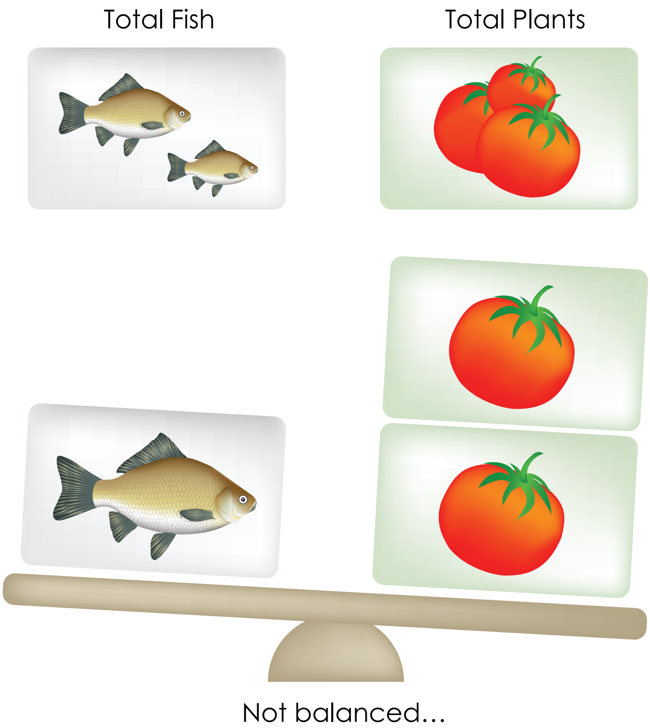
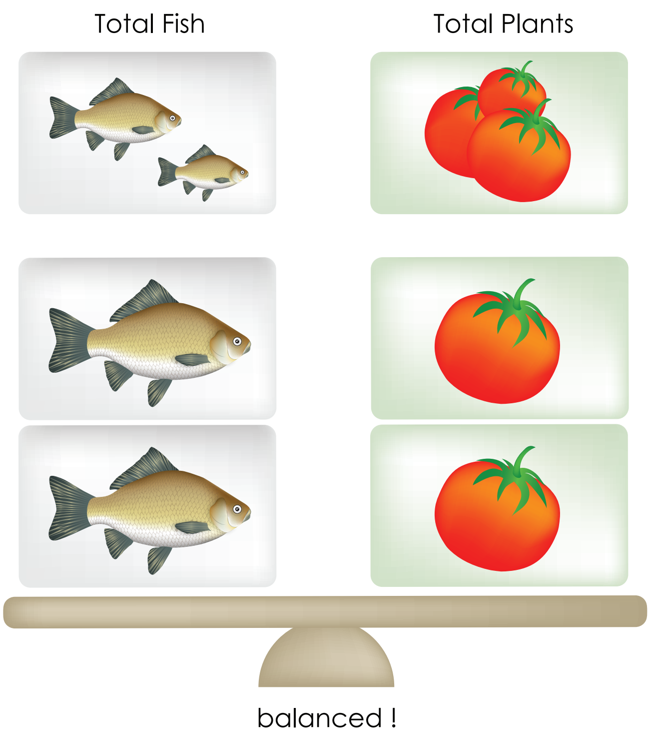
Example 2: This time an aquaponic farmer decides he/she wants to produce twice the amount of vegetables in his unit. He/she doubles the hydroponic area (number of plants) **without** increasing the fish stocking density (number of fish) or expanding the bio-filter. As the vegetables begin to grow, nutrient deficiencies begin to develop all through the vegetables as there is not enough nutrients in the fish waste to grow double the amount of vegetables. The consequence, although not as fatal as in Example 1, will be a very poor vegetable crop.

Fig 2.11 Not Balanced Unit



The major lesson from both examples is that achieving maximum production from aquaponics means maintaining an good working balance between fish waste and vegetable nutrient demand, while making sure you have enough surface area to grow a bacteria colony to convert all the waste. This balance between the fish and plants is usually called the **biomass ratio:** (Equal amount of **fish** to **plants, or more accurately put, fish feed to plant nutrient demand**) and although it is important to follow this ratio for good aquaponic food production, the workable range of fish to plant is large and forgiving.

Fig 2.12 Balanced!



How then do you balance a system?

It is important to consider this question now, but a fuller understanding will become clear later in the manual (Chapter 8). For the time-being, we will mention some of the main variables that make up the answer and a key ratio that simplifies the whole process.

The main variables to consider when balancing a unit are:

- What capacity you want your system to function (the higher the capacity the more complex a balancing act)
- Method of aquaponic production (Flood and drain method, NFT method or floating raft method – these will be discussed later)
- Type of fish (carnivorous fish or omnivorous fish)
- Type of fish food (in particular, the percentage of crude protein)
- Type of plants (leafy greens or fruiting vegetables)
- Type of plant production: Monoculture, polyculture, single batch or staggered production
- Environmental and water quality conditions (including pH, water temperature)
- Method of filtration (solids capture and removal and/or bio filtration)

Simplifying the Equation Using the Feed Rate Ratio:

Although the list above seems long and complicated, extensive research has been completed, particularly by Dr. James Rakocy at the University of Virgin Islands, to simplify the method of balancing a unit down to a single ratio called the **Feed Rate Ratio**. This ratio is a combination of the most important variables which include: fish feed, vegetable type and square meters of vegetable growing space.

This ratio below tells you the amount of fish food to use for every square meter of growing space your aquaponics system has for both leafy green vegetables and for fruiting vegetables:

Fish feed (of 32% protein)/meter squared of growing space (grams/m2) per day:

Leafy green vegetables	**20-50 grams/m2 per day**
Fruiting vegetables	**50-80 grams/ m2 per day**

N.B. the actual figures above are lower than what is recommended by Dr.Rakocy. These modified figures are based on years experience with small scale units which have a different design to the large units on which the Feed Rate Ratio was calculated.

The extra amount of grams per square meter seen for fruiting vegetables is to account for the greater amount of nutrients needed for this plant relative to leafy green vegetables. Once followed, this ratio will generate a balanced eco-system for the fish, plants and bacteria when the appropriate bio-filtration is applied. It's also important to know that although extensive research has been conducted on this Feed Rate Ratio, this is only a *guide* to balancing your unit, as other variables may have larger impacts at different stages in the season, i.e. water temperature during the winter.

Along with the **Feed Rate Ratio**, there are two other simple and complementary methods to make sure the aquaponics system is balanced:

- **Checking Fish and Plants**: Simply put, your fish and plants will tell you if your unit is balanced. If deficiencies appear on your plants then it's safe to say not enough fish waste is begin pro duced (assuming all other water parameters are optimal for aquaponics). If fish start to die it is more than likely due to toxic ammonia or nitrite levels caused by too much waste for the biofilter component to handle (assuming all other water parameter are optimal for fish).

