# Testing the water…

## Basic Water Quality Testing for Aquaponic Systems

GoFish Workshop
July 31, 2022

RuthEllen Klinger-Bowen
rckb@hawaii.edu

# What parameters to test?

- What water parameters affect my plants the most?
- What water parameters affect my fish the most?
- How much do I want to spend, without compromising how "accurate" I need to be?

# Water chemistry parameters important in aquaponics

- Temperature (ºF or ºC)
- Dissolved Oxygen  (ppm or %) saturation)
- pH (range of 1 – 14)
- Ammonia (ppm)
- Nitrites (ppm)
- Nitrates (ppm)
- Total Alkalinity
- Conductivity (µSm/cm or mSm/cm) / Total Dissolved Solids (TDS) / Total Hardness

# Temperature

- Affects whole aquaponic ecosystem
- Ammonia toxicity increases with increasing temperatures (fish)
- Increased temperature decreases oxygen solubility (D.O.) (fish/plants/bacteria (nitrifiers))
- As temperatures decrease, the fish's immune system to ward off diseases is compromised.
- Growth, physiology, reproduction and health of fish/plants/nitrifiers heavily influenced by temperature.
- <u>Rapid temperature shifts</u> most influential stressor rather than the temperature itself

**Note:** Must be taken on site

# Dissolved Oxygen

- ***Definition*** **– amount of oxygen dissolved in water**
- **Important to fish survival, plant growth, and nitrification**
- **Maintain ≥6.0 ppm for optimal aquaponics (>80% saturation)**
- **Oxygen levels decreases with higher biomass and increasing temperatures**

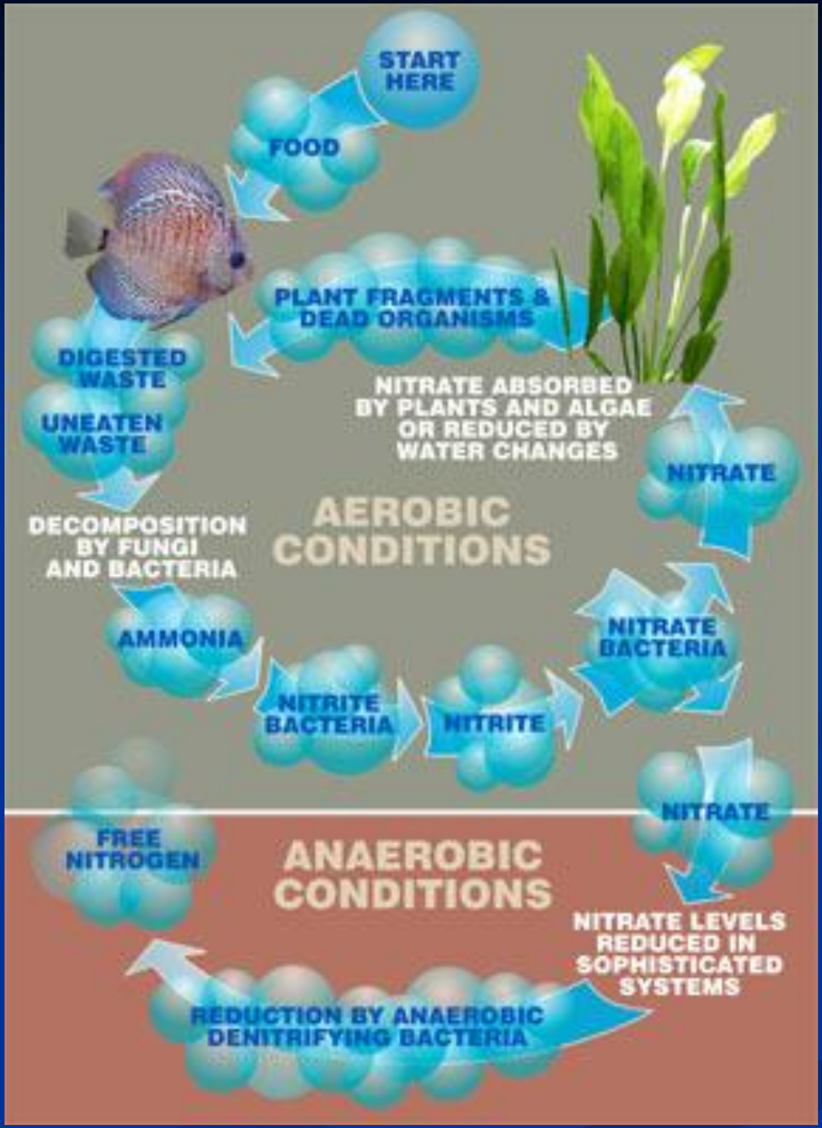
**Note: Must be taken on site**

# During a low (<6.0 ppm) D.O.

- Uptake of nutrients and respiration through the plant roots decreases
- Fish will become stressed
- Conversion time from nitrogen parameters will lag
- Preventive measure – additional aeration (air pump)

# Nitrogen cycle in an aquaponic setting

- Three Nitrogen (N) parameters that are tested: Ammonia, Nitrites, and Nitrates.
- Nitrogen (N) enters system in feed (as protein)
- Fish eat, metabolize, then excrete waste products as <u>ammonia</u> (also excretes ammonia through gills)
- Bacteria convert to <u>nitrites</u> and then to <u>nitrates</u>
- Plants can utilize all nitrogen forms but prefer nitrates

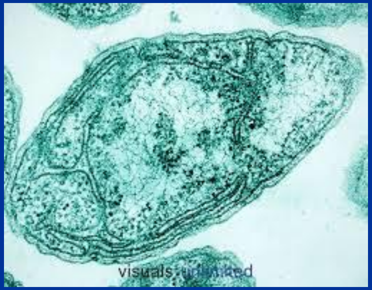



Source: http://www.liveaquaria.com/PIC/article.cfm?aid=78

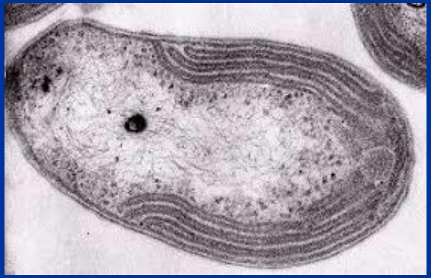
# Nitrifying Bacteria

- **Ammonia Oxidizing Bacteria (AOB): *Nitrosomonas***
  - **Converts ammonia to nitrites**

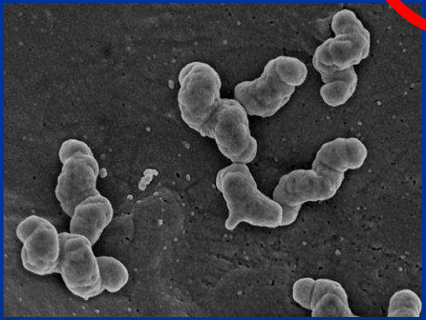
$$55\ NH_4^+ + 5\ CO_2 + 76\ O_2 \rightarrow C_5H_7NO_2 + 54\ NO_2^- + 52\ H_2O + 109\ H^+$$



