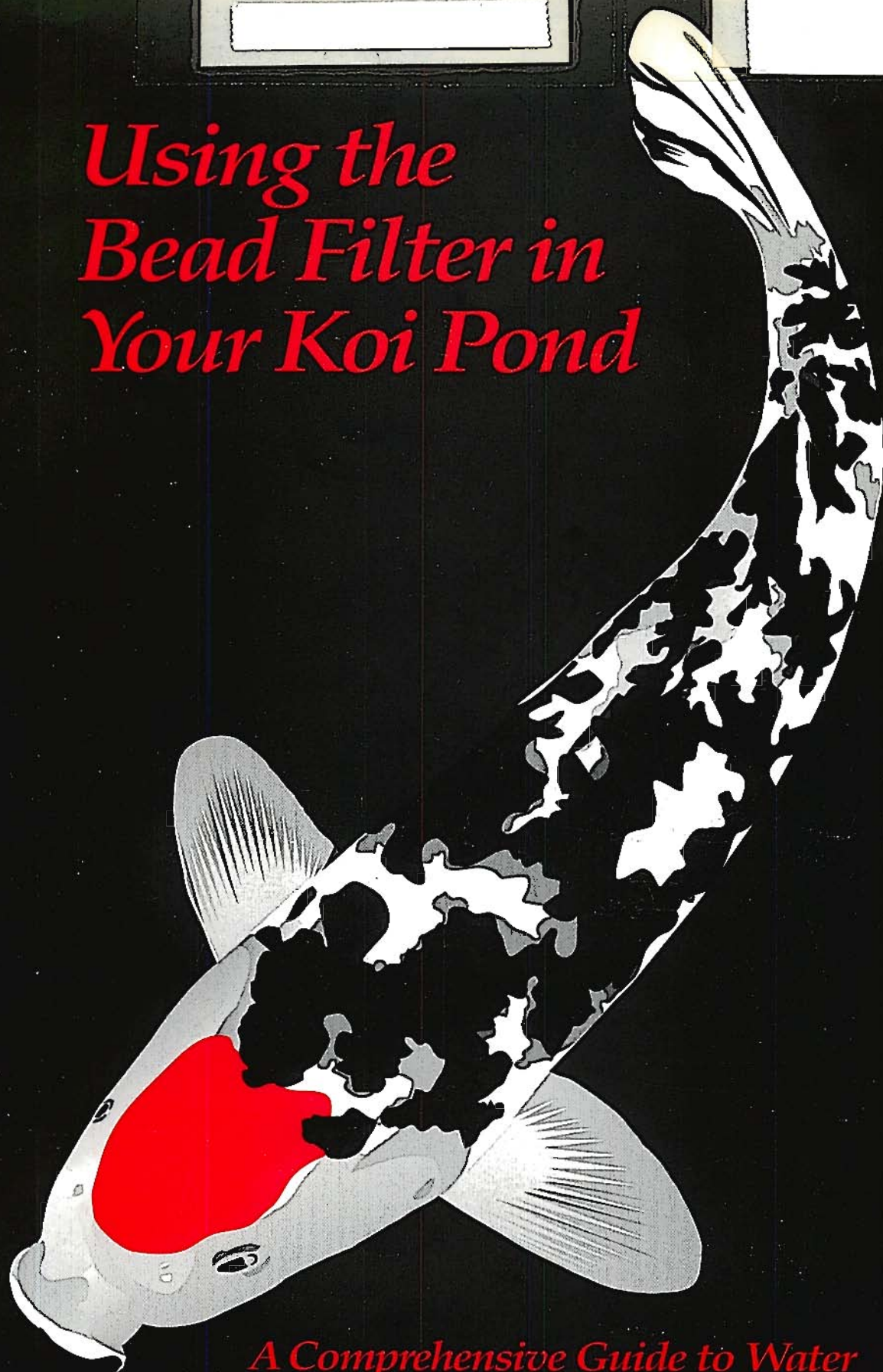# Using the Bead Filter in Your Koi Pond

A Comprehensive Guide to Water Quality Management

Ronald F. Malone
Kelly A Rusch
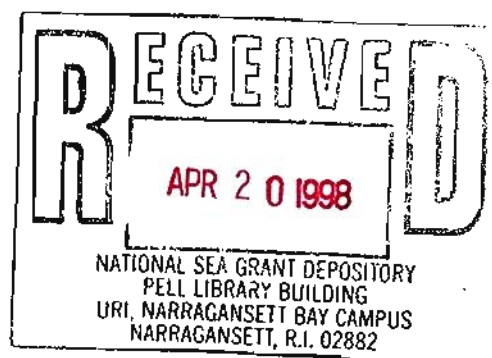
Using the Bead Filter in Your Koi Pond

A Comprehensive Guide to Water Quality Management

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Koi hobbyists can be described as a cross between aquarium enthusiasts and natural pond owners. On one hand, koi owners desire the clean, clear waters exhibited by aquariums so that they can see their fish. On the other hand, size dictates that koi ponds be placed in the outdoor environment, as are natural ponds, where they are subject to the same climatic variations. The desires of the owners and the realities of the environment present a management situation unique to koi hobbyists.

The first step in maintaining a successful koi pond is understanding the difference between koi ponds, which are generally lined, and the typical mud ponds used to stock bass, catfish, and sunfish. Mud ponds have the capacity to naturally assimilate wastes and maintain adequate water quality for the survival of aquatic organisms. In lined ponds, however, the burden of water quality maintenance is in human hands. Consequently, the management of recirculating koi ponds requires a basic knowledge of several water quality parameters and their importance, interrelationships, and influences on the pond. This management issue is confounded by the effects of weather on koi ponds, particularly with respect to algal blooms.

Secondly, the koi hobbyist must understand that clear water is not necessarily clean water. The koi enthusiast is motivated by aesthetics, which dictate that koi ponds have clear water, but the koi owner's desire for clear water sometimes over-shadows the fish's need for clean water. Clear water is desired by koi hobbyists in order to view their fish, but the water may not be of adequate quality to support aquatic life. Clean water, on the other hand, provides an environment suitable for the fish, but doesn't guarantee visibility. The lack of distinction between the desires of the koi owners and the needs of the koi often leads to a poor understanding of (1) the purpose of the filtration system, and (2) the selection of the proper filtration components.

The primary objective of a filtration system is to provide the clean water needed to ensure the survival of the fish. At the most basic level, a filtration device must provide proper solids capture and nitrification to maintain solids, total ammonia nitrogen (TAN), and nitrite within acceptable limits. Most koi hobbyists will find that even if filtration is adequate to meet water quality needs, algal blooms turn their ponds pea-soup green during the summer months. Most of the solids capture devices that are practical for koi ponds remove particles down to 20 microns, with a few capable of removal to 5-10 microns. Most of the planktonic algae found in koi ponds are too small for efficient removal by these devices. Additionally, the doubling time of most algae is usually shorter than the turnover rate of the pond; thus, the algae grow faster than they can be removed. Clarifying a pond so the koi are viewable is not required for the health of the fish, so that identifying a mechanism to maintain clear water is a secondary objective in pond filtration.

This manual is aimed at providing the koi hobbyist with (1) an overview of the important water quality parameters and their interrelationships, (2) a discussion of the basic principles of biological and physical filtration using floating bead filters, and (3) a presentation of the role of algae in aquatic ecosystems and suggestions for control.

The quality of a body of water may be defined several ways, depending on its use. Generally, koi ponds are thought to have good water quality if the water is clear and fish are visible, but this is a common misconception. Clear water does not necessarily denote clean water. In fact, some of the healthiest and most productive water may be turbid, while crystal clear water can be unproductive and unable to support much biological activity. Different water quality standards are required for various systems based on intended use. Recirculating koi ponds must adhere to two sets of water quality standards, one set for the health of the fish and the other for the bacterial populations contained in the biofilter; often these sets overlap each other. Maintaining good quality within any water body requires a basic understanding of important characteristics and their interrelationships and influences on the system. This chapter briefly reviews these.

Oxygen

Air consists of 21 percent oxygen and approximately 78 percent nitrogen by volume. Oxygen dissolves poorly, and can exist in water only at low concentrations. Even so, dissolved oxygen (DO) is essential for the respiration of a wide variety of animals and bacteria in the aquatic environment. Aquatic systems containing free oxygen molecules are termed **aerobic** and those without are **anaerobic**. Anaerobic systems will not support higher forms of life and are characterized by the presence of noxious chemicals, such as hydrogen sulfide, which can cause odors. In a healthy pond environment, anaerobic conditions are normally found in the bottom sediments, whereas the overlying waters remain aerobic and are capable of supporting diverse aquatic life.

Oxygen in the air is measured in terms of its partial pressure as atmospheres (atm) or as millimeters of mercury (mm Hg); 760 mm Hg is equivalent to 1 atm. Dissolved oxygen is measured in units of oxygen mass (milligrams) per volume of water (liters). Consequently, water with 6 mg-O_2/l contains 6 milligrams of dissolved oxygen in every liter of water. Sometimes, levels of dissolved oxygen are expressed in parts per million (ppm). Six mg-O_2/l is equivalent to 6 ppm because one liter of water weighs about one million milligrams. To directly compare the oxygen available to humans with that dissolved in the water and available to fish, you must convert the partial pressure of atmospheric oxygen to mg/l, which is approximately 300 mg-O_2/l. Consequently, humans have 50 more times the oxygen available for use than fish, indicating the importance of maintaining adequate dissolved oxygen levels in ponds.

The atmosphere serves as an oxygen reservoir for aquatic systems. Oxygen movement into (**reaeration**) or out of (**deaeration**) the water is strictly a physical process reflecting the relative level of molecular oxygen activity. When the level of molecular activity in the water is in balance with the level of molecular oxygen activity in the overlying air, the exchange processes are in equilibrium and the water is said to be at its **saturation** concentration. If the dissolved oxygen concentration is below the saturation level, there will be a net movement of oxygen into the water from the air. When the aqueous level rises above the gaseous level, the flow reverses, adding oxygen to the atmosphere. The saturation concentration is controlled by the gaseous oxygen pressure. Changes in elevation or atmospheric thickness (as measured by barometric pressure) can alter the level of gaseous molecular oxygen activity, affecting the balance point (the saturation level) of the water (Figure 1.1).
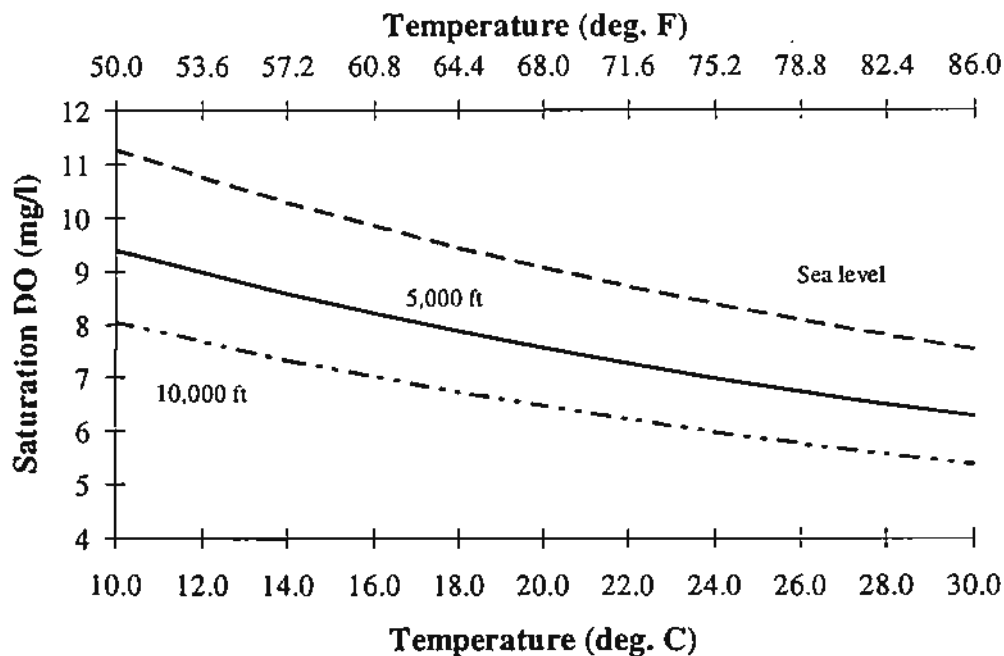
Figure 1.1. The saturation concentration of dissolved oxygen is a function of elevation and temperature.
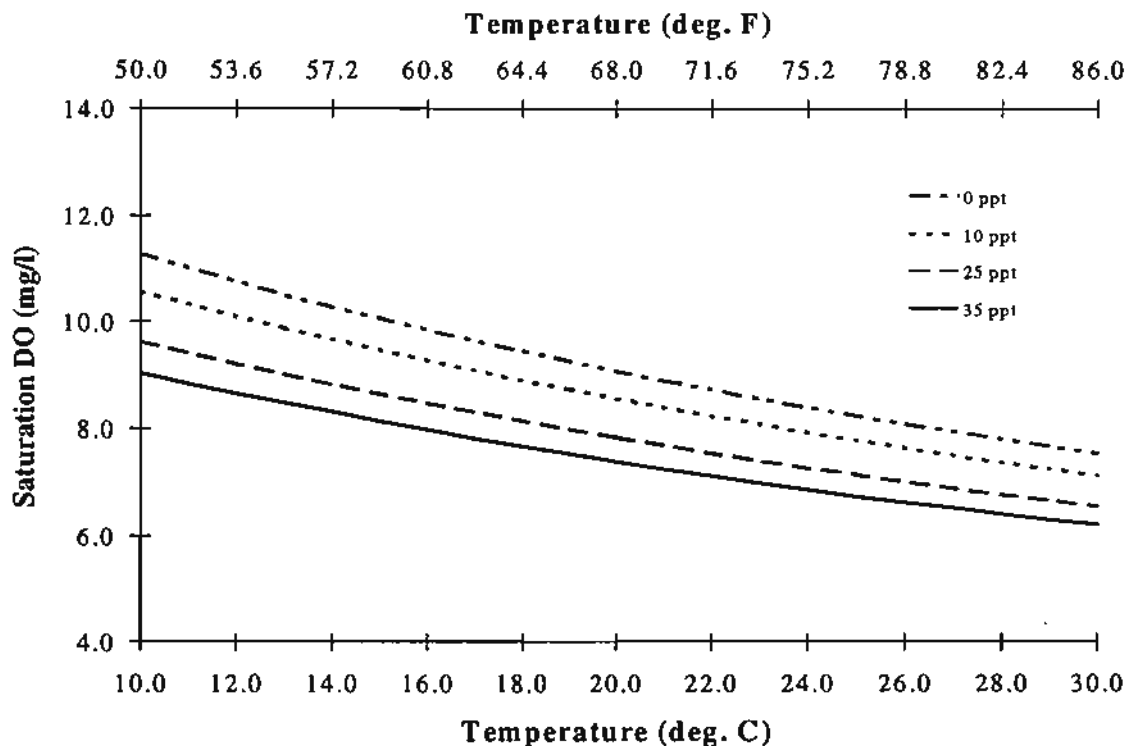
Figure 1.2. The saturation concentration of dissolved oxygen is also affected by salinity (graph for sea level).

Thus, the saturation level of fresh water in Denver, Colorado, with an elevation of 5,280 feet above sea level and a thin atmosphere (0.85 atm) at 77°F is only 6.85 mg-O_2/l. At sea level near New Orleans, Louisiana, it is 8.2 mg-O_2/l. The saturation level at both locations will be subject to minor fluctuations as the barometric pressure changes with the passage of high and low pressure areas. The most accurate estimates of saturation level are made by using the actual barometric pressure for the day of interest.

