Water Recirculating Systems for Salmonid Production in North America

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Outline

- RAS for salmon smolt in N. America
  - ✓Systems in Canada Maritimes and Maine
  - ✓Systems in British Columbia
  - ✓State & Federal culture systems
- Design considerations used for smolt RAS in North America

Why Recirculating Systems for Salmon?

- RAS increases production on a given water resource
- RAS provides the controlled environment
  - increase 4-8ºC ground water to 10-15ºC
  - Increase hardness, alkalinity, and/or salinity of typically extremely soft water supplies
    - Reduce fungal problems
    - Increase blood buffering capacity
    - Improve smoltification
- Some claim RAS produce superior smolt

Why Recirculating Systems?

- Provide strict biosecurity:
  - ✓ Locate on smaller “pathogen-free” ground water resources;
    - smaller inlet flows are cheaper to disinfect.
  - ✓ Smaller discharge flows are easier to screen and prevent escapement;
  - ✓ Only certified pathogen free eggs are stocked
    - to prevent introduction of obligate fish pathogens

Recirculating Systems for Salmon

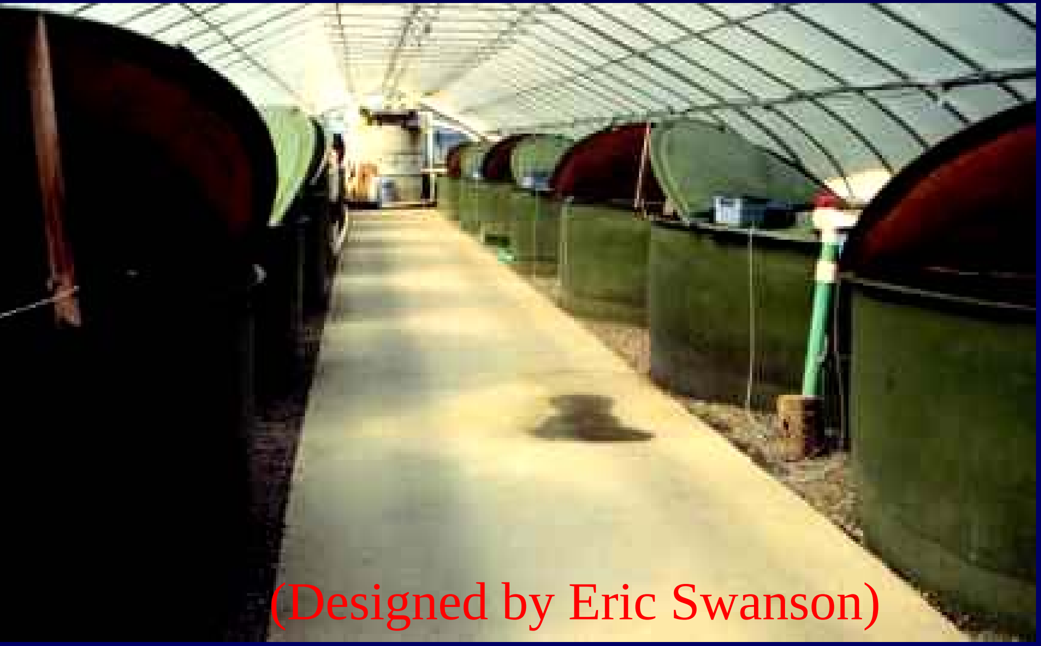
- Commonly used for:
  - ✓ Egg incubation/hatching
  - ✓ First feeding to fry/parr production
  - ✓ Smolt production
  - ✓ Broodstock

RAS for Salmon Smolt Production

- East Coast – Canadian Maritimes and Maine
  - ✓ Penobscot Hatchery (ME)
  - ✓ Atlantic Silver (Canada)
  - ✓ Buckmans Creek (Canada)
  - ✓ Oak Bay – smolt & broodstock (Canada)
  - ✓ Green Acres Fish Hatchery (Canada)
  - ✓ Bingham Hatchery (ME)
    - Flow-through system retrofit
  - ✓ Others

Penobscot Smolt Hatchery

- Typical older design (built in late 1980's or 1990's)
  - Slow (~2 hr) culture tank turn over rates
    - in-tank aeration and airlifts break-up solids within the tank
  - Oversized (hard to clean) pump sumps
  - Unique but less reliable fluidized-sand biofilter design
  - Less than optimal aeration column design + oxygenation
  - No ozone, typically brown & turbid water with high CO_2



(Designed by Eric Swanson)

Oak Bay Hatchery, Cooke Aquaculture (NB)

- Series of recent retrofits & upgrades
  - ✓ smolt & broodstock

(Swanson-type design)

RAS for Salmon Smolt Production

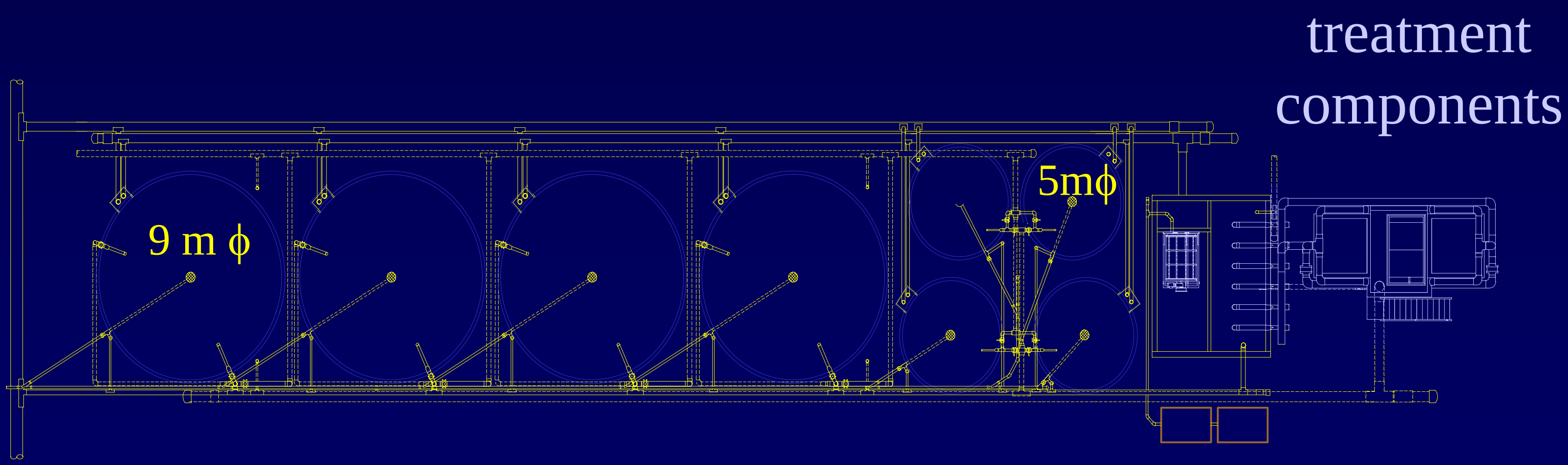
- British Columbia, initial hesitation to use RAS for salmon smolt production.
- Smolt production capacity in RAS's in British Columbia now exceeds ~5 million smolt annually and is expanding.
  - ✓ Stolt's Crystal Waters Hatchery (Port Alice)
    - Flow-through retrofit – 1st large RAS installed in mid-1990's.
  - ✓ Target Marine Hatchery (Sechelt)
  - ✓ Marine Harvest:
    - Big Tree Creek Hatchery (Campbell River)
    - Dalyrumpl (Campbell River)
    - Wolf Creek Hatchery (Prince Rupert)
  - ✓ West Coast Fish Culture (Powell River) & others in BC.

Target Marine Hatcheries

- Two recirc modules for salmon smolt production (Sechelt, BC)

Target Marine Hatcheries

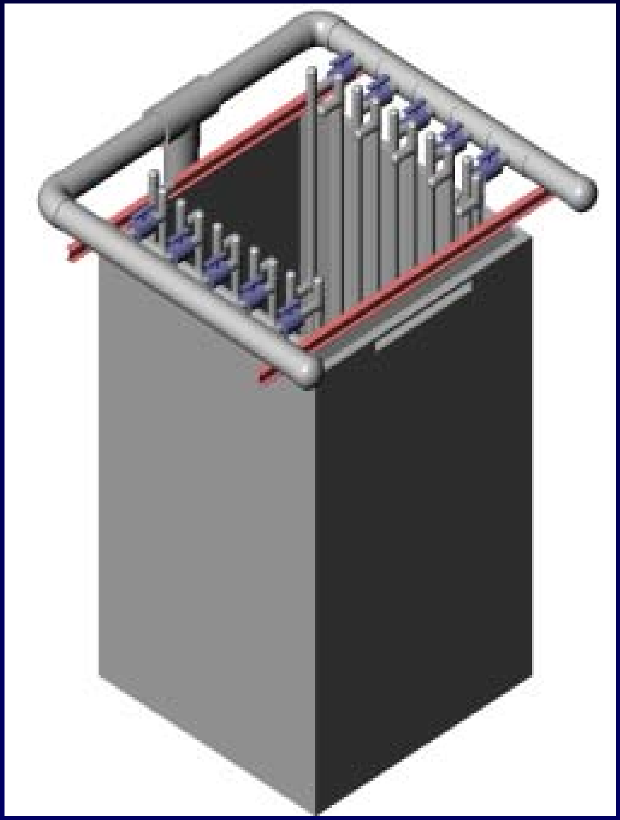
- Compact layout of a RAS module.
  - ✓ About 10 m^3/min recycle flow



(designed by PRAqua Technologies)

Target Marine Hatchery (BC)

- Pipe manifold type fluidized sand biofilter



Courtesy of PRAqua Technologies (BC)

Marine Harvest Big Tree Creek Hatchery

- Three recirc systems (~10 m^3/min/system) for salmon smolt production (BEST SMOLT)

