Water Quality: A Holistic Approach

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It is a mantra spoken by all involved in the fishkeeping hobby: "water quality, water quality, water quality." The novice aquarist is told by the advanced hobbyist, store employees, equipment manufacturers and magazine writers, water quality is the number one factor that determines your success in this hobby (success being measured by being able to keep the fish alive). In time, as the novice progresses to the advanced stage success will be measured by number of fish species bred and maintaining 'hard to keep' fish. This, in turn, is also a factor of controlling water quality. And the words are true: water quality means everything in this hobby. There are filters to maintain it, chemical additives to make it, test kits to measure it. But what exactly is 'it'?

A great paradox in this hobby is that even though everyone knows they want and need good water quality, few seem to be able to define what is meant by water quality, and what is good versus poor. The reason may be that water quality is more a dynamic term than a concrete set of numbers. The actual concentration of the various components that make-up water quality will vary depending on the type of aquarium. Good water quality for a marine fish-only tank might be poor water quality for a reef aquarium. Just as good water quality for a South American Discus aquarium will not be the best water quality for a Lake Tanganyikan cichlid tank.

Further, water quality is more than just the value of one or two chemical measurements. For instance, a tank with no ammonia and nitrite may, on the surface, seem to have good water quality but when, upon further inspection, dissolved oxygen is found to be zero, one has to conclude that the water quality is actually extremely poor, especially since the fish are probably dead.

Therefore, for the purposes of our discussion, I will define water quality as simply the sum of the various chemical, biological and physical characteristics of water. Whether the totality of the characteristics is good or poor depends upon the fish and invertebrates to be kept in the system in question.

In reality, to be successful in managing water quality, this holistic approach, as I call it, entails thinking about not only what the actual measurements are and should be but also what may have caused them to get that way and how the situation can be rectified (*e.g.,* curing the disease not just masking the symptoms). Thus, to be water quality aware requires a basic knowledge about what the various water quality characteristics are and how they affect the organisms in the aquarium. It also means thinking about the system before adding the many different kinds of water conditioners and making wholesale changes. Most freshwater fish tolerate a wide range of water quality values but they do not always survive sudden changes.

Basically, water quality is a report card on the aquarium water. The components of this report card would include the items listed in Table 1. Some components I define as critical. This means that if they are not within a certain range loss of aquatic life will occur rapidly (in hours versus days or weeks). Usually the critical ones are the same for all types of aquaria (*i.e.,* all aquaria must have a sufficient amount of dissolved oxygen), and while the target value may vary slightly, it must be maintained within a narrow range.

Non-critical factors are those that can slowly increase (or decrease), usually greatly, and the fish will not die (*e.g.,* phosphate, nitrate and total hardness). For different aquarium set-ups different water quality factors will gain (or lose) import. For example, if the goal is to spawn Discus soft water is important but Discus and many other South American fish will live in hard water. Thus, water hardness only becomes a significant factor only under certain circumstances.

Before setting-up an aquarium and stocking it with fish, you should have at least a rough idea of the water quality needs of the fish so the system can be tailored to meet those needs. Reading books and magazines, asking fellow hobbyists and seeking advice at your local fish store, gather this data. Once, the general characteristics are known decisions came be made about what products may have to be purchased to get the water quality to where it should be.

As stated above, water quality is dynamic. As an aquarium is stocked with fish and the fish fed, many physical, chemical and biological processes begin which can change the water quality - usually for the poorer. These processes include the continued addition of acid (via nitrification) that causes the pH to always tend to drop. Others are the constant formation of nitrate and inputs of dissolved organic compounds.

The way these changes are counteracted is through the correct selection of the filter system. The purpose of the filtration system is to control and slow the changes so as to maintain the water quality at an acceptable set of values. The other, very important, way to stop deteriorating water quality is through a program of regular partial water changes.

Below is a short introduction to the major water quality factors of principal concern for an aquarium. A good working knowledge of these will help you understand the biological, chemical and physical characteristics of your aquarium water which will hopefully lead to better management practices.

Ammonia is the principal excretory product of most aquarium organisms. Inputs of ammonia cannot be eliminated from the aquarium. But ammonia is toxic, acutely and chronically, to fish and invertebrates thus it is a critical water quality factor. Ammonia should be maintained below 0.1 mg/L-N (total ammonia measured in unit of nitrogen) in the aquarium. The most efficient way to do this is by the establishment of a biological filter. A biological filter is a collection of naturally occurring bacteria that oxidize ammonia to nitrite, and other bacteria, which then convert nitrite to nitrate.