The saturation level is also affected by temperature and salt content. Increases in temperature stimulate the molecular activity of dissolved oxygen more than the gaseous oxygen, lowering the saturation level. Fresh water near freezing (4°C) and at sea level is capable of holding 13.1 mg-O_2/l at saturation, whereas the same water in mid-summer (30°C) can hold only 7.5 mg-O_2/l. Salt content interferes with the penetration of gaseous molecules, causing a similar decline in saturation level with increasing salinity (Figure 1.2). The DO saturation level near New Orleans, for example, drops to 6.7 mg-O_2/l for seawater (36 parts per thousand, or ppt) at 77°C as opposed to the freshwater value of 8.2 mg-O_2/l.

When the term "dissolved oxygen level" is used, it implies an instantaneous measurement of the actual oxygen level found in the water. This value only rarely corresponds with the saturation level in most aquatic systems, because the activities of oxygen consumers (bacteria and fish) generally outweigh the ability of reaeration processes to replace it, most often resulting in lower DO levels (Figure 1.3). Enriched natural waters often display a diurnal pattern of oxygen concentration. Values well above saturation (10-20 ppm) are evident in the sunny part of the day as oxygen-generating plants and algae provide
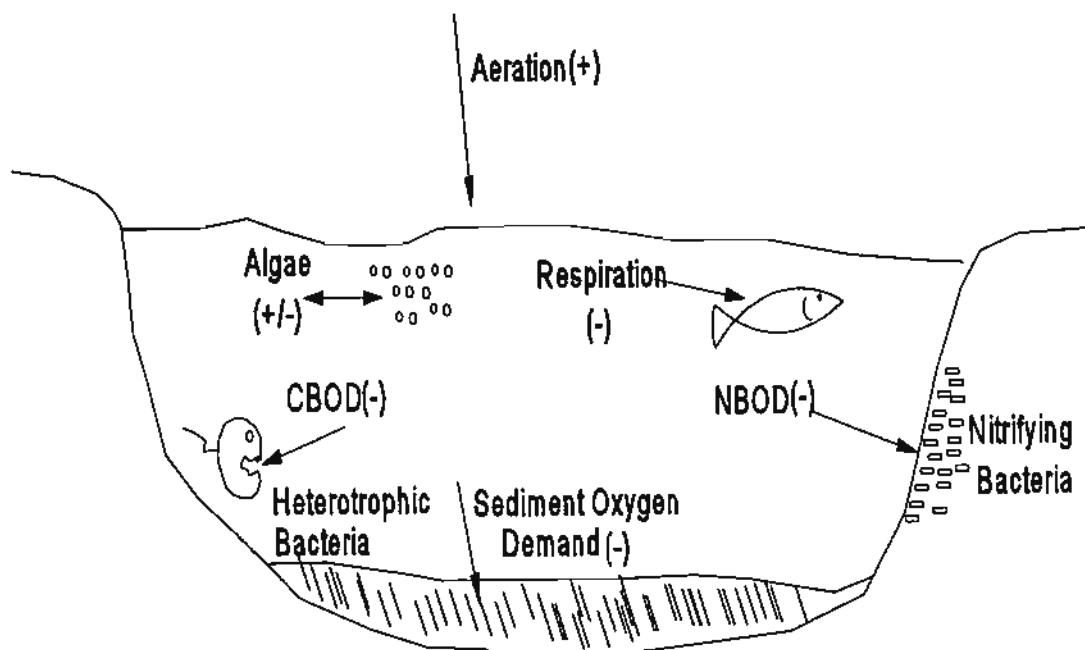
Figure 1.3. Dissolved oxygen is generated and consumed by many processes in the aquatic environment (+, addition; -, deletion).

more than the bacteria and fish need. At night, however, the lack of light causes a decline in oxygen production and oxygen levels rapidly drop as, first, deaeration and then respiration reduce levels often well below saturation (1-5 ppm). If the aeration capabilities of the water are not sufficient to balance the oxygen demands, anaerobic conditions can develop, killing the fish.

Pond or recirculating waters contain fine particulate or dissolved organic materials that can serve as food for heterotrophic bacterial communities, which in turn consume large amounts of oxygen. The potential impact of these dissolved organics on the water's oxygen supply is estimated by measuring the water's **carbonaceous biochemical oxygen demand (or CBOD)**. The CBOD of a sample is measured by observing the oxygen drop in a sealed bottle over a fixed number of days (usually five). The number of days used in the test is indicated by a suffix, i.e., $CBOD_5$. A high $CBOD_5$ (>15 mg-O_2/l) implies that a lot of bacterial activity will occur in the water throughout the day and night as the bacteria attack the suspended or dissolved organics. The organic material that accumulates in koi ponds is usually derived from uneaten fish food or feces, although in some cases decaying plant or animal matter can be a significant contributor to the problem.

The **nitrogenous biochemical oxygen demand (or NBOD)** is a second major cause of oxygen loss in aquatic systems. NBOD is a measure of the amount of oxygen (mg-O_2/l) that is consumed by the nitrifying bacteria as they convert **total ammonia nitrogen (TAN)** to nitrate (mg-N/l). Approximately 4.57 milligrams of oxygen are consumed for each milligram of TAN converted to nitrate nitrogen. TAN is directly excreted into the water by a wide variety of aquatic organisms and is very difficult to remove without bacterial activity. Unless the water is rapidly flushed, the water's NBOD must be satisfied within the system. TAN is also produced as a by-product of the decay of sediments and sludges as the bacteria break down proteins and amino acids to form ammonia.

The third major reason for oxygen loss in an aquatic system is the **sediment oxygen demand** (or SOD, mg-O_2/m^2/day), which is the amount of oxygen consumed by the bacteria as they attack the organic material that has settled or been captured to form a sediment or sludge deposit. Composed largely of particles of uneaten food, feces, dead algae, decaying plant matter, and biofloc, accumulated sediments can dominate oxygen dynamics. Both winter and summer fishkills in natural ponds caused by oxygen depletion can be attributed to oxygen consumption by the sediments. This should not be surprising as most of the mass of waste materials generated within or falling into a lake are large and sink rapidly to rot on the bottom. In recirculating systems, upward of 80 percent of the oxygen demanded by fish wastes can be explained by consideration of the oxygen demand of sludges accumulating in the clarifier or biofilter.

Finally, oxygen can be lost through respiration of the fish in ponds or tanks where fish density is held artificially high. The rate of oxygen consumption can be estimated for average conditions at a given temperature, but will vary widely during the day depending on the activity of the fish. A standard rule of thumb is that fish consume 100 grams of oxygen per pound of feed given. The peak respiration rates for fish usually occur during feeding periods when competition for food encourages high levels of activity among all the fish at once. The minimum occurs at night while all the fish are at rest.

Low dissolved oxygen. The most common symptom of inadequate oxygen supply is that your fish gasp at the surface of the water. This problem is prevalent during the hot summer months because warmer water holds less oxygen. If your aerator is working, check to make sure the line is not

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kinked or plugged. If you are using air stones, check to make sure they are not clogged. Clogged air stones can be easily cleaned by soaking them in muriatic acid. The other crucial period in which a low oxygen level can put your koi under stress is during power failures. If your pond is heavily loaded and no back-up aeration system is in place, your fish can consume the oxygen in the water within a matter of minutes to a few hours (depending on loading). To avoid this situation, it is advisable to install a battery-operated back-up aeration device that is automatically activated by a pressure switch if your main aeration source loses power.

pH

The pH characterizes the **hydrogen ion (H^+)** activity in water. Water molecules are inherently unstable, constantly disassociating into hydrogen ions and **hydroxide ions (OH^-)**:

$$H_2O \leftrightarrow H^+ + OH^-$$

Hydrogen and hydroxide ions are both highly reactive and they determine to a large extent how many chemicals interact with water. Chemicals that release hydroxide ions as they disassociate in water are called **bases**, while those that produce hydrogen ions are considered **acids**.

pH has a range between 0 and 14 on an inverted logarithmic scale measuring the hydrogen ion activity in the water. Since the scale is inverted, higher pH values indicate fewer hydrogen ions than lower pH values. Additionally, because the scale is a logarithmic index, a change in the pH scale of 1 implies a tenfold change in the hydrogen ion concentration. Water with a pH of 7 is said to be neutral since the number of hydrogen ions and hydroxide ions are equivalent. Waters with pH values below 7 are dominated by hydrogen ion activity and are considered acidic. pH values above 7 are considered basic and

the aquatic environment is controlled by the behavior of the hydroxide ions rather than the greatly outnumbered hydrogen ions.

The natural waters from which most of our aquatic animal stocks are derived display a wide range of pH values. Clean, unpolluted rainwater has a pH value just below 7.0, whereas acid rain in urbanized areas can have a pH of 3.0. Once rain reaches the earth, the pH of the water is controlled by geology and is then modified by activities of man, bacteria, and algae. Most commonly, the resulting aquatic ecosystems will display pH values between 6.0 and 10.0. The pH of the water in which an aquatic organism evolves controls several aspects of its physiology; many adapt poorly to the chemistry of water with the wrong pH. The same is true of many bacteria, algae, and aquatic plants. Table 1.1 identifies ecosystems and landforms commonly associated the pH scale. pH will vary over time and is influenced by carbon dioxide and alkalinity levels in the water.

Carbon Dioxide. Air contains only 0.035 percent carbon dioxide (CO_2) by volume. However, CO_2 is nearly 30 times as soluble in water as oxygen. Carbon dioxide moves across the air-water interface according to the same physical process described for dissolved oxygen. When the molecular activity of carbon dioxide in the atmosphere equals that in the water, the water is said to be saturated. The saturation concentration is affected by both the temperature and partial pressure (in atm) of gaseous CO_2. For example, under normal atmospheric conditions, and at a temperature of 77°C, the CO_2 level in water is approximately 0.53 mg/l. Once in solution, aqueous CO_2 combines with water molecules to form carbonic acid, which affects the pH and alkalinity of the water:

$$CO_{2(aq)} + H_2O \leftrightarrow H_2CO_3$$
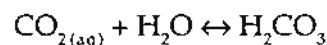
Table 1.1. The Relationship Between pH and Aquatic Systems

pH Range	Comment
6.0-7.0	Associated with swamp backwater areas; ammonium ion (NH_4^+) predominates; ammonia toxicity is rare; nitrifying bacteria are severely inhibited; nitrite toxicity is common; calcareous media and metals will dissolve.
7.0-8.0	Normal range for marsh and estuary systems; optimum range for recirculating system operation; ammonium ion (NH_4^+) predominates; ammonia toxicity is rare; nitrification process mildly inhibited at lower end of range.
8.0-9.0	Normal range for ocean waters; ammonia toxicity can be a problem; optimum range for nitrifying bacteria.
9.0-10.0	Associated with algal blooms in natural waters; molecular ammonia predominates; ammonia highly toxic; nitrifying bacteria are inhibited; calcium carbonates and metals precipitate.

As with dissolved oxygen, "carbon dioxide level" refers to the instantaneous measurement of the actual carbon dioxide found in the water. Unless the waters are well aerated and low in biological activity, most aquatic systems exhibit supersaturated levels of carbon dioxide, because the respiratory activities of the aquatic animals, bacteria, and algae produce CO_2 faster than the deaeration processes can strip it from the water. Production within natural systems tends to exhibit diurnal patterns of both CO_2 and pH. During the mid-morning to mid-afternoon hours, the amount of CO_2 removed from the water by photosynthetic algae outweighs respiratory processes, resulting in dramatically reduced CO_2 levels and increased pH levels. Contrarily, nighttime activity leads to increased CO_2 levels and lower pH values.

Alkalinity. Alkalinity is a measure of the ability of water to resist a pH change in the face of acid addition. A variety of bases and weak acids can react with free hydrogen ions, effectively absorbing them and preventing what would otherwise be a dramatic change in the number of hydrogen ions. The two most important bases contributing to alkalinity in surface waters are the carbonate ion (CO_3^{-2}) and the bicarbonate ion (HCO_3^-). These two ions are produced as acidic waters interact with minerals in the soils. Limestone ($CaCO_3$), for example, will dissolve and ultimately absorb two hydrogen ions before its carbonate component is converted to carbon dioxide gas:

$$CaCO_3 \leftrightarrow Ca^{+2} + CO_3^{-2}$$
{*Limestone dissolves releasing carbonate*}

$$CO_3^{-2} + H^- \leftrightarrow HCO_3^-$$
{*Carbonate absorbs an H^+ forming bicarbonate*}

$$HCO_3^- + H^+ \leftrightarrow CO_2 + H_2O$$
{*Bicarbonate absorbs an H^+ forming carbon dioxide*}
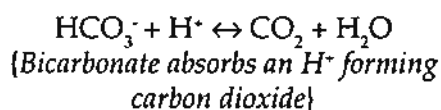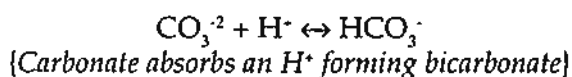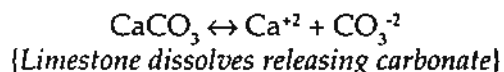
The presence of hydroxide ions also can contribute to alkalinity, while the hydrogen ions detract from it. Recognizing this, the total alkalinity (in units of mg-$CaCO_3$ /l) of a sample is normally defined as the product of the sum of the molar

concentration of these critical ions and a conversion factor:

$$ALK = 50,000(2[CO_3^{-2}] + [HCO_3^-] + [OH^-] - [H^+])$$

Alkalinity is expressed in terms of an equivalent amount of $CaCO_3$ buffering capacity, since at any time a myriad of bases can be contributing to neutralization of the hydrogen ions.

The mineral content of a region's soils generally controls the alkalinity of its waters. Regions that have rock formations dominated by sedimentary rocks (limestone) formed from historic sea beds tend to produce alkaline waters. Areas dominated by volcanic igneous rocks tend to display waters with little buffering capacity. Those with well-leached soils, such as tropical rain forests, tend to have waters with little capacity to resist pH drops.

Natural waters with high alkalinity (>100 mg-$CaCO_3$/l) tend to display pH values above 8, while natural waters with low alkalinity (<50 mg-$CaCO_3$/l) are usually acidic. The pH is actually controlled by the ratio of the carbon dioxide level and its carbonate counterparts. If the carbon dioxide level is at equilibrium with the atmosphere (about 0.53 mg-CO_2/l), then an increase in alkalinity causes a corresponding rise in pH. In many recirculating systems, however, the alkalinity is artificially controlled. Under these conditions, if the CO_2 level rises, the pH drops; conversely, reductions in carbon dioxide cause a rise in pH. Thus, the respiration of fish in a high-density system can easily raise the carbon dioxide a hundredfold (to about 50 mg-CO_2/l), overwhelming the natural tendencies to produce water with high alkalinity and pH. In outdoor ponds, algal blooms can deplete carbon dioxide so rapidly that high pH values can occur in water with very little alkalinity. Koi hobbyists will do well to remember that the pH of water is controlled by both carbon dioxide and alkalinity; further, generalities have little application to manipulated systems.