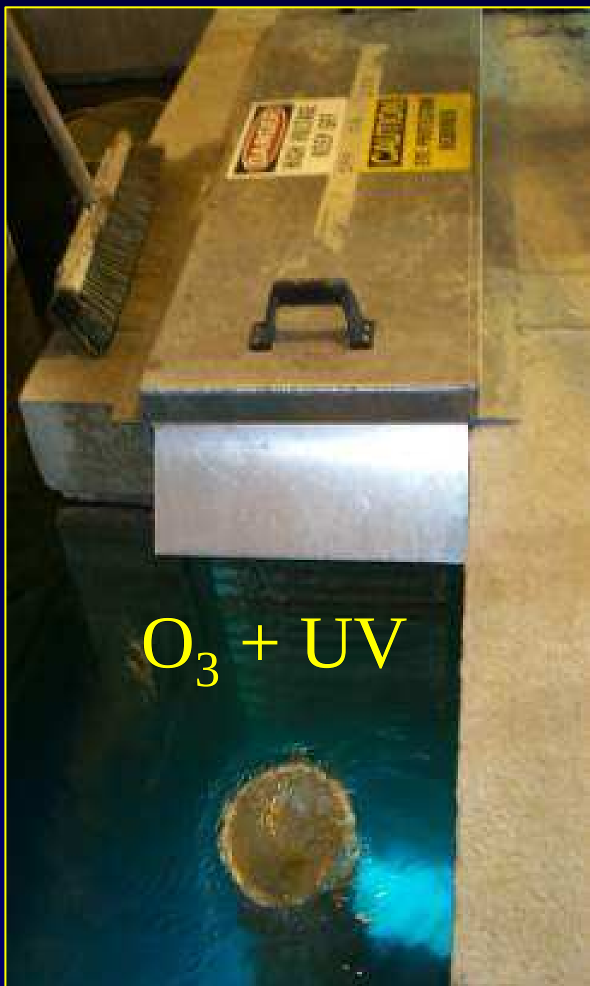
(designed by PRAqua Techn.)

Big Tree Creek Smolt RAS

- Drum filtration, pump through fluidized-sand biofilters, gravity flow through stripping column, low head oxygenation (plus O_3), and UV irradiation
  - ✓ Excellent water quality (clear water) & high quality smolt

Marine Harvest Big Tree Creek Hatchery

- 1^{st} feeding salmon fry RAS (~ 4 m^3/min)



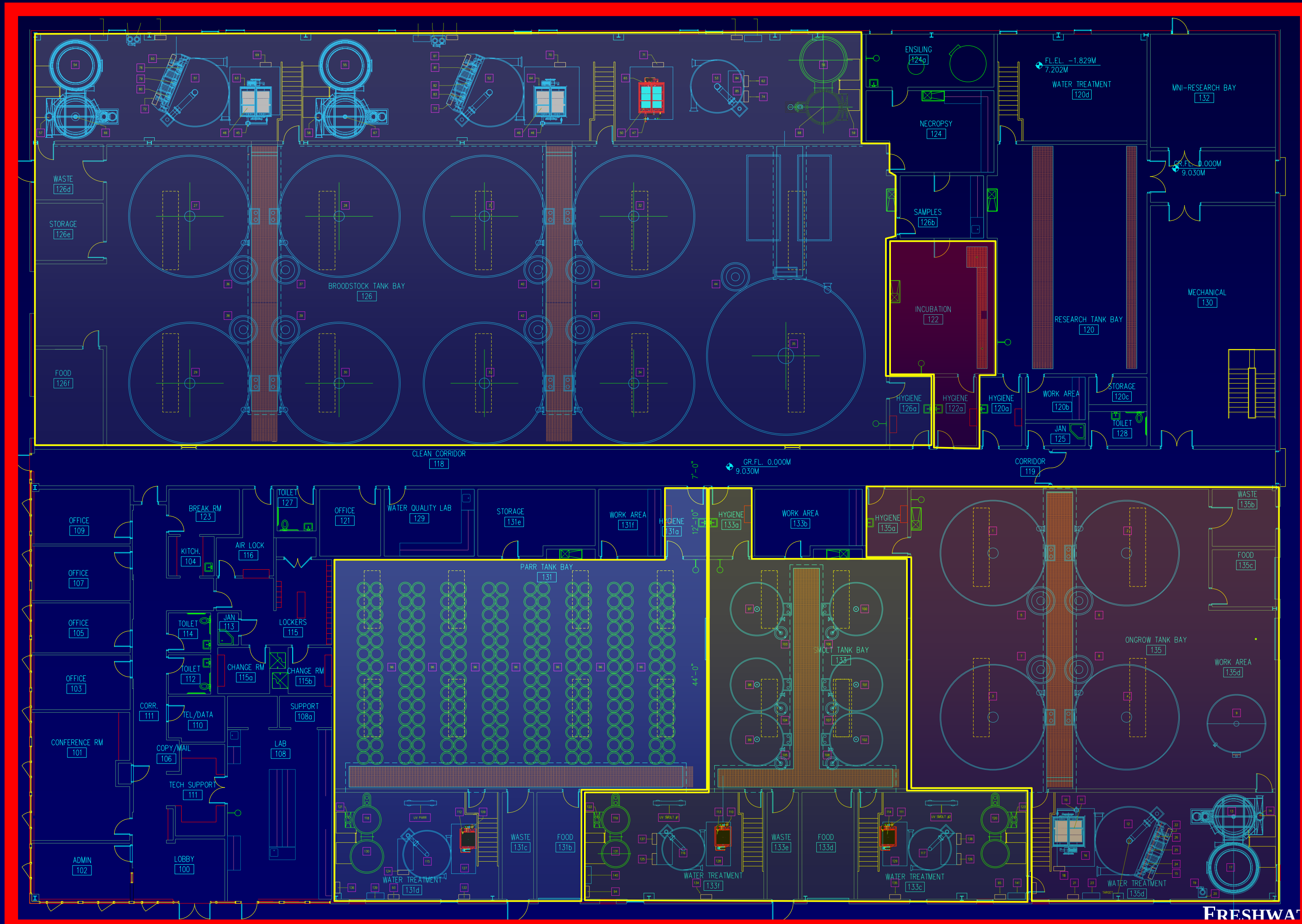
Marine Harvest Big Tree Creek Hatchery

- Hatching system to incubate eggs @ 3ºC

State & Federal Culture Systems

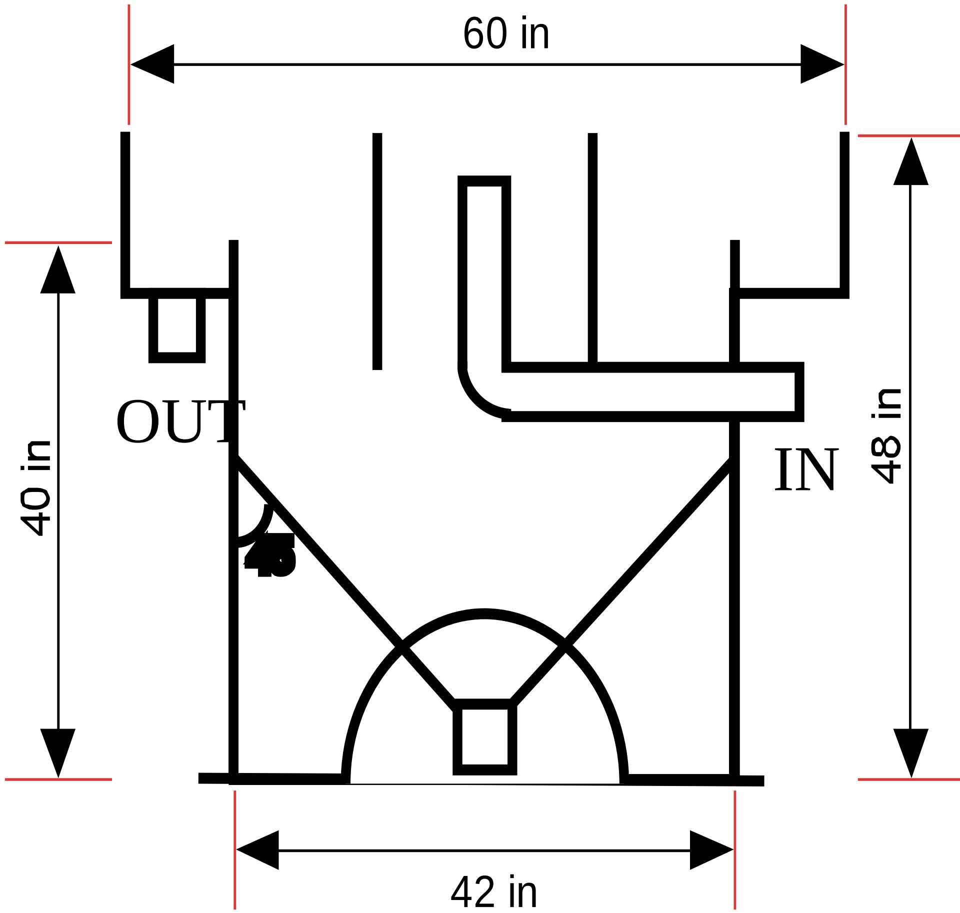
- USDA ARS National Cold Water Marine Aquaculture Center (Franklin, ME)
  - ✓ Atlantic salmon broodstock development facility
- White River National Fish Hatchery (Bethel, VT)
  - ✓ Atlantic salmon smolt restoration hatchery
- Alaska Fish & Game
  - ✓ Fairbanks Sports Fish Hatchery (under construction)
  - ✓ Anchorage Sports Fish Hatchery (under design)
    - 8 foot ball fields under one roof!

