Water Quality Fundamentals

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Intensive Aquaculture

- *Cage culture*
- *Pond culture*
- *Long lines*
- *Flow through systems*
- *Recirculating Aquaculture Systems (RAS)*

Deakin University - Aquaculture Research Centre

Cage culture in dams

Mussel longline culture

Victorian fish hatchery raceways

RAS Aquaria

- *Benefits*
  - *High density stocking*
  - *Self-contained production systems*
  - *Greater control over the culture environment*
  - Increased bio-security
  - *Minimal water exchange ~10% system volume/24hrs*

RAS Aquaria

- *Limitations*
  - *Capital outlay*
  - *Disease containment*
  - *Mechanical failure, oxygen depletion, toxin levels*
  - *Skilled labour required to maintain, monitoring often intensified*
  - *Water Quality*

Why is water quality important?

What we strive to achieve

What we aim to avoid

What we strive to achieve

Water Quality is Key Stone

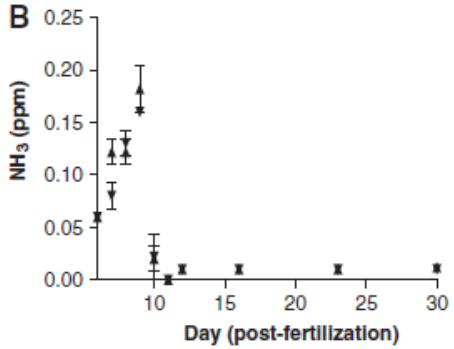
- *Aquariums are complex dynamic biological systems affected by multiple variable interactions*
- *Water quality is critical to the successful operation of any aquaria holding system*
- *Changes can range from seconds to minutes, minutes to hours, and days to months*
- *Consistent condition and routine monitoring is required*

Water Quality

- *Minimal scientific consensus throughout industry*
- *Most current standards are based on*
  - *USEPA Red Book (1976)*
  - *What has been done traditionally*
  - *What appears successful in the laboratory setting*
- *Minimal numbers of controlled studies have been done to evaluate what parameters are best for captive zebrafish*

Ammonia Example

- USEPA Red Book (1976) recommends
  - <0.02mg/L NH_3 for freshwater life
- Best et al. (2010) reported
  - 0.18mg/L NH_3 with no obvious detrimental effects to 9dpf zebrafish alevin



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A Novel Method for Rearing First-Feeding Larval Zebrafish: Polyculture with Type L Saltwater Rotifers (*Brachionus plicatilis*)

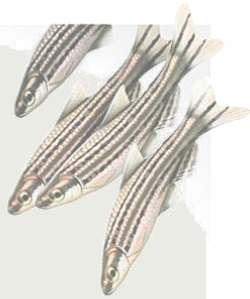
Jason Best,[1] Isaac Adatto,[1] Jason Cockington,[2] Althea James,[1] and Christian Lawrence[1]

Take home message

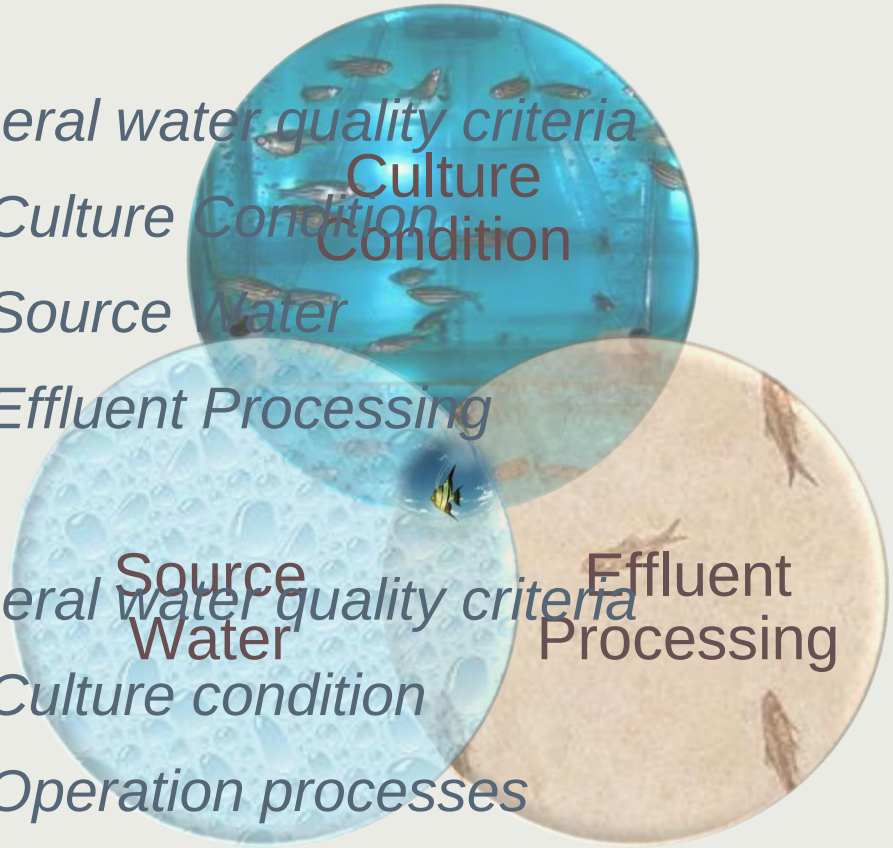
- *Selection of water quality parameters should be*
  - *Species specific*
  - *Life stage specific*

- *More controlled experimentation is required to identify optimal rearing conditions*

Controlling Water Quality



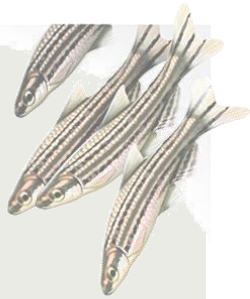
- *General water quality criteria*
  - *Culture Condition*
  - *Source Water*
  - *Effluent Processing*