Nitrogen

The element nitrogen occurs in several forms in an aquatic system (Table 1.2, Figure 1.4). Approximately 80 percent of the earth's atmosphere is composed of the relatively inert nitrogen gas (N_2), which is poorly soluble (about one-half as soluble as oxygen). Nitrogen behaves like oxygen, except that there is no demand for the gas in a typical aquatic system. Thus, the waters are almost always at or above saturation. The dissolved nitrogen gas has little biological impact so long as it is near or below its saturation level. If, however, the water becomes enriched in nitrogen it tends to form small bubbles, which escape to the atmosphere. If fish are in this enriched water, nitrogen bubbles form in their blood stream, causing the "gas bubble" disease that is often crippling or fatal. Gas bubble disease historically occurred in flow-through fish hatcheries fed by highly pressurized waters from the bases of large dams. Water accepts more nitrogen gas under high pressure but, on entering fish raceways, tends to release it, killing the fish. Recirculating system experts learned about gas bubble disease when they tried to increase air injection pressures to accelerate the transfer of oxygen into water. The approach was unsuccessful because the increased pressure also transferred excessive nitrogen gas, creating super-saturated N_2 gas conditions. Similar problems can occur when air leaks into the suction side of a water pump, allowing air to mix with the water in the pressurized discharge lines.

Concentrations of all dissolved nitrogen forms are expressed as mass of nitrogen (milligrams) found in the compound per unit volume (liters). Thus, 3.0 mg NO_3-N/l indicates that the nitrate level is equivalent to 3.0 milligrams nitrogen per liter of water.

Table 1.2. The Major Forms of Nitrogen in an Aquatic System

Form	Abbreviation	Importance
Nitrogen Gas	N_2	Inert gas; no significance so long as below saturation level.
Organic Nitrogen	ORG-N	Decays to release ammonia.
Molecular Ammonia	NH_3	Highly toxic form; predominates at high pH levels.
Total Ammonia	$NH_3 + NH_4^+$	Sum of molecular and ionized ammonia found in water; converted to nitrite; typically measured in the ammonia test.
Nitrite	NO_2^-	Highly toxic nitrogen form; converted to nitrate.
Nitrate	NO_3^-	Stable, nontoxic form of nitrogen.
Ammonium Ion	NH_4^+	Moderately toxic form; predominates at low pH levels.

Organic Nitrogen. Nitrogen is an essential element required for the growth of all living plants and animals. A basic building block in the formation of amino acids and proteins, nitrogen is one of the controlling factors in the rate of growth for a wide variety of plants and algae. Crops and lawns are often fertilized with nitrogen to enhance growth. In nature, a few types of blue-green algae and bacteria have evolved the ability to remove inorganic nitrogen gas (N_2) from water and convert it to organic nitrogen, i.e., nitrogen-containing organic compounds. The organic nitrogen generated by these primitive life forms enters the food chain where it contributes to the growth of a wide variety of higher plants and animals.

The term **organic nitrogen (ORG-N)** refers to the level of nitrogen bound in organic compounds. Organic nitrogen can be further classified as "particulate organic nitrogen" or "dissolved organic nitrogen" according to whether the organic material has been degraded to the molecular level or is still recognizable as a particle.

The direct impact of ORG-N in aquatic systems depends upon its form. Living algae, which are composed of about 6 percent nitrogen, will show up in an organic nitrogen measurement. Their direct impact on a body of water is considerably different from that of an uneaten food particle at about 16 percent nitrogen. Both, however, have the indirect potential to be degraded by bacteria to produce the inorganic nitrogen forms of nitrogen (ammonia, nitrite, and nitrate), which pose some of the greatest threats to fish in artificially constructed systems. Lying at the center of the nitrogen cycle, the level of organic nitrogen forms the apex that determines the intensity of nitrogen metabolism in an ecosystem (see Figure 1.4).

Ammonia. When organic compounds containing nitrogen are broken down by bacterial action, un-ionized ammonia (NH_3) is produced. Ammonia is also produced as a waste product of protein metabolism from most aquatic organisms, and from excreted organic compounds that may be readily converted to ammonia. Fish excrete
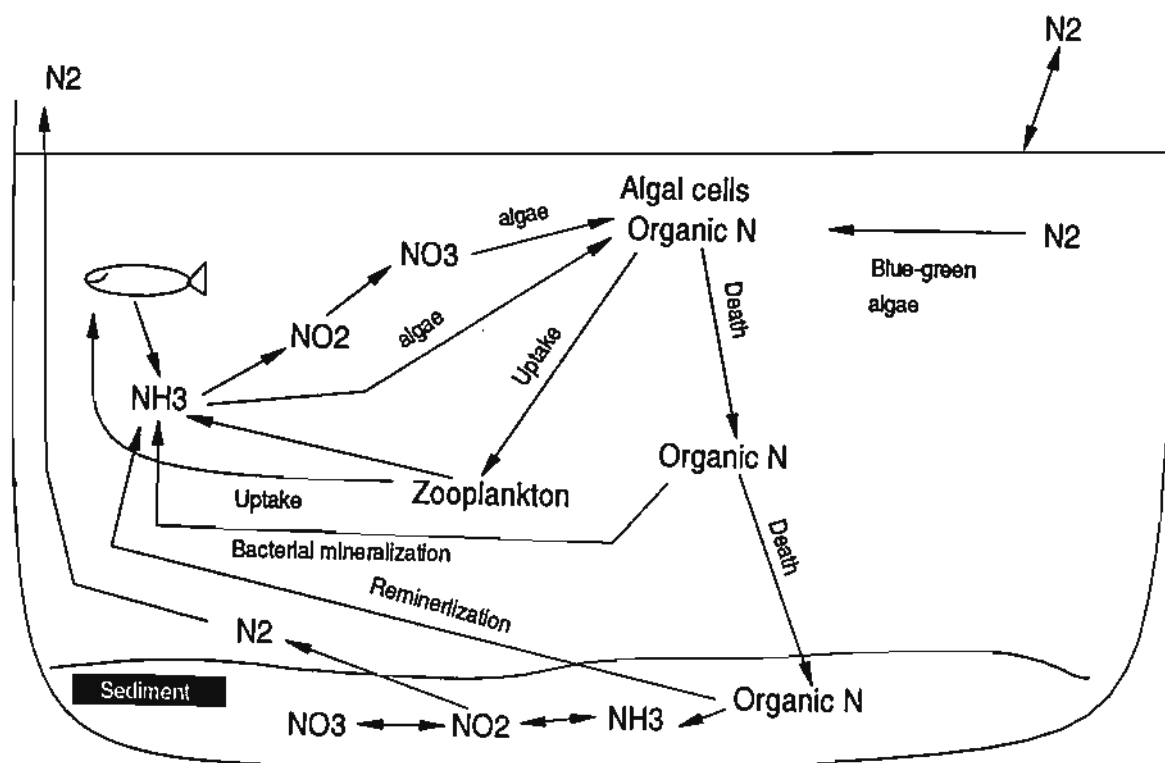
Figure 1.4. Nitrogen interactions in the aquatic system are complex.

ammonia directly to the water through their gills. Upon contact with water, the ammonia molecules interact with the hydrogen ion to form the **ammonium ion (NH$_4$$^+$):**

$$NH_3 + H^+ \leftrightarrow NH$$
(pH determines the ammonia form)

Un-ionized ammonia is highly toxic to aquatic organisms, whereas the ammonium ion is relatively inert. NH$_3$ also behaves as a poorly soluble gas, while NH$_4$$^+$ is an aqueous ion. To eliminate a dependency on the highly variable pH, the level of ammonia in water is measured by the parameter **total ammonia nitrogen (TAN)**, which is the summed amount of nitrogen found in either of the ammonia forms:
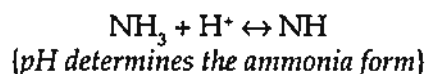
$$TAN = NH_3\text{-}N + NH_4^+\text{-}N$$
(TAN measures both types of ammonia)

To determine the potential toxicity of TAN, the fraction that occurs as NH$_3$ must be selected from a table or chart, e.g.,

Table 1.3, which reflects the effects of pH. As Table 1.3 depicts, ammonia toxicity problems generally occur at higher pH and temperature levels where the NH$_3$ form dominates.

Removal of ammonia is difficult. Gaseous NH$_3$ can be removed by gas stripping, but this is only effective with pH values (>10), which are outside the range of interest to the koi hobbyist. Ion exchange resins are available that extract NH$_3$ directly, but they are extremely difficult to recharge. Under anaerobic conditions, ammonia is stable, frequently building up concentration in sludge blankets that can diffuse into overlying waters. Fortunately, a genus of bacteria, *Nitrosomonas*, lives by extracting energy from the oxidation of ammonia. These bacteria occur wherever oxygen and ammonia are available, completing a critical leg of the nitrogen cycle by a conversion process called **nitrification.**

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Table 1.3. Un-ionized Ammonia as a Function of pH (Fraction of Total Ammonia Nitrogen)

Temp (°C)	pH				
	6.5	7	7.5	8	8.5
0	.000	.001	.003	.010	.030
5	.000	.001	.004	.010	.040
10	.001	.002	.006	.020	.060
15	.001	.003	.009	.030	.080
20	.001	.004	.012	.040	.110
25	.002	.006	.018	.050	.150
30	.003	.008	.025	.070	.200
35	.004	.011	.034	.100	.260

$$2NH_3 + 5O_2 \rightarrow 2NO + 6H_2O$$
(Ammonia is converted to nitrite by bacteria)
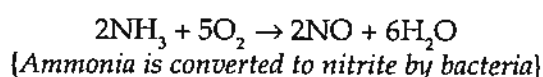
In streams and lakes, *Nitrosomonas* most often exists at the sediment-water interface, converting ammonia as it diffuses upwards and utilizing oxygen diffusing downward from the water column into the sediments.

Ammonia Toxicity. The most common symptom of ammonia toxicity is that the koi stop eating and become lethargic. Total ammonia nitrogen levels in a pond will increase for one of several reasons. First, if the fish are overfed, the uneaten food will sink to the bottom, decay, and release ammonia, increasing the load on your filter. Take your fish off feed for a few days until they respond actively when food is offered. Second, there may be so many koi in your pond that the wastes produced exceed the capacity of your filter. The more fish you have, the more waste ammonia is generated, and the more work your filter has to do to keep the water clean. Third, you may not be operating the filter properly. Bead filters (see detailed discussion in Chapter 2) capture solids and

nitrify at the same time; thus, they must be properly operated to ensure optimum nitrification. Fourth, check the pH and alkalinity of the water. If the pH is high (> 8.0), a large percentage of the ammonia in the water will be in the molecular form (NH_3) which is very toxic to fish. If your alkalinity is low (< 100 mg-$CaCO_3$/L), add sodium bicarbonate or, depending on your water source, add fresh water to replenish some of the alkalinity. Nitrifying bacteria consume alkalinity as they convert ammonia to nitrate.

Nitrite. Nitrite may be present in water in the form of the **nitrite ion (NO)** or **nitrous acid (HNO_2)**

$$NO_2^- + H^+ \leftrightarrow HNO_2$$
(The form of nitrite changes with pH)
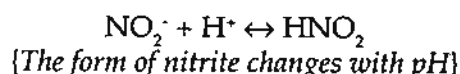
Aquatic organisms do not produce nitrite directly. Nitrite is an intermediate product of both the aerobic **nitrification** and the anaerobic **denitrification** bacterial processes. It is rarely found in natural systems at high concentrations, since its conversion is very rapid in comparison with its rate of

production from ammonia (aerobically) or nitrate (anaerobically). It is very toxic to fish and invertebrates, because it oxidizes hemoglobin to methemoglobin in the blood (as carbon monoxide does with human hemoglobin), turning the blood and gills brown (brown blood disease) and hindering respiration. Although some researchers have suggested that the toxic effects of nitrite stem from interactions with the nitrous acid form, the relationship between pH and toxicity is not as firmly established for nitrite as it is for ammonia.

Nitrite produced from the action of *Nitrosomonas* bacteria is converted to nitrate primarily by the *Nitrobacter* genus of bacteria, in the second leg of the nitrification process:

$$2NO_2^- + O_2 \rightarrow 2NO_3^-$$
(*Nitrite is converted to nitrate by Nitrobacter bacteria*)
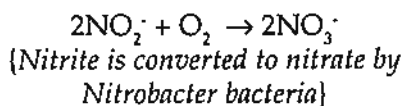
Nitrite has been largely overlooked as a problem in the early aquaculture literature. *Nitrobacter* converts nitrite to nitrate faster than *Nitrosomonas* produces it under most conditions. So nitrite was rarely a problem in lightly loaded ponds and was not an issue in flow-through raceways designed to flush rather than convert ammonia. However, *Nitrobacter* grows slower than *Nitrosomonas*, causing serious problems for high-density recirculating systems during periods of acclimation. Further, *Nitrobacter* is more sensitive to low dissolved oxygen levels and can rapidly become a problem when dissolved oxygen levels drop in heavily loaded or poorly designed biofiltration units. Nitrite is constantly produced in sludge blankets or enriched sediments where oxygen becomes depleted and partial denitrification takes place. Low levels of nitrite become a chronic problem in systems with poor sediment transport schemes.

Nitrite Toxicity. High nitrite concentrations usually occur in a pond when the biofilter is not properly working or when the system is overloaded. Fish under stress from nitrite toxicity will stop eating and congregate near the surface gasping for oxygen. As you recall, nitrite oxidizes the hemoglobin to methemoglobin in the blood, which interferes with respiration. The addition of salt (NaCl, uniodized) at a concentration of approximately 50 mg/l may help alleviate some of the stress as the chlorides interfere with the nitrite transport mechanisms across the gills, thus preventing reactions in the bloodstream. Note, however, that chlorides fail to protect many marine species. Invertebrates remain highly sensitive to nitrite toxicity, perhaps reflecting differences in their biochemistry.

To correct the situation, stop feeding for several days until the fish become more active and then resume feeding slowly until they are fully recovered. If high nitrite levels persist, a partial water change can be done to reduce the concentration.

Nitrate. Nitrate is the stable, oxidized end product of the nitrification process. Virtually all nitrogen added to the system, except inert nitrogen gas, ends up as nitrate. It is generally considered nontoxic, although many species are sensitive to nitrate concentrations. Marine invertebrates and some South American rain forest fishes are sensitive to concentrations as low as 50 mg-N/l. Hardy species, however, appear virtually unaffected and display no indication of stress to concentrations greater than 500 mg-N/l. High nitrate levels in ground waters are responsible for a human disorder, "methemoglobinemia," or the "blue baby syndrome," stemming from interference with oxygen transport mechanisms across the placenta. Guidelines for drinking water are usually around 10 mg-N/l for this reason.

Nitrate is removed from aquaculture systems by one of three mechanisms. In ponds and natural lakes, great amounts of nitrate are utilized by plants as an essential nutrient. Nitrate is a common ingredient in fertilizers for lawns and crops and is one cause of algal blooms. Secondly, nitrate is

converted back to nitrogen gas through the process of denitrification. Occurring principally in near-surface sediments, denitrification is implemented by anaerobic bacteria that utilize organics as an energy source and reduce the nitrate via nitrite to nitrogen gas through complex biochemical pathways. Since aquaculture systems are organically enriched and high in nitrates, denitrification will occur wherever sludges accumulate or dissolved oxygen levels become depressed to near zero. Finally, nitrate is simply flushed from many systems as the water is periodically exchanged. The extent of water reuse in large commercial systems is often determined from the nitrate accumulation rate, although few data exist to document upper limiting nitrate concentrations.

Solids

The analysis of solids is complicated by the many different forms that exist in water. In addition to sediments, solids may occur as small particles suspended in the water column or as dissolved molecules. The topic is further complicated by the variety of means available to measure solids concentrations, some developed for accuracy and others for convenience. Understanding the different implications of the various parameters is important to the aquatic hobbyist. The following subsections describe the various parameters.