USDA ARS National Cold Water Marine Aquaculture Center



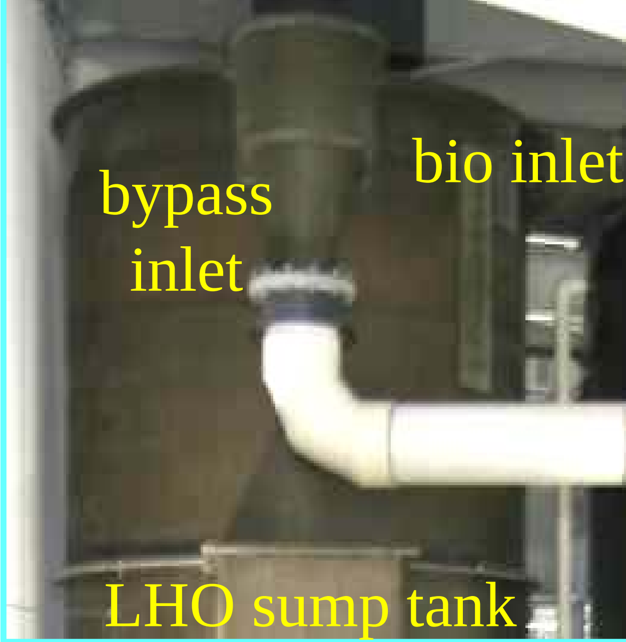
USDA ARS, Franklin, ME

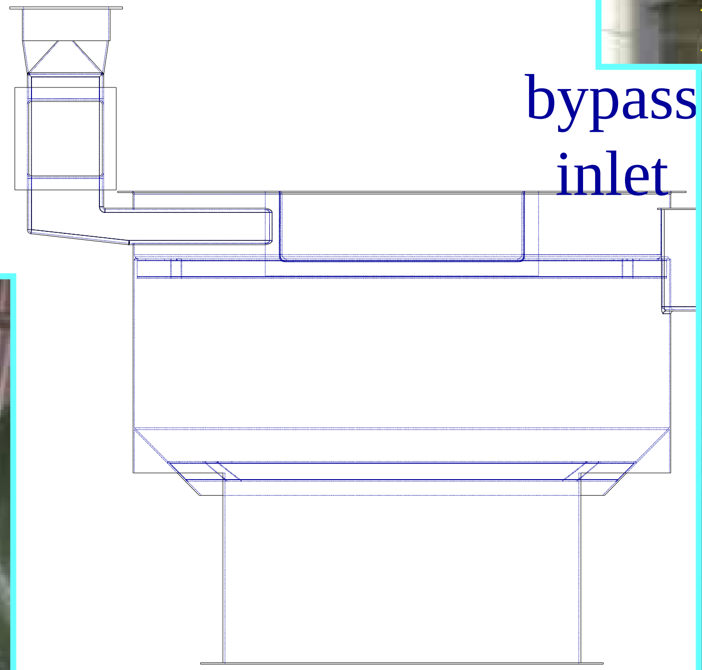
Radial Flow Settlers



(vessels were stumpier than was optimal)

CO_2 Stripping



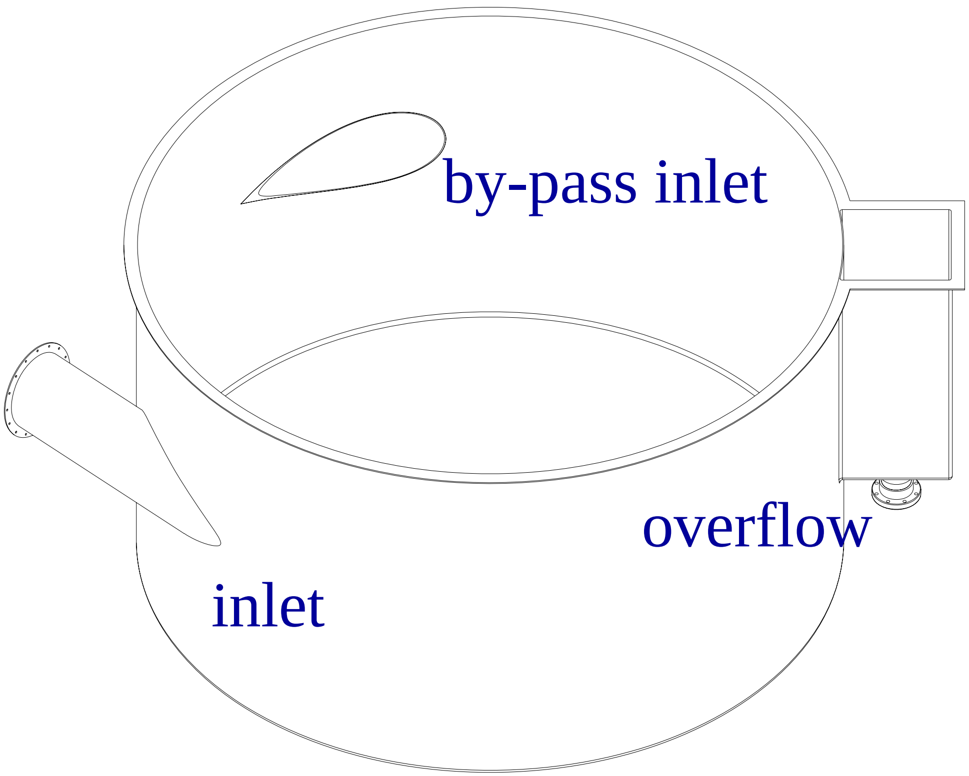


FRP Construction

Low Head Oxygenator

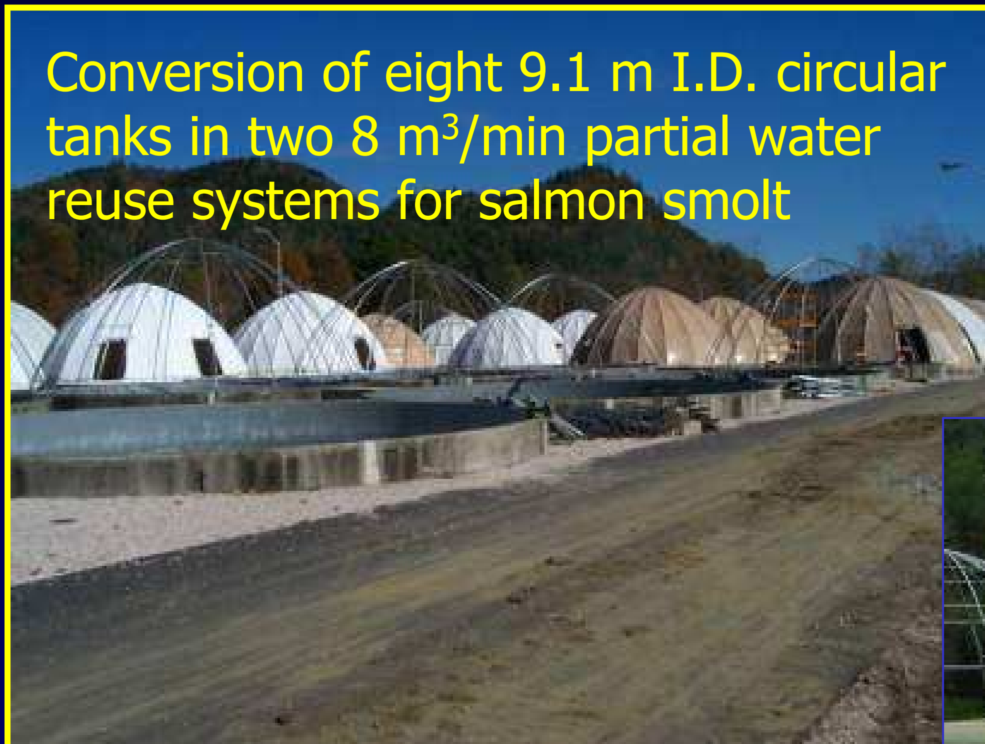
- Water falling from CO_2 stripper is directed to perimeter of LHO, away from distribution orifices
- Creates O_2 of 100-200%, adds O_3, drives out N_2

Self-Cleaning Pump Sump



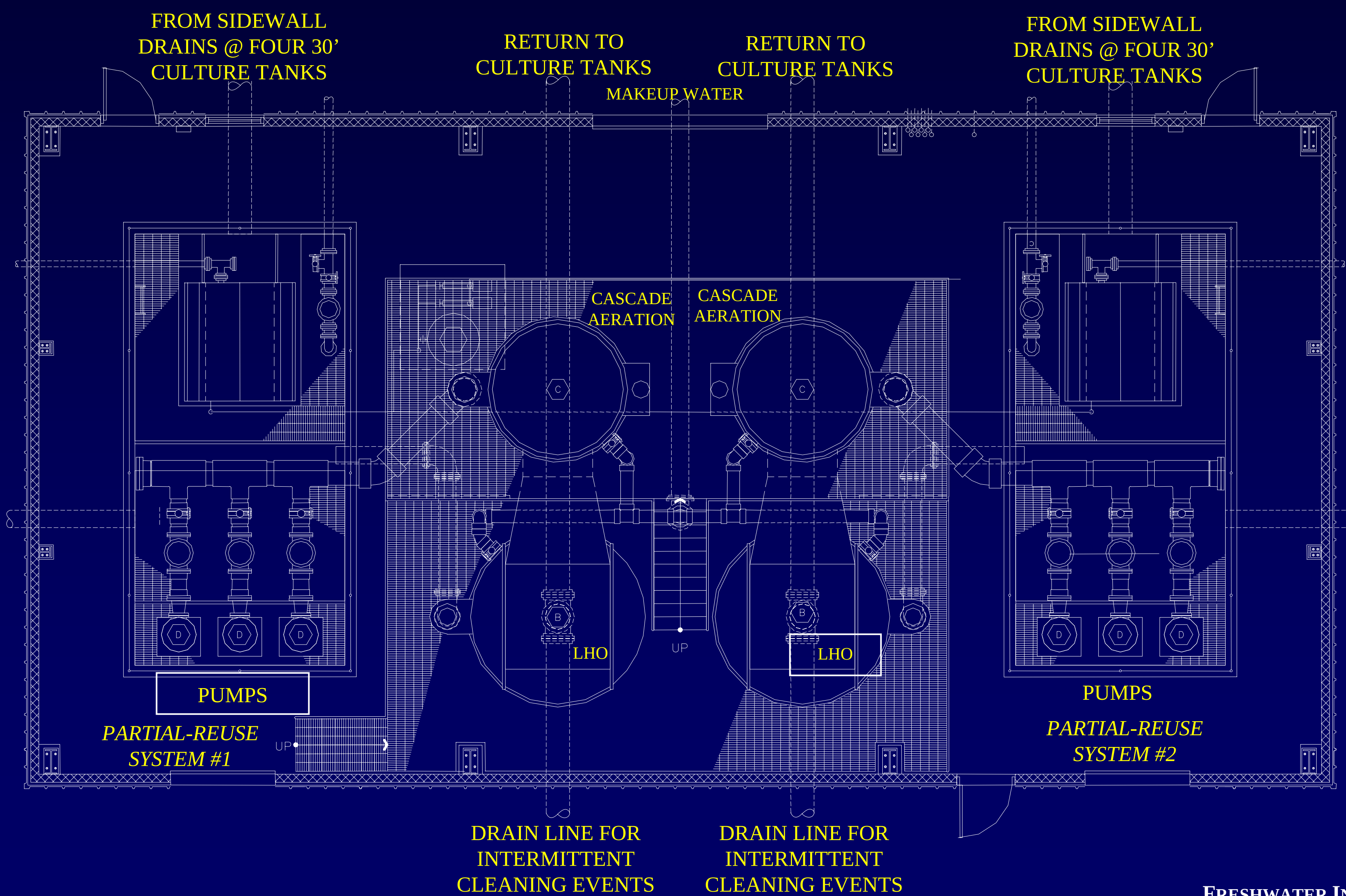
drawing courtesy of Marine Biotech

Partial RAS @ USFWS White River National Fish Hatchery (VT)



Conversion of eight 9.1 m I.D. circular tanks in two 8 m^3/min partial water reuse systems for salmon smolt

Partial RAS @ White River NFH



RAS Design Concepts in North America

RAS Design

- RAS design & management must provide sufficient water quality to maintain healthy and fast growing fish.

