Designing a Flow Through Raceway System for Salmonids - Westers' Design

North Central Aquaculture Conference
Toledo, Ohio
February 22-23, 2014

Chris Weeks

Intensive Flow-Through Systems

Salmon and trout - often raised intensively in flow-through systems.

Other species also to lesser degree.
Temperature key factor for optimal growth.

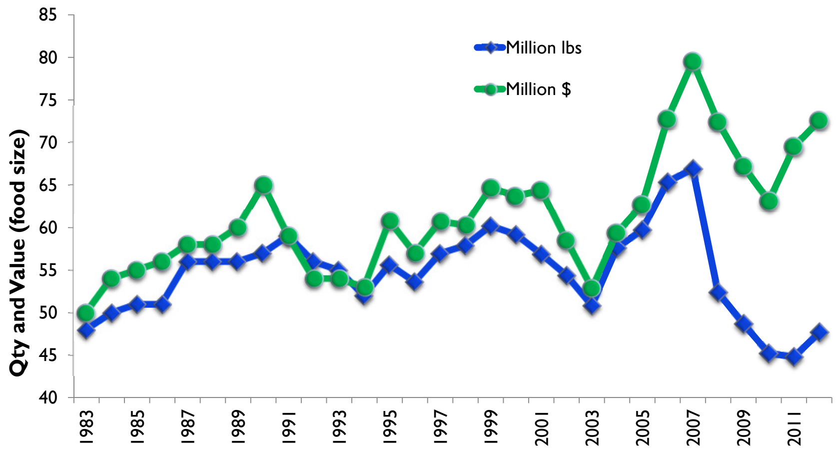
Idaho trout industry – largest US trout production systems.

40-50 million lbs/yr.

Approximately 10 million pounds annual production in other US states.


Courtesy: Clear Springs Foods, Inc.

US Rainbow Trout Production



FISH REARING UNITS

Fish Rearing Units

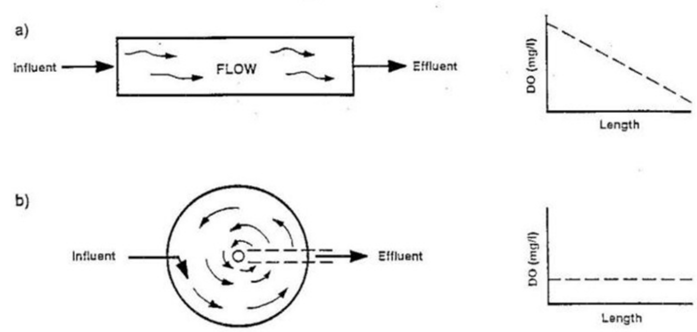
Primary Shapes:

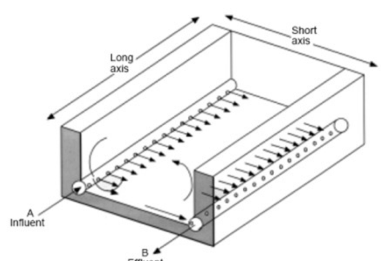
- Round and Oval Tanks
- Rectangular Raceways
  - Earthen Ponds (mixed)

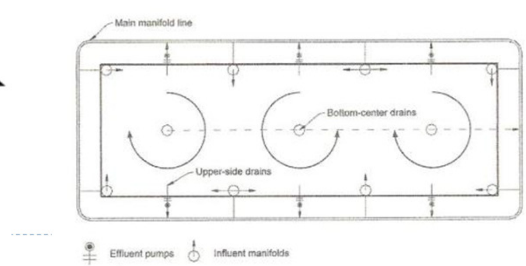
Main Flow Patterns:

- Circular (mixing)
- Plug flow (gradient)
  - Cross flow and Mixed cell (mixing)

Linear raceway (a) and round tank (b) flow pattern and dissolved oxygen characteristics.