Total Solids. Total solids (TS) measurements are primarily used to determine the solids content of semiliquid sludge generated from treatment facilities. The most common unit is percent, with 100 percent solids being equivalent to 1,000 milligrams of dry solids per liter. Sludges with 1-3 percent solids content will flow easily and behave much like water. When the water content of sludge rises to 10 percent, it becomes too thick to pump and must be treated much like solid waste.

The parameter total volatile solids (TVS) is a measure of the amount of organic material that is found in sludge. Normally expressed in mg/l, TVS levels provide an indication of a material's potential for biological decay. Sludge with a high TVS value tends to stink as it rots. Conversely, a sludge with a low TVS value can be discarded with little concern for secondary generation of obnoxious odors.

Total Suspended Solids. Total suspended solids (TSS, in mg/l) are the dry biomass of suspended particles large enough (>1 micron) to settle in the water. The organic portion of the suspended particles can be estimated by the volatile suspended solids (VSS, in mg/l). Most of the small particles found in an aquaculture system will be reflected in the suspended solids measurement. Feces, uneaten food, algae, zooplankton, biofloc, and debris particles that are too small to settle rapidly are suspended in the water column indefinitely, increasing TSS. Suspended solids in aquaculture systems tend to have a high organic content, i.e., the VSS value is almost as large as the TSS value. Nearly 85 percent of the BOD in a typical recirculating system is caused by the suspended solids.

High suspended solids concentrations (>15 mg/l) can cause gill damage and respiratory problems in some clean-water fishes such as trout and salmon. The smaller particles (<20 microns) are the most damaging. Other fishes (channel catfish, carp) seem totally unaffected by high suspended solids.

In nature, most suspended solids are removed by settling. The settleable solids test (in units of ml/l) is a standard measurement technique to estimate the amounts of solids that can be removed (by volume) in one hour. In recirculating systems, these can be removed by a number of methods including screening and filtration. When

considering removal techniques, consideration should be given to the sizes of particles that comprise the suspended solids. Settling and screening are most effective for larger particles (>100 and >40 microns, respectively), whereas granular filters are capable of capturing the smaller particles, but generally entail moderately high head losses.

Turbidity. Water is said to be "clear" when it can be easily penetrated by visible light, and submerged objects can be distinguished by reflected light. Conversely, suspended particulate matter in the water scatters and absorbs light, creating the condition termed **turbidity**. Turbidity, by definition, is the amount of white light scattered or absorbed by the water. Small particles (< 10 microns) are the most effective at light scattering and, thus, their concentration limits the water's clarity. These small particles are called *colloids*. They are so small that they possess many characteristics that would normally be only attributed to dissolved particles. They will not settle and can be removed only very slowly by physical techniques. Turbidity is most commonly measured in units of **NTUs (nephelometric turbidity units)**, corresponding to the instrument used to measure the scattering of light.

Mixing clay in water produces a colloidal suspension with high turbidity (>100 NTU). A very common colloidal solution is milk. Although opaque (>1000 NTU), milk contains few discernible solids. Display aquaria generally try to meet a turbidity standard of 0.1 NTUs, while most koi hobbyists would view a pool of 1-2 NTUs as clear and 10 NTUs as totally unacceptable. Although very important to the hobbyist, high turbidity (< 100 NTUs) has no adverse impact on the fish.

Total Dissolved Solids. Total dissolved solids (TDS) is a measure of the dry mass (mg/l) of all the dissolved solids in water. Most of the colloidal particles will be included in a total dissolved solids measurement. Unpolluted rainwater has a TDS approaching 0 mg/l. Full-strength seawater contains about 36,000 mg/l of dissolved salts. This concentration is so high that it is often expressed as salinity in parts per thousand, or 36 ppt. The Great Salt Lake in northern Utah has a salt content approaching 365 ppt. The TDS measurement includes all the salts and dissolved organic molecules present and its impact on animals varies with its composition. TDS is used as a crude indicator of the type of water being used. Waters with TDS concentrations below 500 mg/l are considered most valuable because they are well suited for drinking. At 5,000 mg/l (5 ppt), water is considered brackish and unsuitable for human consumption.

Conductivity (in units of mhos/cm) is a measure of water's ability to transmit an electrical current. It is a gross, indirect measurement of the concentration of ions and consequently can be used to estimate TDS levels. The relationship between conductivity and total dissolved solids changes with the ion composition because divalent (Ca^{+2}, Mg^{+2}, CO_3^{-2}) and trivalent ions (F_e^{+3}, PO_4^{-3}) transmit electricity better than monovalent ions (Na^+, Cl^-, H^+, OH^-, HCO_3^-, NO_3^-).

Ion Balance. Fish are sensitive to the salt content of their waters. Each species has evolved an osmoregulatory system that maintains a constant salt-ion balance in its bloodstream through movement of salts or water across the gill membranes. Fresh and saltwater species generally show poor tolerance to large changes in their salinity regimes. Brackish water species have evolved in estuary systems with salinity that varies over a wide range and are thus generally unaffected by slow changes in salinity.

Without replacement or removal, certain chemicals either diminish or increase in concentration over time in a

recirculating system. This gradual change will change the salt balance in the system and cause problems if not addressed.

Temperature

Water temperature controls the metabolic rate of all organisms in the aquatic system and the maximum amounts of dissolved gases, such as oxygen, that the water can hold. As temperature increases, the amount of dissolved oxygen in the water decreases, while the rate at which oxygen is consumed by aquatic organisms increases. Thus, as temperature goes up, the dissolved oxygen level falls.

Hardness

Hardness is a measure of the concentration of the polyvalent (mostly divalent) cations found in water. The most prevalent divalent cation in most surface waters is calcium, Ca^{+2}, which is released when sedimentary rocks, most notably limestone dissolve. Surface waters are usually classified with respect to the degree of hardness (Table 1.4). The hardness varies considerably with geographical location, and reflects the geological formations with which the waters come in contact.

In some areas, magnesium (Mg^{+2}) or ferrous iron (Fe^{+2}) may be significant contributors to hardness, although the latter is not stable under aerobic conditions. People generally recognize water's hardness because divalent ions tend to react with the surfactants in soaps. Hand soaps lather well in soft water but tend to "curdle" in hard water.

Because hardness can stem from any of several cations, its concentration is expressed in units of $mg\text{-}CaCO_3/l$. Water with a hardness of 100 $mg\text{-}CaCO_3/l$ contains only 40 mg/l of the calcium ion (Ca^{+2}), assuming there was no magnesium or iron present. The terms *hardness* and *alkalinity* are often confused because they are both expressed in terms of calcium carbonate equivalents. In a natural setting, hard waters do tend to be alkaline, particularly when the soils are rich in limestone, which releases both calcium and carbonate upon dissolution. However, this is not always the case. There are a number of ways in which the formation (or loss) of carbonates do not affect hardness. Recycled aquaculture waters are carefully managed and there is little relationship between hardness and alkalinity.

Divalent ions are metabolically important to aquatic organisms. Calcium is a major component in bones and shells and is required in aquatic animals to maintain proper osmotic pressure between their body

Table 1.4. Classification of Waters According to the Degree of Hardness
(From Sawyer et al., 1994)

Total Hardness (mg-CaCO$_3$/l)	Degree of Hardness
0-75	Soft
75-100	Moderately Hard
150-300	Hard
>300	Very Hard

fluids and the aqueous environment. Many sensitive species cannot exist outside the hardness range in which they evolved. Minimum hardness guidelines of 50 mg-CaCO$_3$/l for the culture of channel catfish, hybrid striped bass, and crayfish have been established. Many species, however, can adapt to wide ranges of hardness.

Phosphorus

Phosphorus is most often the limiting nutrient for plant and algal growth. It is also an essential nutrient for animals and is included in all fish feeds. Fish, however, are inefficient at extracting phosphorus from the feeds; thus, phosphorus tends to build up in the system's waters. High phosphorus concentrations appear to have no adverse impact on cultured fish and invertebrates, but do contribute to algal blooms in outdoor systems exposed to light. Phosphorus is found in water as organic phosphorus (ORG-P) or as the inorganic mineral, **phosphate** (Figure 1.5). The actual form of the phosphate ion changes with pH, but is commonly represented by the chemical formulation PO$_4^{-3}$. Phosphates may exist also as HPO$_4^{-2}$ or H$_2$PO$_4^{-}$. Phosphates are not stable under aerobic conditions in the presence of a variety of cations. Depending on the pH, they react with calcium, iron, or manganese to form mineral solids, which precipitate out of the water. These same minerals, however, return to solution if they find their way into anaerobic pockets in the sediments.

The main concern about phosphorus is its capacity to stimulate algal growth. The combination of high nutrient levels and sunlight leads to "green water" as algal populations "bloom". These high algal concentrations increase organic loading on the system and can lead to sudden oxygen depletion as dead algae decay on the pond's
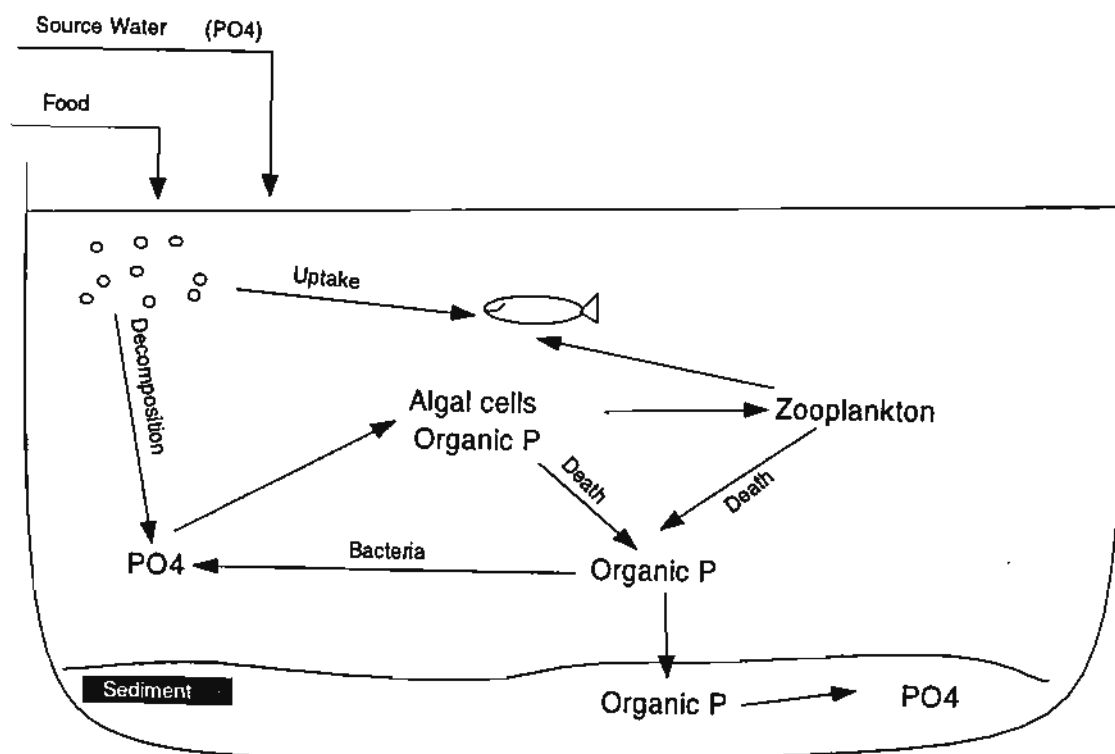
Figure 1.5. Phosphorus cycles between organic and inorganic forms in ponds, resulting in available phosphorus for algal uptake and growth.

bottom. Additionally, nighttime algal respiration may impose as much or more oxygen demand on a pond as the fish. Catfish ponds in the south are often equipped with nighttime aerators to compensate for this phenomenon. Since it is costly, if not impossible, to eliminate the source of the phosphorus, other strategies must be used to control the algae or the problems they produce.

Color

A buildup of refractory organics leads to a brown (tea) water condition in a pond. Most commonly associated with decaying leaves, these refractory organics consist of certain dissolved chemicals that are highly resistant to bacterial breakdown. In the fall, leaves that fall into the pond sink to the bottom where they are broken down by microbial activity. Those chemicals that cannot be attacked by fungus, protozoa, and bacteria become dissolved. Refractory organics consisting of large molecules cannot be removed by a physical filter. They are too small, and the bacteria in the bio-filters cannot break them down, so they just accumulate gradually, turning the water a tea-like brown color. Another source of refractory organics is the feed placed in the pond. All fish feed contains nondigestible organics that can lead to refractory organic buildup. Some high quality feeds are specifically formulated to reduce the quantity of refractory compounds, but all contribute to the problem. Bacteria attack the organics that the fish can't digest, and whatever the bacteria cannot break down ends up in the water.

Brown water presents no health threat to the fish. Tea-colored water is common in backwater swamps where fish abound. The chemicals causing the problem (humic acids and tannins) are chemically inert and do not contribute to a pond's oxygen consumption. They can, however, affect the aesthetic quality of a system full of fish.

Iron

Iron exists in anaerobic waters in the form of the **ferrous ion (Fe^{+2})** and in aerobic waters as the **ferric ion (Fe^{+3})**. Ferric ions are not stable and react with hydroxides (OH^-) or phosphates to form a solid, which precipitates out of solution. Iron levels are most often expressed in terms of total iron in mg/l, including ferrous and ferric ions and precipitates that have not settled.

Iron, particularly the ferrous ion, is highly toxic to aquatic organisms. This is not normally a problem in natural waters because the conversion from ferrous iron to a ferric-based solid is rapid in the presence of oxygen and as it settles, the iron is quickly removed from the water. However, most fish die rapidly when held in an uncoated iron container. Additionally, iron concentrations in groundwater can be very high. Use of iron-tainted groundwater as replacement water can rapidly lead to iron toxicity. The presence of iron around koi ponds should be avoided. Steel components should be of high quality and not rusty.

Iron is removed from large water facilities through aeration, pH adjustment, and filtration. Aeration and pH adjustment accelerate the conversion of ferrous iron to ferric hydroxide, which under quiescent conditions, forms particles large enough to be captured by sand filtration. On a smaller scale, iron can be removed by ion exchange resins. Home-sized units are available for remote locations not served by a central water supply.

Because koi are beautiful, most hobbyists prefer to keep their fish in lined pods instead of natural, mud-bottom ponds to maintain aesthetic appeal. However, separating the water column from a mud bottom or other natural substrate breaks the link with nature. The mud in a mud-bottomed pond contains the bacteria necessary to assimilate the wastes produced by the fish and keep the quality of the water adequate for the health of the koi. The use of concrete or lined ponds forces the koi hobbyist to assume all responsibility for the health of the fish by installing a mechanism for treating the water. These types of ponds are called recirculating systems because the water circulates from the pond through a filter and back to the pond. The most important component of a recirculating system is the filtration unit. There are several different approaches and philosophies concerning the treatment of wastes generated in a recirculating system. Regardless of the approach selected, two operations must be executed in order to maintain the proper water quality in a koi pond: physical filtration or clarification for solids removal and biological filtration for the reduction of soluble nitrogen and organic matter. This chapter discusses the use of floating bead filters, which combine both solids removal and biological filtration in one unit.