- RAS's are designed to support a given carrying capacity, i.e., feed level

Water Quality Within RAS

- Water quality within RAS depends upon the water flow (Q) and efficiency of waste removal (f_{rem}) at each unit process:
  - ✓ Solids capture
    - filtration
    - Sedimentation
    - ozonation
  - ✓ Carbon dioxide removal
    - aeration
  - ✓ Ammonia removal
    - biofiltration

RAS Design

- Achieving 100% waste removal efficiency every pass would produce water quality of flow-through system.
  - GOAL!!!

Water Quality Within RAS

- Treatment efficiency (f_{rem}) controls water quality!
  - ✓ Not system exchange rate!

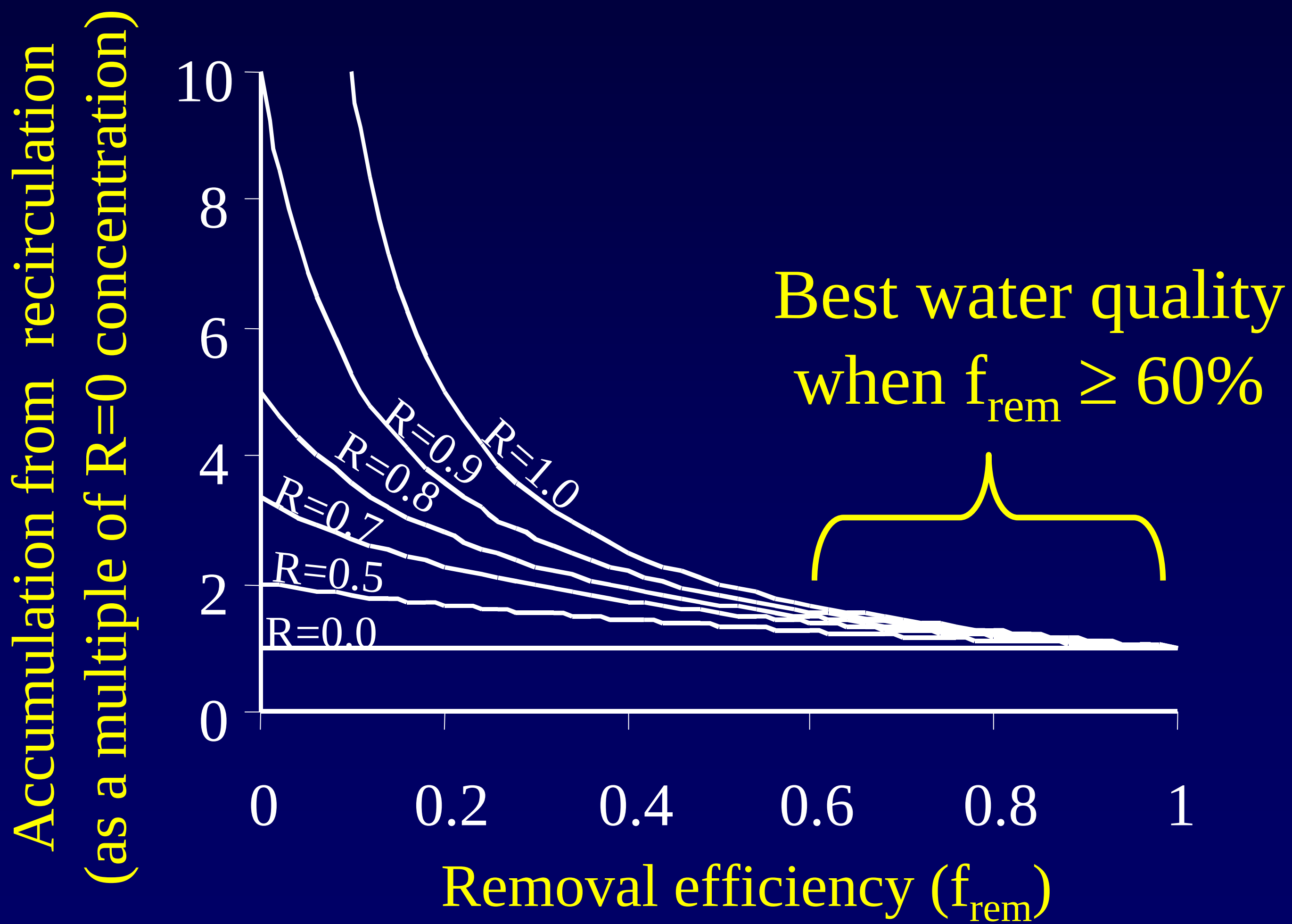
EXAMPLE: @ f_{rem}=0.8, R=0.8 to 0.99

$$[waste]_{\text{tank}} = \left\{ \frac{1}{1 - R + \left(R \cdot f_{rem}\right)} \right\} \cdot \frac{P_{waste}}{Q}$$

$$= \{1.19 \text{ to } 1.25\} \cdot \{\text{single pass outlet conc.}\}$$

Water Quality Within RAS

- Treatment efficiency (f_{rem}) controls water quality!



RAS Design

BMP #1:

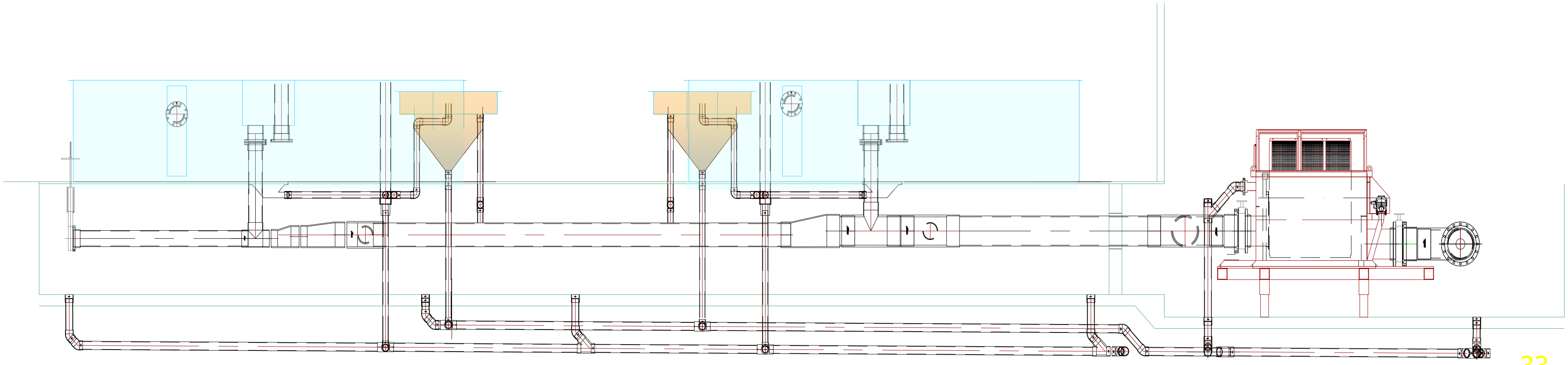
select unit processes that provide high waste removal efficiencies within coldwater RAS!