***Nitrosomas***



***Nitrobacter***



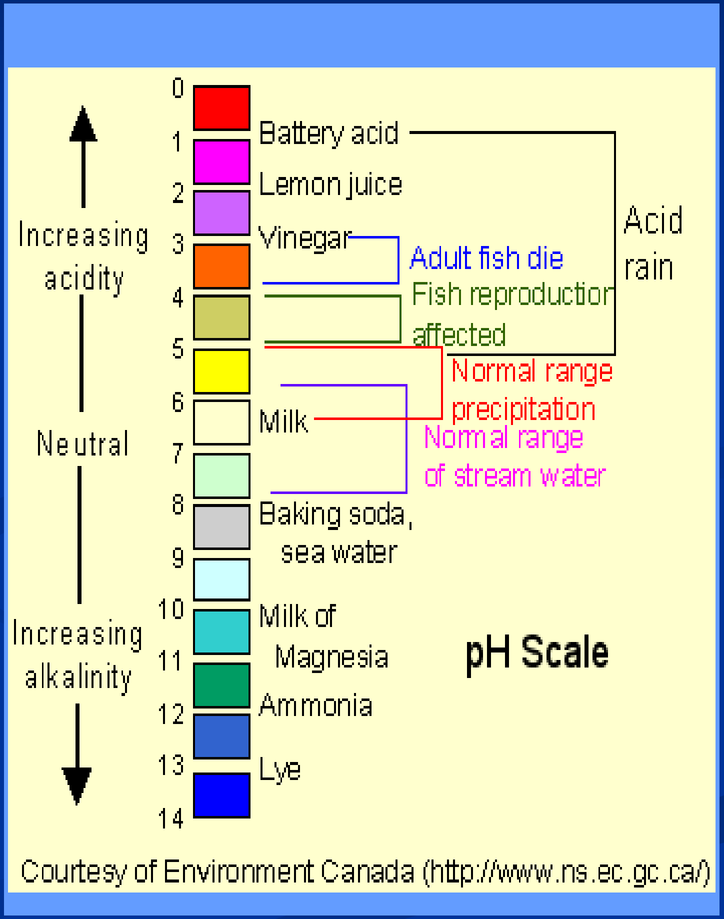
***Nitrospira***

- **Nitrite Oxidizing Bacteria (NOB): *Nitrobacter/Nitrospira***
  - **Converts nitrites to nitrates**

$$400\ NO_2^- + 5\ CO_2 + NH_4^+ + 195\ O_2 + 2\ H_2O \rightarrow C_5H_7NO_2 + 400\ NO_3^- + H^+$$

# pH (Power of Hydrogen)

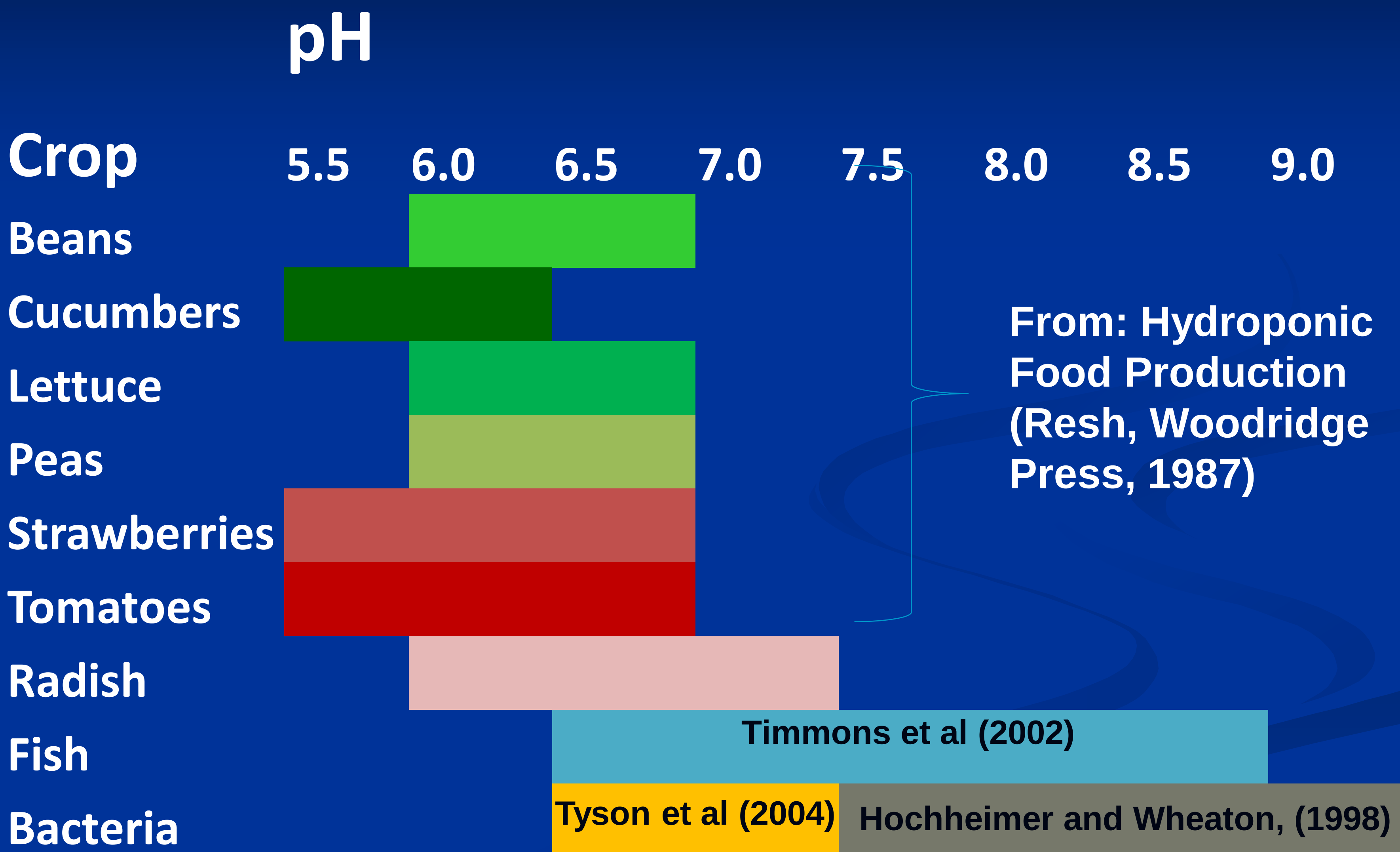
- Based on the amount of hydrogen ions (H+) are present (acidic/basic)
- ***Scale*** 1 – 14 (no units)
- Negative scale so pH 7 has less $H^+$ ions than pH 6
- Logarithmic scale so pH 7 has 10x less H+ ions than pH 6 and 100x less than pH 5



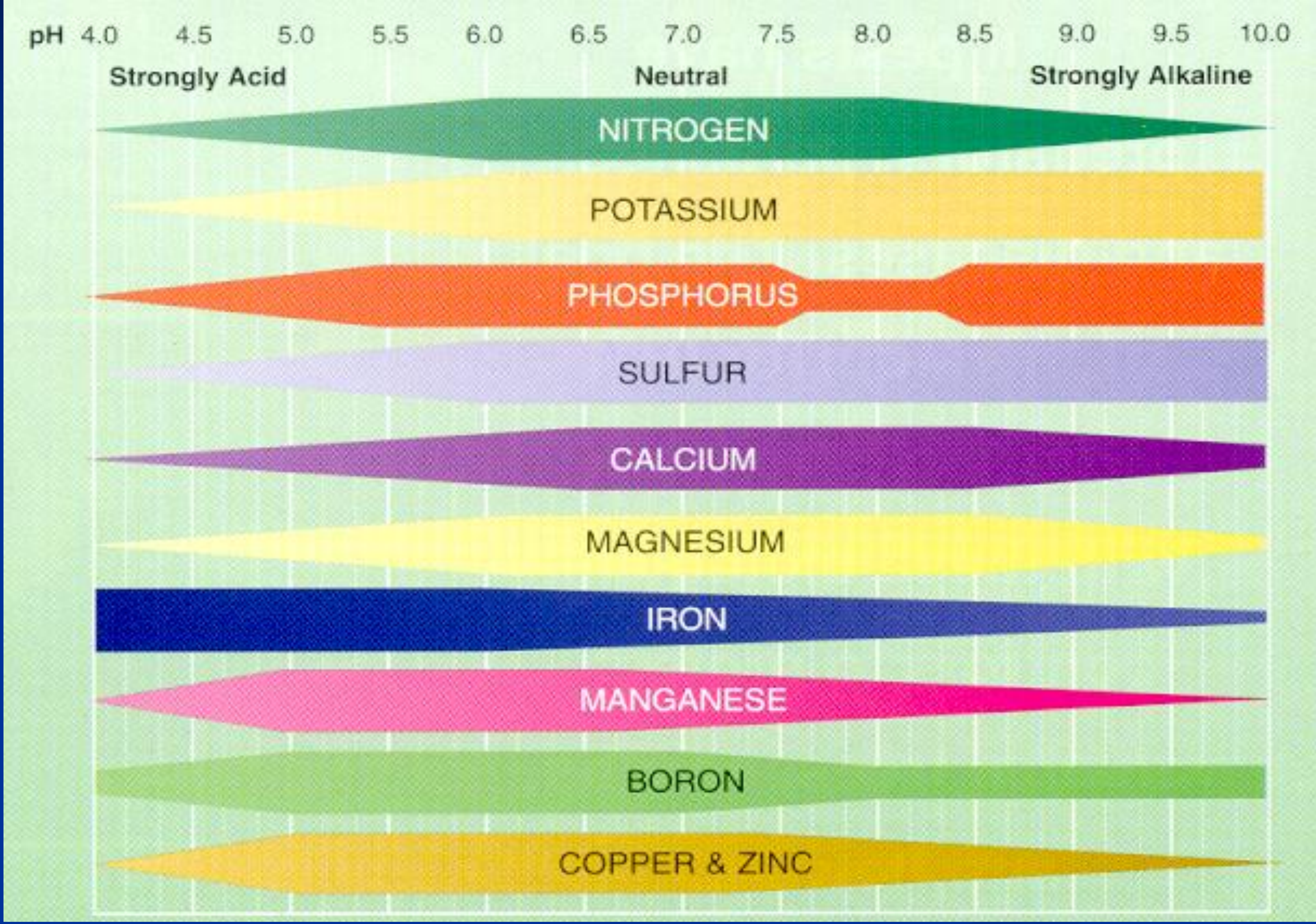
# Why take pH measurements?