- **Testing for Nitrate**: This method, which is far more accurate than the previous, involves testing the nitrate levels in the water weekly, using simple inexpensive water tests.

If nitrate levels are high (above 150 mg/L) over a period of 2-4 weeks, the grams of fish feed per square meter can be slightly reduced to lower the nitrate level.

If nitrate levels are low (2-5 mg/L or lower) over a period of 2-4 weeks the grams of fish feed per square meter can be increased slightly to make sure there's enough nutrients for the vegetables.

It is very important to test for nitrate levels every week to make sure system is properly balanced. Nitrate levels are also an indicator or levels of other nutrients in the water.

Fig 2.13 Nitrate Test Kit Materials

Finally, It's important to highlight again that all of the calculations and ratios referenced in this last section including: fish stocking density, planting capacity, bio-filtration amounts, will all be explained in much greater depth in the following chapters (especially in chapter 8 – Unit Management). What's important at this stage is to have an understanding of how vital it is to balance the eco-system within aquaponics and to highlight simple methods and strategies to do so.

Chapter Summary

- Aquaponics is combining fish farming and vegetable growing all in one re-circulating system.

- The same nitrification process that happens on land also occurs in an aquaponics system. In this process bacteria convert dissolved fish waste, which is essentially ammonia (NH_3), into nitrite (NO_2) and then into nitrate (NO_3) which plants use as food.

- The most important part of aquaponics, the bacteria, is invisible! In aquaponics we need to keep the bacteria healthy so the system will work. The key factors for healthy bacteria are: water temperature, pH, oxygen and surface area on media where micro organisms can grow.

- To be successful at growing plants **YOU MUST BALANCE** the amount of fish feed given daily with the amount of plants growing (Fish Feed Ratio). The ratio for leafy green plants is 20-50 grams of food per square meter of growing space per day ($g/m^2/day$); the ratio for fruiting vegetables is 50-80 $g/m^2/day$.

- If the system is not properly balanced fish will die due to ammonia toxicity while plants will show nutrient deficiencies. Good management implies the monitoring of nitrate levels by using aquarium test kits to make sure the unit it balanced.

- If Nitrate is too high (Above 120 mg/l) it is wise to reduce the amount of feed per day. If nitrate is too low (1-5 mg/l) the amount of fish feed per day should be increased.

Chapter 3) Water Quality

Chapter Introduction:

This chapter describes everything an aquaponic farmer needs to know about managing an aquaponics using freshwater. The chapter begins by setting the framework and comments on the importance of good water quality for successful aquaponic food production. Following this, each of the 5 major water quality parameters will be discussed in detail. We will also discuss how to manipulate some of the parameters. We will then apply the knowledge learned about each parameter in order to discern the best source of water to use when replenishing an aquaponics unit. Having worked through this chapter, the reader will then be able to move on to learning how an aquaponics unit is designed based on all of the limitations and factors discussed in this chapter.

1) Initial Comments: The Importance of Water Quality

Let us begin with some initial comments about water and water quality for aquaponics in order to set the framework for this chapter:

- Water is the life-blood of an aquaponics system. It is the medium through which all essential macro and micro nutrients are transported to the plants, and the medium through which the fish receive their oxygen. Thus, it is one of the most important topics to understand fully.

- There are 5 key water quality parameters for small-scale aquaponics that we will discuss in this chapter. When focusing on each parameter, always keep in mind the impact it has on all three organisms in the unit, fish, plants and bacteria. Knowing the effects of each parameter is crucial.

- Unfortunately some aspects of the water quality and water chemistry knowledge needed for aquaponics can be complicated, but don't be scared off as there are very simple water test kits that make the actual management relatively simple. We can liken it to understanding how to drive a car: you may not understand all, or even many, of the individual components that make the car run but you can still drive it successfully by following simple procedures.

- Water testing is **essential** to keeping good water quality in your system. It must be done **every week**.

Fig 3.1 Essential Water Test Kits for Aquaponics

2) Working Within the Tolerance Range for Each Organism

Before we can begin describing the major water quality parameters for aquaponics, we must first comment on ranges of tolerance for the 3 organisms. As discussed in Chapter 2, aquaponics is primarily about balancing an eco-system of 3 organisms; fish, plants and bacteria. Each organism in an aquaponics unit has a specific tolerance range for each parameter of water quality (See first table below). The tolerance ranges are relatively similar for all 3 organisms but there is need for compromise occasionally – meaning that not every organism will always be functioning at its optimum level. This will become clearer as we look at the tables below.

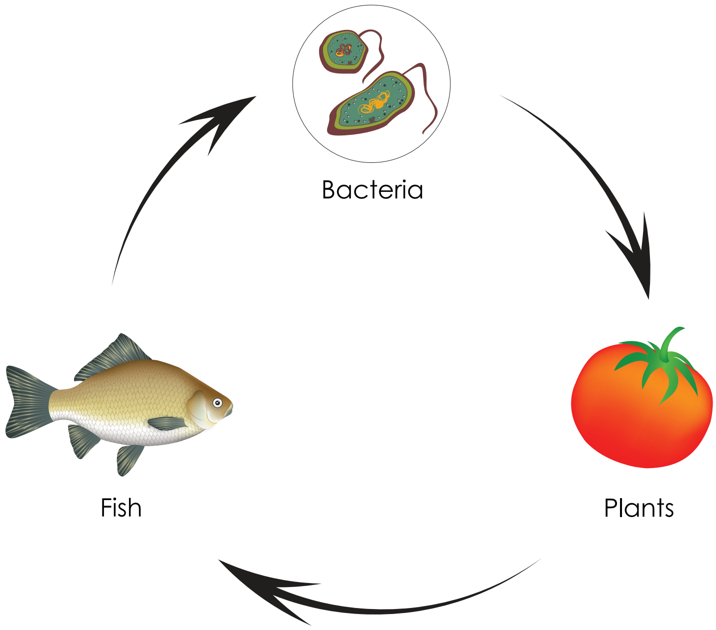


Fig 3.2 The Aquaponics Cycle

Table.3.1 General Water Quality Tolerances for Fish (Warm & cold water), Plants and Bacteria						
Organism type	Water Temp. (°C)	Ph	Total Ammonia (mg/L)	Nitrite (mg/L)	Nitrate (mg/l)	Dissolved Oxygen (mg/l)
Warm Water Fish (i.e. tilapia, catfish, carp)	22-32	6 – 8.5	<3	<1	>400	4-6
Cold Water Fish (i.e. trout, salmon, sole)	10- 18	6 – 8.5	<1	<0.1	>400	6-8
Plants (grow hydroponically)	16 – 30	5.5-7.5	<30	<1	-	>3
Bacteria (nitrifying)	14 – 34	6-8.5	<3	<1	-	4-8

The second table (below) illustrates the actual compromise for aquaponics that is needed for the key water quality parameters. The two more challenging parameters to find a compromise are **pH** and **Temperature**. Taking the figures in the first table, although the pH tolerance range for each organism is quite varied, a compromise of 6-7 (which is close to a neutral pH) can be found so that each organism can thrive.

