **SRAC recommends maintaining 0.05 mg-N/L (unionized)**
- Ammonia is removed by conversion to nitrite or microbial biomass

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Nitrite Nitrogen (NO_2)

- NO_2 is formed when ammonia is oxidized by nitrifying bacteria

$$NH_3 + 1.5\,O_2 \rightarrow NO_2^- + H_2O + H^+$$

- Nitrite is not as toxic as ammonia, but can still be toxic and must be removed
  - Nitrite binds with hemoglobin in the fish blood forming methemoglobin, which cannot transport oxygen
  - Nitrite toxicity can be reduced by increasing the chloride concentration
  - SRAC recommends maintaining a nitrite concentration of less than 1 mg/L
- Nitrite is removed by conversion to nitrate

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Nitrate Nitrogen (NO_3)

- Not of direct concern in aquaculture
  - Most species of fish can tolerate extremely high levels of nitrate (>200 mg/L)
- Nitrate is formed from the oxidation of nitrite
- It can be removed by denitrification
  - Conversion to nitrogen gas (N_2)
  - Requires anaerobic conditions
  - Regenerates alkalinity

Ammonia (NH_3) and Nitrite (NO_2) Removal

- Critical in all recirculating systems (except extensive)
  - Must be removed at the rate it's produced
  - Less efficient removal requires higher flow rates
- Air stripping
  - Ammonia volatilization, requires pH adjustment
  - No affect on nitrite removal, but limits nitrite production
- Ion exchange
  - Very costly, produces salt brine waste
  - No affect on nitrite removal, but limits nitrite production
- **Biological filtration**
  - **Cheapest and most widely used method**

Attached Growth Biofiltration

- Uses media with high surface area to volume ratio
  - Nitrifying bacteria attach to media and grow there
  - Gravel, sand, plastic beads, plastic rings, plastic plates
- As ammonia- and nitrite-laden water pass through the filter, the nitrogen is oxidized to nitrite and nitrate by the nitrifying bacteria
  - *Nitrosomonas* convert NH_3 to NO_2
  - *Nitrobacter* convert NO_2 to NO_3

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Common Biofilter Technologies

- Rotating biological contactor
  - Medium rotates on shaft in and out of water
- Trickling filter
  - Water trickles down through medium
- Expandable media filter
  - Same bead filters discussed in DOC removal
- Fluidized bed reactor
  - Upflow suspends sand for colonization
- Mixed bed reactor
  - Water flows through plastic beads

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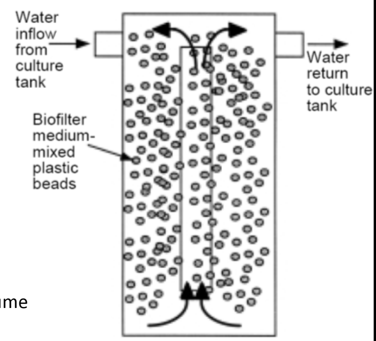
Mixed Bed Reactors

- Cross b/t upflow plastic bead filters and fluidized bed reactors
- Plastic medium in constant motion
- Neutral buoyancy so mixing by water flow
- Removal rates of 400-575g-TAN/m³/day = 16-23 kg-feed/day per m³ of filter medium
- SSA = 800-1150 m²/m³
- Tank should be 1.5x volume of media required



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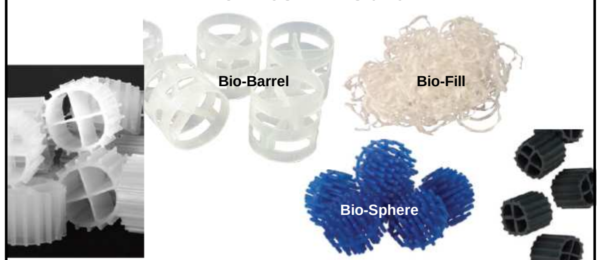
Biofilter Media



From 2011 Aquatic Ecosystems Catalog:

	ft²/ft³	Size	Price
Bio-Fill™	250	Ribbon	49.00/ft³
Bio-Sphere, 1½"	98	1½"	42.55/ft³
Bio-Sphere, 1"	160	1"	57.68/ft³
Bio Barrel, 1"	64	1"	43.85/ft³
Bio Barrel, 1½"	44	1½"	33.90/ft³
Bio Barrel, 2"	33	2"	22.25/ft³
Bio Strata, 8 mil	110	4' Length	41.46/ft³
Bio Strata, 8 mil	68	4' Length	19.53/ft³

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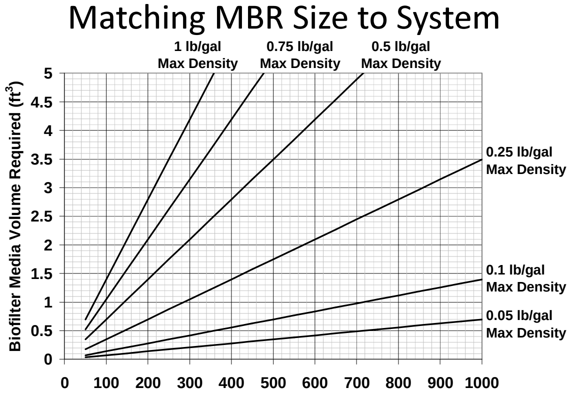
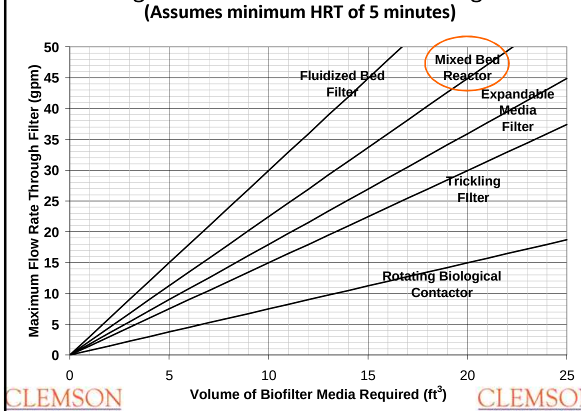
Matching MBR Size to System