- *General water quality criteria*
  - *Culture condition*
  - *Operation processes*

Colt, Aqua. Eng. 2006

Temperature and Water Quality



- *Temperature tolerance*
  - *6.7-41.7°C*
  - *Target = 28.5°C*

Culture Condition

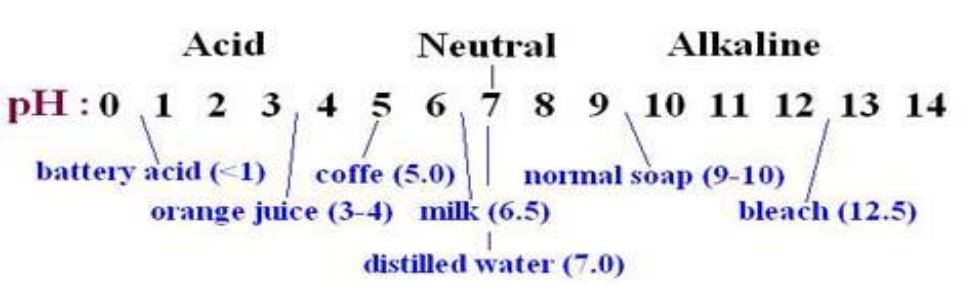
- Impacts overall water chemistry characteristics in addition to direct impact on aquatic animals

Lawrence, Aquaculture 2007

Power of Hydrogen (pH)

- *pH tolerance*
  - *6.0-9.5*
  - *Target = 7.5-8*

- Measurement of basic, acidic, or neutral qualities of a solution
- Will fluctuate in rec
  - Respiration
  - Nitrification



http://www.all-about-ph.com/ph-scale.html

Power of Hydrogen (pH)

- pH changes must be done gradually
- A drop from 7 to 6 represents the water becoming 10 times more acidic

- High pH causes:
  - increases in concentration of NH_3 (most toxic form)
- Low pH causes:
  - decreases in activity of nitrifying bacteria
  - increases toxicity of heavy metals

Power of Hydrogen (pH)

- Respiration effect
  - Increased CO_2 will decrease pH
  - Depending on alkalinity, can $\downarrow NH_3$:NH_4^+ in TAN

- Nitrification effect
  - Nitrification consumes alkalinity, decreasing pH
  - NH_3 toxicity decreases with decreasing pH
  - Nitrifying bacteria have reduced growth and activity at pH levels below 6.4

Power of Hydrogen (pH)

- Buffering pH often necessary
  - Daily – Sodium Bicarbonate ($NaHCO_3$)
  - Periodic – Coral or Oyster shells ($CaCO_3$)
  - Must be done slowly to avoid rapid and excessive pH level changes

- Important to understand water hardness and alkalinity before adjusting pH

Hardness

- *Hardness Tolerance*
  - *75-200ppm $CaCO_3$*
  - *Target >100ppm*

- *General Hardness (GH)*
  - *cations - Ca^{++} + Mg^{++}*
- *Alkalintiy / Carbonate Hardness (KH)*
  - *anions* - $HC0_3^-$ + CO_3^{--}

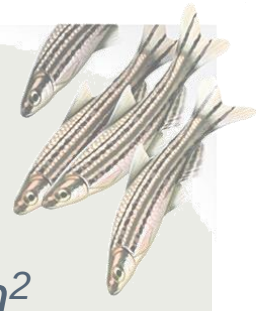
General Hardness

- *The sum concentrations of calcium, magnesium, and other divalent cations*
- *Effected by the geology of the watershed of the source*
- Freshwater fish blood ions are higher than the water

- *Increasing hardness:*
  - *Decreases osmoregulatory stress*
  - *Decreases the toxicity of dissolved metals like copper and zinc*

Carbonate Hardness

- *Sum of bicarbonate (HCO_3^-) and carbonate (CO_3^{--}) anions in the water*
- *Reflects the buffering capacity of the water or the stability of pH*
- *Dissolved metals (copper, zinc, and aluminium) are more toxic to fish in water of low alkalinity*



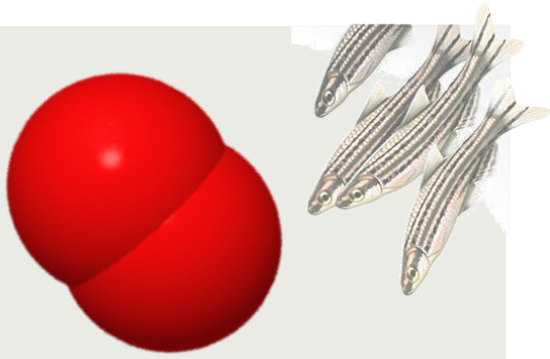
Salinity and Conductivity

- *Salinity Tolerance*
  - *0.2-2.0ppt*
  - *Target 0.25-0.75ppt*
- *Salinity measures salts of the alkali metals or magnesium*
- *300-4000µS/cm²*
  - *Target 300-1200µS*
- *Capacity of water to conduct an electrical current*
- *Conductivity Tolerance*
- *Can both be modified by addition of balanced salt formulations*
- *Evaporation of water will increase both*

Salinity and Conductivity

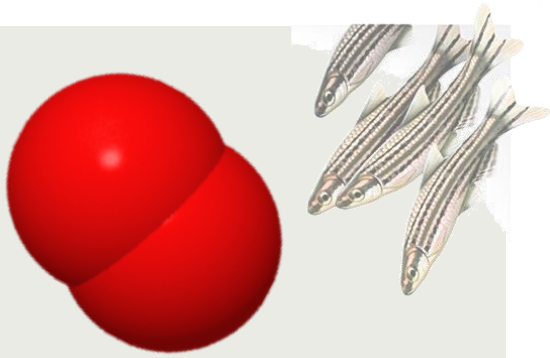
- Na^+ are necessary for ammonium (NH_4^+) excretion and ion regulatory function
- High salt
  - Fresh water animals cannot excrete enough ions
- Low salt
  - Fresh water animals will fight to retain ions
- These processes have a high metabolic cost to the animals