- Too low or too high pH affects fish/bacteria health and nutrient availability to plants (nutrient lock-out)
- High pH increases ammonia toxicity to fish
- Through natural nitrification process, pH in aquaponic systems trend towards being acidic – typically need add a buffer (crushed oyster or coral)

# pH optima for various biota in an aquaponic system



# Impact of pH on nutrient availability in plants




http://www.rivendelldistribution.com/docs/availability_vs_pH.pdf

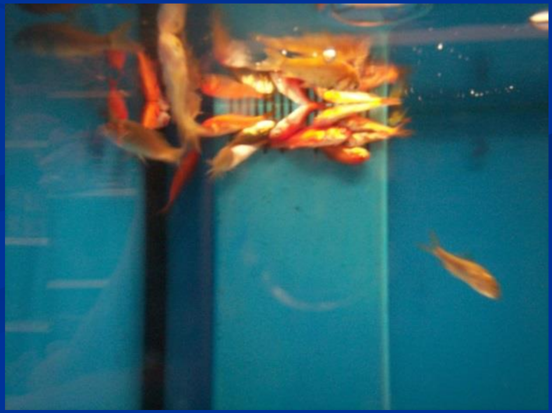
# Ammonia

- What is measured is the total ammonia nitrogen or TAN
- TAN = Ionized (nontoxic) form $NH_4^+$ + un-ionized (toxic) form $NH_3^{-}$
- Both forms are constantly moving back and forth, and is highly dependent on pH and temperature

$$NH_4^+ \leftrightarrow NH_3^{-}$$

# Ammonia effects on fish

- Essentially disrupts function/structure of fish tissues
- Affects central nervous system, internal organs, and gills
  - Toxic ammonia as low as 0.02 ppm can damage gills
  - Fish will “spin” in the water column
- Causes secondary infection due to stress, physical damage, mortality



# How to calculate toxic ammonia

***The higher the temperature and/or pH, the higher the toxic form ammonia will be present***

**Un-ionized Ammonia (NH3) Factor Chart**

| | pH: | 6.0 | 6.2 | 6.4 | 6.6 | 6.8 | 7.0 | 7.2 | 7.4 |
|---|---|---|---|---|---|---|---|---|---|
| **Temp C** | **Temp F** | | | | | | | | |
| 18 | 64.4 | 0.000343 | 0.000543 | 0.000860 | 0.001360 | 0.002160 | 0.003420 | 0.005400 | 0.008540 |
| 19 | 66.2 | 0.000369 | 0.000584 | 0.000926 | 0.001470 | 0.002320 | 0.003680 | 0.005810 | 0.009180 |
| 20 | 68.0 | 0.000397 | 0.000629 | 0.000996 | 0.001580 | 0.002500 | 0.003960 | 0.006250 | 0.009880 |
| 21 | 69.8 | 0.000427 | 0.000676 | 0.001072 | 0.001700 | 0.002690 | 0.004250 | 0.006720 | 0.010610 |
| 22 | 71.6 | 0.000459 | 0.000727 | 0.001152 | 0.001820 | 0.002890 | 0.004570 | 0.007220 | 0.011400 |
| 23 | 73.4 | 0.000493 | 0.000781 | 0.001238 | 0.001960 | 0.003100 | 0.004910 | 0.007760 | 0.012240 |
| 24 | 75.2 | 0.000530 | 0.000839 | 0.001330 | 0.002100 | 0.003330 | 0.005270 | 0.008330 | 0.013100 |
| 25 | 77.0 | 0.000568 | 0.000901 | 0.001430 | 0.002260 | 0.003580 | 0.005660 | 0.008930 | 0.014100 |
| 26 | 78.8 | 0.000610 | 0.000966 | 0.001530 | 0.002420 | 0.003840 | 0.006070 | 0.009580 | 0.015100 |
| 27 | 80.6 | 0.000654 | 0.001036 | 0.001640 | 0.002600 | 0.004110 | 0.006500 | 0.010270 | 0.016200 |
| 28 | 82.4 | 0.000701 | 0.001111 | 0.001760 | 0.002790 | 0.004410 | 0.006970 | 0.011000 | 0.017300 |
| 29 | 84.2 | 0.000751 | 0.001190 | 0.001880 | 0.002980 | 0.004720 | 0.007460 | 0.011780 | 0.018500 |
| 30 | 86.0 | 0.000805 | 0.001270 | 0.002020 | 0.003200 | 0.005050 | 0.007990 | 0.012600 | 0.019800 |
| 31 | 87.8 | 0.000861 | 0.001360 | 0.002160 | 0.003420 | 0.005410 | 0.008550 | 0.013500 | 0.021200 |
| 32 | 89.6 | 0.000921 | 0.001460 | 0.002310 | 0.003660 | 0.005790 | 0.009140 | 0.014400 | 0.022600 |