Raceway	**Round**
Requires 1.5 – 3.0 x more wall area	Largest volume to wall ratio
Water quality gradient	Homogeneous mixing
Uniform velocity	Variable velocity
Low velocity	High or low velocity
Velocity flow rate dependent	Velocity independent of flow rate

Raceway	**Round**
Not self cleaning	Can be self- cleaning
Can operate at very high exchange rate (R)	Limited water exchange
Poor fish distribution	More even distribution
Easy to corner fish	Difficult to harvest fish by traditional methods

Raceway	Round
Difficult feed distribution	Easy feed distribution
Can compare water quality “in” with “out”	Homogeneous mixing
Hyperoxic possible with pure O2	Immediate mixing of O2
Complete water replacement (100%)	Partial (65%) replacement

Velocity

Velocity of 3.0 cm/s (0.1ft/s) = “Good” hydraulics

Still far too low for channel cleaning

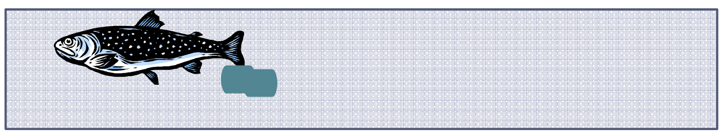
Almost all raceways function as settling chambers!

The Linear Raceway

Law – Preservation of fecal matter

Very Important: Fecal matter must not be destroyed! It's specific gravity is only 1.19. A particle of **100** µm requires **50 +** min to settle a depth of **0.76** ***m*** **(2.5').**

It will drift out of the raceway.



The Linear Raceway

<u>Velocity Summary</u> (for salmonids):

- 10cm+ fish had better growth @ a minimum velocity of **4.5** cm/s
- 10cm+ fish have a safe velocity V_s of **22** cm/s
- Tanks are self cleaning at **10 – 20** cm/s

Typical raceway (example) @ R=4 has a velocity of **3.3** cm/s

Raceway System Design Factors

Recommended raceway velocity ≥ 3.0 cm/s

Recommended length to width ratio: 10:1

Velocity (cm/s) R and Length (m): $v = \frac{L \times R}{36}$

Length (m) Rearing Volume (m3) width (m) and depth (m):

$$W = \sqrt{\frac{RV}{10 \times D}} \qquad L = \frac{RV}{W \times D} + W$$

Raceway System Design Factors

Recommended DO_{IN} as high as 130% saturation

Recommended DO_{OUT} is 60% saturation

Good starting exchange rate:

R = 4 four turnovers/hr
Every 15 minutes.

for midsize and grow out raceway design.

Covered Production Raceways A, B & C & Microscreen / Recirculation Bldg (far left)

"Michigan Columns" oxygenation/degassing (N_2).

Harrietta State Hatchery, MI

Low Head Oxygen Unit on Production Raceway - 950 gpm Inflow Box & Valve

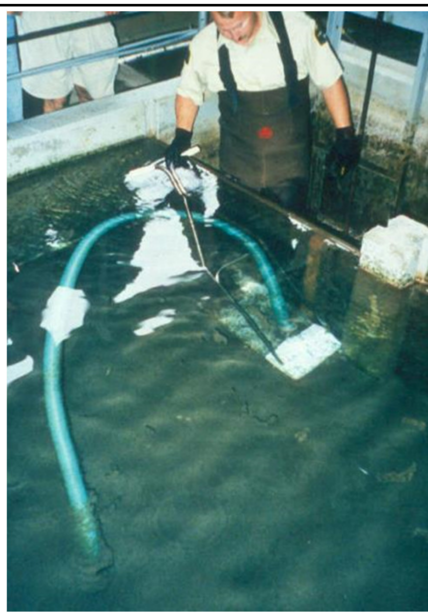
Interior Raceway Bldg Four 100’ x 10’ RWY Units with Flow Baffles