Bioclarifiers that employ floating plastic beads as filter media have been used since the mid 1970s for water treatment in high-density fish systems (Cooley, 1979). Although successful, the operation of these early air-washed filters was poorly understood, and their use was limited. In the late 1980s, Wimberly (1990) demonstrated that a hydraulically washed bead filter was capable of performing both solids control and biofiltration for a high-density catfish rearing system. These

results stimulated additional research on bead filters. The development of mechanically washed units that were compact and simple to operate (Malone and Coffin, 1993) overcame many of the operational difficulties experienced by earlier designs. Shortly thereafter, the convenient "bubble-washed" or "hourglass" configuration was developed and tested for use with tanks and outdoor ponds. Since 1989, bead filters have been tested on systems for raising foodfish such as tilapia, catfish, striped bass, and trout, along with a wide variety of specialized applications including ornamental fish, alligators, crayfish, crabs, and oysters.

Interest in the use of bead filters to clean koi ponds stemmed from the use of carp in recirculating systems to assist in the resuspension of solids. Sludge deposits in recirculating systems cause difficulties with oxygen and nitrite management. Koi, with their natural habit of "mouthing" bottom sediments, assure that no sludge deposits accumulate in the system (Figure 2.1). The bead filters easily capture the sediments once they are disturbed by the koi, resulting in the sediments' rapid removal from the tank. Thus, the natural harmony that exists between the koi and the bead filter was extended to the management of outdoor pools.

Both mechanically washed and bubble-washed bead filters can be used to purify the water in outdoor pools. The filters are similar in operation, providing both clarification and biofiltration for the pond's waters. Large pools supporting several hundred pounds of koi are most commonly maintained by mechanically washed filters, whereas smaller pools containing a moderate number of fish are well served by the bubble-washed units and their simple mode of operation. This
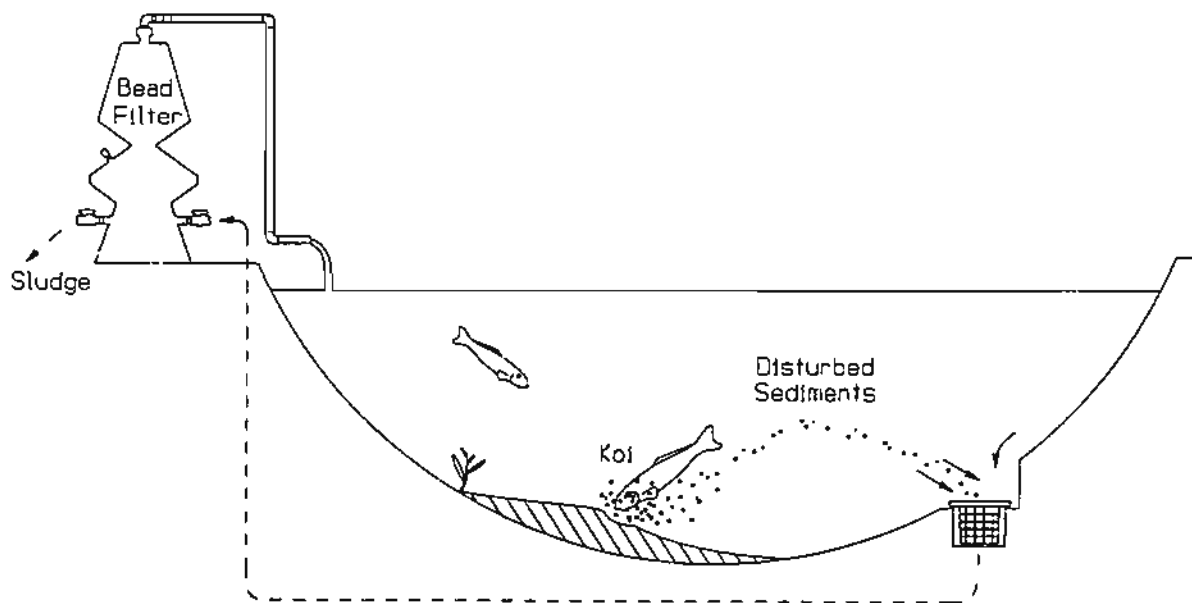
Figure 2.1. The koi and the bead filter work together to keep recirculating ponds clean.
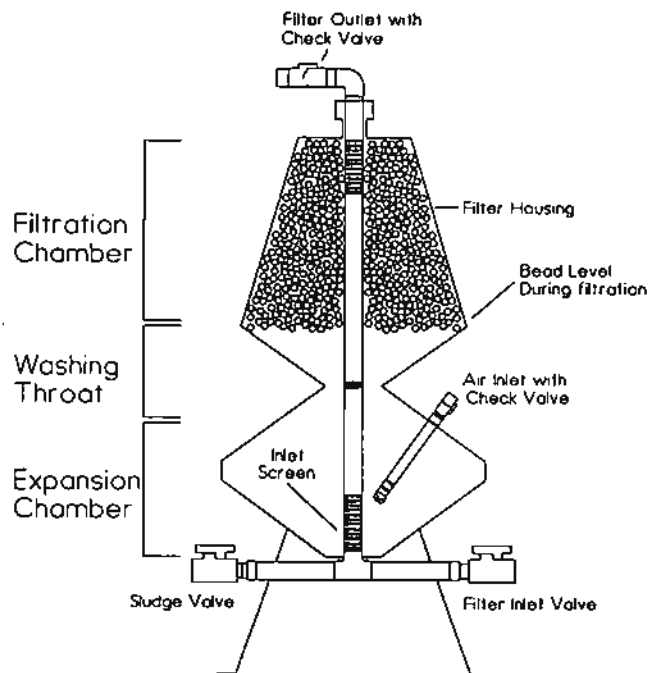

Figure 2.2. "Hourglass" or "bubble-washed" bead filters use a bed of floating plastic beads, providing for simultaneous clarification and biofiltration.

document focuses on the use of the bubble-washed units because the use of the mechanically washed units is documented elsewhere (Malone et al., 1993).

Description

Figure 2.2 (Malone, 1993) is a cross-section of the typical bubble-washed bead filter. Because of its distinctive shape, the unit is called an "hourglass" bead filter. The filter itself contains no moving parts, and its body has three major zones: (1) the filtration chamber, (2) the washing throat, and (3) the expansion chamber. Water from the holding tank or pond enters the filter through a slotted inlet pipe at the bottom of the lower chamber, passes upward through the washing throat and the bead bed contained within the filtration chamber, and exits through a slotted discharge pipe at the top of the upper chamber. The inlet pipe also serves as the sludge discharge line. The filter is equipped with an air inlet line that terminates below the center of the washing throat. The filter is normally operated with four valves (inlet, sludge, air, and discharge). Check valves are sometimes used on the air inlet and water outlet lines to simplify the backwash operation.

The beads used in the filters are spherical, approximately 1/8 inch in diameter, and are made from a food-grade, low-density polyethylene plastic with a specific gravity of 0.92. They float and fill the filtration chamber when the filter is operational. One cubic foot of beads has about 400 square feet of surface area (400 ft^2/ft^3, **specific surface area**) that provides a substrate for bacterial growth. The beads are very durable and never have to be replaced.

Theory of Operation

Bead filters provide both clarification and biofiltration. They operate very much like a submerged rock bed or under-gravel filter, and they also afford ease of cleaning.

Classified as **expandable granular biofilters** or EGBs, they are distinguished by the use of a floating granular medium. The packed bed of beads captures solids, while simultaneously supporting colonies of bacteria that attack dissolved wastes in the water. Hence, bead filters dramatically simplify operations by providing these two important water reconditioning processes in a single unit.

Clarification is the process of removing suspended solids from water. Suspended solids in a pond consist of particles (less than 100 microns) of partially digested food, debris, algae, bacteria, clay, and silt, that are small enough to stay suspended in water for an extended period of time. Fine suspended solids tend to interfere with the clarity of the water, whereas the larger organic particles pose a serious waste load problem by consuming tremendous amounts of oxygen and adversely affecting the pond's ecological health.

Bead filters remove suspended solids by at least four different mechanisms as the recirculated pond water is passed through the plastic bead bed (Table 2.1). Physical straining is probably the most dominant mechanism for the larger particles (>80 microns). Most of the remaining suspended particles (20-80 microns) are probably removed by interception, a subtle process caused by collisions between the particle and the bead surface. The finest particles (<20 microns) are removed by bead filtration, but at a slower rate. It is believed that bioabsorption, the capture of particles by the bacterial biofilm, is the dominant process attacking these fine particles. Bead filters are considered excellent clarification units, capable of maintaining display quality water at high waste loading rates.

Biofiltration is the process of removing dissolved nitrogenous and organic matter from the water. Given the

Table 2.1. Mechanisms Contributing to the Capture of Solids in a Bead Filter

Mechanism	Comment
Straining	Direct capture of larger particles as they pass into small openings between the beads.
Settling	Sinking of suspended solids onto the surface of the beads.
Interception	Impact of particles directly onto the surface of a bead.
Bioabsorption	Small particles are captured and absorbed into the sticky biofilm.

proper conditions, the bacteria grow in a thin film that coats the surface of each bead—more than 600,000 of them in each cubic foot of media (Figure 2.3). There are literally hundreds of different species of bacteria at work in a biofilter. Most of them fall into the category of "heterotrophic" bacteria, which actively break down organic materials into carbon dioxide and water. The most important, however, are broadly described as nitrifying bacteria, consisting primarily of the genera *Nitrosomonas* and *Nitrobacter*, which are responsible for converting the toxic nitrogen forms of ammonia and nitrite to relatively harmless nitrate (Figure 2.4). Management of biofiltration is critical at the high loadings associated with the indoor culture of food or ornamental fish. Several parameters that influence nitrification have been identified (Table 2.2) and studied. The pond hobbyist should be familiar with these factors. However, the pond itself generally contains a very active population of nitrifying bacteria and the fish loadings are generally a lot lower than in foodfish systems, so the filter's performance criteria can be relaxed somewhat.

Acclimation

A flourishing biofilm layer on the media is required for efficient biofiltration. The bacterial culture, which grows on the beads, performs the biochemical reactions that are critical in the purification of recycled water. Initially, the biofilter has no bacteria and a culture must be started. Acclimation is the initial growth of a bacterial culture in a biofilter, or the response of an established culture to a change in loading. Fortunately, the process of biofilter acclimation occurs spontaneously. It just takes a little food and time for the bacteria to respond. The best way to acclimate a recirculating system with a biofilter is to add a few hardy fish, turtles, or mollusks to the system and start feeding them. The heterotrophic bacteria grow rapidly and quickly populate the beads. However, nitrifying bacteria multiply more slowly and may require as many as 30 days (two to three weeks is more typical) to establish a functional culture.

Figure 2.5 illustrates the classical pattern of total ammonia nitrogen (TAN) and nitrite concentrations observed during filter acclimation with fish. The process starts with an increase in TAN concentration. You will know that the first nitrifiers, *Nitrosomonas*, which are responsible for converting ammonia to nitrite, are present in large numbers when the ammonia that builds up through fish excretion suddenly (within 36 hours) drops to near zero levels. At the same time, there will be a jump in nitrite levels, followed by a more gradual increase that will continue until the second group of bacteria, *Nitrobacter*, catch up with their new food supply and the nitrite concentrations plummet. The filter is now considered acclimated to a light loading. This initial

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Table 2.2. Water Quality Factors Affecting Nitrification in the Biofilter
(After Malone and Coffin, 1993)

Primary Parameter	Desired Range	Importance	References
Total Ammonia Nitrogen (TAN)	<1.0 mg/L	Rates of nitrification are directly proportional to TAN concentration. Exposure of biofilms to high TAN levels enhances filter performance.	Knowles et al., 1965 Chitta, 1993
Nitrite (NO_2-N)	<1.0 mg/L	Conversion of nitrite usually does not limit biofilter performance unless low dissolved oxygen exists or the filter has been shock-loaded.	Manthe et al., 1985b
Dissolved Oxygen (DO)	>2.0 mg/L in the filter effluent	High oxygen levels are desirable in biofilters since the nitrifying bacteria only function in the presence of oxygen. Additionally, decay processes that occur in the absence of oxygen produce obnoxious chemicals and odors that contribute to off-flavors.	Sharma and Alhert, 1977 Downing et al., 1964 Manthe et al., 1985a
pH	7.5 - 8.0	Low pH values (below 7.0) inhibit nitrification kinetics	Shieh and LaMotta, 1979 Paz, 1984
Alkalinity (ALK)	>150 mg/L as $CACO_3$	Alkalinity controls the pH level and the bicarbonate ion (the principal alkalinity component) is a preferred carbon source for nitrifying bacteria. Low alkalinity levels inhibit nitrification in the biofilter.	Allain, 1988 Paz, 1984
Temperature	25 - 30°C	Temperature controls the heterotrophic and nitrifying bacterial conversion rates.	Downing et al., 1964 Sharma and Ahlert, 1977

stage of acclimation is critical because, during this period, working populations of bacteria that can effectively attack the specific wastes produced by the animals become established. These bacterial populations adjust to operate under the water quality conditions and temperature regime of your system. This adapted colony of bacteria will remain in the biofilter for years if it is managed according to some common-sense principles.

Table 2.3 summarizes steps you can take to accelerate the initial acclimation of the bead filter. These procedures can reduce acclimation time to as little as a week in a warm-water system. One of the principal limitations of acclimating a filter
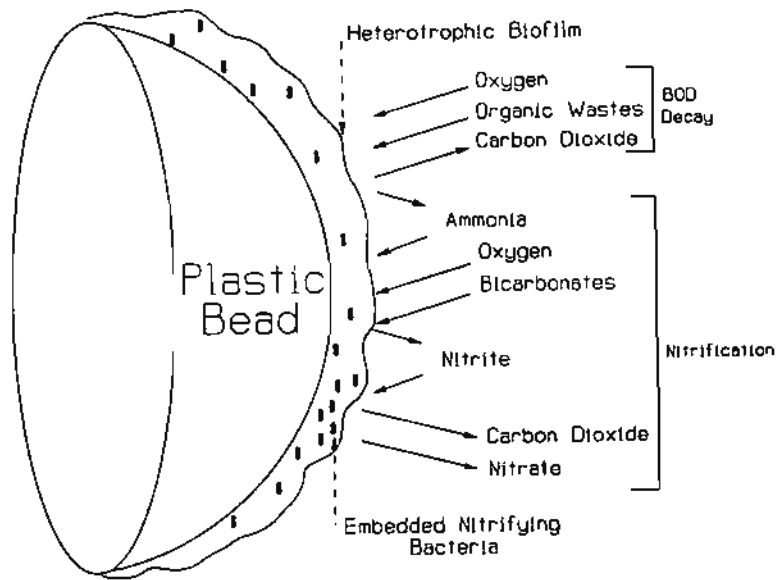
Figure 2.3. The bacterial film that coats each bead contains the nitrifying bacteria population.
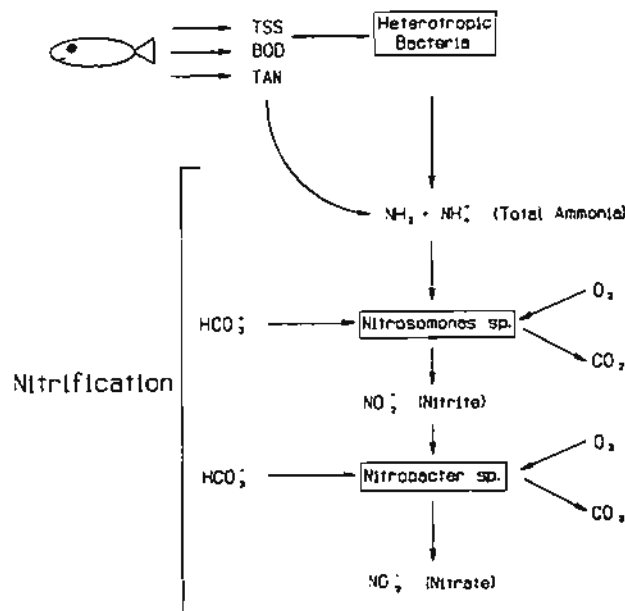
Figure 2.4. Two specialized types of nitrifying bacteria convert toxic ammonia and nitrite to the relatively safe nitrate. Bicarbonate ions and oxygen are consumed in large amounts during this process.

with animals alone is that little or no nitrite is available for the growth of *Nitrobacter* until the *Nitrosomonas* population has become established. This means that the very slow-growing *Nitrobacter* will be delayed for over a week. You can cut a week off the acclimation time simply by adding nitrite (in the form of $NaNO_2$) at the start. Do not backwash the bead filter during acclimation. Backwashing will deplete the beneficial bacteria before they become well established in the filter.