| | pH: | 7.6 | 7.8 | 8.0 | 8.2 | 8.4 | 8.6 | 8.8 | 9.0 |
|---|---|---|---|---|---|---|---|---|---|
| **Temp C** | **Temp F** | | | | | | | | |
| 18 | 64.4 | 0.013500 | 0.021200 | 0.033100 | 0.051500 | 0.079300 | 0.120100 | 0.178000 | 0.255000 |
| 19 | 66.2 | 0.014500 | 0.022800 | 0.035600 | 0.055200 | 0.084800 | 0.128000 | 0.189000 | 0.270000 |
| 20 | 68.0 | 0.015600 | 0.024400 | 0.038200 | 0.059200 | 0.090700 | 0.136000 | 0.200000 | 0.284000 |
| 21 | 69.8 | 0.016700 | 0.026200 | 0.041000 | 0.063400 | 0.096900 | 0.145000 | 0.212000 | 0.299000 |
| 22 | 71.6 | 0.018000 | 0.028200 | 0.043900 | 0.067800 | 0.103400 | 0.155000 | 0.225000 | 0.315000 |
| 23 | 73.4 | 0.019300 | 0.030200 | 0.047000 | 0.072500 | 0.110300 | 0.164000 | 0.237000 | 0.330000 |
| 24 | 75.2 | 0.020700 | 0.032400 | 0.050300 | 0.077500 | 0.117500 | 0.174000 | 0.251000 | 0.346000 |
| 25 | 77.0 | 0.022100 | 0.034600 | 0.053800 | 0.082700 | 0.125000 | 0.185000 | 0.264000 | 0.363000 |
| 26 | 78.8 | 0.023700 | 0.037100 | 0.057500 | 0.088200 | 0.133000 | 0.195000 | 0.278000 | 0.379000 |
| 27 | 80.6 | 0.025400 | 0.039700 | 0.061400 | 0.094000 | 0.141000 | 0.207000 | 0.292000 | 0.396000 |
| 28 | 82.4 | 0.027200 | 0.042400 | 0.065600 | 0.100100 | 0.150000 | 0.218000 | 0.307000 | 0.412000 |
| 29 | 84.2 | 0.029100 | 0.045300 | 0.069900 | 0.106500 | 0.159000 | 0.230000 | 0.322000 | 0.429000 |
| 30 | 86.0 | 0.031100 | 0.048300 | 0.074500 | 0.113200 | 0.168000 | 0.243000 | 0.337000 | 0.446000 |
| 31 | 87.8 | 0.033200 | 0.051600 | 0.079400 | 0.120200 | 0.178000 | 0.255000 | 0.352000 | 0.463000 |
| 32 | 89.6 | 0.035400 | 0.055000 | 0.084400 | 0.128000 | 0.188000 | 0.269000 | 0.368000 | 0.480000 |

**RED = toxic zone assuming ammonia measuring 1.0 ppm**

**Measured Ammonia = Ammonium NH4+ and Ammonia NH3**

NH3 = Un-ionized ammonia; toxic to fish when > 0.05 ppm

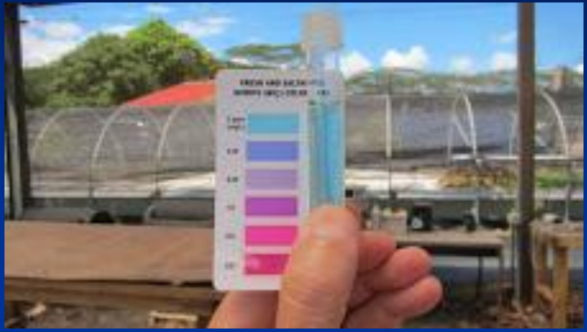
NH4+ = Ionized ammonia = much LESS toxic to fish

**Take your ammonia reading in ppm and multiply by the factor from the chart:**

Example: Temp 26 C, pH 7.0, Ammonia = 0.50 ppm: **0.50 ppm * 0.00607 = 0.003035 ppm NH3**

(Do not convert the factor to a percent by dividing by 100 - that has already been done)

# Nitrite ($NO_2$) effects on fish



- Acute high levels are toxic
- Prolonged low levels toxic
- $NO_2$ should always measure ZERO!
- $NO_2$ acts like carbon monoxide, prevents oxygen from binding to the fish's blood hemoglobin (called brown blood disease)

# Nitrate ($NO_3$)effects on fish

- Least toxic of nitrogenous forms
- Most fish can tolerate prolonged levels of >400 ppm
- Target for aquaponic systems is >100 ppm

# Let’s Test the Water!


- pH
- TAN
- Nitrites
- Nitrates


API Freshwater Master Kit

- ✓ Rinse tubes with sample water prior to testing
- ✓ Childproof caps (Press red tab and twist)
- ✓ Use the vial tops when mixing