Nitrite is formed either by the oxidation of ammonia (nitrification) or the reduction of nitrate (denitrification). Nitrite is toxic to fish and some invertebrates and should be maintained below 0.1 mg/L-N. It is also a critical water quality factor. The bacteria that oxidize nitrite to nitrate seem to be more easily effected (negatively) by sudden changes in water conditions and poor water quality (low pH, high organics), especially in marine aquaria. Any sudden increase in the nitrite concentration of an established aquarium is cause for immediate concern on the part of the hobbyist. The filter should be checked and serviced when high nitrite is detected. A partial water change should also be performed.

Nitrate is the end product of nitrification. The vast majority of aquaria accumulate nitrate as they do not contain a denitrifying filter. Nitrate levels of several hundred milligrams per liter are common in aquaria (small ones like hobbyists have or large ones like the Living Seas in Epcot). In general, nitrate should be maintained below 50 mg/L (measured as NO_3--N) but it is not a critical water quality factor. The most common ways to reduce nitrate are water changes and growing live plants in the aquarium. More sophisticated systems such as denitrifying filters are also available. A denitrifying filter creates an anaerobic region where anaerobic bacteria can grow and reduce nitrate to nitrogen gas. But they can be complex and easily disturbed which kills the anaerobic bacteria. A poorly run denitrifying filter does not convert nitrate all the way to nitrogen gas but instead produces nitrite. This can poison the tank, killing the occupants. For some aquaria, such as marine reef tanks nitrate can be a nuisance as it may promote the rampant grow on algae. In this case, aquarists strive for the lowest nitrate value possible (10 mg/L or less NO_3-N).

pH is the measure of the hydrogen ion concentration in water. A fundamental difference between freshwater and seawater ecosystems is that the pH in seawater changes very little over time. The pH of freshwater systems, on the other hand, can change drastically over short periods of time. Thus, most freshwater fish can tolerate a change of up to 3 or 4 full pH units (depending upon the time interval and the particular fish). Marine fish do not display the same resiliency. They can withstand a slow pH change of perhaps 0.5 to 0.8 pH units but only down to about 7.5.

Alkalinity is the buffering capacity of water. Buffering is the capacity of the water to accept acids without a drop in pH. Acids are produced naturally in the aquarium as a by-product of the nitrogen cycle, among other processes. Most aquaria situations (reef tank, marine fish tank, African reef lake cichlid tanks) need a relatively high level of alkalinity. But other aquarium set-ups, such as South American Discus tanks and Southeast Asian barb and danios set-ups, would normally have a low pH (5.8 to 6.8). This is hard to achieve when the water has alkalinity. Thus, before the pH can be successfully lowered the alkalinity must first be consumed. This can be done by adding acid until the pH drops or by removing the alkalinity by deionization or reverse osmosis.

Total Hardness is the sum of the calcium and magnesium in the water. Hardness is not much of a concern for marine fish tanks except for reef aquaria where calcium is important as it is utilized by corals to build their calcareous structure. For reef tanks, 350 to 400 ppm of calcium is recommended. For freshwater aquaria, total hardness is not generally a concern unless your water is at one extreme and the fish you wish prefer water at the other extreme. Most fish can tolerate a wide range of hardness values and it is not worth the effort to continually adjust hardness. If one wishes to adjust the total hardness it can be lowered by using ion exchange resins. To increase hard add calcium and magnesium.

Many hobbyists and writers confuse alkalinity, pH and total hardness. While related in a general fashion, they are distinct water quality characteristics each with a specific definition. There is no one right set of values for these measurements - it depends upon the type of aquarium (and, therefore, the fish) you want to have. It is important to realize they are not the same thing and there are different ways to raise, lower and remove them.

Phosphorus is basically a nutrient for algae and plants, it is not toxic. A large amount of phosphorus in an aquarium can lead to unsightly algae blooms. For most aquarists, the easiest way to reduce phosphate is with a water change. Phosphate inputs cannot be entirely eliminated as fish feeds are heavy in phosphate (in various forms) as it is an important part of the basic energy system of living cells. Aquarium test kits only measure soluble reactive phosphate (also called orthophosphate) but much phosphate is bound to organic matter and not measured by these test kits.

Dissolved Oxygen is the most critical water quality characteristic of the aquarium. Fish and other aquatic organisms cannot survive in water devoid of oxygen. Chronic low levels of oxygen lead to stress and secondary bacterial infections. The amount of oxygen water can hold is a physical constant that depends mostly upon the water temperature and salinity. Warm salty water holds considerably less oxygen than cold freshwater. The most effective way to increase the oxygen concentration in water is to agitate the water surface. While bubbling air in the water does work, it is not as efficient as vigorous surface movement.

Total Dissolved Solids (TDS) is a measure of the amount of salts dissolved in the water. TDS is not a critical water quality measurement but can be used as an indicator of deteriorating water quality. Over time, the TDS of aquarium water will increase. This is due to increased dissolved substances from feeding, water evaporation and other processes. Unless regular water changes are performed these substances will increase as reflected by the TDS measurement.