Note: Biofilter tank volume should be ~1.5x biofilter media volume required

Determining Max Flow Rate Allowed Through Biofilter

(Assumes minimum HRT of 5 minutes)



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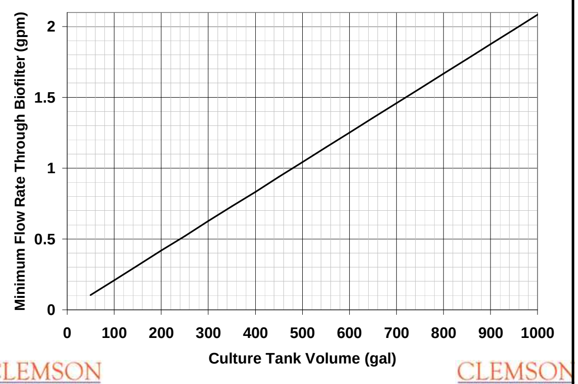
Determining Min Flow Rate Required Through Biofilter

(Assumes three culture tank exchanges per day)



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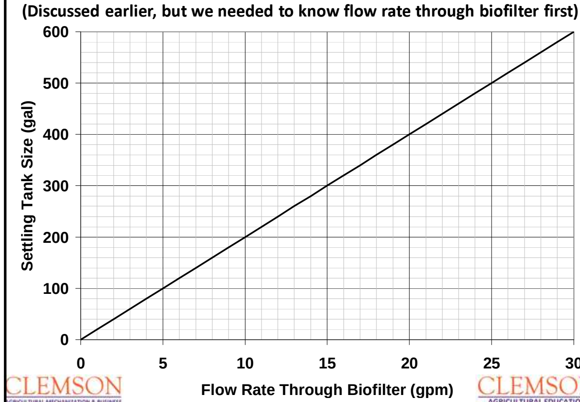
Determining Size of Settling Tank

(Discussed earlier, but we needed to know flow rate through biofilter first)



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Aeration

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Dissolved Gases

- Fish growth will suffer at suboptimal conditions
  - DO in culture tank should be maintained at 5 mg/L
  - DO in submerged nitrification tanks should be at least 2 mg/L
  - CO_2 in culture tank should not exceed 20 mg/L
- O_2 consumption will mainly be a function of feed rate and nitrification method
  - Oxygen supply must equal oxygen consumption
  - Good solids removal and non-submerged nitrification = 0.3 kg O_2 per kg feed added
  - Solids retention and submerged nitrification = 0.7 kg O_2 per kg feed added
- Aeration failure can lead to total loss of fish in tank(s) within only 30 minutes

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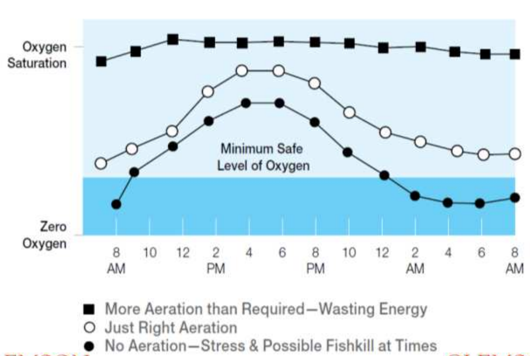
Aeration Management



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Aeration and Degassing Methods

- Air diffusers
  - Bubbling of air or pure oxygen into water

- Surface agitators
  - Paddlewheels or pumps that sling water into air to increase oxygen exchange rate

- Packed columns
  - Work similar to trickling filter where water drips down through media

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Diffused Aeration

- Regenerative blowers are used to deliver air through porous “air stones” placed on bottom of tank
  - Bubbles are created that exchange O_2 to water as they rise
- Transfer O_2 at an average rate of 0.45 kg O_2 per kW-hr at typical tank conditions

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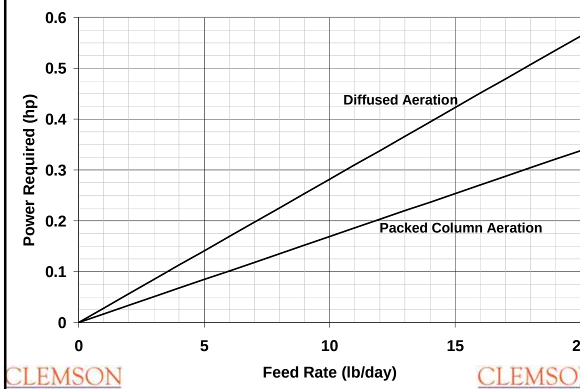
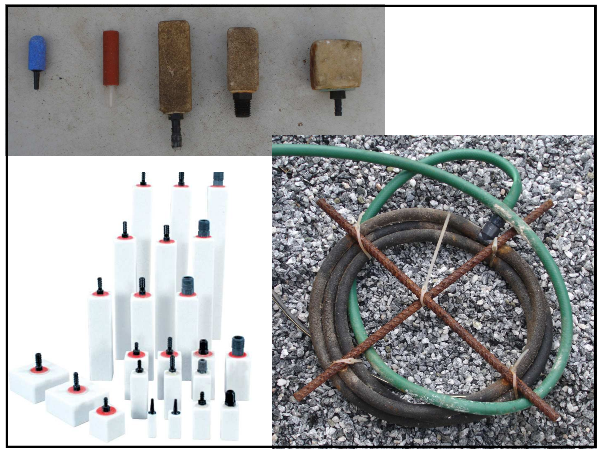
Aeration Power Requirements