Table 3.2 Ideal Parameters for Aquaponics (A compromise for all 3 organisms)						
	Water Temp. (°C)	Ph	Total Ammonia – N (mg/L)	Nitrite (mg/L)	Nitrate (mg/l)	Dissolved Oxygen (mg/l)
Aquaponics	18-30	6-7	<1	<1	5-120	>5

Fig, 3.3 Compromises for Water PH Levels and Water Temperature Levels for Aquaponic Food Production

For temperature, the key variables are fish and, to a lesser extent, vegetable species as bacteria and most of the popular vegetables can grow within the large tolerance range of 18-30°C. For fish, cold water species like trout will simply not grow in the higher end of this range; for warm water fish like tilapia, they will stop feeding at 18°C or lower and die in temperatures below 14° C. Given this, a large compromise range can be found at 18-30°C yet it is also important to know the optimal and vital tolerances of the fish species that is locally available (see chapter 7).

Speaking generally, we are maintaining an eco-system within water quality parameters that satisfy the successful growth of fish, vegetables and bacteria simultaneously. Yet there are some recommendations described in this chapter (ph adjustment using acid or base) to slightly manipulate the parameters so that all 3 organisms can function as best as possible in sub-optimal scenarios.

3) The 5 Most Important Water Quality Parameters

A) Oxygen:

Oxygen or Dissolved Oxygen (the term used for oxygen present in water) is essential for all three organisms, plants, fish and bacteria, to live. It is also the parameter that brings the greatest threat of fish mortality, as fish may die within hours of an extreme drop in Dissolved Oxygen (DO) within the unit. Thus, monitoring DO levels is very important yet it is difficult to do accurately as digital/liquid DO testers can be very expensive or difficult to find. Yet for small-scale units other methods are used instead such as: monitoring fish behaviour and plant performance, insuring water and air pumps are constantly circulating the water thus replenishing and stabilising the DO level.

The optimum levels for each organism to thrive are between 5-8 mg/L of DO. Some species of fish including carp and tilapia can tolerate levels as low at 1-3 mg/L, but it is much safer to have the levels higher for aquaponics, as all three organisms demand the use of DO in the water.

In general, oxygen is dissolved into the water from the atmosphere at a rate which is dependant the surface area of the water. In natural conditions fish can survive in such water, but whenever production intensifies (higher fish densities) the amount of oxygen naturally dissolved is not enough to meet the demands for fish, plants and bacteria. Thus, other sources of oxygen, such as dynamic water flow (which help dissolve more atmospheric oxygen into the water) and aerators need to be integrated into the system design. This will be discussed in Chapter 4.

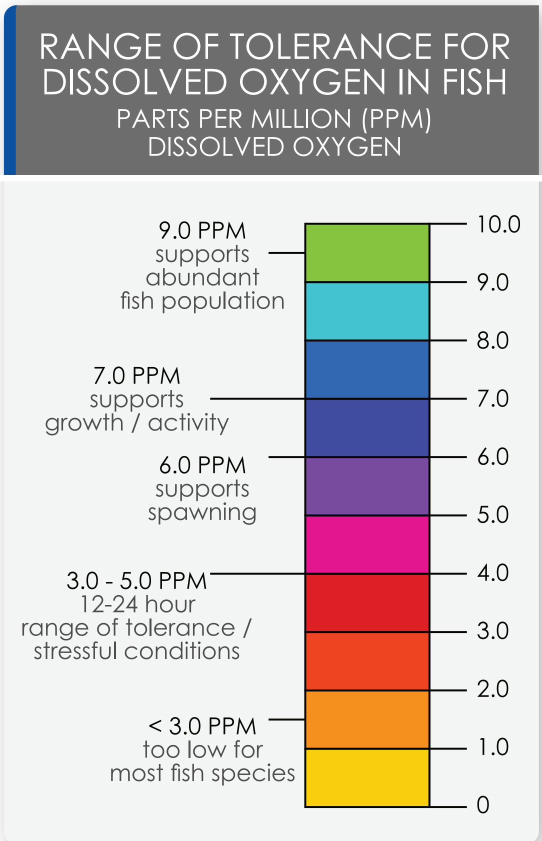


Fig 3.4 Dissolved Oxygen Tolerances for Fish

Dissolved Oxygen and Water Temperature

Water temperature and **DO** have a unique relationship which will impact aquaponic food production at certain times during the year. As water temperature rises above the optimum levels for aquaponics (18-30°C),the capacity for water to hold DO begins to decrease. As such, it is reccommeded to include aeration using air pumps, particularly to stay within the optimum levels of dissolved oxygen if water temperature increases.

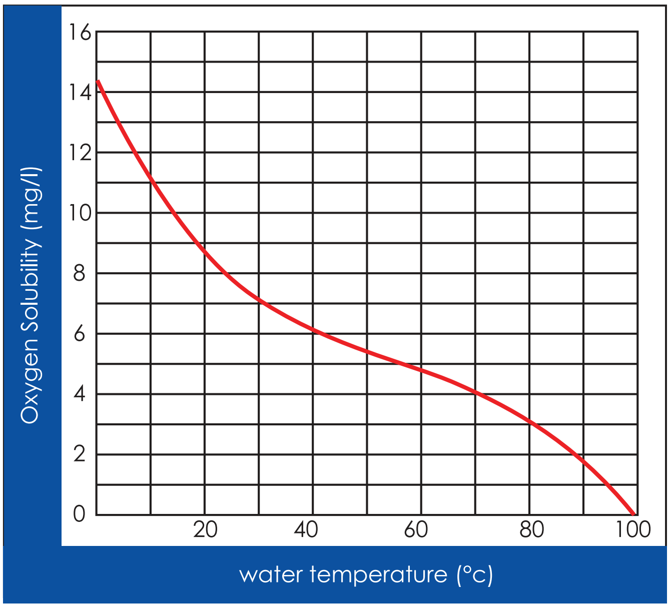


Fig 3.5 the Ratio Between Dissolved Oxygen & Temperature in Fresh Water

Table 3.3 Dissolved Oxygen Levels	
Organism type	**Dissolved Oxygen (mg/l)**
Warm Water Fish (i.e. tilapia, catfish, carp)	4-6
Cold Water Fish (i.e. trout, salmon, sole)	6-8
Plants (grow hydro-ponically)	>3
Bacteria (nitrifying)	4-8
Compromise for all 3 in Aquaponics	>5

Fig. 3.6 Diagram Showing H^+ & OH^- Ions at Different pH Levels

B) pH (Power/Potential of Hydrogen)

pH is another massively important water quality parameter for aquaponic food production, particularly because it determines the availability of nutrients for plants. In general terms, the pH of a solution or a substance is said to be either acidic or alkaline. pH is measured on a scale which ranges from 1-14 and the point on the pH scale at which both terms meet is pH =7, which is also known as neutral. Anything below this point is acidic, while anything above is alkaline. For aquaponics, we need to reach a bit further in our comprehension of pH to understand the impact it has on the health of our 3 organisms and how to properly maintain it.