Ammonia

**How fast this cycle occurs is highly dependent on oxygen, temperature, pH, and buffering capacity of the water.**

Nitrites

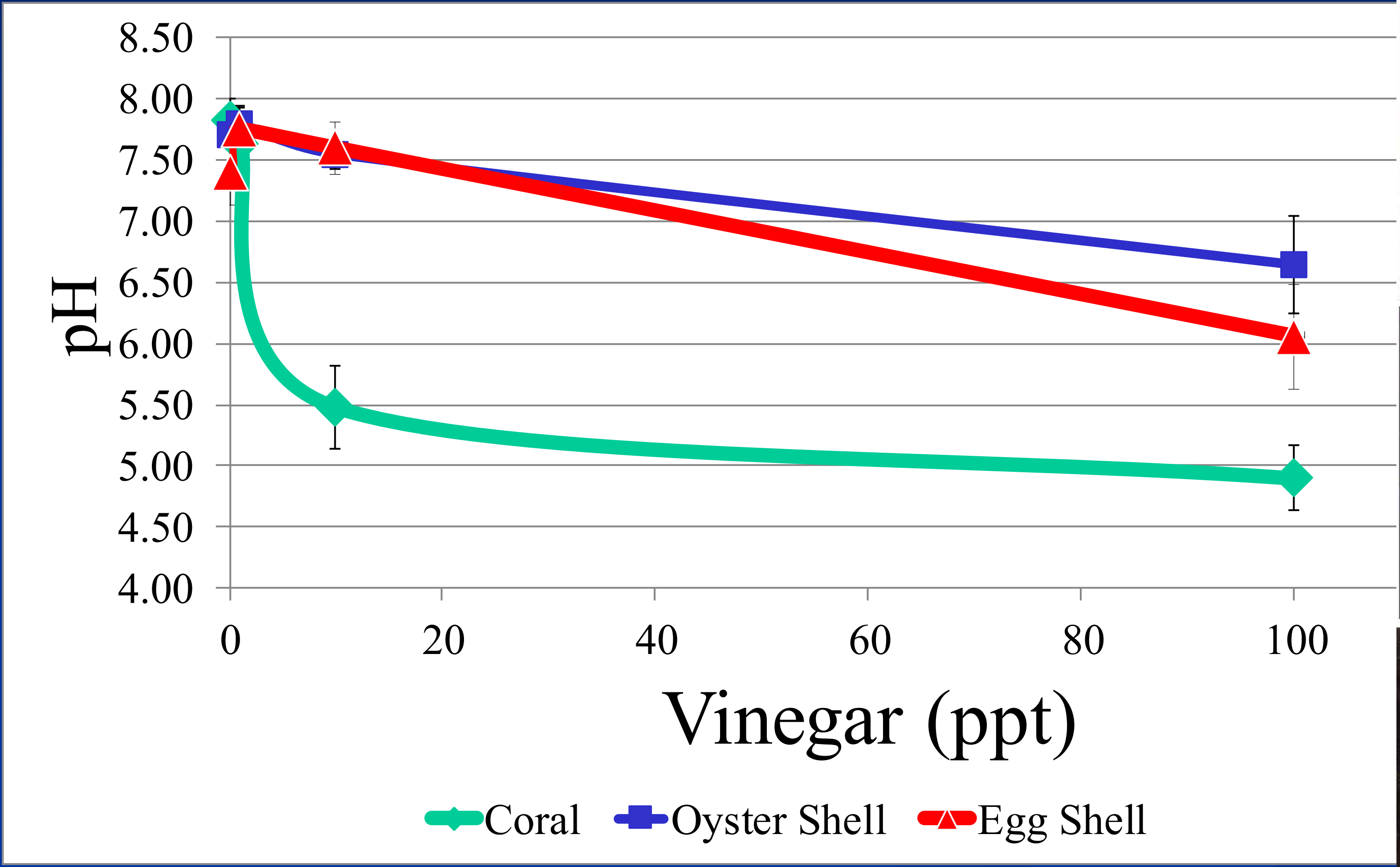
Nitrates

# Buffering Capacity

## Total Alkalinity

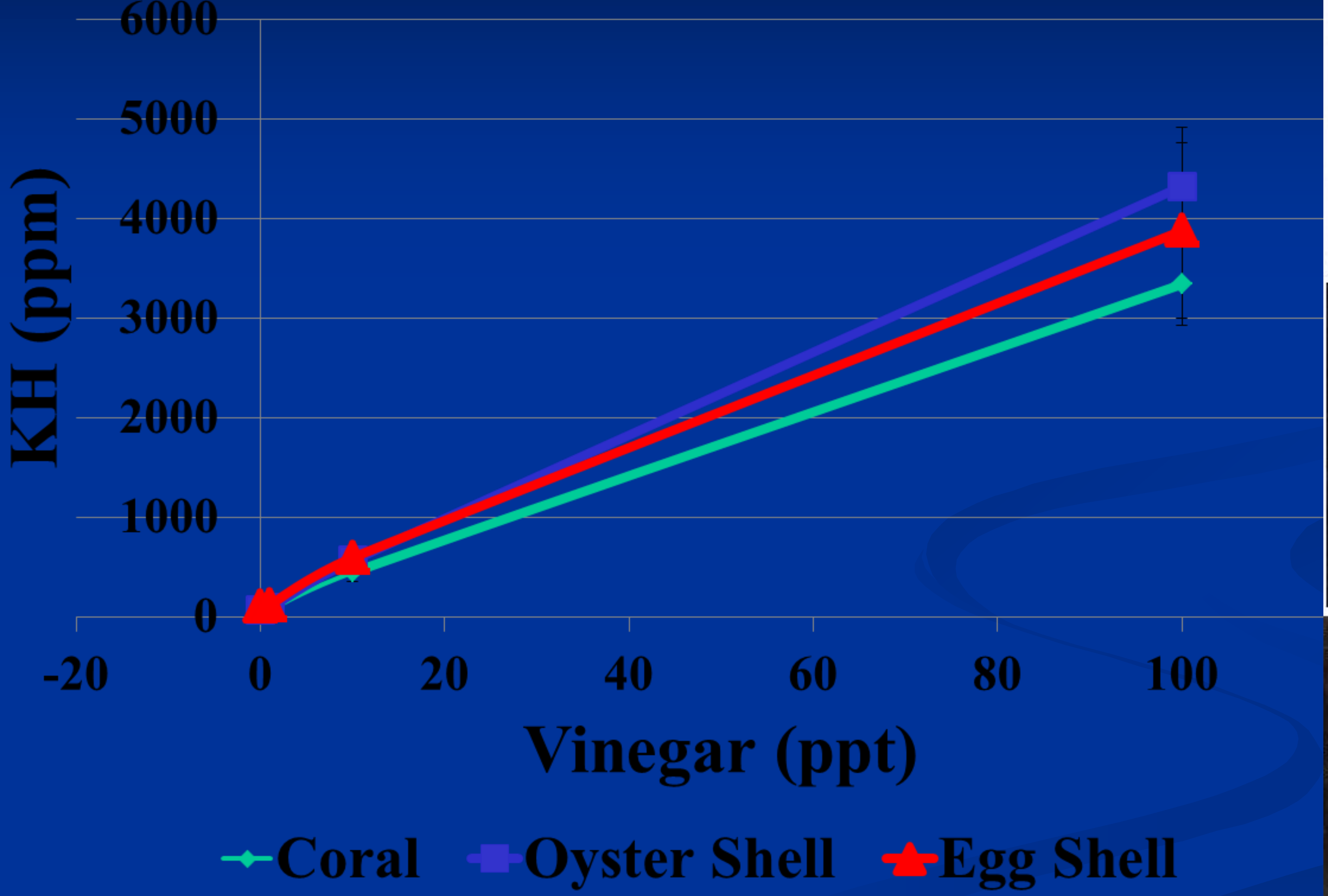
- Ability to withstand changes in pH.
- Expressed as ppm $CaCO_3$, meq/L, or dKH (KH)
- Total concentration of bases (reacts with and neutralizes acids)
  - Carbonates and Bicarbonates are the most important
  - Hydroxides, Phosphates, and Borates are minor contributors
- FW Range 50 – 200 ppm; 100 ppm ideal
- What makes a good buffer for aquaponic systems?