Dissolved Oxygen



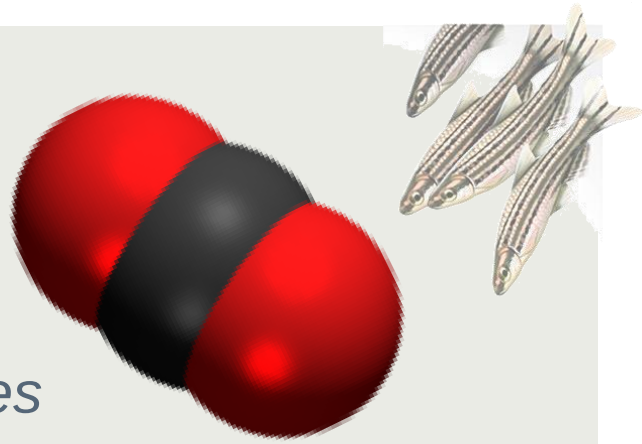
- *Target > 6 mg/L or > 80 % saturation*
- *100% saturation @28°C = 7.8mg/L*
- *As water temperature increases the maximum DO saturation level decreases*
- *Can be modified by the use of mechanical aeration devises, degassing towers, trickle filters, or by the introduction of oxygen gas*
  - *>100% saturation can be dangerous*
  - *Different than total gas pressure (TGP)*

Dissolved Oxygen



- Saturation >100%
  - Hyperoxia (delicate to manage)
  - Indicator of Gas Bubble Disease (GBD)
- Hyperoxia
  - Used to manage densely populated, docile species
  - Respiration decreases (CO_2 is retained)
  - Kidneys retain HCO_3^- to balance blood pH

Carbon Dioxide



- *Target < 5mg/L*
- *Elevated CO_2 reduces growth rates*
- *High CO_2 causes nephrocalcinosis*
- *Increasing CO_2 reduces pH*
  - *↓ NH_3 toxicity, ↑ heavy metal toxicity*
- *Tested and recorded infrequently*
- *Can be reduced by use of degassing towers, packed columns, trickle filters, etc*

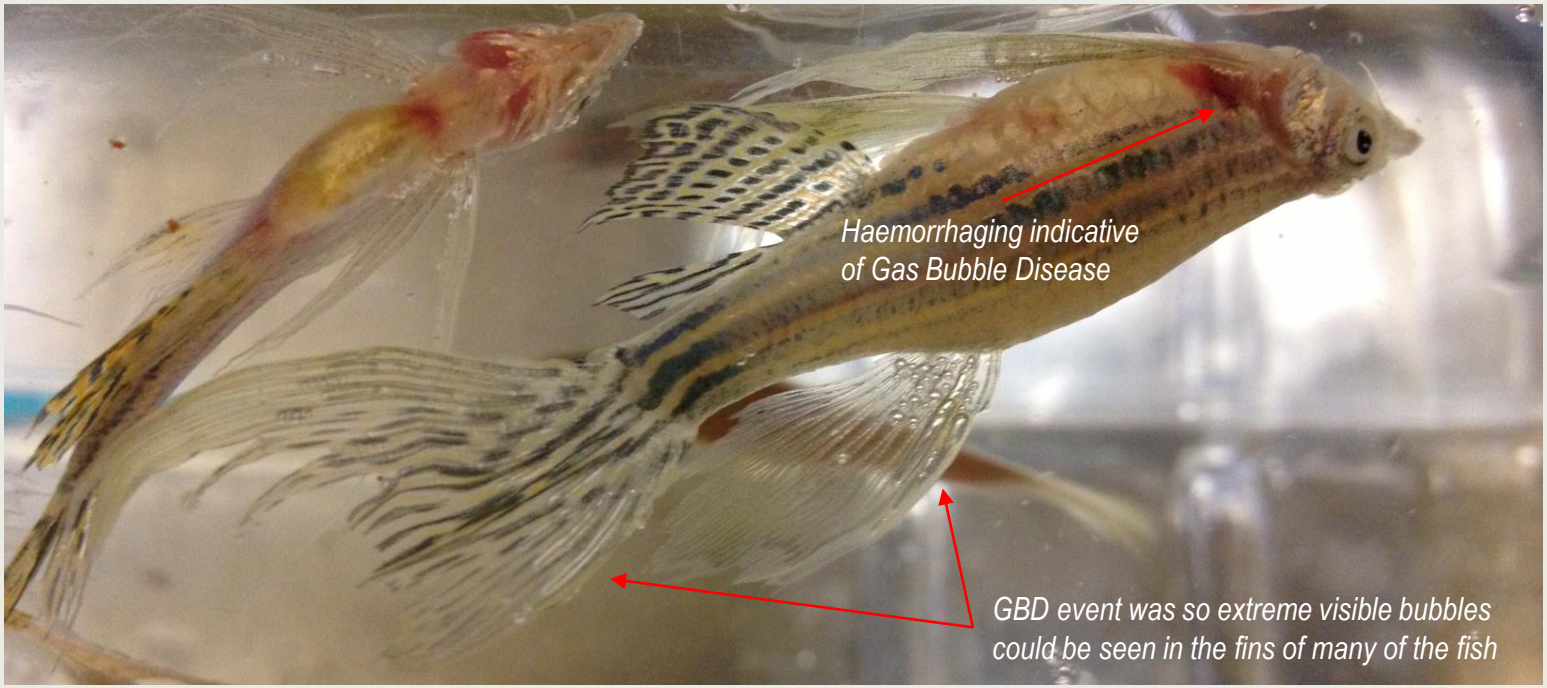
Colt, Aqua. Eng. 2006

Total Gas Pressure

- When the total pressure of all the gases in the water exceeds the ambient atmospheric pressure at the water surface, supersaturation exists
- The effect of excessive supersaturation on fish has been well documented, and if supersaturation exceeds the established safe levels, massive fish kills can occur
  - Gas Bubble Disease