The term pH is actually defined as the amount of hydrogen ions in a body of water. Pure water (H_2O) is made up of one oxygen and two hydrogen molecules bonded together. Once in a large water body, the molecules disassociate from each other into **H^+ ions** and **OH^- ions,**whichfloat in the water body looking to bond with other molecules. The pH value is the total number of freely associated **H^+ ions** in the water.

Measuring pH: There are two important aspects to explain about the pH scale that the diagram below will help illustrate:

1) **The scale is negative**; meaning that the pH of 7 has actually less hydrogen ions (H^+) than the pH value of 6.

2) **The scale is logarithmic**: meaning that a pH of 7 has actually 10 times less H^+ ions than a pH of 6 (because the scale is negative) and 100 times less H^+ ions than the pH of 5.

So for example: If the pH of an aquaponics unit is recorded at 8 and then two weeks later the value is recorded at 7, the water now has **ten times more** freely associated H^+ ions – because the scale is **negative** and **logarithmic**.

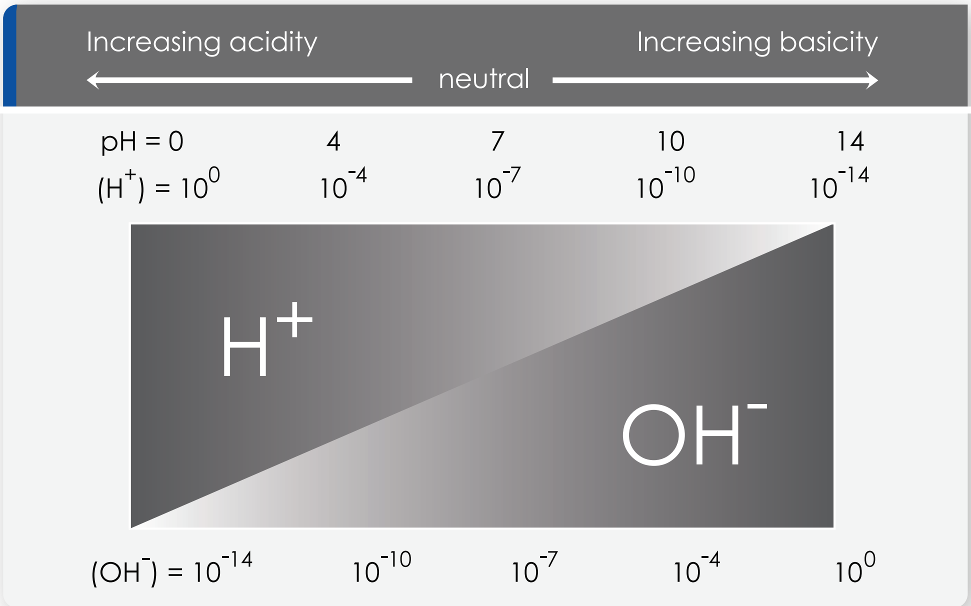


Fig. 3.6 Diagram Showing the Impact of pH on Nutrient Availability in Water

Why is pH So Important for Aquaponics?

The pH of the water has a major impact on the *plants* and *bacteria*.

For plants: the pH of water controls the plants access to micro and macro-nutrients. The diagram to the right shows the 13 essential nutrients and their availability at certain pH levels. At a pH of 6-6.5 all of the nutrients are readily available but as the pH level increases up to and beyond 7.5, nutrients such as iron, phosphorus and manganese become difficult for plants to access, leading to nutrient deficiencies.

*If the pH is **too high** (above 8): Plants cannot take up essential nutrients like iron or phosphorus.*

For Bacteria: As discussed in Chapter 2 both nitrifying bacteria groups have a wide Phtolerancerange of 6-8.5/ Yet outside these ranges, the bacteria's capacity to convert ammonia into nitrate reduces.

*If pH is **too low** (Below 6.0): ammonia levels will begin to increase, as the bacteria stop converting ammonia to nitrate, leading to an unbalanced system*