# Buffering Capacity of Natural Buffers at Different Concentrations of Vinegar

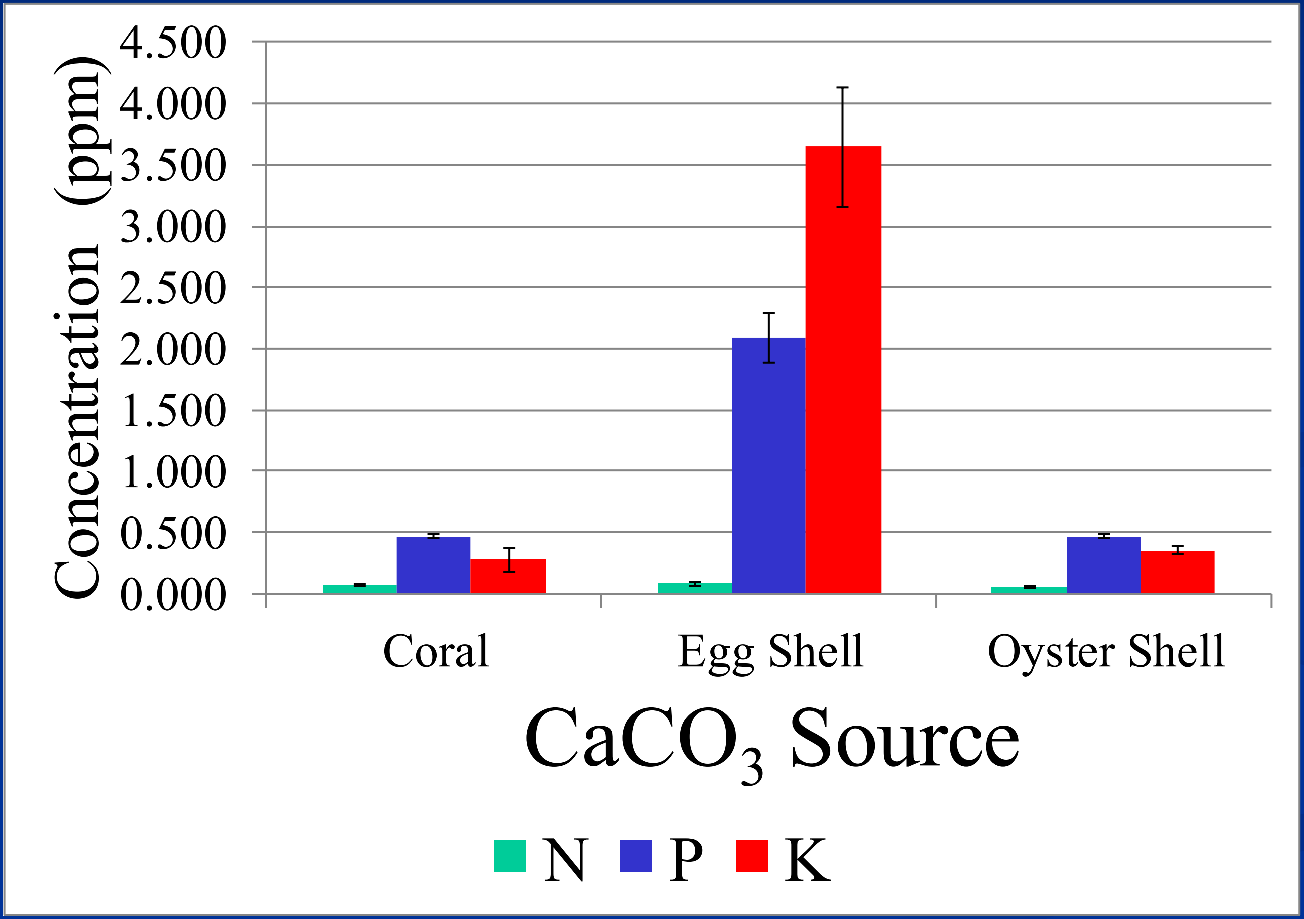





# Carbonate (KH) at Different Concentrations of Vinegar




# Nitrogen, Phosphorus, Potassium Extract from $CaCO_3$ Sources

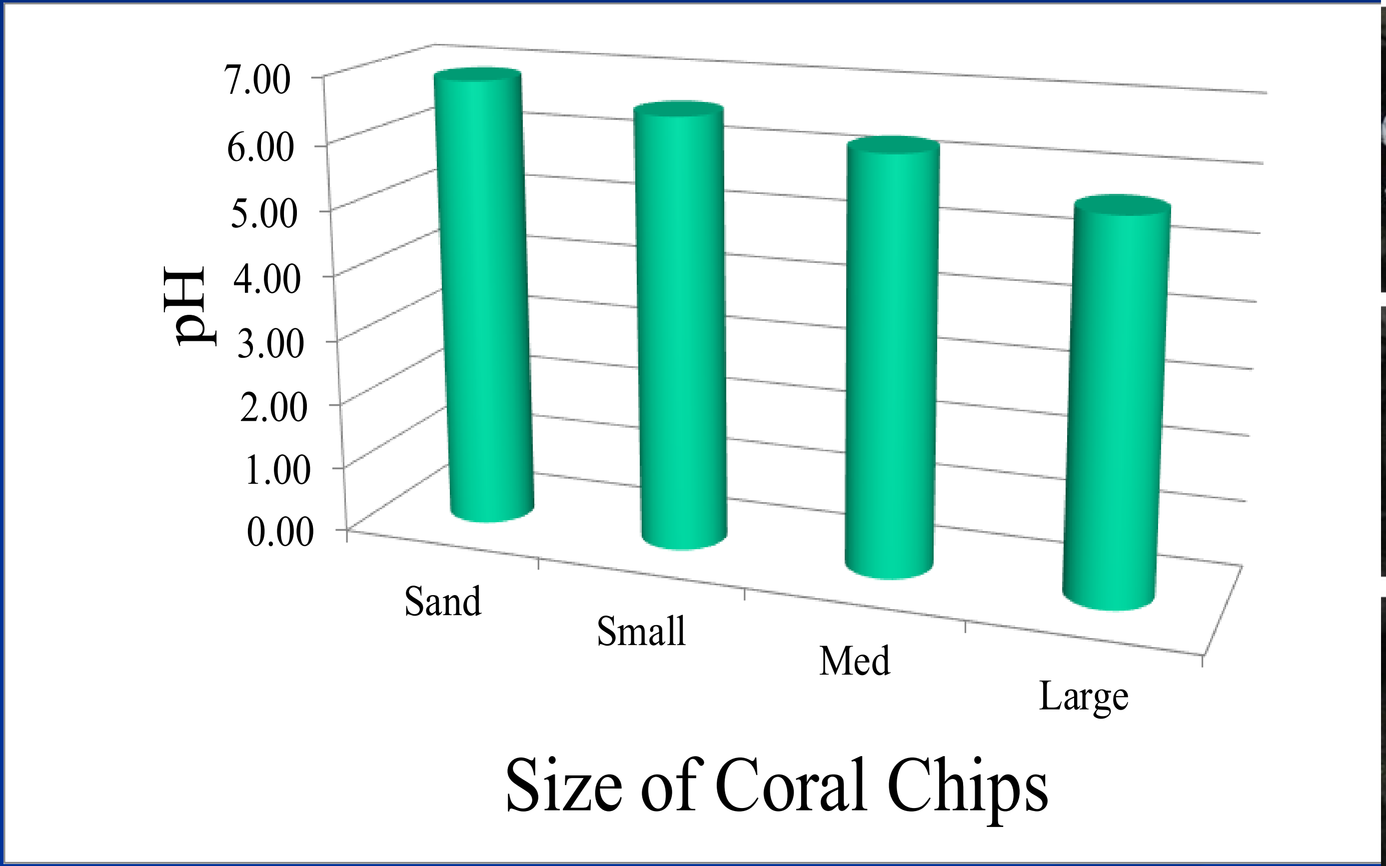



Coral Chips

Egg Shell

Oyster Shell

# pH versus Size of Coral
## (Vinegar 1:100, Coral 10 Grams)



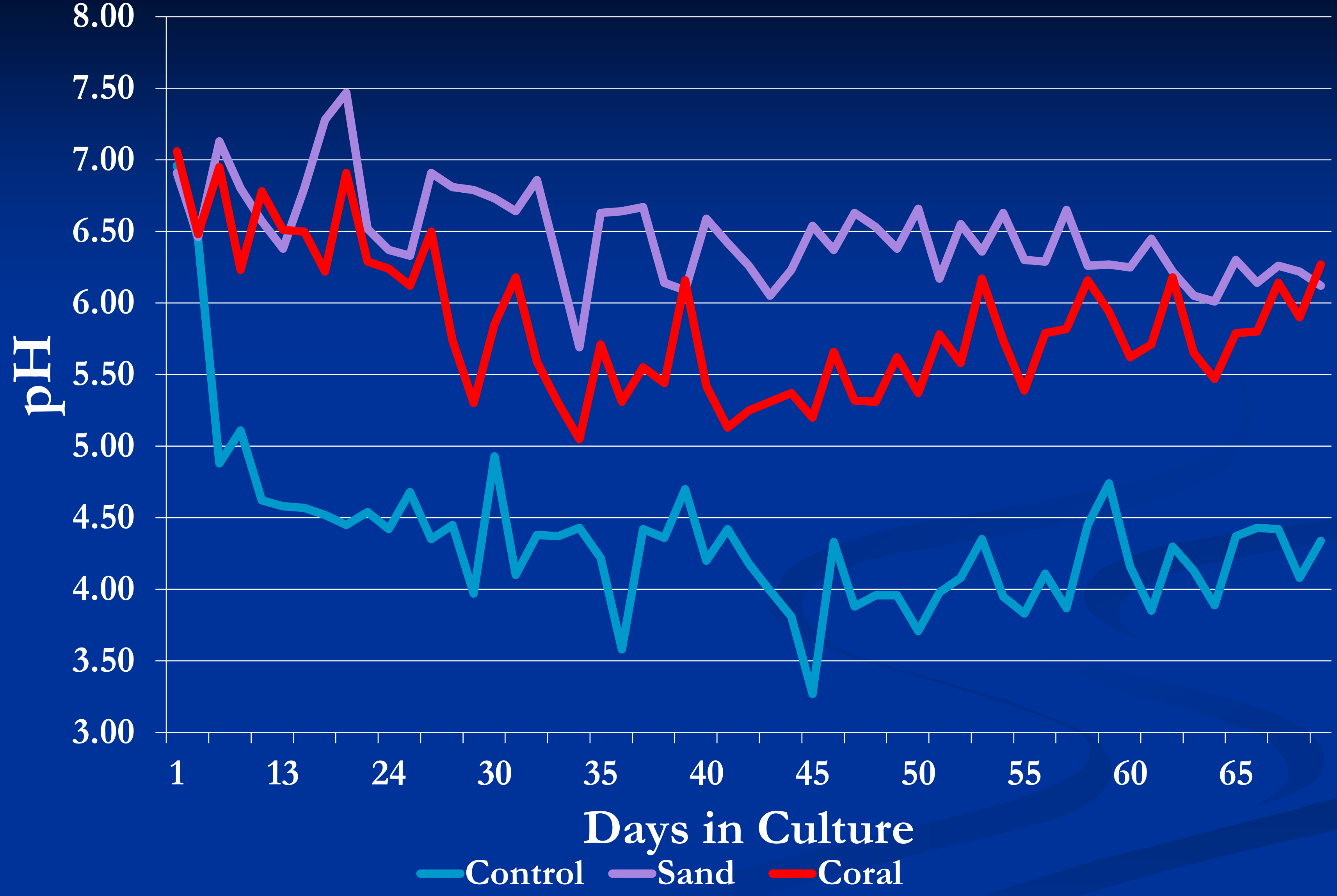

Sand

Small

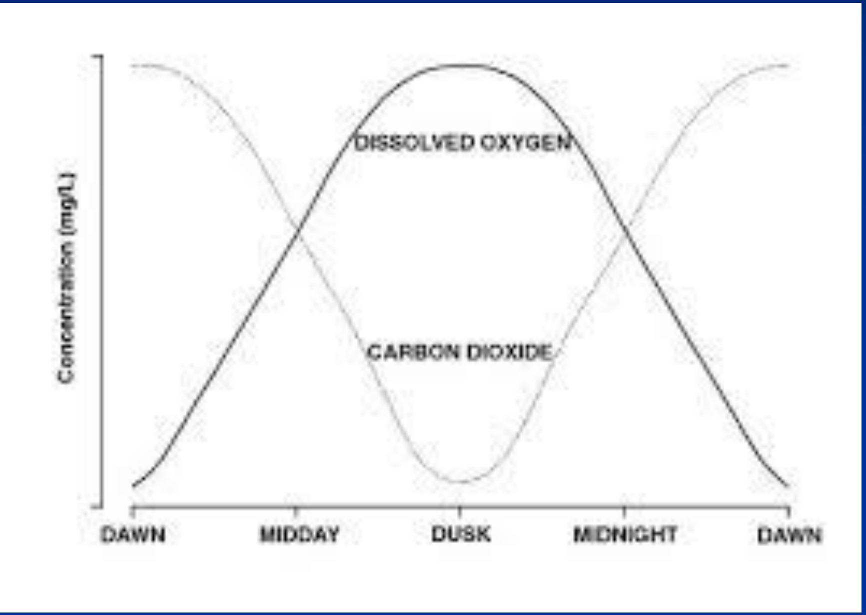
Medium

Large

# Impact of Buffers on pH

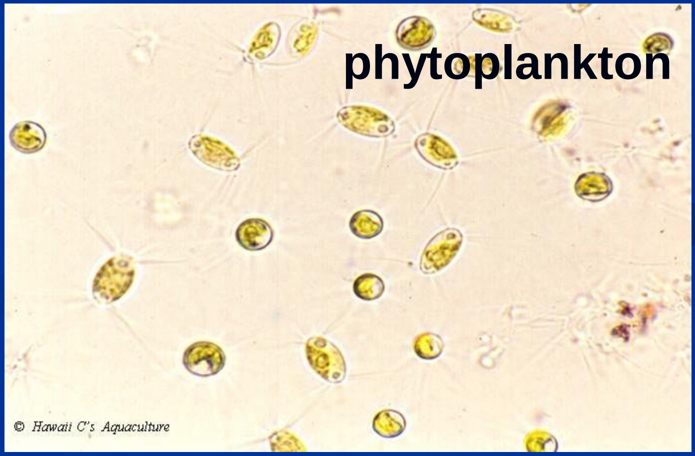


# Is my pH going to change so much that I have to worry about it?





**$CO_2$ spontaneously combines with $H_2O$ and makes carbonic acid ($H_2CO_3$ ). In a greenwater system $CO_2$ is removed by phytoplankton to make starch and sugars via photosynthesis. Less $CO_2$ means less $H_2CO_3$ resulting in fluctuations in pH.**



# Aquaponics = Tank Cover

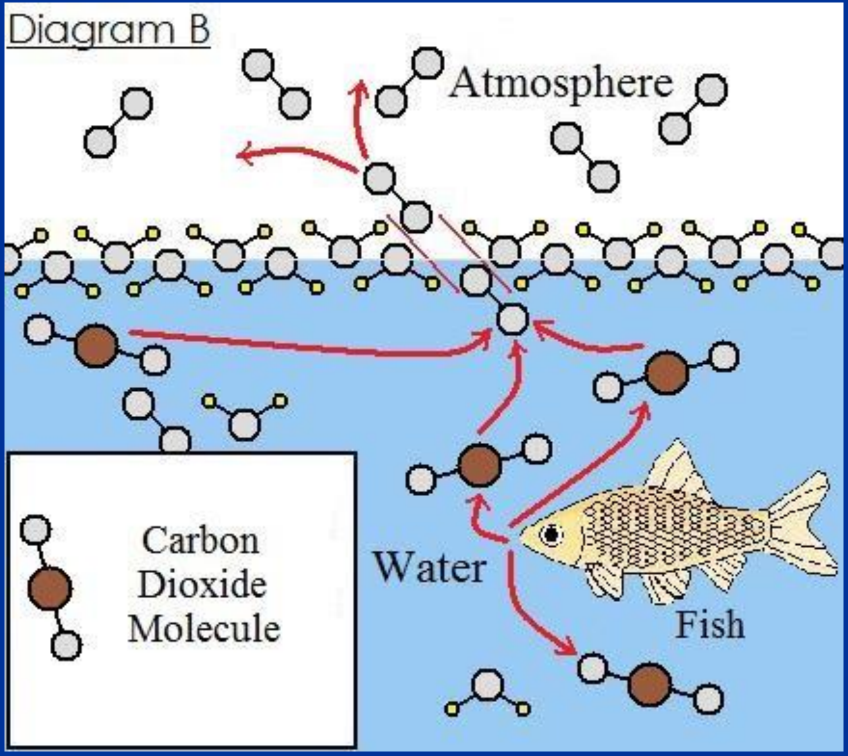
Uncovered tank

Covered tank