Sweetwater Blower Specifications

Model Number	Cfm Free Air @ Inches Water 20"	30"	40"	50"	Max Duty	Hp	Running Watts Input @ Inches Water	Price (Including Filter)
S11A ❶ ❷	13	3	—	—	34"	1/8	198/20"	$ 488.58
S21 ❶ ❷	27	19	7	—	43"	1/3	377/30"	537.60
S31 ❶ ❷	34	28	21	16	56"	1/2	471/30"	578.65
S313 ❶	34	28	21	16	56"	1/2	410/30"	597.22
S41 ❶ ❷	70	65	53	36	58"	1	971/40"	704.63
S43 ❷	70	65	53	36	58"	1	860/40"	706.77
S45 ❷	110	100	90	80	65"	1 1/2	1,430/40"	944.85
S453 ❷	110	100	90	80	65"	1 1/2	1,500/40"	944.85
S51 ❷	135	120	110	100	65"	2 1/2	1,760/40"	1,015.38
S53 ❷	135	120	110	100	65"	2 1/2	1,750/40"	983.48
S61 ❸	190	180	165	—	45"	2 1/2	2,600/40"	1,380.33
S63 ❸	190	180	165	160	80"	3 1/2	3,260/60"	1,289.40
S631 ❸ ❺	190	180	165	160	75"	3 1/2	3,400/60"	1,402.03
S651 ❸	190	180	165	160	100"	5	3,710/80"	1,479.40
S653 ❸	190	180	165	160	110"	5	3,520/80"	1,486.80
S56 ❸	120	120	118	117	280"	6	4,000/150"	2,206.06
S69 ❸	250	245	230	210	110"	5 1/2	4,190/60"	1,981.12
S73 ❸	390	375	350	330	125"	10	7,640/80"	2,400.00
2S41 ❹	78	74	70	61	110"	1+1	800/80"	—
S15	650	640	630	610	125"	15	11,000/80"	5,064.91
S18P	720	710	690	650	105"	18	12,000/80"	4,696.92
S18S	410	405	400	395	200"	18	12,000/80"	4,696.92
S30P	1,275	1,230	1,200	1,190	125"	30	20,000/80"	8,898.22
S30S	650	640	630	625	225"	30	20,000/80"	8,898.22

Aquatic Ecosystems 2011



Aquatic Ecosystems
Air Stone Specifications

	Length in	cm	aes	Avg. cfm	Each	20+
ASI-3	2	5	5	.2	$ 3.05	2.75
ASI-5	3	7.6	8	.3	4.20	3.78
ASI-8	3	7.6	10	.35	6.06	5.45
ASI-15	6	15	14	.5	10.37	9.33
ASI-23	9	23	20	.75	14.82	13.34
ASI-30	12	30	27	1.0	20.26	18.24

Aquatic Ecosystems 2011

Electrical Power Failure

- Assume power goes out to a warm-water system that is at oxygen saturation
- If fish are stocked at ¼ lb per gallon
  - DO would decrease 3 mg/L in only 16 minutes
- If fish are stocked at ½ lb per gallon
  - DO would decrease 3 mg/L in only 6 minutes

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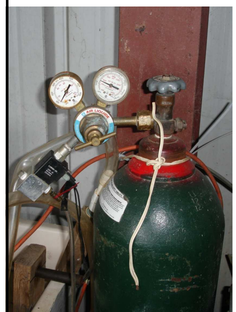
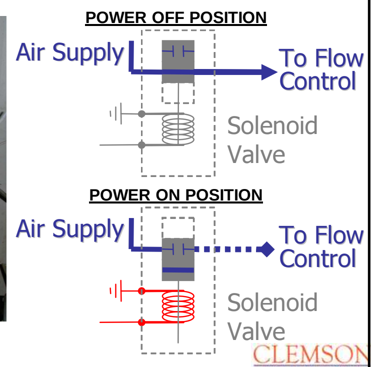
Plan for Power Failure

- Standby electrical generation on automatic transfer switch
- Oxygen bottles on electrical solenoid valves
  - Automatically initiate flow of oxygen when power is removed
- Phone alarm systems to alert operator of power failure

Emergency Oxygen Tank Setup





Water Quality

Water Quality Management

- Water quality must be monitored and controlled in order to maintain optimum fish growth
  - Temperature
  - DO
  - CO_2
  - pH
  - Ammonia
  - Nitrite
  - Solids
  - Alkalinity
  - Chlorides
  - Nitrate

Sample Record Sheets

Daily Measurements

Date/Time	Feed Applied	Temp	DO	pH	TAN	Nitrite	Mort	Notes	% of TAN Unionized	Unionized Ammonia