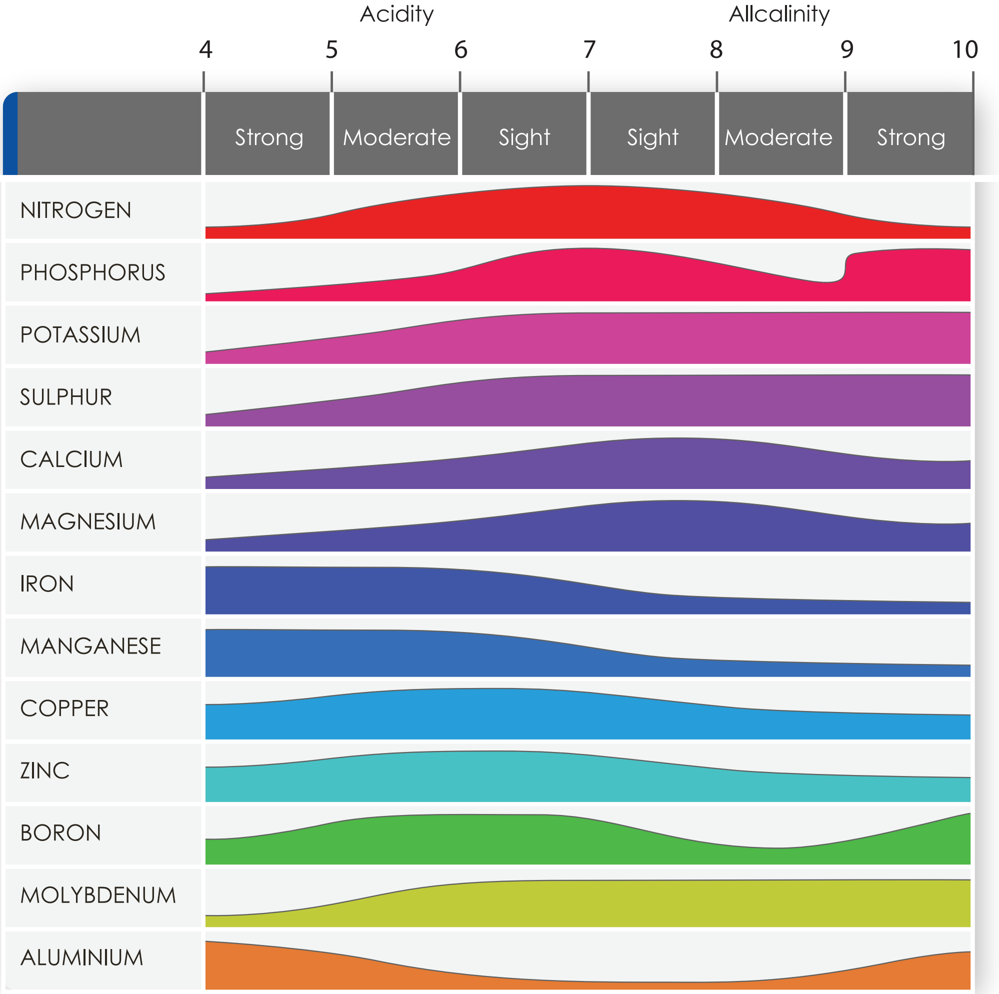


Fig. 3.6 Diagram Showing the Impact of pH on Nutrient Availability in Water

Finally, although less important than for plants and bacteria, different fish have specific tolerance ranges for pH. The most popular fish for aquaponics, such as tilapia or common carp, have a pH tolerance range between 6-8.5.

In conclusion, the **optimum pH range for aquaponics** is **6-7.** This range will keep the bacteria functioning at a high capacity, while allowing the plants full access to all the essential micro and macro-nutrients.

Table 3.4
pH Levels

Organism type	pH
Warm Water Fish (i.e. tilapia, catfish, carp)	6 - 8.5
Cold Water Fish (i.e. trout, salmon, sole)	6 - 8.5
Plants (grow hydroponically)	5.5 - 7.5
Bacteria (nitrifying)	6 - 8.5
Compromise for all 3 in Aquaponics	6 - 7

Natural processes affecting pH in aquaponics

Finally, there are many biological and chemical processes that take place in an aquaponics system that affect the pH of the water, some more significantly than others. Below is a list of the main processes that will in some way affect the pH:

- **The nitrification process**: The pH of an aquaponics system will be lowered naturally over a season, as weak concentrations of nitric acid are produced from the nitrification process (this is also dependant on Hardness levels of the water, see section 5 for more details) .
- **Fish stocking density (carbon dioxide)**: Carbon dioxide released from fish will naturally lower pH as carbon dioxide converts naturually into carbonic acid upon contacting the water. The larger the fish stocking density of the unit, the more carbon dioxide will be released, hence impacting the overall pH level.
- **Water temperature**: The higher the water temperature, the more active the fish will become, leading to greater levels of carbon dioxide being released into the water. Again, this will lower the pH level.

Table 3.5
Water Temp. (°C) Levels

Organism type	Water Temp. (°C)
Warm Water Fish (i.e. tilapia, catfish, carp)	22 - 32
Cold Water Fish (i.e. trout, salmon, sole)	10 - 18
Plants (grow hydroponically)	16 - 30
Bacteria (nitrifying)	14 - 34
Compromise for all 3 in Aquaponics	18 - 30

C) Temperature (18-30 Deg. C)

Water temperature has been mentioned in the sections on compromising the tolerance ranges, pH and Dissolved Oxygen, as it is crucial for fully functioning bacteria, healthy growing plants and the life of the fish.

The box on the right gives the optimum levels for each organism. Both warm water fish (tilapia, common carp, catfish) and bacteria enjoy higher water temperatures (22-29°C) relative to many popular vegetables (lettuce, swiss chard, cucumbers), which in general grow better in temperatures of 18-26° Celsius. For cold water fish (trout), they will struggle to grow in temperatures much great than 18°C. Thus, a large compromise range is found at roughly 18-30° Celsius. For more information on optimal temperature ranges for individual plants and fish, see chapter 6 & 7 on plant and fish production respectively, and annex 2 which provides key growing information on 12 popular vegetables.

Regarding unit management, the more constant the water temperature during the day and night, the more productive your system will be. Therefore, fish tanks and bio-filters should be protected from the sun. This will also remove the threat of algae growing in your unit (the impacts of algae growth will be briefly explained in the next section of this chapter).

D) Total Nitrogen: Ammonia (NH_3), Nitrite (NO_2), Nitrate (NO_3)

The last two parameters describe the levels of specific nutrients in the water. The first comes from the fish waste (nitrogen) and the second (carbon), is already present in the water used to fill and replenish the unit and in fish waste also. First we will discuss total nitrogen.

All forms of nitrogen (NH_3, NO_2 and NO_3) can be used or absorbed by plants, but nitrate is by far the most accessible. In a fully functioning aquaponics unit, ammonia and nitrite levels will always be from 0.25-1 mg/L as the bacteria present will convert almost all the ammonia and nitrite into nitrate.

Table 3.6 - Ammonia, Nitrite & Nitrate Levels

Organism type	Total Ammonia (mg/L)	Nitrite (mg/L)	Nitrate (mg/l)
Warm Water Fish (i.e. tilapia, catfish, carp)	3>	1>	>400
Cold Water Fish (i.e. trout, salmon, sole)	1>	0.1>	>400
Plants (grow hydroponically)	30>	1>	-
Bacteria (nitrifying)	3>	1>	-
Compromise for all 3 in Aquaponics	1>	1>	5-120

Impacts of high Ammonia (NH_3):

- NH_3 can be toxic to fish such as tilapia and carp at levels as low as 1 mg/L (*In reality, ammonia toxicity for fish is actually dependent on the pH and temperature. The relationship between ammonia, pH and water temperature is rather completed but to simplify matters, the higher the pH and water temperature, the more toxic ammonia will be to fish)*. Prolonged exposure at this level (1mg/L) and above, and fish gills will suffer damage resulting in impaired respiration.The damage to the gills will restrict other processes from functioning correctly, leading to a suppressed immune system and eventual death. At higher levels of ammonia, effects are immediate and numerous deaths can occur rapidly. However, lower levels, over a long period of time, can still result in increased incidence of disease and more fish loss.

- Root systems of some vegetables (tomatoes, cucumbers) will also suffer damages in excessive concentrations of ammonia (above 30 mg/L).

- Bacteria will suffer dramatically at high levels of ammonia. Ammonia is essentially a anti-bacterial agent and at levels of 4 mg/L and higher, it will inhibit and drastically reduce the effectiveness of the nitrifying bacteria.