Colt, Aqua. Eng. 2006

Gas Bubble Disease



Chlorine and Chloramine

- Chloramine
  - Target = 0 mg/L (ppm)
  - Chloramine = Chlorine + Ammonia
  - 0.01 ppm is acutely toxic to fish
- Neutralise - commercial products (Nov-Aqua® , AmQuel® or Safe®), or Sodium Thiosulfate
- Remove - filtration using activated carbon

Chlorine and Chloramine

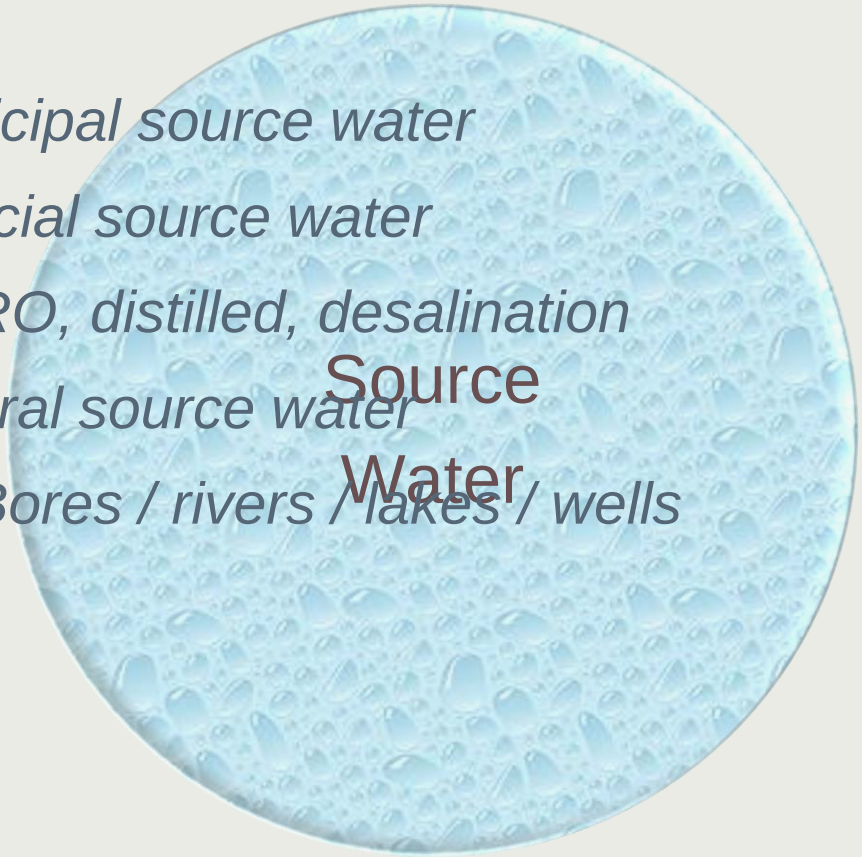
- Chlorine
  - Target = 0 mg/L (ppm)
  - Zebrafish can tolerate low Cl_2 (0.5 -1ppm)
  - Human smelling threshold is ~ 0.2 – 0.4 ppm
- Neutralise or remove – same as chloramine, or aeration over time (only for chlorine)
- Chronic exposure can damage skin, eyes, and gills
- Municipal water systems typically have 0.5 to 1.0 mg/L residual concentrations of chlorine present

Culture Condition Guidelines

- Temperature: 18 – 24 (24-28^{O}C)
- Alkalinity: 50-150 mg/L
- Hardness: 80-300+ mg/L
- pH: 6.0-8.0
- Salinity: 0.5 -1g/L(ppt)
- Conductivity: 300-1500µS
- Un-ionized ammonia: (NH_3): < 0.02mg/L
- Nitrite: (NO_2^-): < 1mg/L
- Nitrate: (NO_3^-): < 50mg/L
- Chlorine: 0mg/L
- DO_2 : > 6 mg/L or > 80 % saturation
- CO_2: < 5mg/L

Source Water Water Quality

- *Municipal source water*
- *Artificial source water*
  - *RO, distilled, desalination*
- *Natural source water*
  - *Bores / rivers / lakes / wells*



Municipal Supply Water

Benefits	Limitations
Availability	*Government regulated quality*
Cheap	*Limited pathogen control*
Conditioning optional for culture use	*Limited control over culture condition*
Minimal waste volumes	*Requires pre-treatment* *Activated Carbon – Chlorine/Chloramine/Cu^{2+}*

Heavy Metals

- *Most important*
  - *Cadmium, copper, zinc, aluminium*
- *Source*
  - *Corrosion of pipes and fittings*
  - *Poor quality feed stuffs*
- *Dissolved metals are more toxic to fish in water of low alkalinity*

Heavy Metals

- *Action level for heavy metal presence (µg/L)*

Metal	Freshwater				Seawater
	500[a]	100[a]	10[a]	1[a]	
Copper	35	9	1.3	0.18	3.1
Zinc	460	120	17	2.4	81
Cadmium	0.75	0.25	0.049	0.01	8.8

[a] Hardness (mg/L as $CaCO_3$).