Weekly Measurements

Date	Alkalinity	Hardness	Sample #	Sample Wt.	Avg. Wt.	Total #	Total Wt.	% BW	Daily Feed

	Temp	D.O. mg/L	pH Units	Alkalinity mg/L
Trout	45–68°F/7–20°C	5–12	5.5–8	50–250
Hybrid Striped Bass	70–85°F/21–29°C	4–10	6–8	50–250
Tilapia	75–90°F/24–32°C	3–10	6–8	50–250
Goldfish/Koi	65–75°F/18–24°C	4–10	6–8	50–250
Shrimp (Freshwater)	68–80°F/20–27°C	4–10	6.5–9	60–100
Shrimp (Saltwater)	60–75°F/16–24°C	4–10	6–8.5	50–250
Minnows Shiners	60–75°F/16–24°C	4–10	6–8	50–250
Tropical Fish (Freshwater)	72–84°F/22–29°C	4–10	6–8	50–250

	CO_2 mg/L	Un-Ionized Ammonia mg/L	Nitrite mg/L	Hardness mg/L	Chloride mg/L
Trout	0–20	0–.02	0–.2	50–350	0–1,500
Hybrid Striped Bass	0–25	0–.03	0–.8	50–350	0–1,500
Tilapia	0–30	0–.04	0–.8	50–350	0–5,000
Goldfish/Koi	0–25	0–.08	0–.6	50–350	0–2,000
Shrimp (Freshwater)	0–20	0–.05	0–.9	60–250	0–1,500
Shrimp (Saltwater)	0–15	0–.01	0–.1	50–350	13,000–18,000
Minnows Shiners	0–25	0–.03	0–.6	50–350	0–2,500
Tropical Fish (Freshwater)	0–20	0–.03	0–.9	50–350	0–2,500

Aquatic Ecosystems 2011

Water Temperature

- Must be maintained within optimum range
  - Speeds fish growth
  - Improves feed conversion efficiency
  - Improves disease resistance
- Temperature control
  - Electrical immersion heaters
  - Gas or electric heating units
  - Heat pumps
  - For most tank systems, the room air temperature is regulated, rather than the water temperature

Dissolved Oxygen Concentration

- Should be maintained above 5 mg/L
- Oxygen stress evidenced by fish gathering at surface
  - Solution: Additional aeration, improved aeration efficiency, temperature reduction, feed reduction, better solids removal (suspended and/or settleable)
- Distributing feedings over entire day (rather than once or twice) will help with peak oxygen loadings

Water Quality Test Kit

Test	Range
Ammonia Nitrogen	.2–3 mg/L
Nitrite	.05–.8 mg/L
pH	5–10
Alkalinity	0–200 mg/L
Carbon Dioxide	0–50 mg/L
Chloride	0–200 mg/L
Dissolved Oxygen	0–10 mg/L
Hardness	0–200 mg/L
Temperature	-5–45°C

LMAQ2

Carbon Dioxide

- CO_2 presence interferes with fish's ability to uptake oxygen
- Generally high CO_2 concentrations are accompanied by low DO concentrations
  - So symptoms are similar, increased aeration is best solution

pH and Alkalinity

- pH is measure of hydrogen ion (H^+) concentration
  - Neutral pH is 7; lower is acidic; higher is basic
- Alkalinity is measure of water's capacity to neutralize acidity
  - Bicarbonate (HCO_3^-) and carbonate (CO_3^-)
- Nitrification produces acid (H^+), which combines with bases
  - Alkalinity is therefore consumed and pH will drop, potentially affecting fish health
- Alkalinity replacement methods:
  - (1) Direct addition (sodium bicarbonate is best)
  - (2) Establishment of anaerobic zone for denitrification

SRAC Publication No. 451

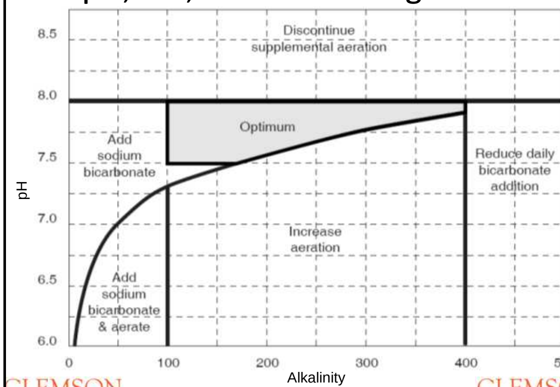
pH

- Some fish can tolerate a wide range of pH, but rapid changes are dangerous
  - Never change the pH more than one unit per hour
- Nitrifying bacteria are more sensitive to pH levels than many fish (prefer between 7 and 8)
  - Nitrifiers will drive pH down due to formation of CO_2, which creates carbonic acid
  - Algae will drive pH up, due to removal of CO_2
- pH in a recirculating system will be more stable if an anaerobic area (lack of oxygen) is provided for denitrification

Alkalinity

- If no denitrification occurs and pH trend is downward
  - Sodium bicarbonate should be added at a rate of about 20% of the daily feed rate
  - Alkalinity and hardness should be maintained at least 50 to 100 mg/L as calcium carbonate
  - Calcium should be added to adjust hardness

pH, DO, and Alk Management



Allain, 1988, M.S. Thesis, LSU

Ammonia

- Ammonia exists in two forms: ionized (NH_4^+) and unionized (NH_3)
  - The unionized form is toxic to fish
  - The proportion of these is dictated by temperature and pH
- Ammonia toxicity slows growth, causes tissue damage, and death
- Monitor ammonia daily
  - Manage feed, waste, and biofilter properly for long-term ammonia control
  - Manage pH for short term ammonia control