Raceway Solids Collection & Removal is Critical
Typical Raceway Quiescent Zone

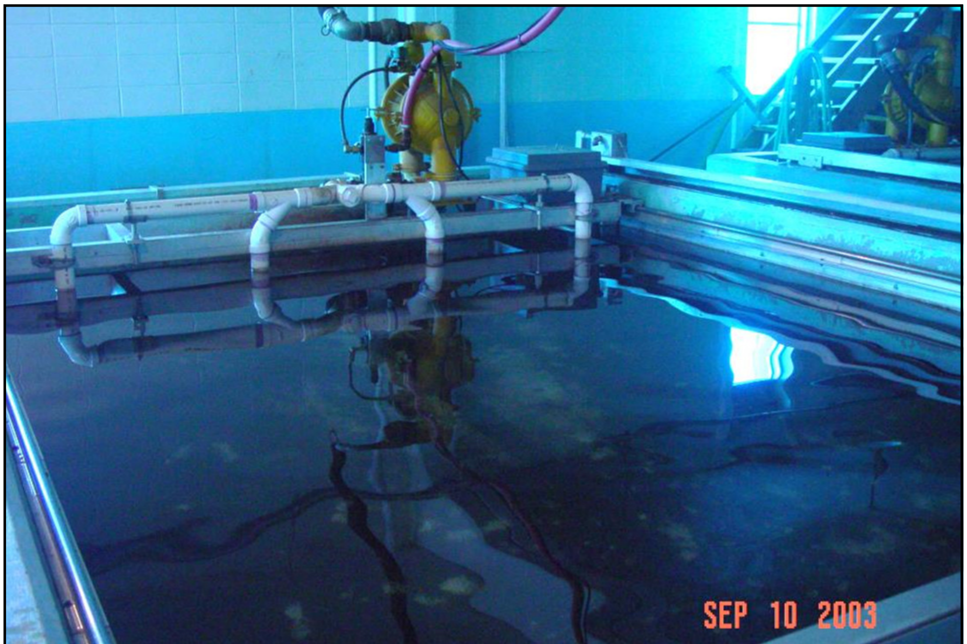
Flow Blocking Wing above QZ to Minimize Water Loss during Solids Transfer to Clarifier

Rearing Unit Solids Collection, Removal and Disposal are Key

- QZ Cleaning with Flow Blocking Wing



- Vacuuming Solids from Raceway QZ Area



- Automated High Frequency Vacuuming Solids in QZ
  Minimizes nutrient leeching

- 40 micron Rotary Drum Microscreen (total flow solids recovery)


SEP 9 2003


SEP 10 2003

Round Tank Rearing Units

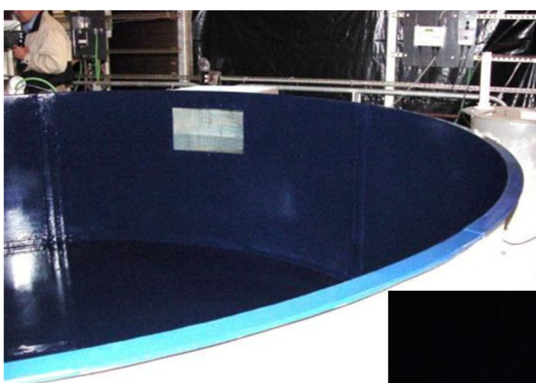
Typical overall water turnover is 63.2%.
Round tanks act as mixed flow reactors.

- All fish are exposed to selected tolerance limits
  - recommended DO_{MIN} = 7 - 8 mg/l.
- Requires higher O_2 concentrations as raceways to achieve same level of production.
- Allow for inflow of O_2 supersaturated water
  - recommended upper limit = 200% saturation.

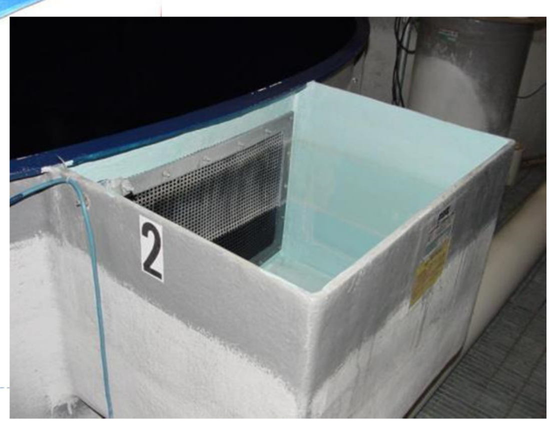
Round Tank Flow Characteristics

Water velocities are controllable to a large extent
- Most critical factor is inlet and outlet design
- Tests showed velocities of 20 to 235 cm/s were achieved with exchange rates of 0.5 to 1.2/hr