- Treatment efficiency (f_{rem}) $\geq$ 0.6

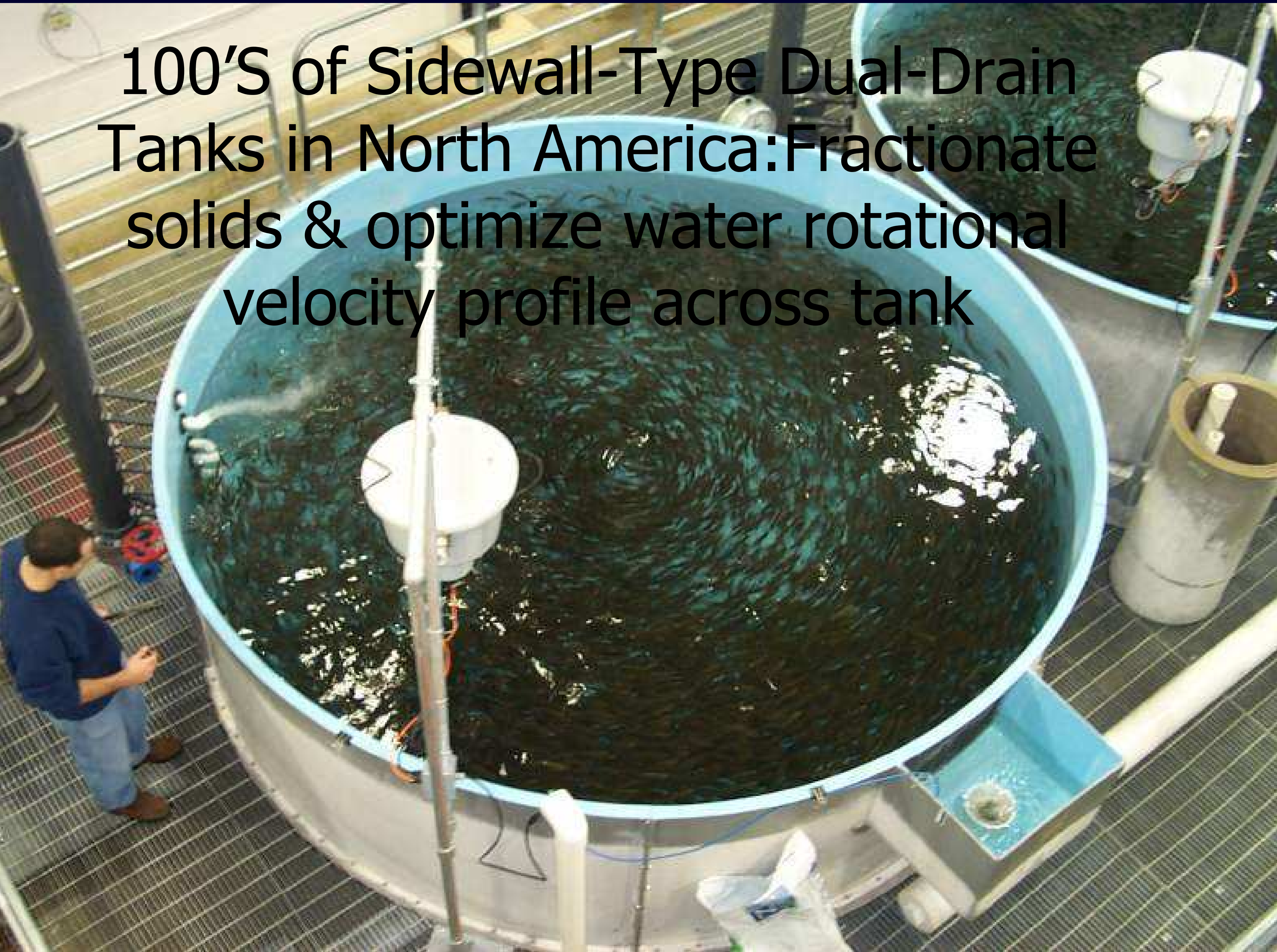
RAS Design

BMP #1.1:

- Concentrate Solids with Dual-Drain Tanks
  - ✓ Use radial flow settlers to improve TSS capture in concentrated underflow (f_{rem} = 60 - 80%)
- Treat Entire RAS Flow with Drum Filters



100’S of Sidewall-Type Dual-Drain Tanks in North America:Fractionate solids & optimize water rotational velocity profile across tank



Large-Scale Circular Tanks

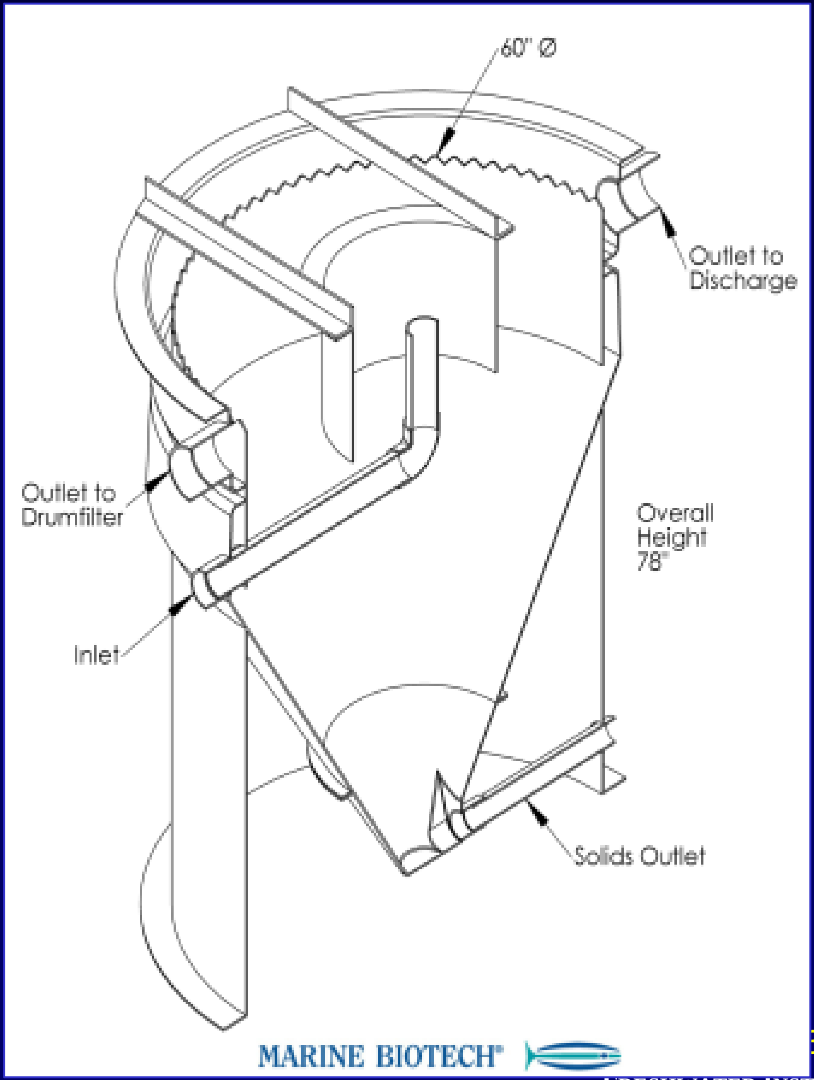
- Rapid solids fractionation using dual-drains

	Partial-reuse system TSS (mg/L)	Fully-recirc system TSS (mg/L)
Tank inlet flow	1.3-1.5	2-3
Side-drain flow	1.9-2.5	3-4
Bottom-drain flow	13-26	15-25

Make-up water contained 0.5 ± 0.2 mg/L TSS

Davidson and Summerfelt. 2004. *Aquacultural Engineering* **32**, 245-271.

Radial Flow Settler Captures Solids More Efficiently than Swirl Separator



Davidson & Summerfelt (2005). Aquacultural Engineering.

RAS Design

BMP #1.2:

Design *forced-ventilated aeration columns* to remove (f_{rem}) $\geq$ 60% of CO_2 each pass through RAS

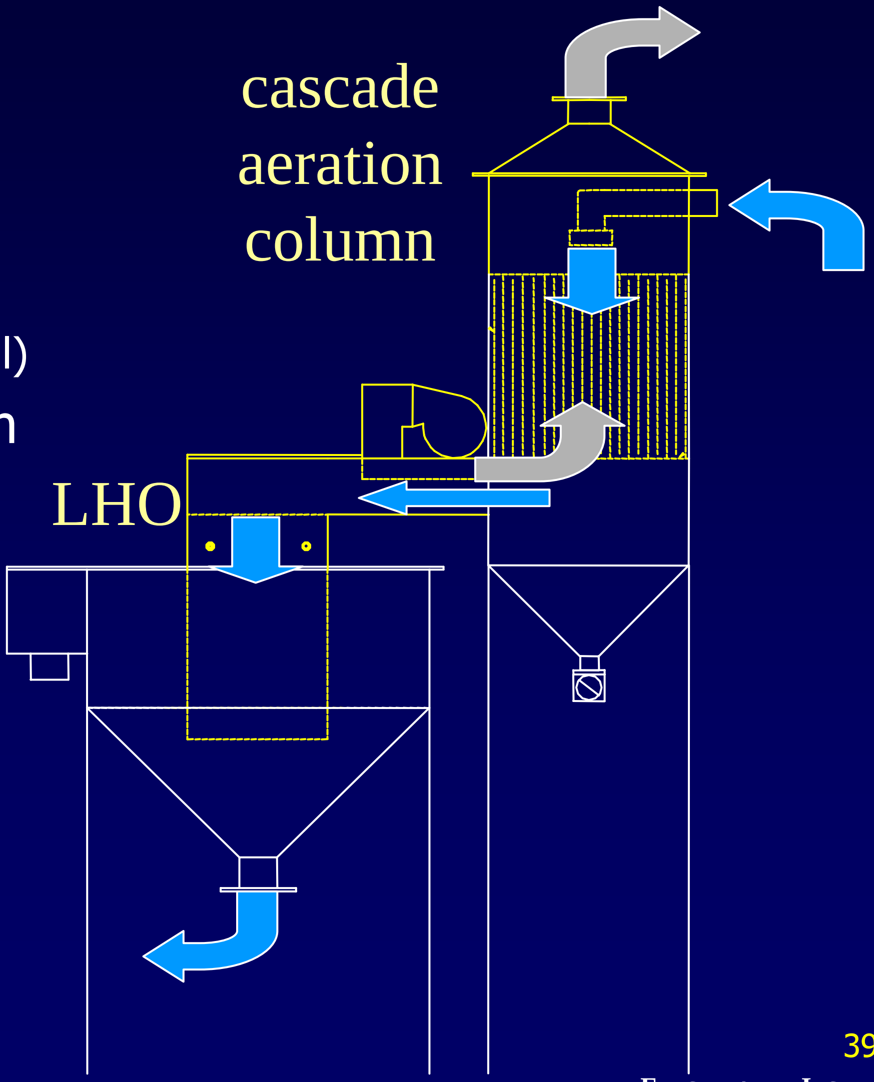
Large Scale Technologies for O_2 & CO_2 Control

- Forced-ventilated cascade aeration columns treat recirculating water before it flows through low head oxygenation units.
- BAT for O_2 & CO_2 control in salmonid RAS's.