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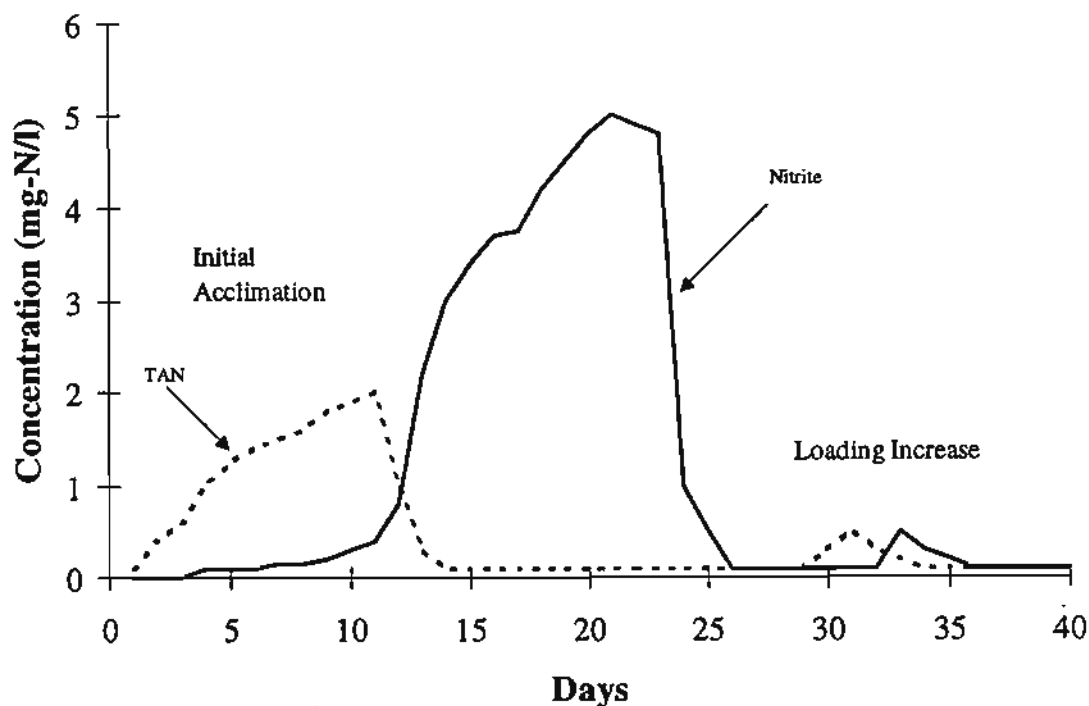
Figure 2.5. Both TAN and nitrite values will peak during filter acclimation. The nitrite peak is usually larger and more dangerous.

Animals used to acclimate the filter should be able to tolerate the ammonia and nitrite that build up. Turtles are the best choice for freshwater systems. Koi can tolerate *short-term* exposure to TAN and nitrite levels of about 5 mg-N/l without harm if you keep the pH between 7.5 and 8.0 and add some sodium chloride (rock salt) or calcium chloride. Chlorides help prevent nitrite toxicity by blocking the nitrite transfer across the gills. The high pH range keeps the TAN in the less toxic NH_4^+ form. It is usually the nitrite peak, which is two to three times as high as the TAN peak, that harms the fish. If the fish show signs of stress (inactivity, lack of appetite, or gaping near the surface), remove them; you will have plenty of food for the bacteria in the water column already. The fish should be reintroduced into the system when both the TAN and nitrite levels fall below 1 mg-N/l. There is always a risk associated with filter acclimation, so don't use your best fish for this purpose.

The initial acclimation assures that the right types of bacteria become well established in the filter. The next step in acclimating the system is to increase the density of animals in moderate increments, allowing time for the bacterial population to catch up with the increased ammonia load produced by the animals. This process is normally undertaken with the animals to be cultured since the TAN and nitrite peaks are small and quickly disappear. In general, an acclimated filter will completely adjust to a sudden increase in fish density (or feed level) within 72 hours. If the increase is moderate — less than one-third — the acclimation will probably occur without noticeable peaks. The process of acclimation to increased loading occurs naturally if the bacteria and animals are allowed to grow together. Bacteria always grow faster than the fish. Once your filter is acclimated, you don't have to worry about it again unless you suddenly increase the fish density by adding a lot of new fish, or when

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Table 2.3. Procedures that Accelerate the Initial Acclimation of a Bead Filter

	Procedure	How Does It Help?
1	Add sodium nitrite at a concentration of 1 mg-N/l on the first day	Allows growth of *Nitrobacter* to start immediately
2	Postpone backwashing bead filter*	Minimizes the loss of biofloc
3	Raise the temperature of the system to 30°C	Accelerates bacterial growth by increasing metabolic rates
4	Adjust the pH to 8.0	Accelerates bacterial growth rates by increasing ammonia (NH_3) concentrations
5	Add sodium bicarbonate to raise the alkalinity to 150 mg-$CaCO_3$/l	Accelerates bacterial growth rates by increasing bicarbonate availability
* Backwash only if hull pressure dictates		

the natural growth processes are disrupted by unnatural changes in the system.

Sizing a Bead Filter

The amount of waste that must be processed by a filter is generally determined by the amount of feed that is added to the pond. It is normally assumed that all feed added is consumed by the fish and their waste production is related to the feeding rate. The bead filter size is expressed as the volume of beads contained in the filter, usually given in cubic feet (Figure 2.6). In a high-density culture system, one cubic foot of beads can provide complete solids capture and nitrification for the wastes produced by feeding about one pound of dry pellets per day (35 percent protein). For highly valued fish such as koi, a design factor of 0.5 pounds of feed per day per cubic foot of beads provides a wide safety margin. At a feeding rate of 2 percent (of body weight), one cubic foot of beads will support 25 to 50 pounds of koi, depending on the temperature and safety factor.

Once sized according to feeding requirements, the hydraulic capacity of the bead filter should be checked against the flow requirements for the pond. Bead filters are normally designed to operate well at a flow rate of about 10 gallons per minute (gpm) per cubic foot of beads. This flow rate will control ammonia buildup in the system and assure that sufficient oxygen is transported to the bacteria, even at peak loads. Flow rates above this level do not adversely affect performance, but may waste energy. Generally, flow rates are maintained below 15 gpm per cubic foot on most bead filter models. The flow capacity, rather than the biofiltration capacity, could be a limiting design factor for a large tank or pond with a low fish population. This limitation can be avoided by routing some of the recirculated flow from the pump directly to the tank, bypassing the bead filter.

Table 2.4 presents the relationships among the volume of a bead filter, feedrate, pounds of fish, and pond size for typical applications. The bead filter sizes indicated

Figure 2.6. The bead filter must be properly sized for the pond. In this temporary setup in the author's backyard, the bead filter is only one-fifth the size required to maintain proper water quality in the pond.

Table 2.4. The Minimum Size of a Bead Filter for a Koi Pond is Primarily
Controlled by the Daily Feedrate. A Properly Sized UV Light
Will Assure Control of Algal Blooms.

Bead Filter Size (Ft³)	Flow Range Gallons Per Minute (gpm)	Maximum Daily Feedrate (Pounds)	Amount of Koi/Goldfish (Pounds)	Typical Pool Volume (Gallons)	UV Light (Watts)
0.5	3-8	0.25	13-25	200-500	15
1	5-15	0.5	25-50	500-1,000	25
2	10-30	1.0	50-100	1,000-3,000	40
4	20-60	2.0	100-200	2,000-7,000	80
5	25-75	2.5	125-250	2,500-10,000	120
10	50-150	5.0	250-500	5,000-20,000	240

are the minimum recommended. Larger bead filters will not necessarily perform better, but will require less frequent backwashing and have a larger safety factor.

Pump Selection

Flow can be provided to the filter by any continuous-duty **centrifugal pump** designed to deliver the desired flowrate at low to moderate pressures. Bubble-washed bead filters may also be operated with small submersible pumps, which are common in the pool industry. Filters with clean beds, operated at the maximum design flowrate, typically have headlosses in the range of 2 to 4 psi, depending on specific characteristics of the plumbing configuration external to the filter. Backwashing is normally performed when the headloss across the filter reaches 5 to 8 psi, reflecting the accumulation of solids and biofloc within the bed. Pumps must be selected to provide the desired flow rate at the peak expected headloss of the filter plus the return piping system. Since the filter is not designed to operate as a pressurized vessel (maximum hull pressure must remain below 15 psi), attachment of other filtration, heating, cooling, or spray head devices that generate back pressures should be avoided on the outlet side of the filter. Generally, a pump that delivers the maximum design flow at about 10 psi will prove satisfactory for most applications. Perhaps the most critical aspect of pump performance is the **shut-off pressure**, which is the maximum pressure the pump can generate when the discharge is closed off. Bead filters inherently accumulate solids as part of both their clarification and biofiltration functions. This leads to a gradual loss of **hydraulic conductivity**, which is normally restored by backwashing. If backwashing is discontinued, or the solids load is unexpectedly high, the filter bed will eventually clog and the filter housing will be subject to the shut-off pressure of the pump. Thus, pumps with shut-off pressures greater than 15 psi should be avoided, or should be installed on the inlet side of the filter with a pressure relief valve capable of venting water at the pump's delivery capacity of 15 psi.

If a nonsubmersible, air-cooled, centrifugal pump is used, the minimum operational pressure of the pump should be considered. If run continuously at low pressures, some common swimming pool pumps are subject to overheating. It is very common for bead filters to operate for extended periods at only 2 psi on the inlet side. Select a pump capable of operating at these low pressures, or place a valve capable of creating back pressure between the pump and the filter, allowing precise regulation of the pump pressure.

In summary, a continuous-duty centrifugal pump that is rated to deliver the desired flow at a pressure of about 10 psi should be selected if the filter is to be heavily loaded. The pump must be able to accommodate the operational range of 2 - 15 psi. Avoid pumps with high shut-off pressures (> 15 psi) or high minimum pressures (> 3 psi).

Plumbing

Proper installation and plumbing of the bead filter will make day-to-day management easier. Table 2.5 presents some general rules for installation that may prove helpful. Recirculating systems are usually plumbed with PVC piping and fittings. Metal fittings are generally avoided because of potential toxicity problems, as both copper and iron ions can be deadly to a wide variety of organisms. A limited number of brass fittings have been substituted for plastic in a variety of freshwater applications without apparent harm, but always use caution when introducing metal to a recirculating environment.

Two critical parameters that control the physical operation of a bead filter are

Table 2.5. Some General Rules for Plumbing a Bead Filter into a Recirculating System or Pond.

- Use PVC schedule 40 or 80 fittings for all pressurized lines.

- Isolate the filter and pump with hard unions, allowing for quick service.

- Never use copper or galvanized iron fittings.

- Use pressure gauges liberally.

- Do not use rubber couplings on the pressure side of the pump.

- Generously apply Teflon® tape, sealant, or glue on fittings on suction side of pump to prevent air entrainment.

- Bead filter discharge *and* sludge lines must have air breaks.

- Use check valves on the filter inlet line to prevent backflow of sludge and maintain pump suction.

- Eliminate or minimize lift on suction side of pump to facilitate priming and increase pumping efficiency.

- Protect pump and treatment units with in-line strainers.

flow and pressure. Bead filters should be plumbed so that the flow rate can be continually observed. A pressure gauge placed on the inlet side of the filter (between the pump and filter) is very helpful for monitoring the pressure drop across the filter. If an additional device, such as a UV light, is connected to the filter's discharge line, a pressure gauge on the discharge side of the filter is also warranted. When two gauges are used, the filter's pressure drop is determined as the difference between the inlet and the discharge gauges.

One of the problems that plagues recirculating fish culture systems is power failures. It is critical that the pumps run continuously and restart automatically with the electricity. As a general rule, air-cooled pumps should be placed close to or below the waterline of their supply reservoir to minimize problems with priming. Also

remember that centrifugal pumps rapidly lose efficiency as the lift on the suction side increases. The pump should be protected against backflow by a check valve placed on its discharge side. The check valve will keep the intake manifold full so that the prime will not be lost and backflow of sludge from the biofilter will be prevented. It does not take much material to jam a propeller, and many pumps lack the starting torque required to initiate rotation when the propeller is jammed. It is absolutely essential that the intakes for recirculating pumps placed on outdoor pools and tanks be protected by an inlet screen. Small fish, leaves, twigs, and other debris can quickly disable pumps and damage expensive treatment components. Many submersible pumps have screens built into their bases. The nonsubmersible pumps may be equipped with inline screen boxes. Unfortunately, these standard screens will not prevent clogging by

filamentous algae or leaves that abound in most pools. Additional protection can be provided by placing the submersible pumps in a grated sump or box. The air cooled units can be protected either by an intake box or a perforated intake line.

Bead filters are prone to bed disruption when bubbles are present in the inlet waters. As the bubbles move through the bed, they resuspend captured particles, causing cloudy water. Bubbles are generally caused by faulty plumbing on the suction side of air cooled centrifugal pumps. Generous use of Teflon® tape on threaded fittings and glued slip fittings used in the construction of the intake manifold will ususally eliminate air entrainment problems. Occasionally, air bubble entrainment can be traced to an airstone in the water close to the intake manifold.

Backwashing

Bead filters operate most of the time in a filtration mode (Figure 2.7a). As the recirculating pond waters pass through the bead bed, solids derived from fish feces, algae, zooplankton, debris, and biofloc

accumulate gradually in the pore spaces between the beads. With light to moderately loaded applications, the clogging process generally occurs over a two- to three-day period. If the filter is left unwashed for an extended period, a gradual decrease in the flow through the filter will occur until the flow rate essentially ceases.