- *Zebrafish hardness target >100mg/L*

Colt, Aqua. Eng. 2006

Municipal Supply Water

- *2012 Brisbane Water Conditions*
  - *Alkaline* — *6.7-8.3pH*
  - *Hard* — 60-220 mg/L $CaCO_3$
  - *Conductivity* — *210-950*µS/cm^2
  - *Heavy metals* — *5-110 µg/L* Cu^{++}
  - *FreeChlorine* — *<0.1-1.6mg/L*

Urban Utilities, 2012

RO Supply Water

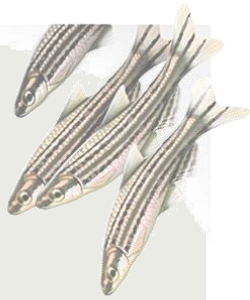
Benefits	Limitations
User specified product quality	*Dedicated equipment*
Good pathogen control (clean water)	*Higher operating cost (membrane replacement)*
Specific control over culture condition	*Requires conditioning for culture use*
	↑ product quality = ↑ waste volumes

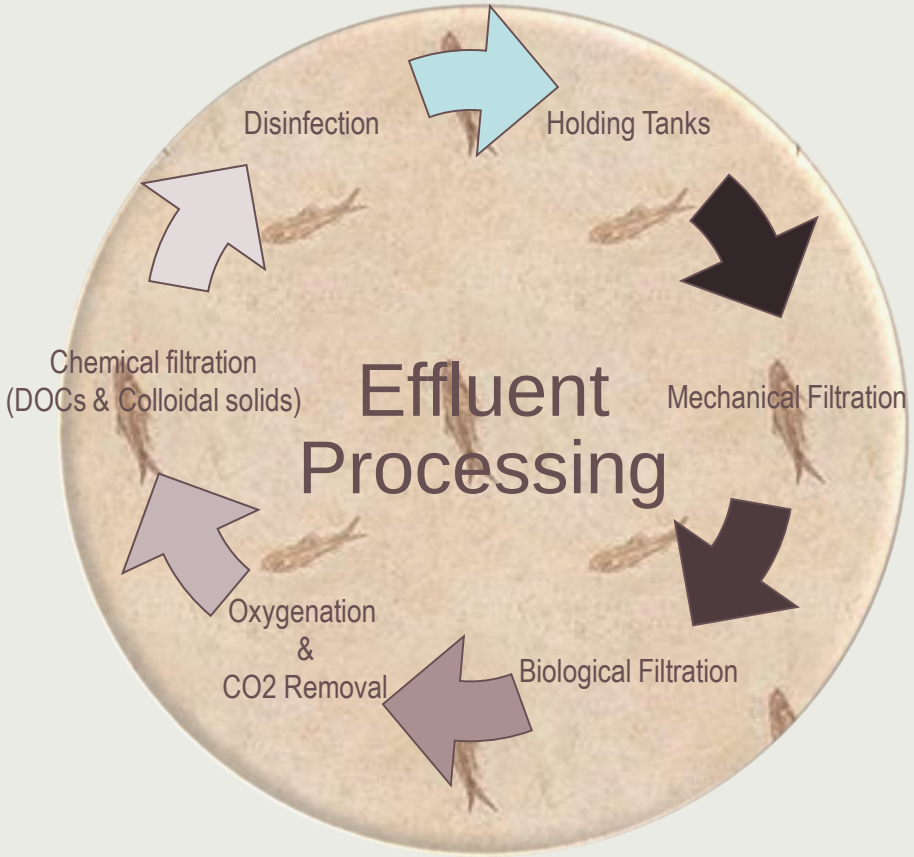
Class3 RO Supply Water

- *Low alkalinity* — *Acid pH ~6.3*
- *Soft* — *0mg/L* $CaCO_3$
- *Conductivity* — *~20* µS/cm^2 *conductivity*

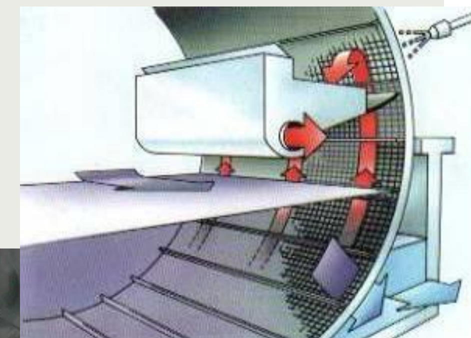
- *Requires conditioning for culture use*
  - *Hardness Generators (↑pH + Ca$^+$ cations)*
  - Marine Sea Salt (↑µS + essential minerals)
- *Typically 7.5pH, >100mg/L* $CaCO_3$*, ~400* µS/cm^2

Recirculating Water Supply Systems (CLS)