- 70% shade cloth
- Prevents algal growth
- Optimal conditions for desirable plants in the grow bed
- Caveat: $CO_2$ through respiration will increase over time

# What Happens to Carbon Dioxide in Water?

**Carbon Dioxide + Water = Carbonic Acid**



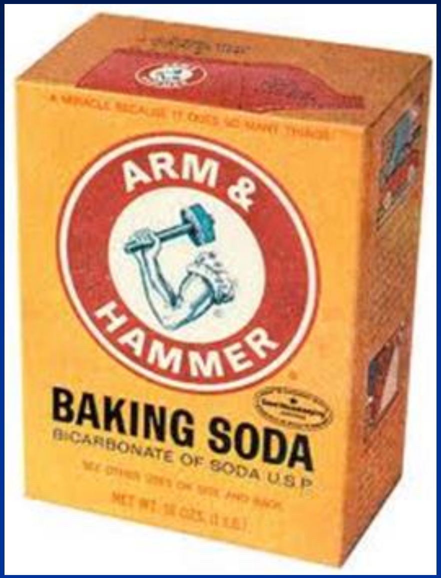

$$CO_2 + H_2O = H_2CO_3$$

$$H_2CO_3 \leftrightarrow HCO_3^- + H^+$$

# What is the pH of Water Before and After Blowing Bubbles?

- Measure pH of the sample water
- Use a straw and blow into the water bottle for 2 minutes (releasing your $CO_2$)
- Measure pH
- Did it change?

# What Happens to Baking Soda in Water?




Baking Soda + Water = Sodium Ion + Hydroxyl Ion + Carbonic Acid

$$NaHCO_3 + H_2O \leftrightarrow Na^+ + OH^- + H_2CO_3$$

$$OH^- + H^+ = H_20$$

# What is the pH of Water with Baking Soda Before and After Blowing Bubbles?

- Add approx. ½ to 1 tsp baking soda to water bottle.
- Mix well
- Measure pH
- Using a straw, blow bubbles in the water, releasing your $CO_2$
- Measure pH
- Did pH change?