Act as “swirl settlers at velocities in excess of 15 to 30 cm/s.
- Allow for better management of fish waste.
  “Cornell-type” dual drain concentrates the majority of the settleable solids in 5-20% of total flow.



Cornell-type dual drain



Round Tank System Design Factors

The ability to control velocity and supersaturate incoming water allow for approximately ½ the exchange rate required for raceways. R = 1.5 to 2.0 is often a good starting point.

Flow rate is related to RV and R by: $Q = \frac{RV \times R}{0.06}$

DO_{IN} can be as high as 200% saturation

Recommended DO_{OUT} is between 7.0 and 8.0 mg/l

Round Tank System Design Factors

Common diameter to depth ratios: 3:1 to 10:1
Smaller tanks with ratios < 3:1 often used for hatcheries.

Tank diameter by: $\mathbf{D} = 2x\sqrt{\frac{\mathbf{RV}}{\pi \times d}}$

Tank size should consider manageability concerns (i.e. harvesting, cleaning, etc.)


Quinebaug Valley Hatchery CT

Production Theory (all systems)

The theory of production of intensive aquaculture systems is based on feed.

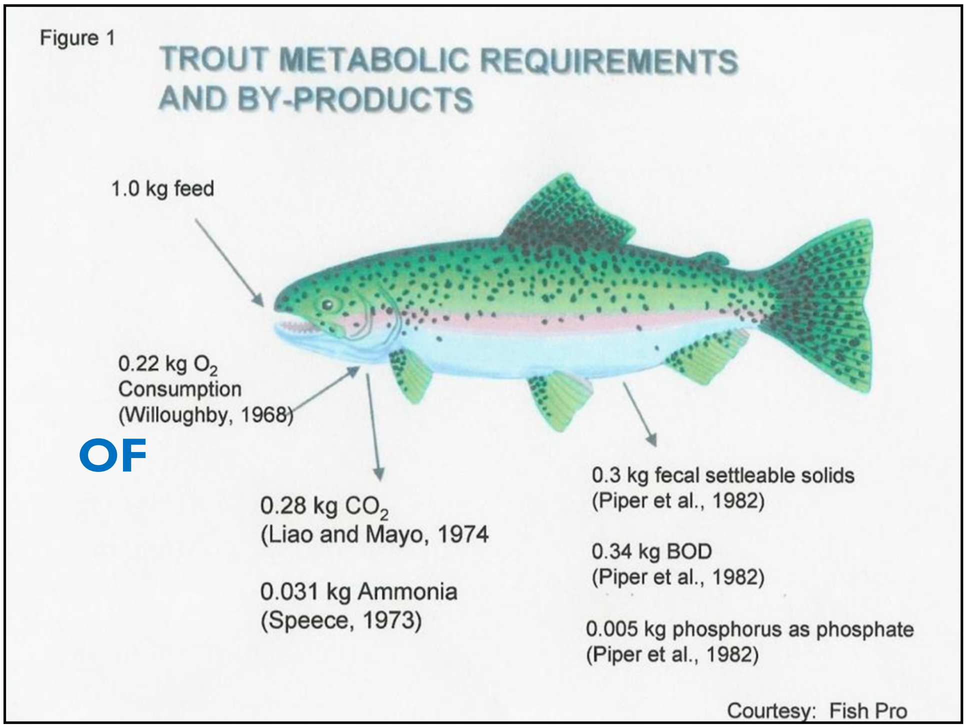
Feed input

↓

Growth and production

↓

O_2 consumption & waste build up to fish tolerance levels



Loading (Ld) And Density

Loading (Ld): Capacity per unit of **Flow** (Q)