Mechanical Filtration



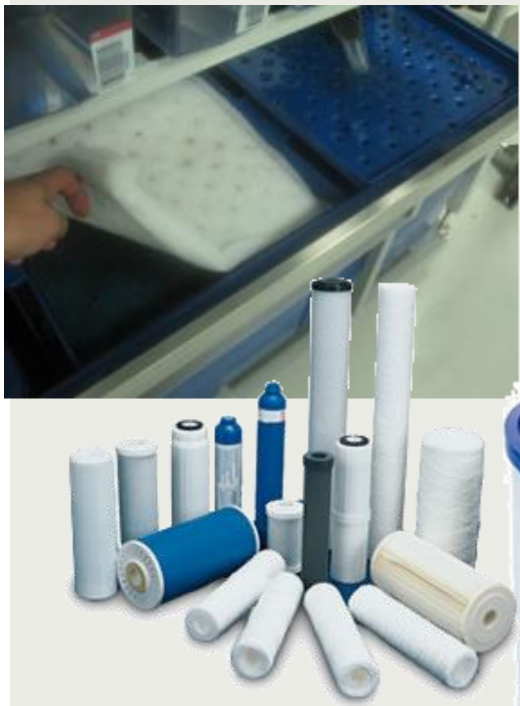
Mechanical Filtration

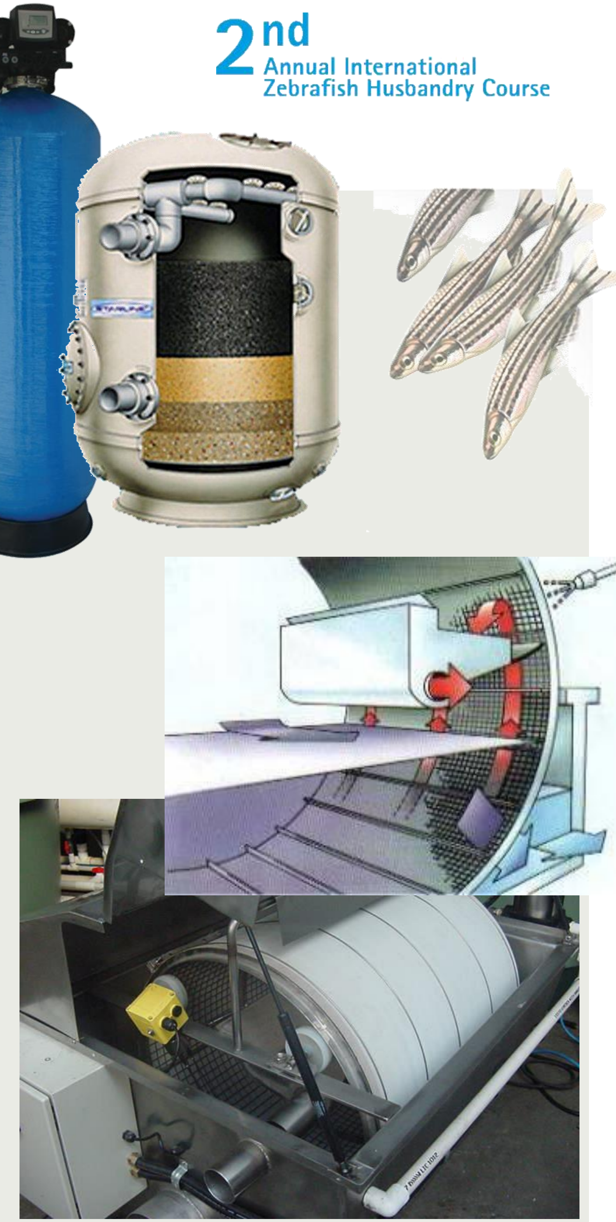
- *Purpose*
  - *Remove large suspended debris*
    - *Range : 10-100µm*
  - *Allows for healthy biofilter growth*
  - *Enhances UV efficacy*

Mechanical Filtration

- *Considerations*
  - *Removes or Isolates waste?*
    - *Welfare impact*
  - *Consumables?*
  - *Technical skill level for operation / maintenance?*
  - *Automation?*
    - *Operating cost impact*

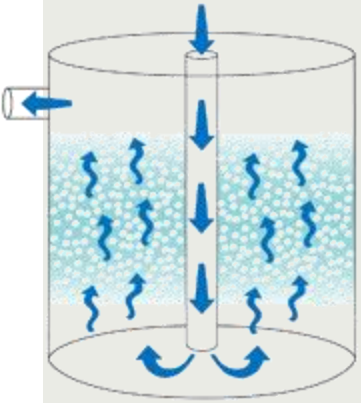
Mechanical Filtration

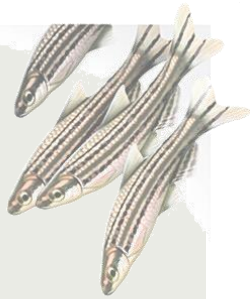




Biological Filtration

- *Includes*
  - *Under-gravel filters*
  - *Fluidized beds*
  - *Trickle filters (wet/dry filters)*
  - *Bead filters*
  - *Media varies by type, shape, size*





Biological Filtration

- *Dedicated media*
  - *Provides substrate for bacterial growth*
  - *Bacteria break down metabolic waste products*

Ammonia

- *Total Ammonia Nitrogen (TAN) = NH_4^+ + NH_3*
  - *TAN species ratio influenced by pH*
- *Majority of waste nitrogen in fish is excreted as NH_3 through gills not as urea*
- *Requires positive gradient between fish and ambient water*
- *As ambient water concentrations increase the outward flow of NH_3 decreases or may stop altogether*
- *Should be kept as low as possible – 0 ppm*

Biological Filter

- 2 types of aerobic microorganisms that colonize aquatic biofilters
  - Heterotrophic bacteria utilize dissolved organic compounds (DOCs)
  - Chemosynthetic bacteria utilize ammonia and nitrite as a food source

- Heterotrophic bacteria grow 5X faster than Chemosynthetic bacteria

Nitrification

- *Toxic ammonia is converted to non-toxic nitrate*

- *Nitrosomonas sp.*
  - $2\ NH_3 + 3\ O_2 \rightarrow 2\ NO_2^- + 2\ H_2O + 2\ H^+$