Impacts of high Nitrite (NO_2):

- High NO_2 levels are mainly problematic for fish. Similarly to ammonia, problems with fish health can arise with concentrations as low as 1 mg/L of nitrite. High levels of NO_2 can immediately lead to rapid fish deaths. Also, at lower levels, over a long period of time, this can still result in increased incidences of disease and more losses.

- Toxic levels of NO_2 prevent the transport of oxygen in the fish, which causes the blood to turn a chocolate-brown colour. This can be seen in fish gills as well. Affected fish frequently appear to be oxygen-deprived, even in water with high concentrations of oxygen. Details on fish health will be covered in more detail in Chapter 7 (Growing fish in aquaponics).

Impacts of Nitrate (NO_3):

- NO_3 is a far safer nutrient for all 3 organisms than both of the above, and obviously the most accessible form of nitrogen for plants. Fish can easily tolerate levels of up to 300+ mg/L with some fish tolerating levels even as high as 400 mg/L. Extremely high levels will have a negative impact on plant roots so it is advisable to keep the nitrate levels between 5-120 mg/L.

E) Water Hardness (Measuring Carbon)

The final key parameter is water hardness, which measures the amount of different carbon-based nutrients in the water. There are two major types of hardness: 1) General Hardness and 2) Carbonate Hardness (also known as **alkalinity**). The first type of hardness does not have a major impact on the aquaponics process, but carbonate hardness has a unique relationship with pH that needs to be explained. In beginning, some brief details on General Hardness should be mentioned.

General Hardness (GH)

GH is essentially the amount of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions present in the aquaponics water. It is measured in parts per million of calcium carbonate ($CaCO_3$).

High **GH** concentrations are found in water sources such as limestone-based aquifers and/or river-beds, as limestone is essentially composed of calcium carbonate ($CaCO_3$). Both ions (Ca^{2+} & Mg^{2+}) are essential plant nutrients and they are taken up as the water flows though the hydroponic components.

Carbonate Hardness (KH):

Carbonate Hardness is the total amount of carbonates (CO_3) and bicarbonates (HCO_3), which are other carbon-based compounds, dissolved in the water. It is also measured in $CaCO_3$ mg/L. In general, water is considered to have high carbonate hardness at levels between 121-180 mg/litre. Water sourced from limestone bedrock wells/aquifers will normally have a high carbonate hardness of roughly 150-180 mg/litre.

pH & KH

Carbonate hardness in water has an impact on the pH level. Simply put, carbonate hardness acts as a buffer (or a resistance) to the lowering of pH caused by the nitrification process in aquaponic systems (i.e. natural acids produced in the nitrification process, *see page 31*). What happens is that carbonates (CO_3) and bicarbonates (HCO_3) bind to the H^+ ions present in acid, thus removing them from the water in their free state. Therefore, the pH will stay constant as the new H^+ ions from the acid are now bound to the carbonates. If no carbonates are present in the water, the pH will freely decrease as acid is produced in the aquaponics unit (*see page 32*). The higher the concentration of carbonate hardness in the water, the longer it will act as a buffer for pH.

The next section describes this process in more detail. It is a rather complicated process but it is **important to understand** for aquaponic (or other soilless culture) practitioners whose available water is naturally very hard (which is normally the case in regions with limestone or chalk bedrock) as pH manipulation will become a vital part of unit management (see section 5 for more on pH manipulation). The summary following the extended description will list what is essential to know regarding hardness for all practitioners.

A More Detailed Explanation of pH & KH in Aquaponics:

Carbonates (CO_3) and bicarbonates (HCO_3) are present in water. Particularly high concentrations are found in water sourced from limestone bedrock. These carbonates have an effect on the pH of water, meaning they have an impact on the number of freely associated H^+ ions in the water (as pH is simply the amount of H^+ ions in water). Their impact is quite simple: the carbonates bond to the freely associated H^+ ions and hence remove them from their free state in water. The equations below illustrate this bonding process:

H^+	+	CO_3	=>	HCO_3	&	H^+	+	HCO_3	=>	H_2CO_3
(Free Hydrogen)		(Carbonate)		(Bi-Carbonate)		(Free Hydrogen)		(Bi-Carbonate)		(Carbonic Acid)

Fig. 3.7 Hydrogen and Carbonate Bonding in Aquaponics

As you can see the carbonates act as buffer for the pH by locking the freely associated H^+ ions into new compounds.

In a functioning aquaponics unit, there are biological and chemical processes that take place constantly and some produce acid, which by definition contains H^+ ions. One example is the creation of nitric acid (HNO_3), which is a by-product from the bacteria involved in the nitrification process. As you can see from the chemical formula of Nitric Acid (**H-**NO_3), it is made up of 1 H^+ ion and 1 nitrate (NO_3) compound. So the constant creation of this acid in an aquaponics unit will increase the number of H^+ ions in the water body, naturally lowering the pH.

If no carbonates are present in the water, the pH will freely decrease as the acid integrates more H^+ ions into the water. But if carbonates & bi-carbonates *are* present, they will react with the nitric acid and bind the hydrogen (H+) ions from the acid, which would usually increase the acidity of the water, to new compounds created in the reaction (carbonic acid, below). The equation below shows this process:

HNO_3	+	$HCO_3^=$	=>	H_2CO_3	+	NO_3
(Nitric Acid)		(Bi-carbonate)		(Carbonic Acid)		(Nitrate)

Fig. 3.8 Bicarbonate and Acid Bonding in Aquaponics

The bicarbonate accepts the hydrogen ions and forms new compounds of carbonic acid and nitrate and the pH of the water stays neutral. When all the carbonates in the water are gone because they've reacted with the nitric acid, the pH will start to lower as there are now no carbonates (buffer) to remove the free hydrogen H+ ions.

It is essential for aquaponics that a certain concentration of carbonate hardness is present at all times in the water, as it can neutralize the acids created naturally and keep the pH at a constant. Otherwise, the unit could be subjected to quick pH changes that will have a negative impact on the fish and bacteria in particular. Fortunately, carbonate hardness is present and even abundant in most water sources available, apart from heavily filtered water. So when you replenish your unit with water from these sources you will also be replenishing the levels of carbonate hardness.

Summary of Essential Points on Hardness:

- General Hardness (GH) is the measurement of calcium and magnesium ions
- Carbonate Hardness (KH) measures the concentration of carbonates and bi-carbonates that buffer the pH (create resistance to pH change).

Optimum levels:

Hardness can be classified along the Water Hardness Scale measured in mg/L:

Soft: 0-60 mg/L; **Moderately Hard**: 60-120 mg/L; **Hard**: 120-180 mg/L; **Very Hard:** >180 mg/L.

The optimum level of both hardness types for aquaponics is roughly between **60-140 mg/L.** It is not vital to check the levels in your unit but it is important that the water you are using to replenish your unit has similar concentrations of carbonate hardness to continue neutralising acid created from the aquaponics process and buffering the pH at its optimum level (6-7).