Ld = **kg/lpm** **lb/gpm**

Density (D): Capacity per unit of **Volume** (**RV**)

D = **kg/m** ^{3} **lb/ft** ^{3}

Relationships **Ld**; **D**; **R**

$$Ld = \frac{D \times 0.06}{R}; \quad D = \frac{Ld \times R}{0.06}; \quad R = \frac{D \times 0.06}{Ld}$$

0.06 = 1.0 lpm x 60min = 60 liters = $0.06m^3$

<u>An Exercise</u> (Application)

Assume R = 4 (turnovers per hour)

Density is 80 kg/m^3

Determine Loading Ld

$$Ld = \frac{D \times 0.06}{R}$$

$$\frac{80 \times 0.06}{4} = 1.2 \text{ kg/lpm}$$

Maximum Biomass (MBM)

Density

Rearing Volume

MBM = D x RV

Flow Rate (Q)

Q = MBM/Ld

RV = 10m^3, D = 60 kg/m^3, Ld = 1.2 kg/lpm

Maximum Biomass (MBM) ?

Flow Rate (Q)?

MBM = D $\times$ RV

60 $\times$ 10 = **600kg** (1,322 lbs)

Q = MBM/Ld

600/1.2 = **500 lpm** (132 gpm)

Exchange Rate, Flow, and Rearing Volume

$$R = \frac{Q \times 0.06}{RV}; \quad Q = \frac{RV \times R}{0.06}; \quad RV = \frac{Q \times 0.06}{R}$$

Example: R = 4, RV = 10 m^3

Q = (10 x 4)/0.06 = 2,670 lpm

Principle Equations (metric)

Ld = (D x 0.06)/R	kg/lpm
MBM = (D x RV)	kg
Q = (RV x R)/0.06	lpm
Q = MBM/Ld	

Available Oxygen

$$AO = DO_{in} - DO_{out}$$

$(DO_{out}$ is min. DO)

$DO_{in} = 10$ $DO_{out} = 6$ **AO = 4.0**

DO_{OUT} target for optimal growth for trout is 60% saturation

Relating fish loading to feed levels (% BW)

Ld = (AO x 100)/(OF x % BW)

AO = (Ld x OF x % BW)/ 100

Loading Values (Ammonia) II

How much TAN is **Toxic Unionized Ammonia** (NH_3)?

This is **pH** and **Temperature** dependent

TAN (what we measure) =

$$\underbrace{NH_3(aq)}_{\text{Toxic}} + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

Percent of total ammonia as toxic unionized over the range of pH and temperature.

pH	Water Temperature 5(41)	10(50)	15(59)	20(68)
6.0	0.01	0.02	0.03	0.04
6.2	0.02	0.03	0.04	0.06
6.4	0.03	0.05	0.07	0.10
6.6	0.05	0.07	0.11	0.16
6.8	0.08	0.12	0.17	0.25
7.0	0.13	0.18	0.27	0.40
7.2	0.20	0.29	0.43	0.63
7.4	0.32	0.47	0.69	1.00
7.6	0.50	0.74	1.08	1.60
7.8	0.79	1.16	1.71	2.45
8.0	1.24	1.83	2.68	3.83
8.2	1.96	2.87	4.18	5.93

Source: G.A. Wedemeyer. 1996. Physiology of Fish in Intensive Culture. Chapman and Hall, New York

50

Ammonia Loading Values

Maximum Unionized Ammonia recommendations

(MUA): Ranges 0.010 to 0.035 **mg/l**

For salmonids – 0.0125 – 0.025

For our exercise "we" select:

MUA = 0.025 mg/l

Provided: High **DO**; Low **CO** $_2$; High Alk (**Na** $^+$)

51

Maximum Allowable Ammonia

System design should not exceed
Maximum Allowable Oxygen (MAO)

MAO = (MUA × OF × 100)/(TANF × %UA)