- *Nitrobacter, Nitrospina sp.*
  - $2\ NO_2^- + 1\ O_2 \rightarrow 2\ NO_3^-$

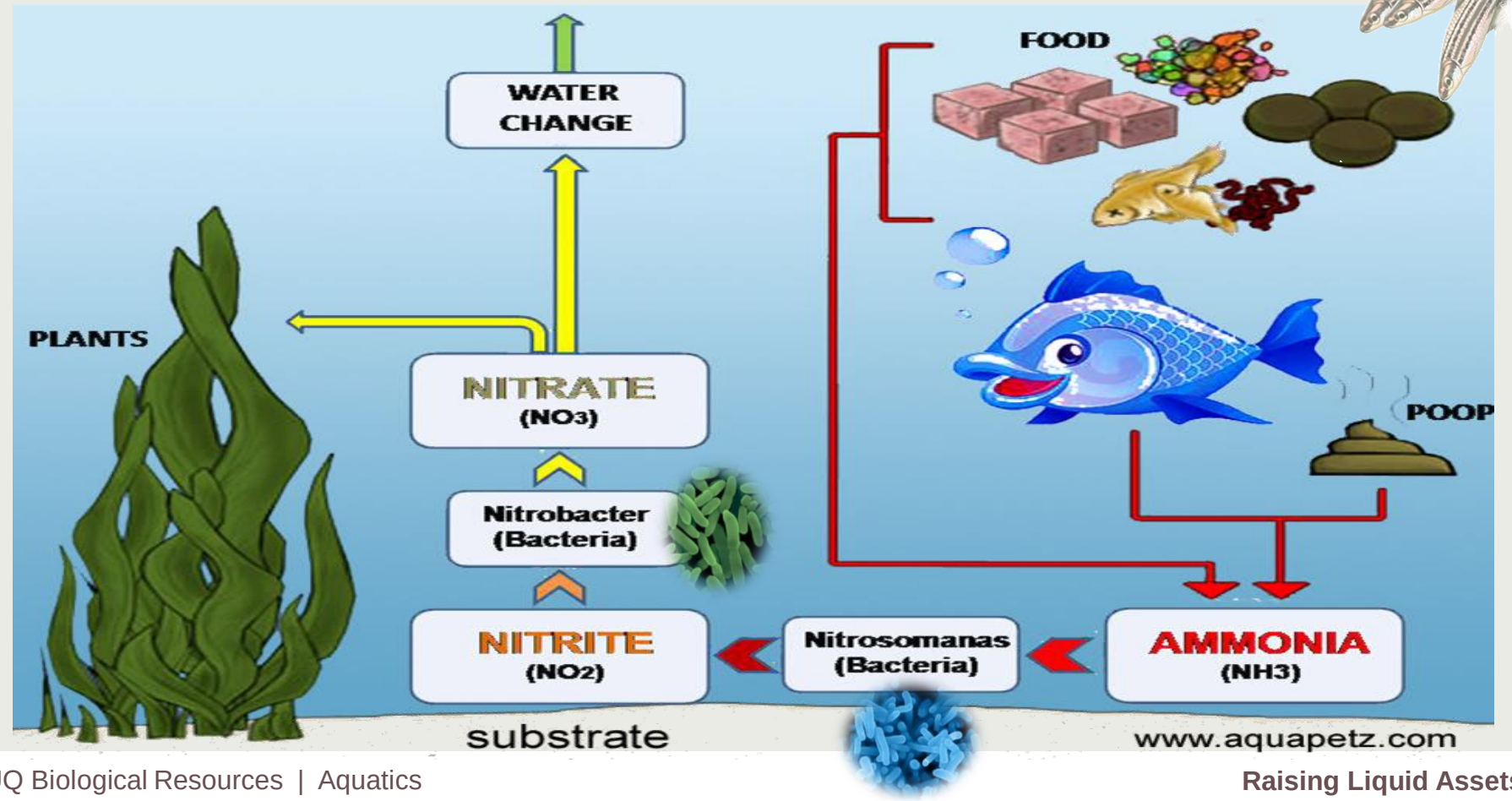
Chen et al, Aqua. Eng. 2006

Nitrification

- *Requires oxygen and alkalinty (↓pH)*
- *1g TAN oxidised to nitrate nitrogen requires*
  - *4.18g of O_2*
  - *7.07g of CO_3^-*
  - *0.17g of bacteria biomass generated*

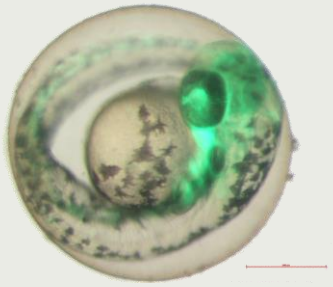
Chen et al, Aqua. Eng. 2006

Aquatic Nitrogen Cycle



Chemical Filtration

- Dissolved wastes are more difficult to remove
- 2 main options for chemical filtration
  - Activated Carbon
  - Foam fractionation (protein skimming)

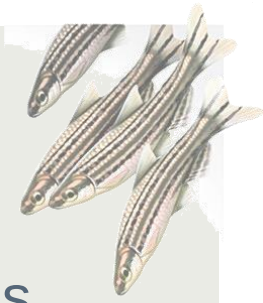


Activated Carbon

- Works by adsorption
  - pollutant molecules in the water are trapped inside the pore structure of the carbon substrate
- Removes
  - Chlorine and Copper ions
  - Dissolved Organic Compounds (DOC's)
  - Colloidal solids

Protein Skimming

- Works by adsorption
  - Hydrophobic pollutant molecules in the water bind to micro bubbles (of air or ozone) rising through a column
  - At the surface the bubbles form a foam and the waste is discharged to the foamate stream



Disinfection

- Focussed at reducing microorganism populations
- 2 main options to consider
  - Ultraviolet irradiation
  - Ozone

Ultraviolet irradiation

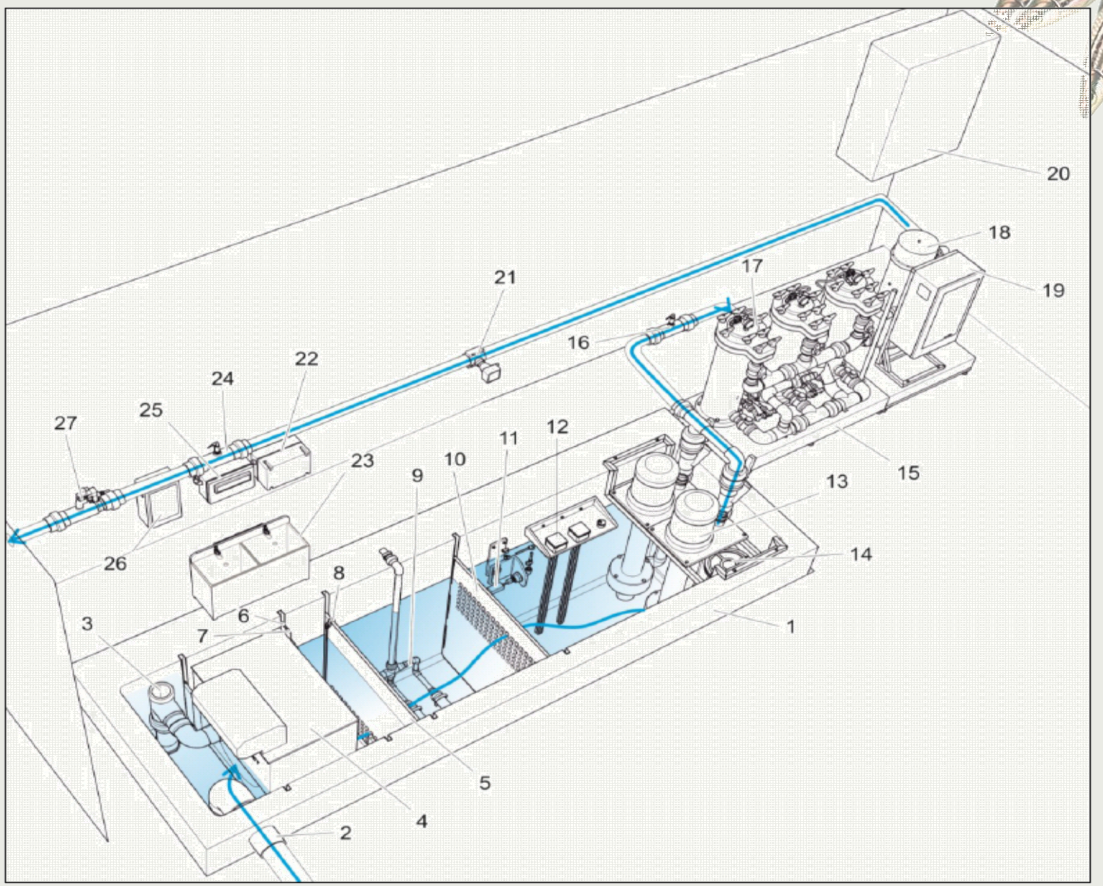
- Effectiveness depends on flow rates, plumbing diameter and unit size/power and Water Quality
  - Presence of particulates decreases efficacy
- Irradiation dose expressed as µJs/cm^2
- Effective bulb life is short (~12 months)