Percentage of Ammonia in Unionized Form

	Temperature (°C)								
pH	16	18	20	22	24	26	28	30	32
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	3.68	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	19.46
8.6	10.56	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	27.64	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	56.30	60.38
9.4	42.68	46.32	50.00	53.45	56.86	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

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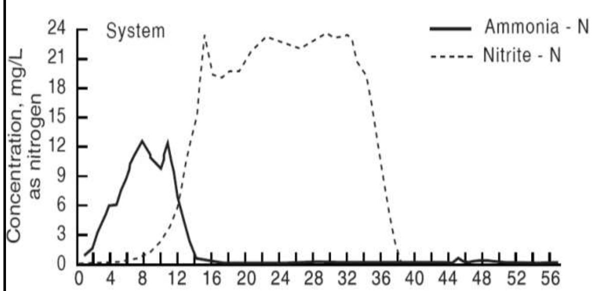
Solutions to Ammonia Problems

- Check biofilter design capacity
- Check biofilter operation
  - Biofilters can take 3-4 weeks to "come online"
- Decrease feed rate or stop feeding
- Check pH, DO, and alkalinity in biofilter
  - Maintain pH above 6.5
  - Maintain DO above 2 mg/L
  - Maintain alkalinity above 50 mg/L as $CaCO_3$
- Exchange 25% water as a "quick fix"

Typical Biofilter Establishment Delays



Nitrite

- Degree of nitrite toxicity varies with species
  - Scaled fish are generally more susceptible to nitrite toxicity
  - Nitrite toxicity can be reduced by increasing salinity (add non-iodized NaCl)
- Nitrite spikes will follow ammonia spikes
  - Reduce or halt feeding if nitrite levels too high
  - Check biofilter operation, sizing, water quality

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Chloride

- As stated before, chloride ions help block nitrite toxicity
- Osmotic stress is loss of ions from fish's body fluids
  - Stress caused by handling, spooking, etc.
  - Chloride and sodium helps relieve osmotic stress
- Maintain 0.2 to 2.0 g/L salt concentration
  - Always add salt slowly (max rate of 0.5 g/L per hour is safe)

Table Salt (NaCl)

1/4	tsp	= 1.6 g
1/2	tsp	= 3.3 g
1	tsp	= 6.5 g
1	Tbsp	= 19.5 g
1/4	cup	= 78 g
1/2	cup	= 156 g
1	cup	= 312 g

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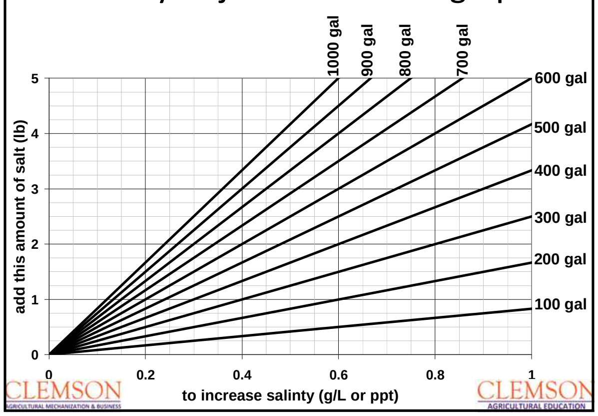
Salinity Adjustment Nomograph



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Management Strategies

Observation	Possible management
Low dissolved oxygen (less than 5 ppm)	■ increase aeration ■ stop feeding until corrected ■ watch for symptoms of new parasite/disease
High carbon dioxide (above 20 ppm)	■ add air stripping column ■ increase aeration ■ watch for symptoms of new paraside/disease
Low pH (less than 6.8)	■ add alkaline buffers (sodium bicarbonate, etc.) ■ reduce feeding rate ■ check ammonia and nitrite concentarations
High ammonia (above 0.05 ppm as un-ionized)	■ exchange system water ■ reduce feeding rate ■ check biofilter, pH, alkalinity, hardness, and dissolved oxygen in the biofilter ■ watch for symptoms of new parasite/disease

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Management Strategies

Observation	Possible management
High nitrite (above 0.5 ppm)	■ exchange system water ■ reduce feeding rate ■ add 5 to 6 ppm chloride per 1 ppm nitrite ■ check biofilter, pH, alkalinity, hardness, and dissolved oxygen in the biofilter ■ watch for symptoms of new parasite/disease
Low alkalinity	■ add alkaline buffers
Low hardness	■ add calcium carbonate or calcium chloride
Discolored/clumped feed	■ purchase new feed and discard old feed ■ watch for symptoms of new parasite/disease

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Fish Management

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Stocking: Tempering

- Fish are generally hauled in cold water
- They should be slowly acclimated to system temperature to avoid shock
  - Temperature changes of more than 5° F at one time should be avoided
  - If temperature difference is more than 5° F, bring them to temperature no faster than 1° F per 20-30 minutes

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Stocking Density

- In commercial systems, fish density (lb/gal) must be at maximum capacity to be economical
  - Must stock at high #/gal density
  - Fish are then divided into separate tanks as fish exceed treatment capacity
- In educational systems, fish should be stocked with regards to **harvest density**
  - Initial density will be low, allowing biofilter to come online slowly
  - Procedures outlined on following slides