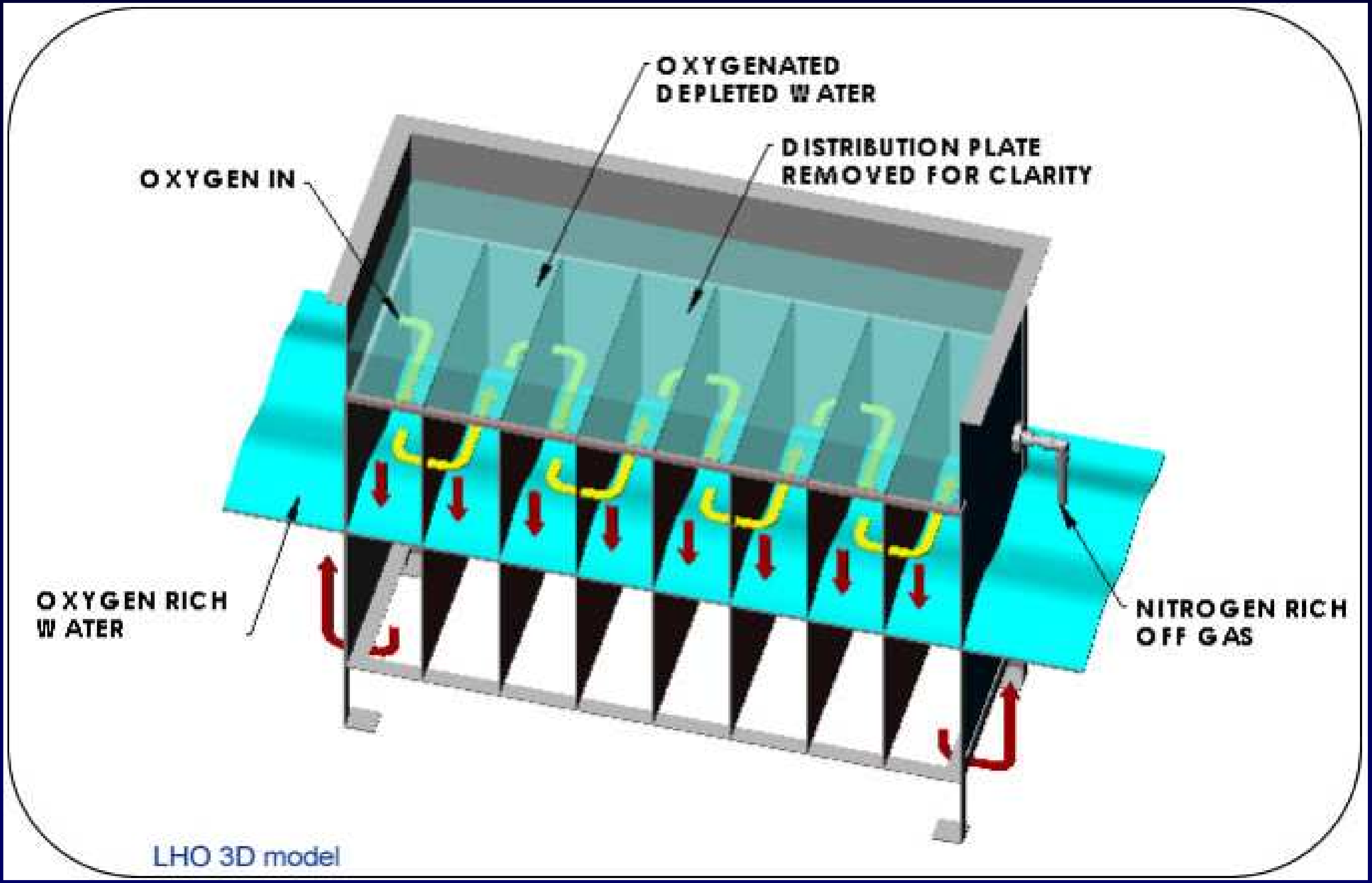
Summerfelt et al. 2000. *Aquacultural Engineering.*

Large Scale Technologies for O_2 & CO_2 Control

- Gas balancing
  - ✓ 1st – strip CO_2
  - ✓ 2nd – add pure O_2 in LHO
    - Sometimes add O_3 in feed gas (disinfection & fine solids removal)
  - ✓ 3rd – maintain O_2 at saturation in culture tanks.



Low Head Oxygenators (LHO)



PRAqua Supplies, Ltd.

Supplemental O_2 Control at each Tank

- Downflow bubble contactor
  - ✓ treats sidestream flow withdrawn from sidewall box
- NO IN-TANK AERATION!!!

RAS Design

BMP #1.3:

design *fluidized-sand biofilters* to remove (f_{rem}) $\geq 80\%$ of TAN each pass and maintain NO_2-N < 0.1-0.2 mg/L

Fluidized-Sand Biofilters

- Fluidized-sand biofilters used in many salmonid RAS
  - ✓ Highly efficient, low cost, compact, and robust.
  - ✓ Sand: Effective Size (D_{10}) = 0.18 mm
    - Expands 60-100% at 0.7 cm/s superficial velocity

Fluidized-Sand Biofilters

- scale to treat large flows > 10 m^3/min
- provide high (≥ 80%) TAN removal efficiencies
- maintain low (≤ 0.1-0.2) NO_2-N levels
- capital cost efficient
  - ✓ high specific surface areas (11,000 m^2/m^3)
  - ✓ low media cost ($40-70/$m^3$ of sand)
- reliable if well designed, non-plugging.

Fluidized-Sand Biofilters

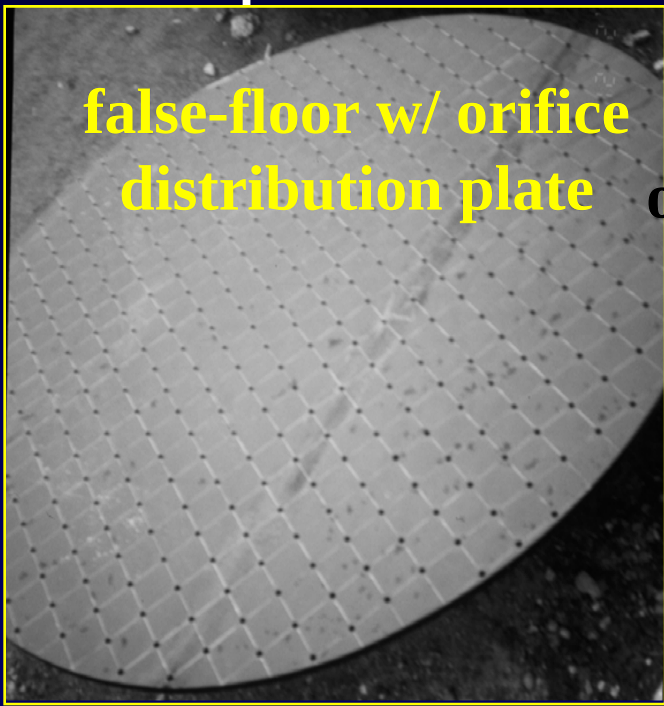
- TAN removal efficiency.

	g TAN removed per day		TAN Removal Efficiency
	per m^2 surface area	per m^3 static sand vol.	
Coldwater fluidized-sand biofilt fine sand, ~11,500 m^2/m^3 D_{10} = 0.17-0.25 mm	0.06	700	70-90%
Warmwater fluidized-sand biofilt coarse sand, ~5,000 m^2/m^3 D_{10} = 0.6-0.8 mm	0.2	1000	10-30%

(summarized by Timmons & Summerfelt, 1998)

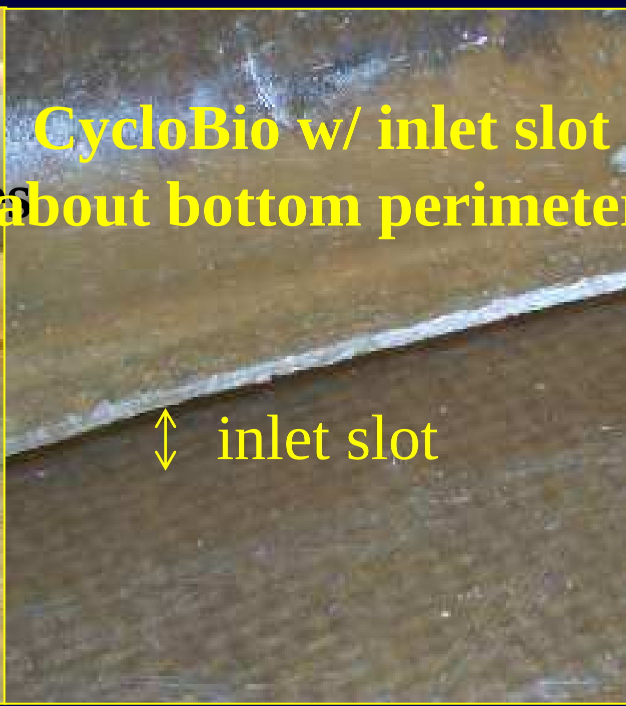
Flow Distribution Mechanisms

- Flow distribution methods vary, but are all important!



orifices distributed across false-floor (controlling ΔP)

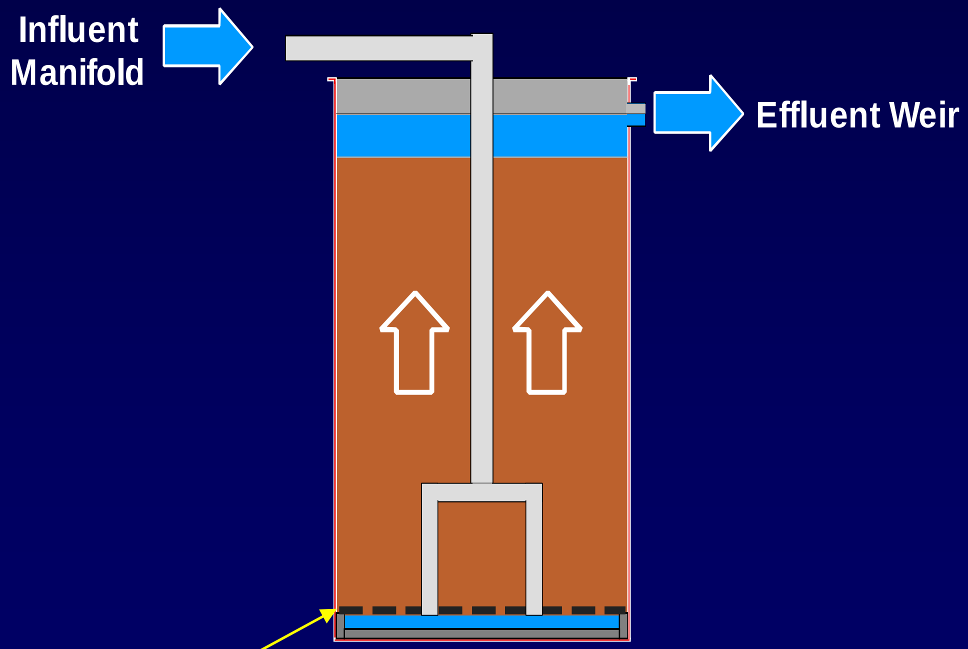
orifices distributed across pipe-manifold (controlling ΔP)



slotted inlet about circumference (NO controlling ΔP)

Distribution Through False Floor

- Eric Swanson's method (used in Maritime Canada) flow injection underneath a false floor.