- Critical: bulb must be replaced regularly and quartz sleeve cleaned and replaced when it becomes cloudy

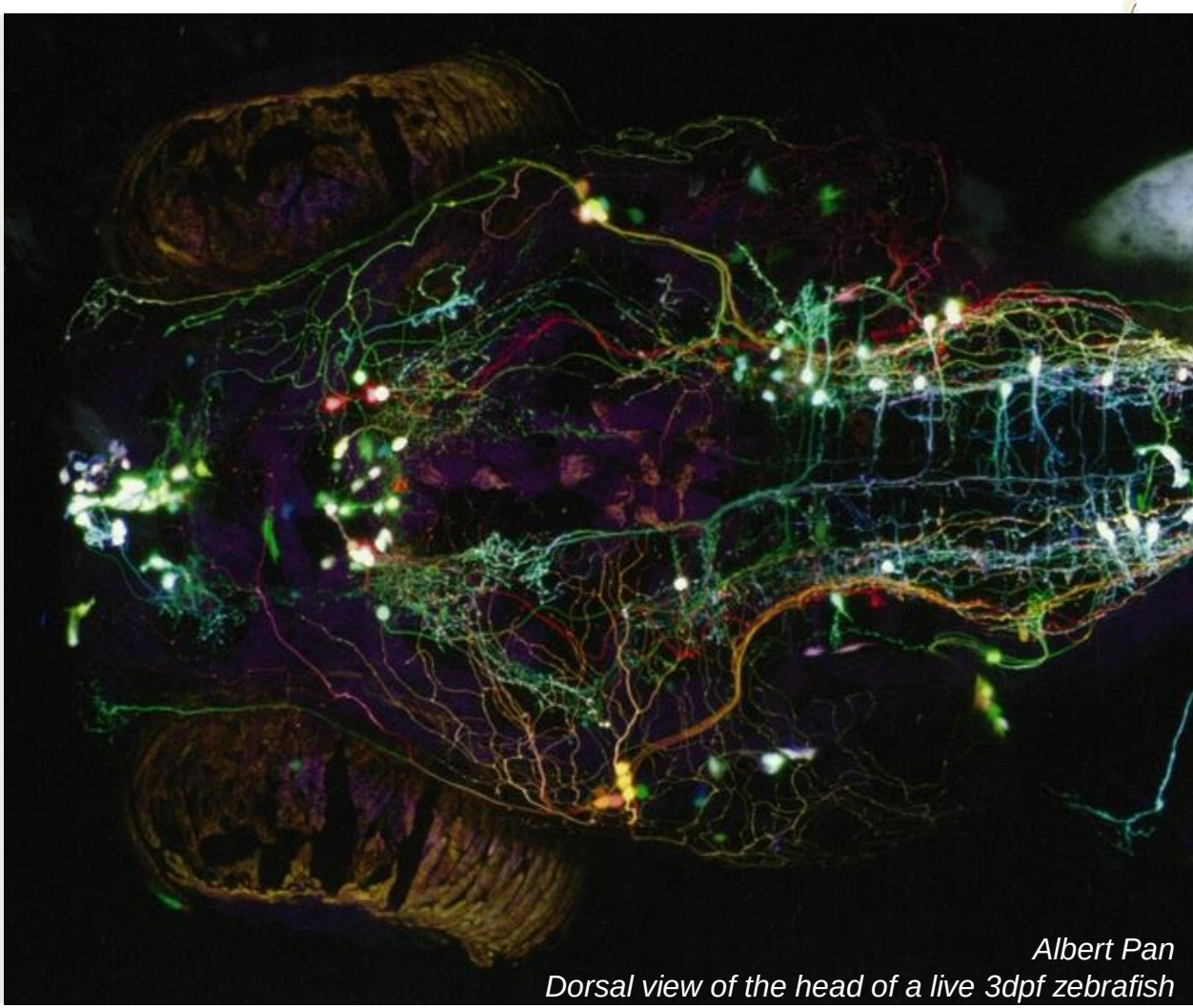
Ozone

- *Higher disinfecting power than UV*
- *Why not commonly implemented?*
  - Higher risk to animals
  - Limited by contact time
- We'll discuss more in next session

Effluent Processing Assembly



Questions?



Albert Pan
Dorsal view of the head of a live 3dpf zebrafish