0.025 250 30 Table

Initial Design Concept - example

- Flow (Q) 5,000 lpm (1,300 gpm)
- Temp 11C (52F)
- Incoming DO_{IN} (100% saturated) = 10.0 mg/l
- PH = 7.6
- Assume N_2 gas corrected below saturation
- Trout growout 50g to 500g
- Maximum Density = 80 kg/m^3 (0.667 lb/g)
- Rectangular raceway
  Depth 0.8 m, L:W = 10:1, min vel 3.0cm/s

Determine raceway design:

1. Rearing volume

(have flow Q, raceway - so start with R = 4)

$$R = \frac{Q \times 0.06}{RV}; \quad Q = \frac{RV \times R}{0.06}; \quad RV = \frac{Q \times 0.06}{R}$$

$$RV = \frac{5000 \times 0.06}{4} = 75 \text{ m}^3$$

(20,000 gal)

Determine raceway design:

2. Length based on velocity 3.0cm/s:

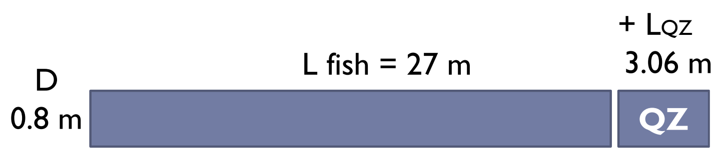
$$v = \frac{L \times R}{36}$$

$$L = \frac{v \times 36}{R} = \frac{3 \times 36}{4} = 27\text{m}$$ (88.6ft)

Determine raceway design:

3. Width

$$W = \sqrt{\frac{RV}{10 \times D}} = \sqrt{\frac{75}{10\text{x}0.8}} = 3.06\text{m}$$



Calculate maximum biomass and number of fish per raceway:

MBM = (D x RV) = 80 x 75 = 6,000 kg

MBM occurs when fish are at max size:

Number per raceway = MBM / max wt/fish
= 6,000/0.5
= 12,000

How many times can we re-use this water based on ammonia limits (aeration between uses)?

Need to know toxic ammonia levels (%UA) and limits (MUA):

Recall pH = 7.6
Temp = 11C

Table 1 Percent of total ammonia as toxic unionized over the range of pH and temperature.

pH	Water Temperature			
	5(41)	**10(50)**	**15(59)**	**20(68)**
6.0	0.01	0.02	0.03	0.04
6.2	0.02	0.03	0.04	0.06
6.4	0.03	0.05	0.07	0.10
6.6	0.05	0.07	0.11	0.16
6.8	0.08	0.12	0.17	0.25
7.0	0.13	0.18	0.27	0.40
7.2	0.20	0.29	0.43	0.63
7.4	0.32	0.47	0.69	1.00
7.6	0.50	0.74 0.81	1.08	1.60
7.8	0.79	1.16	1.71	2.45
8.0	1.24	1.83	2.68	3.83
8.2	1.96	2.87	4.18	5.93

11.6

Source: G.A. Wedemeyer. 1996. Physiology of Fish in Intensive Culture. Chapman and Hall, New York **Highly Recommended!**

59

Maximum Allowable Oxygen

MAO = (MUA × OF × 1.0 × 100)/(TANF × %UA)
= (.025 x 250 x 100)/(30 x 0.81)
= 25.7

Dissolved Oxygen per pass

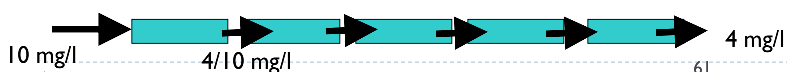
DO_{IN} saturated at 10 mg/l,
we will say DO_{OUT} = 60% Saturation
AO = 10 – 6 = 4

How many times can we re-use this water based on ammonia limits (aeration between uses)?

MUA = 25.7
AO = 4

Passes = MUA / AO
= 25.7 / 4
= 6.4 times
(5 conservative)

Potential Production
= MBM x 5 (single cohort)
= 30,000kg (~66,000lbs)



61

Thanks!

Anyone still awake?

For additional questions contact
Laura Tiu!

-or-

Chris Weeks
weekschr@msu.edu