Dissolved Organic Compounds (DOC) are the result of continuous biological and chemical processes that occur in the aquarium that cannot be eliminated. High levels of DOC inhibit nitrification and increase the biochemical oxygen demand (BOD) (high BOD reduces the amount of oxygen in the water that is available to the fish and invertebrates). The general hobbyist cannot be measure DOC (or BOD) unless they have access to a well-equipped water quality testing laboratory. Fortunately, DOC is easily reduced and controlled by regular water changes and use of activated carbon. Protein skimmers also remove dissolved organic compounds.

Temperature is a critical factor in that the most common fish in the hobby are tropical fish. Generally this means they come from tropical regions where the water is warm. In reality, today most of the freshwater fish in the trade come from fish farms in Florida and Southeast Asia even if they were originally from African, South American or other regions. Still, they require a water temperature of 76°F (24.4°C) to 80° F (26.7°C), sometimes even higher. Tropical fish do not tolerate quick temperature changes so be careful when adding fish to a tank or changing water - try to get the water temperatures of the two waters close before mixing.

Turbidity is not a critical factor; many fish do not naturally live in crystal clear water. But if the aquarium water gets too turbid such that it reaches the point of coating the gills of the fish, they could smother. This is an obvious problem and must be fixed immediately by mechanical filtration and changing the water.

Chlorine is a critical factor as it can quickly kill fish even at very low levels. Chlorine comes from treatment processes of drinking water for human consumption. By law, the water reaching your house must be free of deleterious bacteria. The most common way to achieve this is by maintaining a certain level of chlorine (chloramines) in the water. This disinfects the water, but is can also kill your fish. To get rid of chlorine use one of the many products available for treating your tap water.

When discussing water quality fit for human consumption and recreation, the prime concern is to eliminate bacteria that can cause heath problems. This is generally not a problem in an aquarium. Most of the bacterial infections in fish aquaria are the result of the fish being stressed due to shipping, handling or chronic poor water quality. After a period of time, the natural resistance of the fish weakens and bacterial infections result. These are called secondary bacterial infections because they are the result of another problem that if not fixed means the bacterial infection will reoccur. Other concerns are pesticides and other toxic compounds. These should not be present in a municipal drinking water supply, and therefore, are not considered here. You can call your local water authority and request a copy of their annual water quality report that should tell you just what is in the water you drink (and use to fill your aquarium).

Maintaining good water quality requires diligence and observation. A regular schedule for testing the critical and major water quality characteristics should be established. The values should be noted in a logbook and, if possible, graphed so any changes from normal can be easily spotted. Common things that can change the water quality are; evaporation (only water evaporates thus salts become concentrated), nitrification (produces acid which consumes alkalinity after which pH drops; also produces nitrates), overcrowding and overfeeding (results in increased oxygen consumption from the aquarium water).

It is also wise to practice common sense about water quality. Don't become fanatical about trying to reach and maintain a certain water quality value. The goal should be stability. Most fish can adapt to a wide range of values but they do not tolerate sudden changes well. Maintaining a constant stable environment will go a long way towards ensure your fish livelong, healthy lives. The easiest way to do this is by regular water changes.

Table 1. Values or range of values for water quality for three types of aquaria. In many cases there is no actual data for the factor in question but research has shown the factor to be harmful. Most of the non-critical factors values given are an acceptable range but there are fish that can live outside some of these ranges.

Aquarium Water Quality Report Card

	Freshwater	Seawater-Fish	Seawater-Reef
CHARACTERISTIC			
Chemical			
Ammonia* (mg/L-N)	0.1	0.1	0.1
Nitrite* (mg/L-N)	0.1	0.1	0.1
Nitrate (mg/L-N)	50.0	50.0	10.0
pH	5.0 - 9.0	7.8 - 8.4	8.2 - 8.4
Alkalinity (mEq)	0 - 3	2.0	2.4
Total Hardness (mg/L $CaCO_3$)	0 - 200	NA	350-400 as Ca^{2+}
Orthophosphate (mg/L-P)	1.0	1.0	0.1
Dissolved Oxygen* (mg/L)	>7.0	>6.0	>6.0
Total Dissolved Solids (µS/cm)	50 - 2,000	na	na
Salinity (ppt)	NA	28 - 34	28 - 32
Chlorine (mg/L)	0.01	0.01	0.01
Dissolved Organic Compounds	ND	ND	ND
Phenol	ND	ND	ND
Tannins	ND	ND	ND
Biological			
Bacteria count	ND	ND	ND
Bacteria type	ND	ND	ND
Biochemical Oxygen Demand	ND	ND	ND
Physical			
Temperature* (deg F)	76 - 86	76 - 82	76 - 80
Color (Pt/L)	1.0	1.0	1.0
Turbidity (NTU)	0.1	0.1	0.1

* Critical Water Quality Factor
NA - not applicable to this type of aquarium
ND - no data for aquarium systems available

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