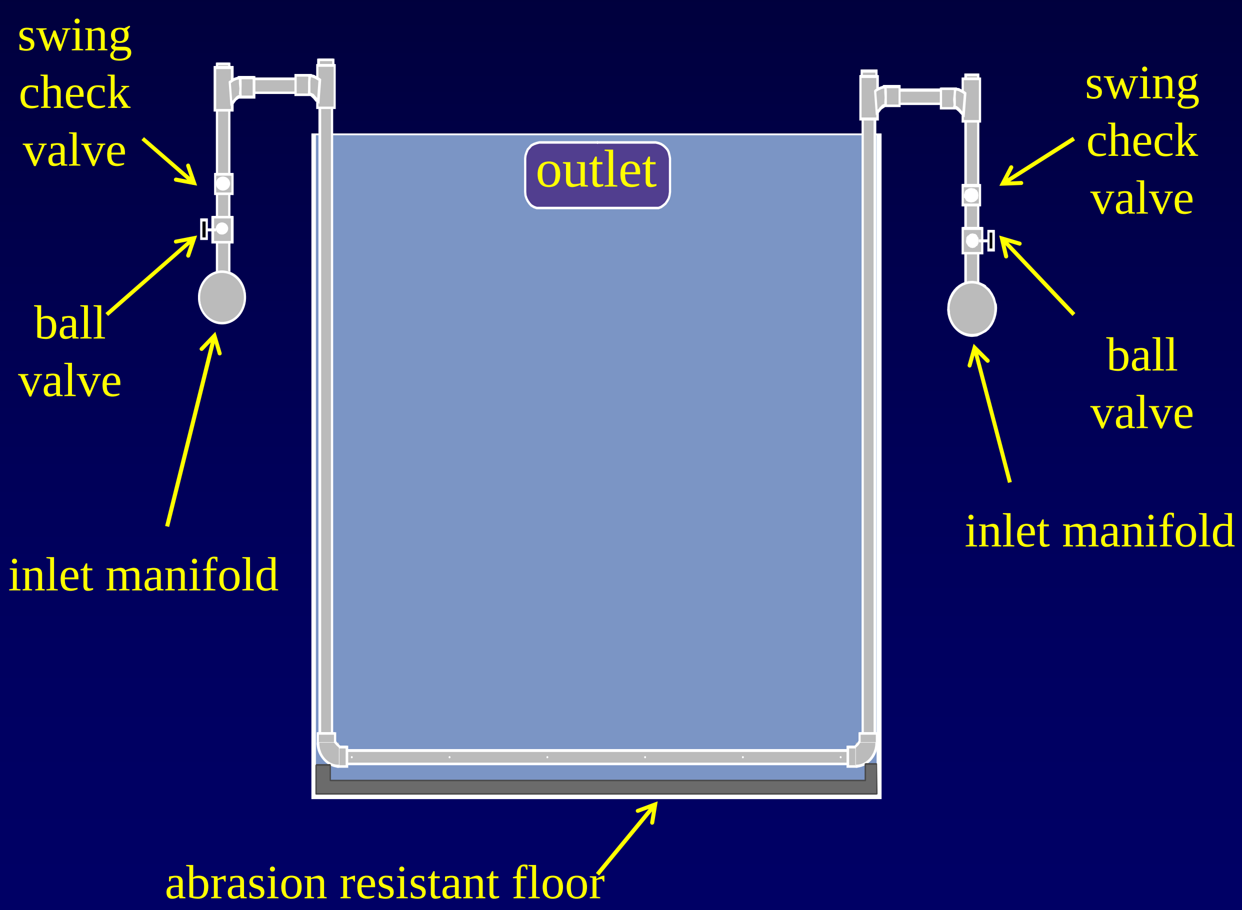


False Floor

false-floor distribution plate

Pipe-Lateral Distribution

- Modified pipe-lateral distribution manifold.



Pipe-Lateral Distribution

- Modified pipe-lateral distribution manifold above abrasion resistant floor

Pipe-Lateral Distribution

- Example FSB in salmon smolt RASs at Marine Harvests Big Tree Creek Hatchery

(system designed by PRAqua Tec

Pipe-Lateral Distribution

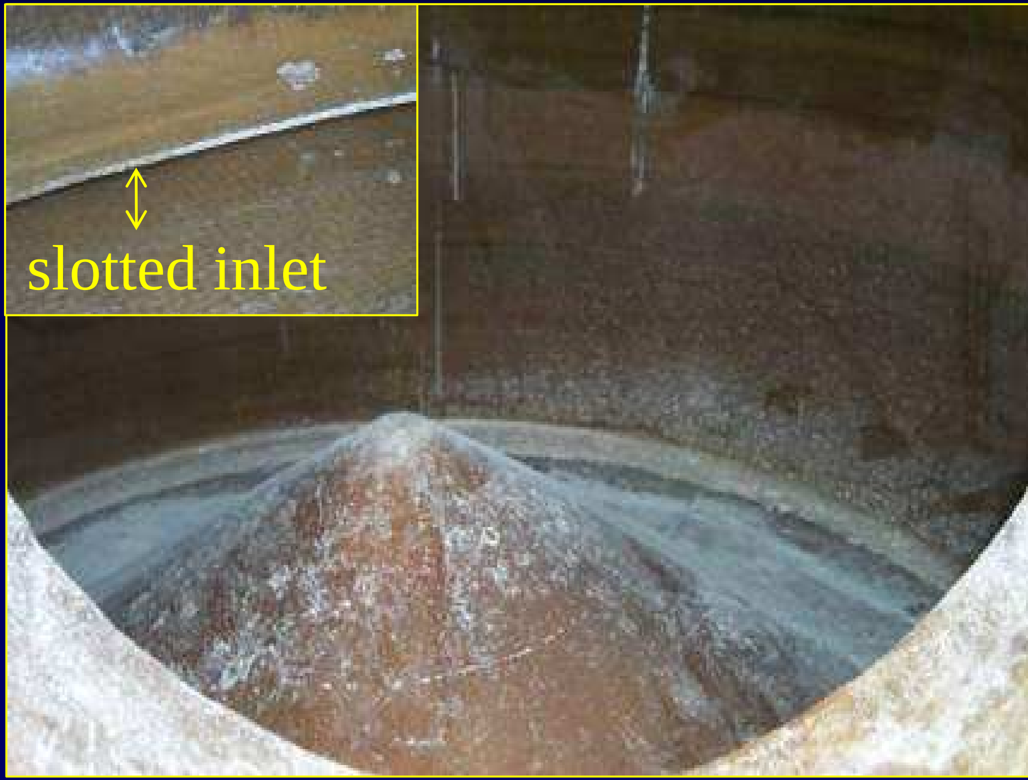
- To create uniform flow distribution:
  - ✓ Pressure drop (ΔP) across orifice should be ≥ headloss through the sand bed (i.e., ≥ depth of static sand):

$$\Delta P_{orif} = \left[\frac{Q_{orif}}{C \cdot A_{orif}}\right]^2 \cdot \frac{1}{2 \cdot g}$$

Q_{orif} = flowrate in m^3/s
A_{orif}= orifice area in m^2
$C = 0.6$ and $g = 9.81\ m/s^2$

Cyclo Biofilter™

- Water injected tangentially into circular plenum and through slotted inlet about its base.
  - ✓ Developed by Marine Biotech Inc. (Beverly, MA)

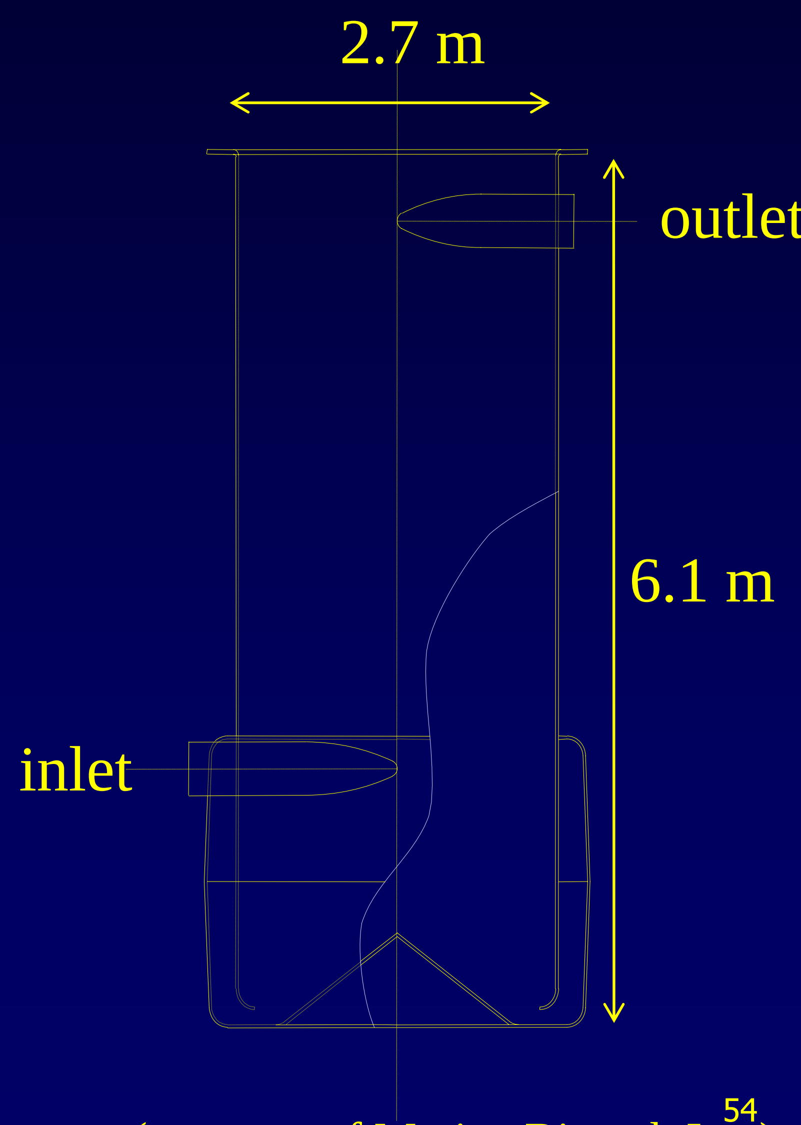


Cyclo Biofilter™

- USDA ARS National Cold Water Marine Aquaculture Center, Franklin, ME
  - ✓ compact trt system
    - 2.74 m dial
  - ✓ 101 kg feed/day sustained capacity
    - lightly loaded
  - ✓ treats 3.5 m^3/min,
    - about 60% of 5 m^3/min RAS flow

Cyclobio FSB @ Freshwater Inst.