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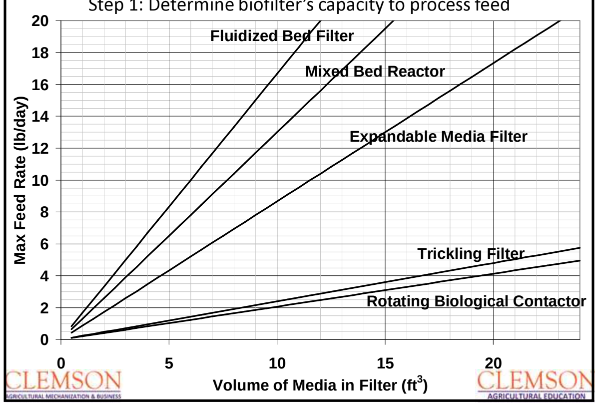
Determining Stocking Density

Step 1: Determine biofilter's capacity to process feed



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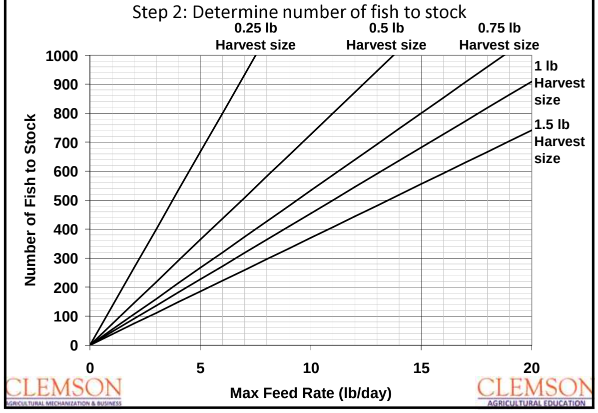
Determining Stocking Density

Step 2: Determine number of fish to stock



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Feeding Rates

- Feeding the proper amount is critical
  - Overfeeding results in poor water quality due to solids accumulation and uneaten feed
- Fish are fed proportional to their body weight
  - Small fish eat a large % body weight per day
  - Large fish eat a small % body weight per day
- Feed only what the fish will consume in 5-10 minutes
  - Better method is to feed based on the recommended percent body weight per day

Average weight per fish (lbs.)	(g)	Body weight consumed (%)
0.02	9	5.0
0.04	18	4.0
0.06	27	3.3
0.25	113	3.0
0.50	227	2.75
0.75	340	2.5
1.0	454	2.2
1.5	681	1.8

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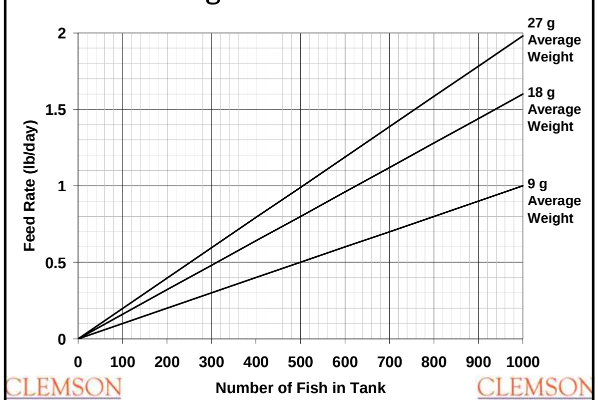
Determining Feed Rate for Small Fish



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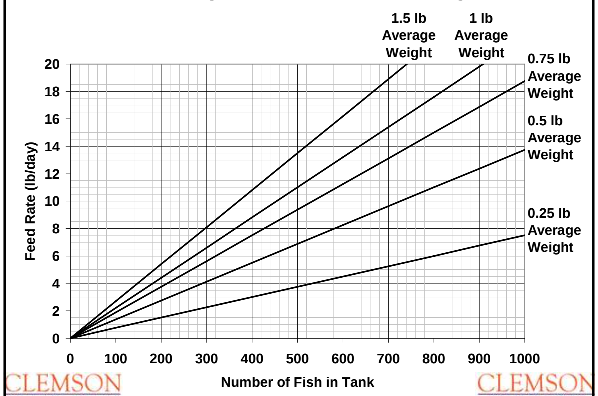
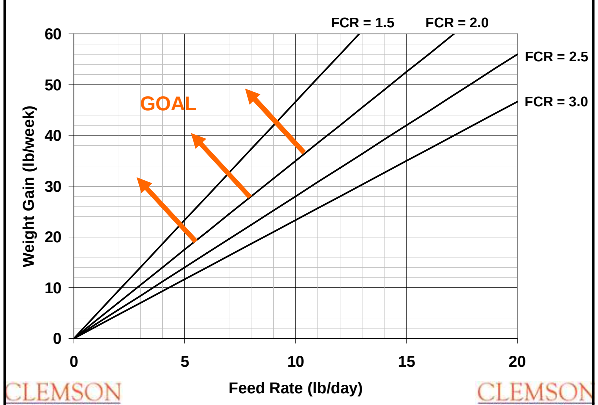
Determining Feed Rate for Large Fish