4) Other Minor Components to Water Quality: Algae and Parasites

Photosynthetic Activity of Algae

We must mention the growth of algae and other photosynthetic growth/activity in aquaponic units and their significance regarding dissolved oxygen levels in water. Algae are microscopic green plants that grow in any body of water that is rich in nutrients (nitrate in particular) and is exposed to sunlight. Algae act as both as source and sink of dissolved oxygen, as during the day they produce oxygen through photosynthesis and then consume oxygen during the night.

Fig 3.9 Algae Growing on PVC Pipe

For aquaponics it is important to remove the threat of algae as they are problematic for many reasons: 1) they will consume the nitrates in the water 2) they can dramatically reduce the dissolved oxygen levels in water at night 3) they will clog/block the smaller pipes within the unit, leading to problems with water circulation 4) they can have a significant impact on pH.

Thankfully, removing the threat of algae is very easy to do. You can simply cover the fish tank and bio-filter with UV protective material so no water in the unit is in direct contact with sunlight. This will inhibit algae from blooming in your unit.

Fig 3.10 Algae Covering the Water Surface

Parasites, Bacteria and Other Small Organisms Living in the Water

It is impossible to completely remove all waterborne bio-threats in your unit, as nasty parasites and bacteria will be present at some stage in your unit water. The most applicable management practise to prevent bio-threats is to grow stress-free fish & plants in highly aerobic conditions with access to all their essential nutrients so each organism can stave off infection or disease using their immune systems. Chapter 8 will cover safety and bio-threats to your unit in more detail.

5) Sourcing your water:

On average an aquaponic system will use between 1-3% of the total water volume daily, depending what type of plants that you are growing. Water will be consumed by the plants and you will also lose water to evaporation and splashing. As such, you will need to top up or replenish the unit periodically. The water source use will have an impact on the water chemistry of the unit. Below is a description of some of the water sources that you can use and the probable chemical make-up of that water.

Yet before, it is important to mention another water quality parameter not previous discussed which is Salinity, simply meaning the concentration of salts (i.e. Sodium Chloride, Magnesium Sulfate) in water. Salinity levels will have a large bearing when deciding which water to use as high salinity in source water can negatively impact vegetable production. Water salinity can be measured using a simple Electric Conductivity (EC) or Total Dissolved Solids (TDS) meter or by checking recent local government reports on water quality. Although the impact of salinity on plant growth varies greatly between plants (*see Vegetable annex for more on vegetable salinity tolerance*), it is recommended to find a lower EC water source if the current source is naturally above 1500 EC (µS/cm) or 800 mg/L.

N.B. EC & TDS meters are used for hydroponics to measure the amount of salts (otherwise known as nutrients) in the water. However, they are not as helpful for aquaponics as nutrients are constantly being created by the nitrification process.

We can apply all the things we have learned about water quality in the chapter when deciding whether each source of water is applicable to use for replenishing your unit:

- **Rainwate**r: Using water collected from precipitation is an excellent source. The water will invariably have a neutral pH and very low concentrations of both types of hardness (KH and GH) and salinity. Rainwater harvesting is also a great practice to do as it will reduce the overhead costs of running your unit.

- **Cistern or aquifer water**: The quality of water taken from wells or cisterns will largely depend on the material of the cistern and bedrock of the aquifer. If the bedrock is limestone then the water will probably have quite high concentrations of hardness, which will have an impact on the pH of the water. Make sure to test the water for hardness, salinity (using an EC or TDS meter) and for any other pollutants to make sure the water is safe to use. If the hardness levels are high you will need to use a type of acid to maintain the pH of your unit within the optimum levels give above (see section 5 for more details). Salinity of aquifer water above 800 mg/L is not recommended (depending on the specific type of vegetable grown).

- **Tap/Municipal Water**: Water coming from the municipal supplies will normally be treated with different chemicals to make sure it is drinkable for humans. The most problematic standard chemicals used for water treatment is chlorine and clorimines, as high concentrations of them harm and potentially kill the fish and the bacteria. If high levels of chlorine are present, simply store the water you want to use to replenish your unit in a container for up to 48 hours, allowing all the chlorine to dissipate into the atmosphere. Afterwards, the water will be safe to use for your units. Also the quality of the water will depend on the bedrock were the initial water is sourced. So again, as in the previous source, check the hardness levels and use acid where appropriate to maintain the pH within the optimum levels above. **Never add more than 10% of municipal water in one day without removing the chlorine first.**

- **Filtered water**: Depending on the type of filtration (i.e. reverse osmosis or carbon filtering), filtered water will have most of the metals and ions removed, making the water very safe to use and relatively easy to manipulate using acid if needed.

6) Measures to manipulate pH

There are simple methods to manipulate the water pH in aquaponic units. In regions with limestone or chalk bedrock, the natural water will invariably be Hard (high alkalinity) meaning there will be a need to periodocially lower the pH using acid. In regions with volcanic bedrock, the natural water will invariably be soft (very low hardness) meaning a need to periodocially add a base or a carbonate buffer to the water.

Lowering pH:

In order to lower the pH in your system to within the ideal range for aquaponics (6-7) you have to lower the carbonate hardness levels first. You do this using acid.

How to Add Acid

First check the pH of the water and write the result down. Afterwards, take a 50 liter bucket and fill it with water from the aquaponics unit. Add 2 ml of acid to the bucket stir the water and check the pH again after 2 hours. If the pH is still above the ideal range continue adding 2ml of acid every 6 hours until you reach the ideal range. When you arrive at this range calculate the amount of acid you have added. Multiply this figure by the total amount of liters in your unit and then divide by 50 to retrieve the amount of acid you need to use to reduce the pH. Spread the amount of acid you need to use over 3-5 days to remove the threat of fish stress caused by a large change in the pH. Overtime, if the pH begins to increase past the optimal range, simply add more acid using the same calculation from above. The maximum amount of acid you should use for a 1000 liter unit in one day is 20-30 ml; any amount more and the fish will suffer.

Phosphoric acid (H_3PO_4) or sulphuric acid (H_2S) can be used to lower the pH yet Phosphoric acid is definitely preferable, particularly in term of health and safety, as it is a relatively mild acid and also phosphorus is a macro-nutrient for plants. Sulphuric acid is only recommended when the hardness levels are extremely high. It is a much stronger acid, meaning it will lower the carbonate hardness and pH using less amounts than you would need using phosphoric acid. This will prevent phosphorus toxicities that will occur if using phosphoric acid to lower pH of extremely hard water.