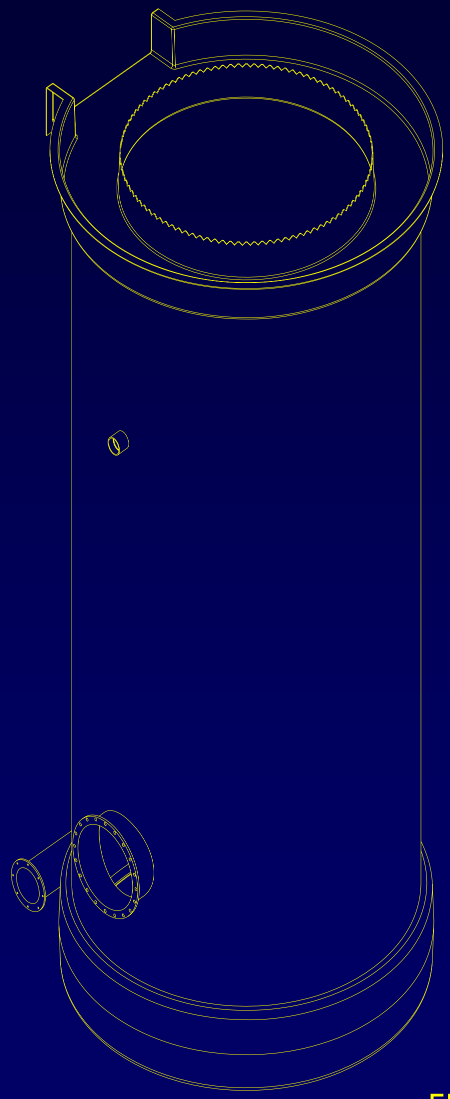
- Dimensions:
  - ✓ 2.7 m (9 ft) dia
- Static sand capacity:
  - ✓ 1.5 m (5 ft) depth
  - ✓ 8.5 m^3 (300 ft^3) volume
  - ✓ assimilates TAN from 160 kg feed/day
  - ✓ $1000-1500 for sand
- treats 3.5 m^3/min,
  - ✓ about 60% of RAS flow
- 4.7 m^3/min RAS flow
  - ✓ Two 5-HP pumps



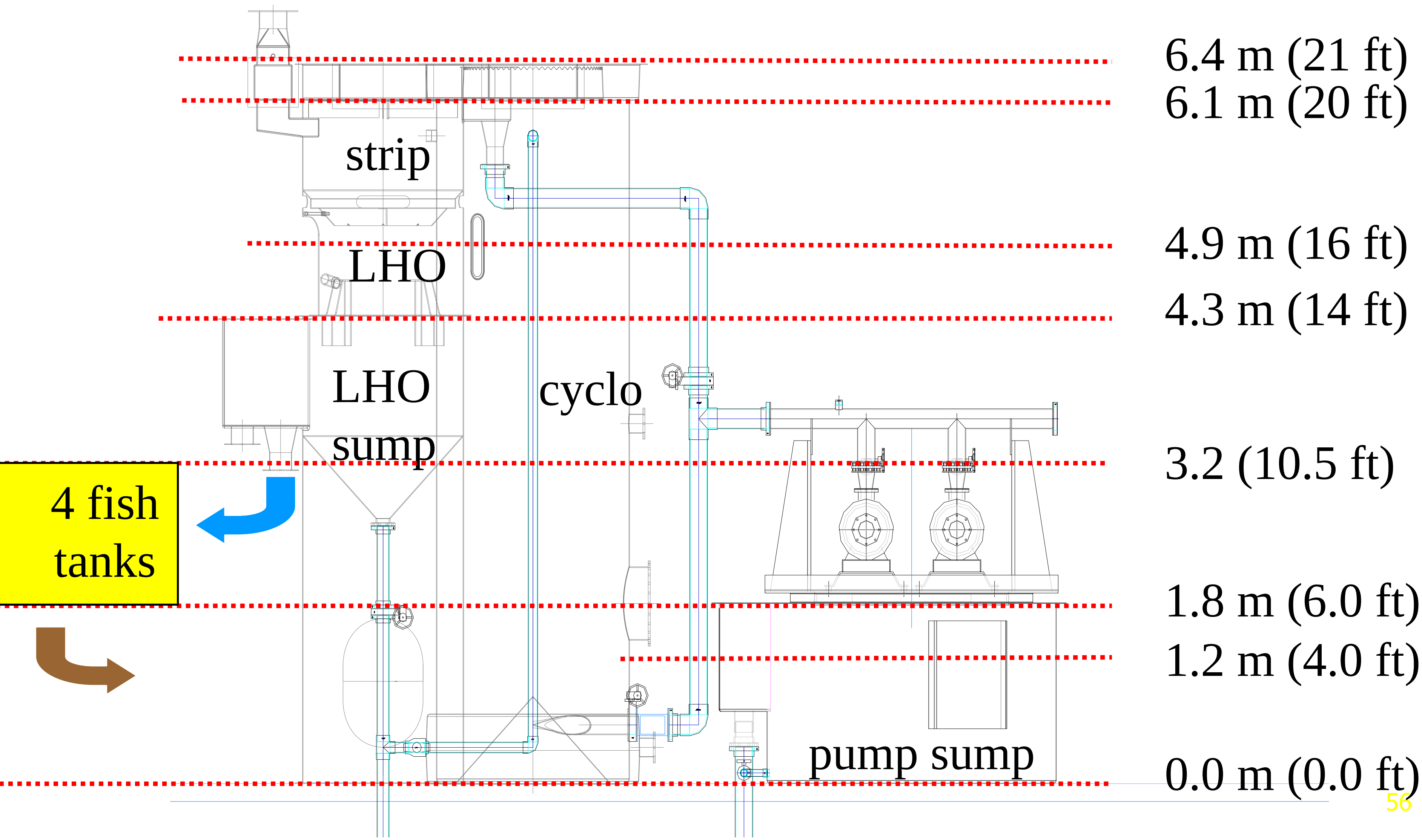
(courtesy of Marine Biotech Inc.)

Process Elevations @ NCWMAC

- Height of Cyclobio was set at 6.4 m :
  - ✓Elevation required to gravity flow
    - from top of cyclobio,
    - through CO_2 stripper,
    - through LHO unit,
    - through LHO head tank,
    - through fish culture tanks,
    - through drum filter, and
    - back to pump sump

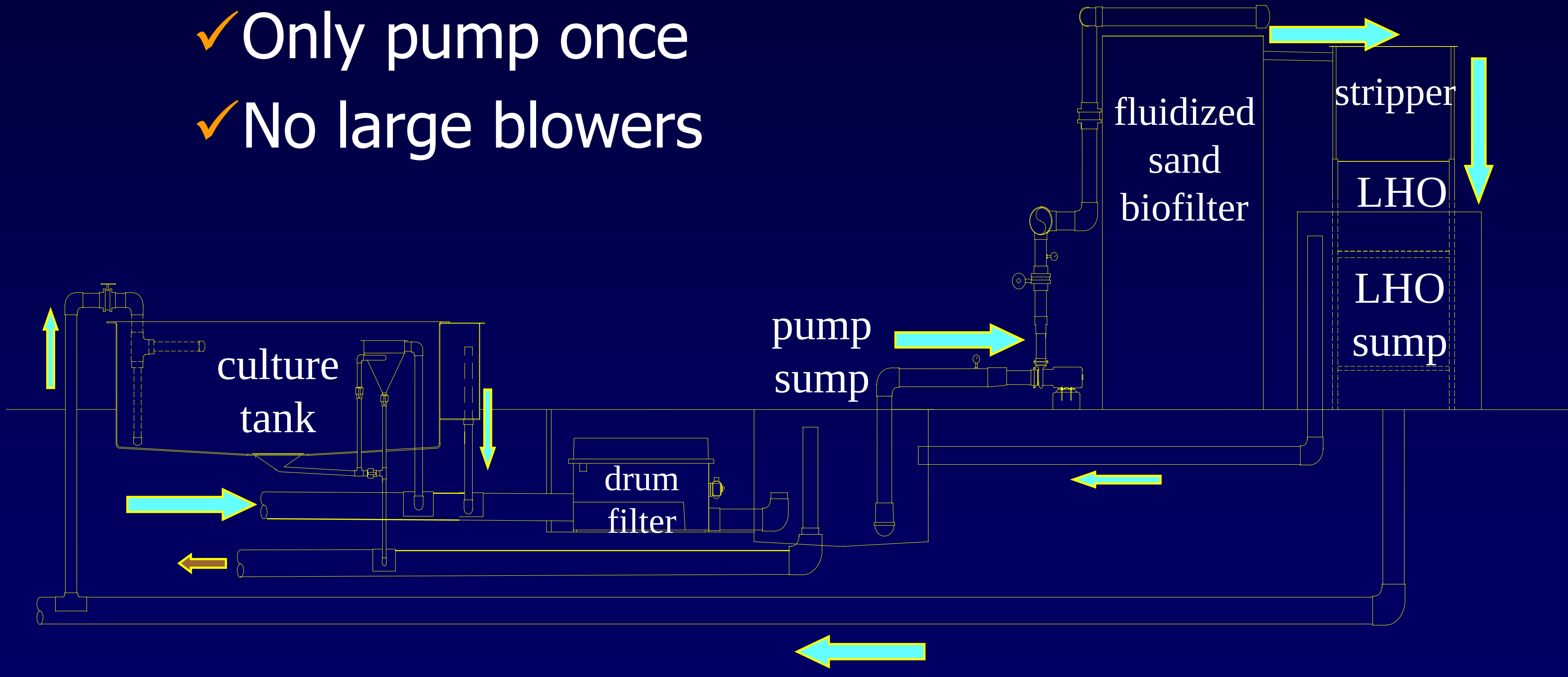


Process Elevations @ NCWMAC



RAS Design

- Typical hydraulic profile;
  - ✓Only pump once
  - ✓No large blowers



(courtesy of PRAqua Technologies)

Thank you for your attention!