Feeding Rate Adjustments

- The feeding rates presented in previous slides are typical for warmwater fish
  - Your fish may differ slightly as a function of temperature, water quality, disease, etc.
- Adjustments can be made as a function of the feed conversion ratio (FCR)
  - FCR is the ratio of the weight of feed added to the weight of fish gain
- An FCR of 1.5 is typical, anything over 2.0 should raise a red flag
  - FCR > 2.0 indicates poor feed conversion efficiency
  - Possibly a result of over-feeding or poor water quality
  - Possibly a result of mortalities in the system



Ways to Improve FCR

- Maintain good water quality
- Distribute daily feed over several feedings
- Make sure feed is well-distributed in unit
- Don't feed in same place in tank every time
- Check for uneaten feed after 5 minutes
  - Increase feed rate if <u>no</u> feed is found
- Check for uneaten feed after 10 minutes
  - Reduce feed rate if feed is found

Feed Care and Storage

- Keep feed fresh by storing in a cool dry place
- Never feed moldy, clumped, or discolored feed
- Date your feed bags when you receive them so that you can keep track of their age
  - Feed should be discarded after 60 days if not kept in refrigerated storage
- Vitamins critical to fish health will deteriorate in old feed
  - "No blood" is a disease associated with old feed deficient in vitamins. The fish will appear pale and their gills will be whitish rather than red.
  - Vitamin C deficiency may lead to "broken back syndrome"

Broken Back Syndrome

Management Strategies

Observation	Possible cause	Possible management
Fish:		
Excitable/darting/erratic swimming	■ excess or intense sounds/lights	reduce sound level/pad sides of tank/reduce light intensity
	■ parasite	examine* fish with symptoms
	■ high ammonia	check ammonia concentration
Flashing/whirling	■ parasite	examine fish with symptoms
Discolorations/sores	■ parasite/bacteria	examine fish with symptoms
Bloated/eyes bulging out	■ virus or bacteria	examine fish with symptoms
	■ gas bubble disease	check for supersaturation and examine fish with symptoms
Lying at surface/not swimming off	■ parasite	examine fish with symptoms
	■ low oxygen	check dissolved oxygen in tank
	■ high ammonia or nitrite	check ammonia and nitrite concentrations
	■ bad feed	check feed for discoloration/clumping and check blood of fish
	■ high carbon dioxide	check carbon dioxide level
Crowding around water inflow/aerators	■ low oxygen	check dissolved oxygen in tank
	■ parasite/disease	examine fish with symptoms
	■ high ammonia or nitrite	check ammonia and nitrite concentrations
	■ bad feed	check feed for discoloration/clumping and check blood of fish

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Management Strategies

Observation	Possible cause	Possible management
Gulping at surface	■ low oxygen	check dissolved oxygen in tank
	■ parasite/disease	examine fish with symptoms
	■ high ammonia or nitrite	check ammonia and nitrite concentrations
	■ high carbon dioxide	check carbon dioxide level
	■ bad feed	check feed for discoloration/clumping and check blood of fish
Reducing feeding	■ low oxygen	check dissolved oxygen in tank
	■ parasite/disease	examine fish with symptoms
	■ high ammonia or nitrite	check ammonia and nitrite concentrations
	■ bad feed	check feed for discoloration/clumping and check blood of fish
Stopping feeding	■ low oxygen	check dissolved oxygen in tank
	■ parasite/disease	examine fish with symptoms
	■ high ammonia or nitrite	check ammonia and nitrite concentrations
Discolored blood – Brown	■ high nitrite	examine fish with symptom; add 5 to 6 ppm chloride for each 1 ppm nitrite; purchase new feed and discard old feed
Clear (no blood)	■ vitamin deficiency	examine fish with symptom; check feed for discoloration/clumping; purchase new feed and discard old feed
Broken back or "S" shaped backbone	■ vitamin deficiency	examine fish with symptom; purchase new feed and discard old feed

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Summary of Basic Equipment

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General Aquaculture Suppliers

(in no particular order)

www.plastic-mart.com

www.keetonaqua.com

www.fishtankshop.com

www.growfish.com

www.aquaculturetanks.com

www.aquaranch.com

www.aquaticeco.com

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Culture Tank: $1-$2 per gallon

- Try to stick to plastics, concrete, fiberglass, or stainless steel
  - Plated and galvanized steel may be toxic to fish
- Be creative to save money…plastic 55-gal drums, water troughs, bathtubs, Rubbermaid containers
- Don't be scared to start small; it's probably wise
  - First timers should start with trying to reach a harvest density of 0.25 lb/gal
  - If you want final product to be a fish fry for 20 people, you'll need to harvest 30 pounds of fish
  - At 0.25 lb/gal, that means you need a 120 gallon culture tank
  - Next year you can try to double production in the same tank and invite 40 people to the fish fry

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Settling Tank: $1-$2 per gallon

- Again, be creative…make sure volume meets requirements discussed earlier
  - Buckets and plastic tubs work great
  - Round tanks are necessary here to establish cyclone-separator effect
  - Conical bottom tanks are a bonus for draining solids, but not a necessity
  - Make sure to include a valve in the bottom of the tank for draining solids
- Depth should be at least equal to diameter, preferably deeper
  - This helps keep settled solids from re-entering flow path

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Biofilter Tank: $1-$2 per gallon

- Biofilter tank is simply a tank to contain the biofilter media
  - Some filter tanks can be made with plastic tubs, short lengths of large diameter PVC pipe, buckets, etc.
- Flow should enter from top or bottom and exit through opposite end
  - This prevents short-circuiting

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Aeration: $1 per gallon?