As flow rate decreases, filter efficiency drops off. This is countered by washing the filter. Bubble-washed bead filters are designed to be self-washing when drained. The top (effluent) line of the filter is equipped with a valve (or check valve) that prevents the backflow of air into the filter's upper chamber when the inlet flow is interrupted and the sludge (or drain) valve on the bottom is opened. This causes a vacuum to form within the filter housing. Also, an air valve (check valve) on the side of the filter is opened to draw air into the filter's lowest chamber as the filter drains (Figure 2.7b). This air injection line is located below the washing throat, between the upper and lower chambers. This constriction is critical to the washing operation. Water dropping out of the
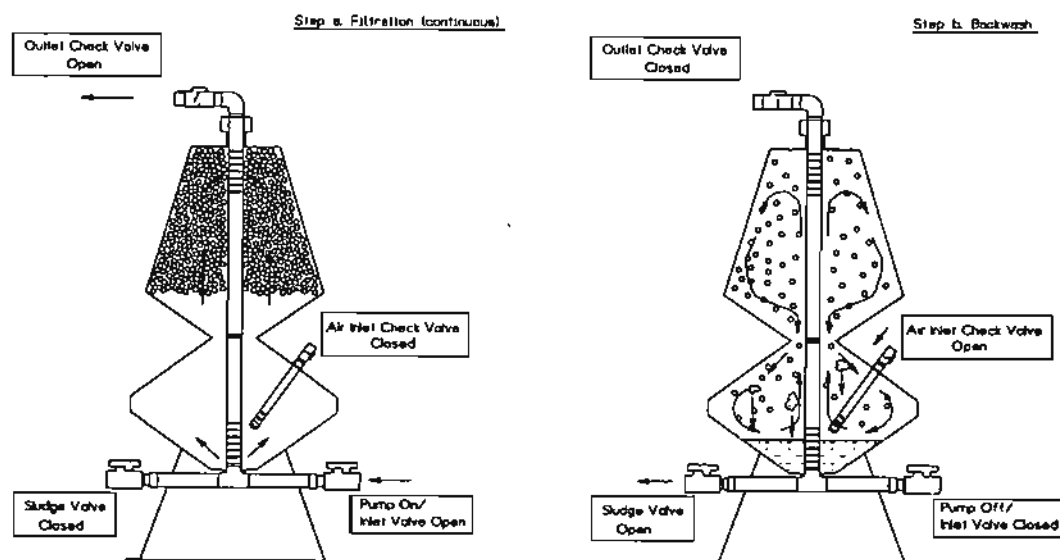
Figure 2.7a,b Bead filters are operated as packed filtration beds most of the time. They must be periodically backwashed to remove captured solids and biofloc.

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filtration head causes the beads to fall and pass through the narrow throat where they are scrubbed further by the rising bubbles. The washing process is complete when the filter is drained and all the beads have dropped into the expansion chamber (Figure 2.7c). The next filtration cycle is started by resetting the valves and refilling the filter with the recirculation pump (Figure 2.7d).

Backwash Frequency

Bead filters used with koi ponds are typically backwashed once or twice a week during the warm summer months and as seldom as once a month when feeding decreases in the winter. An unwashed filter slowly clogs, gradually shutting off the return flow to the pond. This decline in the return flow is usually apparent, providing a convenient reminder of the need to backwash.

The bubble-washed bead filters nitrify best when they are washed frequently. The washing mechanism is so gentle that the damage to the biofilm is minimal and sludges that can produce ammonia as they

decay are removed from the filter with each wash. Koi ponds are rarely loaded heavily enough to test the limits of the filter's nitrification ability, so backwashing interval is not critical. A filter that is washed four times a day would work better, but the improvement in pond quality probably would not be noticeable. So plan to backflush about twice a week in the summer, more often if (1) you notice the bed is gelling, or (2) you are experiencing flow reductions, or (3) it's convenient.

It is important that a "good" backwash be achieved each time. The longer the period between washes, the more likely the bead bed will "gel". Gelling occurs when the beads are left undisturbed so long that the bacteria bridge the gap between beads, effectively joining them together. A good wash is indicated by rapid draining of the filter and a distinct sloshing sound as the bead bed and bubbles interact. Gelling is indicated when the bed drops as a large clump after a few seconds of washing. If this occurs, the interval between backflushing is too long. The filter should be immediately filled and rewashed until it behaves properly. If this is not done, the

Figure 2.7c,d. The backwashing sequence is accomplished by completely draining and refilling the bubble-washed filter.

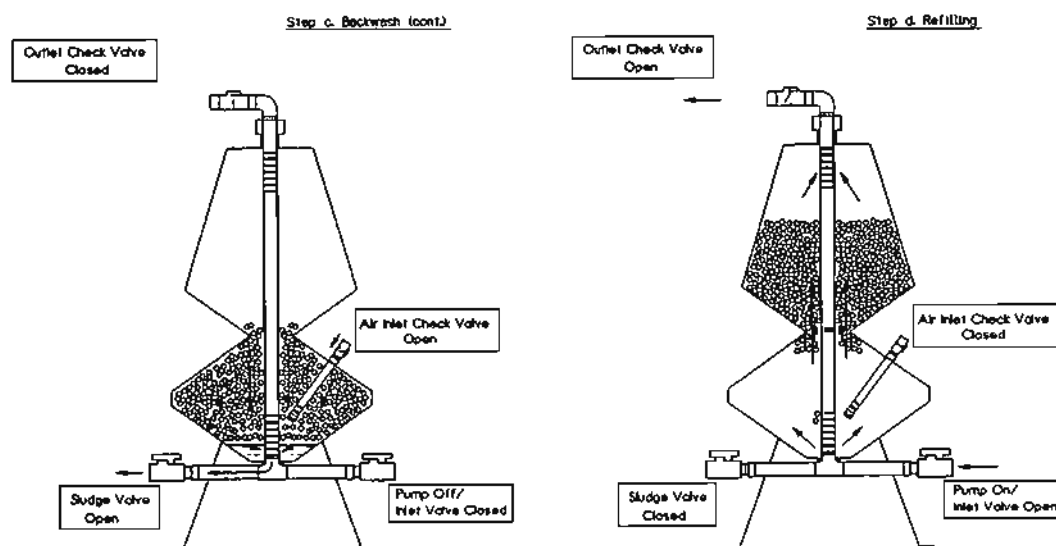problem will just get worse. Once a good wash is obtained, you should shorten the time between routine backwashes.

Undersized filters will have a greater tendency to gel. The sizing criteria presented in Table 2.4 are compatible with backwash intervals of 3 to 7 days for most ponds. Undersized filters are more heavily loaded and therefore gel faster. These filters must be washed more often. Gelling can also result from the clogging of the bottom screen of a bubble-washed filter, which reduces the vigor of the wash.

Washing a bead filter repetitively can compensate for poor sizing or extended backwash intervals. To repetitively wash a filter, refill it and immediately backwash it again. Only 35 percent of the solids are removed with the first good wash. By backwashing the filter a second time, an additional 25 percent of the original mass of sludge will be removed. The removal of the additional sludge will prolong the period of time before the filter must be backwashed again. Filters may be repetitively washed several times without significantly affecting the nitrification ability of the filter.

The best way to monitor backwash efficiency is to keep a daily record of the pressure drop across the filter. This requires a single pressure gauge on the inlet side of the filter when the filter discharges freely back to the pool, or two gauges (inlet and outlet) when the filter is burdened by downstream devices that create back pressures on the discharge line. Record the pressure when the filter is first started or after a sequential washing (four or five times) to establish a baseline for pressure loss across the filter. This initial pressure loss should be low (1-2 psi), but may vary with flow rate. Monitor the pressure buildup and flow reductions that occur as the filtration cycle is extended. As the filter clogs, the flow rate will drop or the pressure will build up depending on the type of pump. The flow rate delivered by many

low-head, submersible pool pumps will drop off without showing any pressure buildup. On the other hand, some commercial swimming pool pumps will show rapid pressure buildups well before the flow is visually evident. The backwash interval should be set so that the inlet pressure before backwashing is always well below 15 psi and before the flow rate is severely limited. Typically, washing sequences are triggered by inlet pressures in the range of 5-8 psi or a flow reduction of about 30 percent. So long as the maximum hull pressure for the filter is not exceeded, the filter will not be damaged if the filtration interval is exceeded or shortened by a few days.

There is an easier way to determine if the backwash interval has been set correctly. Place your ear against the side wall of the filtration chamber while draining the filter. Properly installed filters will continuously emit a muffled bubbling sound as the loosely packed beads swirl through the washing throat. Filters that have been left unwashed for too long tend to have tightly packed beds that stick to the top of the filtration chamber. The bed will drop in a loud "swoosh" a few moments after the draining process is started. This is not a good sign, because these filters will show a high tendency to clog. The back-flush frequency should be increased or the filter should be purged by repetitive washing two or three times in a row. The beads never have to be removed for cleaning or replacement even in badly clogged filters; repetitive washing will correct the problem.

Enhanced Backwashing

Sometimes a bubble-washed filter will stop draining in the middle of a backwash sequence or will drain very slowly. Both of these conditions can be caused by the clumping of the bead bed (the latter can also be caused by a clogged inlet screen), which occurs when heavy loading or long

backwash intervals allow the biofloc to grow too densely between the beads. As a result, the bead bed falls toward the washing throat in large cohesive clumps. If these clumps are larger than the washing throat, they may briefly clog and bridge the throat, allowing the formation of a negative pressure in the filtration chamber that will counteract the discharge suction head formed on the sludge line. When this happens, the filter just stops draining. There is no serious problem here; you have just allowed too much biofloc to grow since the last backwash. The bead clump undoubtedly has the consistency of lumpy pudding and will break up easily if given a chance. The short-term solution is to close the sludge line and repressurize the inlet line by opening the pump's inlet valve (pump must be on) for just a few seconds. This will allow the buoyant clump to rise, away from the throat. The clump will usually break up on the second approach to the washing throat. This process of momentarily reversing flow is called "bumping". It is only necessary when the

filter has been really badly impacted with solids and biofloc. The underlying cause of this problem is either overfeeding or insufficient backwashing, which were discussed earlier. This irritation can also be addressed by increasing the energy available for backwashing.

The energy for backwashing is generated from the **hydrostatic pressure** stored in the filtration chamber. Draining alone is not sufficient to wash the beads, so the bubble-washed filter is configured to release waste while sucking in air below the washing throat. The rate at which the water stored in the filter is drained, and thus the vigor of the washing, is controlled by the siphon head formed between the elevation of the internal end of the air injection line and the elevation of the first air break in the sludge discharge line (Figure 2.8). Typically, hourglass filters are designed with a minimum siphon head of about six inches, which is sufficient for most applications. If the filter is mounted 12 to 24 inches above the ground, a drop pipe can be attached to
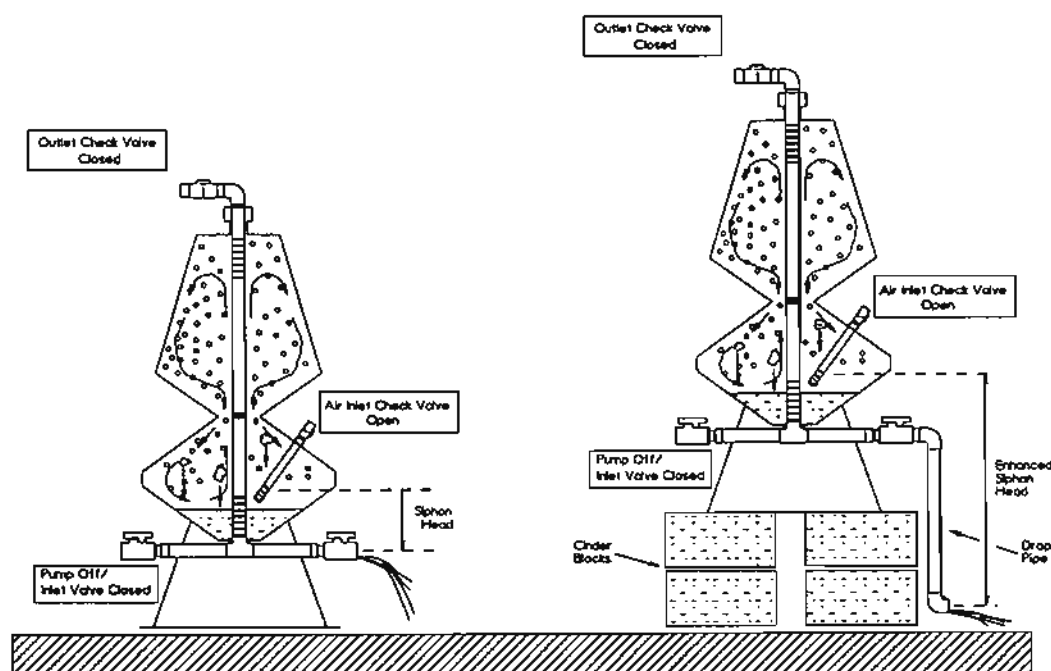

Figure 2.8. The vigor of the backwashing can be substantially increased by elevating the filter and adding a drop pipe.

the sludge discharge line and the siphon head can be increased to 12 to 18 inches, doubling or tripling the rate of draining. This increased siphon head will translate into a quicker and more vigorous wash. Drop pipes dramatically increase the filter's resistance to backwashing problems caused by heavy biofloc development, and will increase the level of loading the filter can handle or permit a longer interval between backwashings.

Disposal of Backwash Waters

Bubble-washed filters are designed to lose 10-15 gallons of water per cubic foot of beads. The discharged waters will display the same dissolved nutrient levels as the pond water; however, they will be burdened with a suspended solids load of 500-1,500 mg/l, reflecting the scouring of the solids accumulated in the filter. These solids tend to be well decomposed by the bacteria in the bead filter and can be discharged directly onto the lawn or a nearby garden. The backwash effluent is enriched with phosphorus and nitrogen (principally nitrates), which act as a low-grade fertilizer for the area of application. The solids show little potential for odor generation and are quickly assimilated into the underlying soils. Alternatively, the backwash waters can be discharged directly to a household sewer line. The wash waters are entirely compatible with centralized or household treatment systems, which are based in large part on the same bacterial communities that effect treatment in the bead filters.

Direct discharge to natural ponds and streams should be avoided. The quantity of water produced is very small and impacts from direct discharges would probably be minimal, but the quality of the water is poor when its solids content is considered. A small retention pool or tiny artificial wet-land, however, would quickly capture the solids and allow runoff into natural systems without impact. Some of the water's

fertilization potential will remain, however, so discharges to pristine systems (such as clear water ponds or trout streams) should be undertaken with care.

Winterizing

The principal threat to the bead filter during the winter is physical damage that may be caused by freezing. If freezing is a threat, the filter and the inlet/outlet pipes should be drained. After the weather warms up, the filter can be returned to service. If the weather remains below freezing, flow to the filter can be maintained, but the backwashing interval should be extended to reflect the koi's decreased feeding rate. If feeding is discontinued, backwashing should be discontinued. Winter conditions will substantially impair the filter's nitrification ability; fortunately, this will probably be matched by a reduced metabolic activity in the fish. The fish, however, will respond more quickly as the weather warms. The feed rate should be slowly increased (over a period of two to three weeks) in the springtime to allow the filter's microbial community to reacclimate. This will avoid exposure of the fish to a springtime ammonia or nitrite peak.

Troubleshooting

Cloudy Water. The most common cause of cloudy water in fish tanks is overfeeding. If too much feed is placed in the tank, it will sink to the bottom and slowly dissolve. As this occurs, released nutrients stimulate rapid growth of bacteria in the water column, causing turbidity. These small 1-10 micron colonies of bacteria will generally grow faster then they can be filtered out. High turbidity readings in the range of 10-20 NTU are often associated with these bacterial blooms, which are typically light brown or brownish gray. The sudden jumps in turbidity are best remedied by suspending feeding. The bacteria will rapidly starve back to a more

natural level within about 48 hours under summertime conditions.

The second cause of turbidity in koi ponds is clay particles. Clay particles cause a cloudiness that is more opaque than bacterial blooms and will not disappear rapidly if feeding is discontinued. Clay particles are so small that they virtually never settle and are difficult to strain out with all but the finest particulate filters. The most effective mechanism for their removal in a bead filter is believed to be bioabsorption. Bacterial colonies absorb them into their biofilm, thus, deactivating the surface charges that otherwise inhibit their removal.