Fig 3.8 Checking the pH Level Using a Digital Meter

Fig 3.8 Phosphoric Acid (H_3PO_4, 85% Concentration)

Increasing pH:

If the pH level drops below 6.5 you can add a base such as calcium or potassium carbonate, which will increase the carbonate hardness and pH together. They are many natural sources of calcium carbonate that you can add into your system including: finely crushed eggshells, finely crushed sea shells, coarse limestone grit, and crushed chalk. Simply add 2-3 handfuls of these sources for a unit with a total volume of 1500 liters either straight into the unit beds/biofilter component or tied in a porous bag and suspended in the sump tank. Continue testing pH over the next few weeks to monitor the increase. Remove the bag if the pH increases past the optimal range (above 7) *N.B. if using sea shells, rinse thoroughly with fresh water to remove any salt before adding into the unit.*

Fig 3.9 Adding Sea Shells in a Net Bag to Release Carbonate into the Aquaponics Unit

7) Water testing

By now it is hopefully coming clear what the important water quality parameters are for successful aquaponic food production, and more crucially, why they are so important. In order to maintain good water quality in your unit, **it is essential to perform water tests every 3-10 days** to make sure all the parameters are within the optimum levels. To some degree the fish and the plants growing in your unit will tell you if something is wrong – as fish may stop eating or plants will show nutrient deficiencies on their leaves, but it is very difficult to identify the exact parameter that is not at its optimum using these indicators.

Fig 3.10 Fresh Water Test Kit Set (including tests for: pH, Ammonia, Nitrite & Nitrate)

Simple water tests are a mandatory requirement for every aquaponic unit. Colour coded freshwater test kits are a simple solution. They should include tests for pH, ammonia, nitrite & nitrate, and even general hardness and carbonate hardness. The test kit shown in the picture above includes colour coded tests for pH, ammonia, nitrite and nitrate. Each test involves pouring 5-10 drops of a re-agent into 5 mls of aquaponic water; each test takes no more than 5 minutes to complete. Other methods include digital pH or nitrate meters (relatively expensive, yet very accurate) or water test strips (cheapest, yet relatively accurate).

The most important tests to perform weekly are **pH**, **nitrate** and **water temperature – these will indicate whether your system is balanced or not.** The results should be recorded each week so the farmer has a good understanding regarding the condition of his unit over a growing season.

Chapter 8 (Unit Management) will go into more depth regarding measures to take if water quality problems occur, but for now, as we come to the end of this chapter, it is important to know that test kits for **ammonia** and **nitrite** are also extremely helpful in order to diagnose problems in the unit. Although they are not essential to monitor weekly they can give very strong indicators of how well the bacteria are converting the fish waste.

Other less accurate signs of ammonia include: yellowish water color, bubbles at the water surface that do not blow up, fish trying to breath while there is a lot of oxygen already.

Fig, 3.11 Coded Water Quality Test Strips

Chapter Summary

- Water is the life-blood of an aquaponics system. It is the medium through which plants received their nutrients and the fish receive their oxygen. Thus, Water Quality is very important to understand well.

- There are 5 key water quality parameters for aquaponics: oxygen, pH, water temperature, total nitrogen concentrations and hardness. Knowing the effects of each parameter on all 3 organisms (fish, plants and bacteria) is crucial.

- Compromises are made for some parameter tolerance ranges for each organism in aquaponics:
  pH range: 6-7; Water temp. range: 18-30°C; Dissolved Oxygen 5-8 mg/L

- There are simple ways to manipulate some water quality parameters. Phosphoric acid and calcium carbonate can be added in small amounts to the water in order to lower or increase the pH respectively.

- Some aspects of the water quality and water chemistry knowledge needed for aquaponics can be complicated, in particular the relationship between pH & hardness, but basic water tests are used to simplify water quality management.

- Water testing is **essential** to keeping good water quality in your system. The 3 tests that should be done **every 3-10 days are**: pH, water temper ature and nitrate to keep an accurate record of the essential water quality parameters over time. Refer to the troubleshooting table in chapter 8 to see when to test for ammonia and nitrite.

Chapter 4) Unit Design

Chapter Introduction:

Having discussed all the major concepts of aquaponics in chapter 2 and 3, we will now start to explain the theory behind the design of the 3 major methods of aquaponics. There are many design aspects to take into consideration as virtually all environmental and biological factors will have an impact on the aquaponics eco-system. The aim of this chapter is to present these aspects in the most accessible way to give a thorough explanation of each component within an aquaponics unit.

Part 1 of this chapter will discuss the factors to consider when selecting a site for your unit including: access to sunlight, wind and rain exposure etc. Having discussed where to place the unit, Part 2 will discuss the general aquaponic components essential for any method of aquaponics including: fish tanks, pumps, the biofilter, the plant growing method (hydroponic component) and associated plumbing materials. Afterwards, we will focus on the 3 methods of aquaponics: 1) the **Media Bed method** and 2) the **Nutrient Film Technique (NFT) method** and 3) the **Deep Water Culture (DWC) method**, giving detailed information on design aspects of each**.** A smaller section on **low stocking density DWC units** will then be given along with a final summary table of each method in order to compare and contrast all 3 methods**.**

Please note, this chapter is designed to only explain the essential unit components and different methods of aquaponics. For more on specific design ratios for different unit components please see Chapter 8,*Aquaponics Calculations: Determining the Size of Your Unit*. This section of the chapter gives information, figures and "rules of thumb" needed to actually design small scale aquaponic units. Also, the final annex of the manual gives a full Step-By-Step account on how to build a small-scale version of the 3 methods explained in this chapter using accessible materials worldwide.

Fig. 4.1-4.5 The Media Bed Method Design

Fig. 4.2

Fig. 4.3

Fig. 4.4

Fig. 4.5

Fig. 4.6-4.10 the Nutrient Film Technique (NFT) method

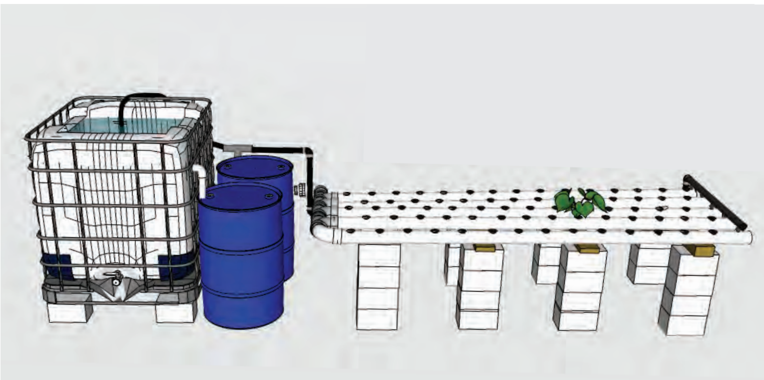


Fig. 4.7

Fig. 4.8

Fig. 4.9

Fig. 4.10