- If diffused aeration is used (most common)
  - Need a regenerative blower or an air pump
  - Make sure power meets requirements from earlier
  - If pump/blower is hot to the touch after running a while, either add more air stones or include a bleeder valve (not enough air is moving)
  - Alternative to air stones are short coils of soaker hose
- If packed column is used
  - Build packed column and place directly over tank (ideally) so that water leaving column enters culture tank
  - Select a pump that matches power requirements

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Scales

- Platform-type scales specifically for aquaculture (such as those made by Ohaus) are ideal
  - But they are expensive ($150 and up)
- A good alternative is a hanging electronic fishing scale
  - Must fabricate a basket to hang from scale
  - For small weight fish, add several to basket and divide weight by number of fish for average
  - Be sure to tare or subtract off for basket weight
  - Only keep fish out of water long enough to weigh them
- Fish can be weighed in water if care is taken that water does not slosh out
  - Helps reduce stress to fish
- You will also need to use a scale for weighing feed
  - Small quantities may need to be measured by volume if resolution on scale isn't good enough

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Pump: $50-$150

- Required to move water from culture tank into settling tank
  - Water can gravity feed from settling tank to biofilter and back to tank
- Consult SRAC No. 372 for pump selection info
  - Make sure pump meets flow requirements determined earlier
- Air lifts are good pump choices for aquaculture
  - http://www.ca.uky.edu/wkrec/AirliftPumps.PDF

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Water Quality Test Kit: $200

- Reagents are best…test strips not very accurate or economical
  - Look for "LaMotte" and "Hach"
- Needs to include tests for:
  - Ammonia (measure daily)
  - Nitrite (measure daily)
  - Nitrate (measure weekly or every two weeks)
  - Hardness (weekly or every two weeks)
  - Alkalinity (weekly or every two weeks)
- If you do not have funds for a pH meter, your kit should also include pH tests

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pH Meter: $100-$250

- pH meters are relatively inexpensive
- Be sure to get one that is designed for measuring water pH, not soil pH
- Follow calibration instructions
- Buffer solutions can be ordered from any aquaculture supplier
- Measure pH daily

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DO Meter: $300-$700

- Oxygen should be measured several times per day if possible
- This one's expensive, but there's really no good alternative
  - YSI is a reputable name in DO meters
- It is possible to titrate sample for DO concentration, but it is very slow
- DO is one of the most critical WQ parameters and cannot be overlooked
- Read instructions with meter and follow all maintenance and calibration procedures
- Take good care of it, you're farming blind without it

Various Other Important Stuff

- Nets
- Thermometer
  - Floating type is cheap and accurate
  - DO meter will likely include temp. probe
- Feed: $1-$2 per lb
  - For most fish, floating fish pellets available at local feed/seed store is suitable
  - Fish smaller than 0.25 lb need crumbled feed or mash
- Tight-sealing trash can to store feed in
- Automatic feeders
  - Really just a luxury
  - If you get them, the type that scatters feed is best
- Brushes, scouring pads
  - Always make sure that cleaning tools are not treated with disinfectants, algaecides, or fungicides

System Sizing Example

- 1,000 gal culture tank at 0.5 lb/gal harvest density
  - Yields 500 lb of fish at harvest
  - 7 ft^3 biofilter media required => 10.5 ft^3 tank = 80 gal
  - Treatment flow rate range: 2-15 gpm, assume 10 gpm
  - 200 gal settling tank required (20 min HRT)
  - Max feed rate allowable = 9 lb/day (based on filter media)
  - Minimum 0.25 hp blower required (based on max feed) Sweetwater S21 blower provides 19 cfm at 30" water
  - 19x 1.0 cfm airstones are required

Budget Considerations

Example #'s for catfish, 1000 gal tank at 0.5 lb/gal harvest

Capital

- Tanks
  - Culture Tank $1,000
  - Biofilter Tank $250
  - Settling Tank $400
- Aeration
  - Regenerative blower $600
  - Air stones $400
- Meters
  - Dissolved oxygen $500
  - pH $150
- Pump $100
- Scales $100
- Plumbing (20% of tank costs?) $330
- Miscellaneous (10% overage?) $420

Total: $4,250
10yr: $425/season

Operating (per season)

- Fish stock
  - 550x 4" catfish @ 5¢/inch $110
- Feed: 1,000 lb
  - 500lb fish @ FCR = 2 $1,000
- Electricity for 200 days
  - Aeration $180
  - Pumping $30
- Labor
- Water quality reagents $300

Total Operating: $1,620
+ Distributed Capital: $425
Investment per harvest: $2,045

Value of harvested fish @$2.65/lb: $1,325

Closing Remarks

Conclusions

- Recirculating systems can be used for many different types of fish production
  - Ornamentals, tropicals, foodfish, fingerling/fry production, baitfish
- Know the fish that you are going to grow
  - Their life history, optimum ranges for water quality, diseases and treatments
- Design your system with excess capacity
  - But run a season or two below capacity to get a hang of it
- Try to get a return on your investment so your system can grow

Finally

- Include emergency aeration in your system!!!!
- Try to have back up pumps and blowers on hand
- Monitor water quality daily, maintain a management record, and plot the data so you can analyze trends
- Reduce fish stress whenever you can
- Aquaculture can be very fun and educational
  - Don't over-do it in the beginning or you will get burned out
  - Start small and work your way up
  - Experiment with different species
  - Visit commercial fish farms

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The End

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