# Conductivity


- Conductivity most important for plant production
- Measure of ability to conduct an electrical current
  - Direct measure of all ion content of the water
  - Higher ion content, higher conductivity
  - Measured in microSiemens/centimeter (µS/cm) or milliSiemens/centimeter (mS/cm)
  - Need an battery operated meter to measure

# Total Dissolved Solids (TDS)

- **Measure for good plant production**
- **Measure of all inorganic solids (minerals, salts, metals) dissolved in water**
- **TDS meters less expensive than conductivity meters**
- **1 ppm TDS = 2 µS/cm conductivity**

# Water Hardness

- Measures amount of ions which have lost two electrons (divalent cations – Ca, Mg, Mn, Fe) in water
- Does not measure monovalent ions such as Na, K, which is important in plant production
- Expressed in many different units (GH, ppm)
- Chemical kits available

# Conductivity vs hardness vs TDS

| Conductivity (µS/cm) | TDS (ppm) | Hardness |
|---|---|---|
| 0 – 140 | 0 – 70 | Very soft |
| 140 – 300 | 70 – 150 | Soft |
| 300 – 500 | 150 – 250 | Slightly hard |
| 500 – 640 | 250 – 320 | Moderately hard |
| 640 – 840 | 320 – 420 | Hard |
| Above 840 | Above 420 | Very hard |

***No matter what parameter you measure, what levels are ideal is dependent on the crops you grow***

# Water test methods

Test Strips

Aquarium Kits



Single Parameter Meters



Aquaculture Kits

Multiparameter meter

# Accuracy vs. Precision

High accuracy but low precision

Low accuracy but high precision

- Accuracy is measuring near the true value
- Precision is getting consistent results

20 lb — 18.9, 21.2, 19.8

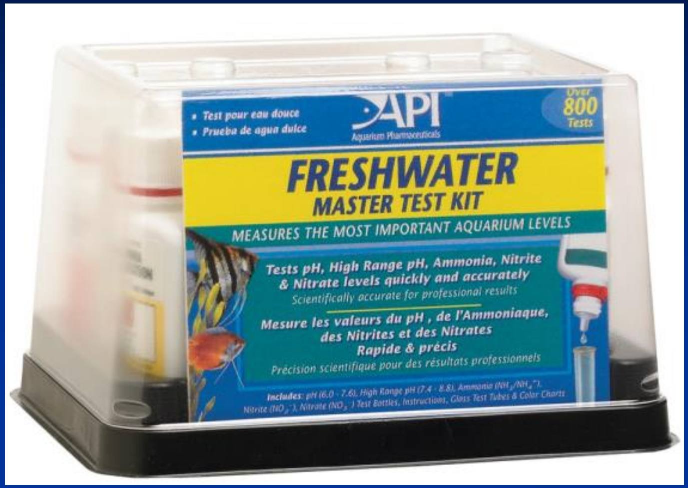
20 lb — 23.1, 23.2, 23.1

# “Aqua” Strips

- Easy to use
- Inexpensive
- Locally available
- Most tests in one strip
- Nitrate up to 200 ppm

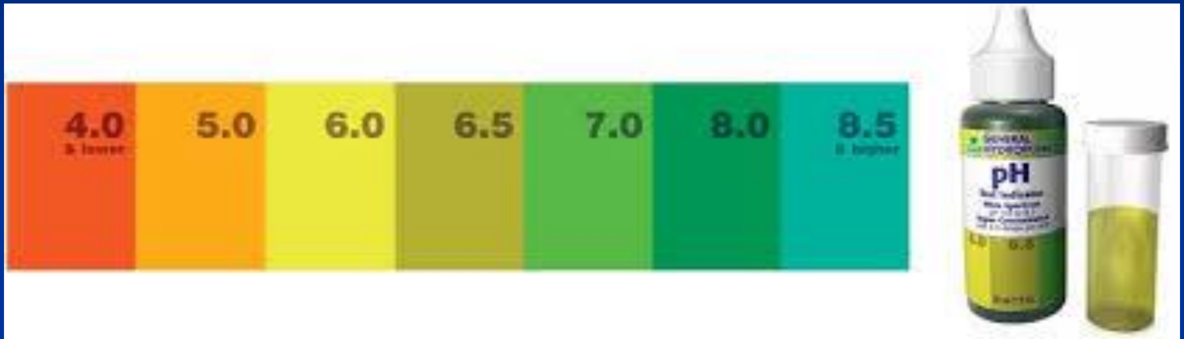
- Inaccurate
- TAN maximum 6.0 ppm
- pH minimum 6.4
- No DO strip

# Aquarium kits




- Easy to use
- Locally available
- Relatively inexpensive (online)
- Nitrate up to 160 ppm
- Precise among testers
- Individual and multiparameter test kits available
- pH minimum 6.0 ppm (Hydroponic kits go lower)
- No D.O.

# API kit vs. Hydroponic kit


Compare the 2 test kits on the water sample

# Aquaculture kits (fish farming kits)


- Hach and LaMotte most common
- Multiple of common parameters can be measured
- Inexpensive over the range and number of tests
- Accurate and precise among testers
- Generally not locally available (must be mail ordered)
- Shipping & Handling plus hazard charge
- TAN maximum 3.0 ppm
- Nitrate individual test that must be ordered separately

# Electronic Meters

- Fairly easy to use
- High range values for all parameters
- Highly accurate and moderately precise


- Some can be expensive
- Must be mail ordered
- Probes/standard separate cost

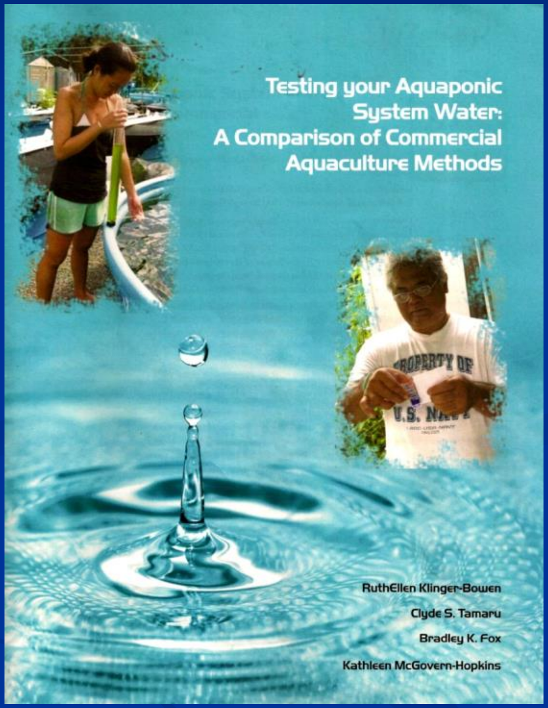
**Exceptions:**

**pH, temp, TDS meters!**

- Special care
- Calibration

# Decide what is right for YOU

- How many systems/tanks will be tested?
- How often will they be tested?
- What is the life expectancy of my water chemistry method and will I use it effectively and efficiently?
- How much do I want to spend?
  - Local vs. mail order/internet
  - Shipping/handling/HAZMAT charges
- How accurate/precise do I need to be?



# Water Chemistry

**Example of a Water Chemistry Data Log**

| Date | Tank | Method | Temp | D.O. | pH | TAN | $NO_2$ | $NO_3$ | TDS |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |

**Temp = temperature recorded as ºC or ºF**
**D.O. = dissolved oxygen (parts per million (ppm) or % saturation**
**TAN = total ammonia nitrogen (ppm)**
**$NO_2$ = nitrite and $NO_3$ = nitrate (ppm)**

# How often do I test?

Photo courtesy of Dr. Clyde Tamaru

- Temperature, D.O., pH, TDS – Daily
- TAN, $NO_2$, & $NO_3$ – Every 2 to 3 days if new system; after one month, 1x/week
- Good exercise for students to learn chemistry and ecosystem health
- Most importantly, record all measurements! If it isn't written done, it did not happen!

# Publications of interest

**FAO Small-Scale Aquaponic Food Production**

**http://www.fao.org/in-action/globefish/publications/details-publication/en/c/338354/**

**Testing your Aquaponic System Water: A Comparison of Commercial Water Chemistry Methods**

**http://www.ctsa.org/files/publications/TestingAquaponicWater.pdf**