The best way to treat turbidity problems caused by clays is to shut off their source, usually either runoff entering the pond or the pond's bottom. It is generally a good idea to limit the amount of surface runoff that flows into your pool from rainstorms. The sudden influx of water with dramatically different temperature and other properties can stress an otherwise healthy population of koi. Additionally, if the water running into the pool has the opportunity to erode bare soil it can trans-port enough clay to cloud up the water for days. If this situation exists, the preferred solution is to divert the offending water flow away from the pond by contouring the yard around the pool. If this is not possible, then the bare soil being eroded should be identified and protected by planting grass, covering with gravel, or concreting over. If the pool is unlined, you will soon find that the bottom can be an endless source of turbidity. It is in the nature of koi and other ornamental goldfish to search for food in the pond's bottom. In the process, the fish "mouth" the mud for wiggling tidbits of food, while discharging a plume of muddy water behind them. Lined pools filtered with a bead filter should not have this problem, as the suspended clays will be removed from the system when the filter is backflushed. Turbidity in unlined pools

with clay soils will persist indefinitely, and even worsen despite filtration. If lining the pool is not feasible, addition of a blanket of coarse sand or small pea gravel will help to protect the clay bottom and reduce the magnitude of the problem.

Brown Water. A buildup of dissolved organic compounds in the tank will lead to a brown (tea) water condition. This condition commonly occurs in enclosed systems through the leaching of prepared feeds. In outdoor ponds, decaying leaves may be the cause. Such compounds are large molecules that stubbornly resist bacterial breakdown. They cannot be removed by a physical filter, and they are not useful sources of energy or nutrients for the biofilter bacteria, so they simply accumulate and gradually turn the water brown. All fish food contains nondigestible organics that can produce this condition. Some high-quality feeds are specially formulated to reduce the quantity of refractory compounds, but all contribute to the problem. Bacteria attack the organics that the fish can't digest, and whatever the bacteria cannot break down ends up in the water.

The brown water condition presents no health threat to the fish. Brown tea-colored water is common in natural waters where fish abound. The chemicals that cause this problem (humic acids and tannins) are chemically inert, and do not contribute to a pond's oxygen consumption. They can, however, affect the aesthetic quality of the system.

The preferred method for control of brown water is reduction of the organic source and water replacement. In outdoor ponds, covering or periodic cleaning can substantially reduce the amount of leaf material entering the tank. Indoors, the use of a high-quality feed will virtually eliminate refractory additions from the feed. When used in combination with slow flushing of a pond (turning over the volume

of the pond every two weeks to a month), source control will virtually eliminate water discoloration as an issue.

A more direct and costly approach to color treatment is ozonation. Ozone (O_3) is a powerful oxidant that chemically attacks refractory organics. Accumulations of color-causing agents that have built up over months can be destroyed in hours with ozone. Ozone, however, is a very aggressive chemical. In the process of destroying the color-causing molecules, it can nearly sterilize the water, killing virtually all organisms, large and small, that it comes in contact with, including koi. For this reason, ozone units must be properly sized and coupled with an offline reactor and ozone stripping unit to assure the safety of the fish. A powerful tool, ozone in the air also presents a health hazard for humans. Therefore, it must be used with care.

Power Failures. Bioclarification will substantially increase the carrying capacity of your pond or pool. Since the filtration system keeps the water clean and the fish healthy, there is a natural tendency to increase an established koi population. This may work as long as electricity is available, but when a power failure occurs, the entire fish population is placed at increased risk of suffocation. A koi pond should never be stocked with more fish than can be sustained over a power outage of 12 hours. If a tank is heavily stocked to take advantage of the filter's carrying capacity, the system must be equipped with a standby power source or pure oxygen delivery system that can maintain the fish during the critical hours until power is restored.

The bead filter itself is largely indifferent to power failures. When the power goes off, the filter will slowly deplete its internal oxygen supply and go anaerobic, killing many higher forms of life in the filter. The critical bacterial populations will be largely unaffected since they are capable

of surviving anaerobic conditions for days if necessary. Damage to the filter can be minimized during extended flow interruptions by draining it. This will leave the beads damp, with some oxygen circulation to minimize damage to the higher organisms that balance out the filter's ecology.

Clogged Intake Screens. The flow rate maintained through a bead filter is critical to the filter's operation. Generally stated, the higher the flow rate, the better the treatment. Filters that do not recover their normal flow rates after backwashing should be investigated to identify the cause. Pressure gauges, if installed, enable the source of the problem to be quickly isolated. If your pump is delivering good pressure and no downstream flow restriction is indicated, the inlet screen may be clogged. All bubble-washed filters are equipped with removable inlet screens for just this situation (Figure 2.9). The inlet screen on a bubble-washed filter is designed to be self-cleaning when the flow is reversed for backwashing. This eliminates most lower screen clogging problems. Clogging of the inlet screen is a rare event. Draining a filter and removing the inlet screen will not damage the filter's bacterial population, but do not inconvenience yourself without good cause. A filter with a clogged inlet screen will drain slowly during the backwash cycle and show no flow improvement after washing.

Two problems have been observed that can defeat the self-cleaning strategy and lead to a clogged inlet screen. The first is the intake of large numbers of filamentous algae (green, thick, hair-like strands of blue-green algae). These algae have a tendency to wrap around the bars of the inlet screen, forming a fine-strand mop. When the flow is reversed for draining, the strands fold backward, jamming the screen openings. The screen must be removed and washed with a garden hose pressure nozzle or brushed to correct this problem. If this
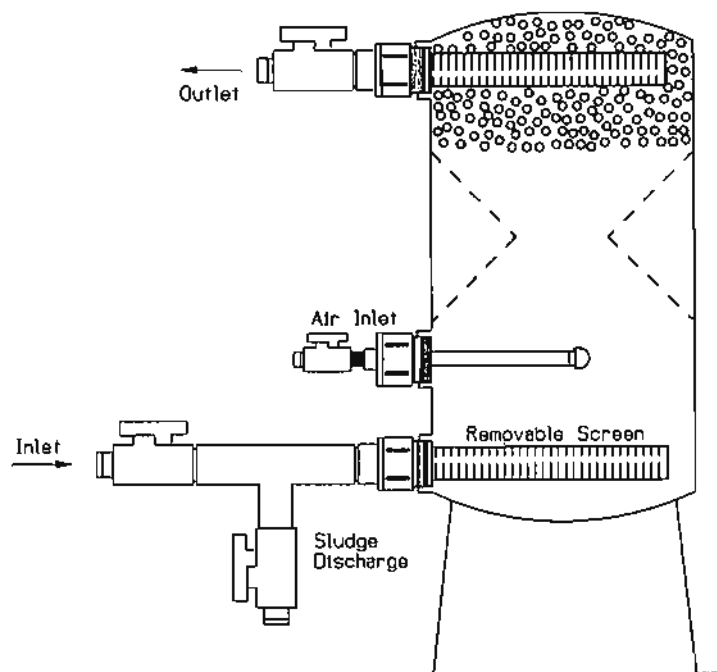
Figure 2.9. This hourglass filter design conceals the washing throat inside a pressure casing. Both the inlet and outlet screens are made from slotted PVC pipes, which are easily removed for cleaning.

becomes a chronic problem, the design of the prescreen before the pump should be reexamined.

In some parts of the country, bryozoans, small sponge-like creatures, can infest the lower screen. This can be controlled by removing the screen and dipping it in a strong bleach solution once or twice a season. Bryozoans are present in most southern ponds. At low densities, they resemble a fractured pipe surface. However, on close inspection they can be seen to form a branching network of interconnected tubes, each terminating with a fan-like "foot" that captures the fine solids upon which they feed. These individual tubes are not much thicker than a thread. At high densities, they appear as a thick reddish layer with a suede-like texture. Colonies can grow to the size of a basketball. They feed on small particles in the water and are almost always found in low densities on the inlet side of the filter (they would starve downstream). Fortunately, they are very soft and easy to remove from an inlet screen by a bleach dip or brushing. If you discover a large colony of bryozoans on your inlet screen, it is a sure sign that either your filter is severely undersized or you are overfeeding. Bryozoans need a lot of organically rich suspended particles to survive. Bead filters will normally keep the water too clean for their growth, even on the inlet side of the filter.

Koi ponds fall victim to two types of algal problems, attached and planktonic (suspended) growth. Attached algae consist of filamentous strands, which adhere to the walls of the ponds and support a population of microorganisms called zooplankton. While many pond owners may not view this attached growth as aesthetically pleasing, it does provide the koi with a valuable live feed source. Planktonic microalgae, on the other hand, cause the notorious "green water" algal blooms. Planktonic algae are microscopic (5-25 m), unicellular organisms that suspend themselves in the water column through one of several mechanisms, making removal very difficult. Offhand, one may think that algal blooms are just a nuisance, preventing the viewing of your fish. Closer scrutiny reveals, however, that planktonic algae have both a positive and negative impact on koi ponds, which will be discussed in later sections.

There are tens of thousands of species of both filamentous and planktonic algae. Those found in koi ponds are mainly from the green (Chlorophyta) or diatom (Chrysophyta) classes but, under low oxygen conditions, blue-greens (Cyanobacteria) may appear. Regardless of form, most algae are photoautotrophic, meaning that they use light and inorganic chemicals (mainly carbon dioxide, nitrogen, and phosphorus) to synthesize cell matter.

Succession of Aquatic Communities

The growth and survival of algae in koi ponds follow generally the same pattern observed in natural water bodies. Aquatic communities are classified by their ability to support life. The trophic level (oligotrophic, mesotrophic, eutrophic, hypereutrophic) or "fertility" refers to the amounts of nutrients and organic matter being cycled through a body of water. Algae play an important

role in the cycling of nutrients and other constituents as part of the progressive food chain. While algae are not responsible for a water body's trophic status, they are an indicator of the degree of fertilization that has been occurring. For example, a new water body contains low levels of nutrients and organic matter, appears clear and free of plant life, is biologically unproductive, and is termed oligotrophic. Well-established water bodies, on the other hand, are green, nutrient-rich, highly productive, and classified as eutrophic. The natural process in which a water body gradually accumulates nutrients, increases productivity, and slowly fills with accumulated solids and organic matter is termed **eutrophication**. Koi ponds are artificially eutrophied because of the recirculating nature of the water and the net gain of nutrients (nitrate and phosphorus) and carbon dioxide. As you increase the fish density and add feed to the system, more and more nutrients are released into the water. As nutrients increase, algae and other microscopic organisms begin to appear and grow, adding two new levels of the food chain to your pond. Since most koi ponds are recirculating, nutrients tend to accumulate, compounding the effects of eutrophication in a short period of time. Consequently, koi ponds must be managed in much the same manner as a lake. The first step in management is understanding the parameters that affect algal growth and the role they play in koi ponds.

Parameters Influencing Growth

Koi ponds, like other outdoor, recirculating finfish systems, are subject to seasonal algal blooms and attached growth because nutrients and carbon dioxide accumulate in the water to levels more than adequate to sustain a healthy algal population. Pigments (chlorophylls, fucoxanthin, carotenoids, etc.) within the algae absorb

light energy and use it to convert carbon dioxide and nutrients into new cell biomass through the process of **photosynthesis**.

The two primary nutrients of concern are nitrogen and phosphorus. Nitrogen is released into the water from three sources: (1) fish excretion, (2) breakdown of uneaten food, and (3) breakdown of accumulated sludge in the bottom of the pond. The form of nitrogen released in each case is ammonia, which, if you recall from the biofiltration section, is converted to nitrate within the biofilter through the process of nitrification. Nitrate, the relatively nontoxic form of nitrogen, tends to accumulate in recirculating systems unless special efforts are made to remove it. Nitrate is also the preferred form of nitrogen for uptake by algal cells. Consequently, the biofiltration process supports the growth of microalgae. The main source of phosphorus addition is from the decomposition of feed. Phosphorus is also added to the water by the death and decay of algal blooms. Since phosphorus is usually present in water in smaller concentrations than nitrogen, it is considered to be the limiting nutrient determining the growth of algae. However, the amount of phosphorus found in recirculating systems is more than adequate to support algal growth.

Carbon dioxide plays a dual role with respect to algae. Carbon dioxide is used by algae as the carbon source for the synthesis of new cell matter. The light energy trapped by algal pigments is used to convert the inorganic carbon in CO_2 into the organic carbon contained within the algal cells. Algae respire carbon dioxide during the night, in much the same manner as fish, and the addition of carbon dioxide by algal respiration can be even more significant than that produced by the fish. Carbon dioxide occurs naturally in any water body through the transfer of the gas from the atmosphere to the liquid medium. Depending on the solubility and partial pressure of carbon dioxide, water can hold approximately 0.53 mg/l under well-aerated, equilibrium conditions. Re-circulating systems, however, tend to become supersaturated with carbon dioxide through the respiratory activities of the fish, bacteria, and algae. With this increased input, carbon dioxide is added to the water faster than it can be stripped out and returned to the atmosphere. The removal of carbon dioxide can be enhanced by heavy aeration or through the use of a degassing column.

Given adequate nutrient and carbon dioxide availability, the growth and survival of algal blooms in koi ponds are a function of several physical factors including temperature, light, hydraulic retention time, and grazing. Most algae tolerate temperatures in the range of 10°C to 30°C, which explains why algae are only prevalent during the spring and summer months. The **hydraulic retention time** is, by definition, the water volume divided by the flow rate. If your koi pond has a mechanism to remove algae, such as a mechanical filter or an ultraviolet light, the amount of time it takes to cycle the entire pond volume through the algal removal device must be less than the doubling time of the algae, in order to make any headway in eliminating the algae. Light, of course, is essential for algae growth. Even if your pond has adequate nutrients and carbon dioxide, without light the photosynthetic process cannot take place. The last factor, grazing, has negligible effect on algae growth. Zooplankton, which feed on algae, are quickly consumed by the koi, thereby never reaching densities high enough to serve as an algal control mechanism.

The Role of Algae in Koi Ponds

Algae can be both beneficial and detrimental to koi ponds, depending on the owner's viewpoint. Algae provide nutrients for newly hatched fry and indirectly act as a color enhancer. As algae grow in a pond, a population of zooplankton will also

develop, which the koi feed on. These natural live feeds are important for developing the intense coloration desired in most koi. Unfortunately, algal blooms prevent viewing of the fish. This is important because sick fish can go undetected for days, or even weeks, if some regular method of viewing is not followed.

Algae influence the water quality of a pond mainly by affecting the balance among dissolved oxygen, pH, carbon dioxide, and nutrients. During photosynthesis, algae produce oxygen, remove nutrients from the water, and take up respired carbon dioxide from both the fish and the algae itself. In heavily stocked ponds, the water quickly becomes supersaturated with carbon dioxide. High CO_2 concentrations can quickly depress the pH of the water to levels below 7 if the operator is not careful to maintain proper alkalinity levels and adequate aeration for stripping. During active periods of photosynthesis, algae quickly strip the CO_2 out of the water, and this can cause pH levels to rise above 9 in a matter of hours. Koi not acclimated to such sharp shifts may initially show signs of stress.

The main concern about algal blooms is the impact on dissolved oxygen. During the part of the day when they are photosynthetically active, algae produce oxygen, adding to that provided by the aeration system. Normally, this is viewed as a benefit. However, heavy periods of photosynthesis can increase dissolved oxygen content to 15 to 20 mg/l. This in itself is not bad, unless the partial pressure of oxygen causes the total pressure of all the gases in the water to exceed 100 percent. As the total pressure starts to exceed 100 percent, *gas bubble disease* can occur in the fish.

At night, both algae and fish consume oxygen from and exhale carbon dioxide to the system. Algae will compete with the fish for the available oxygen in the water. A potentially serious impact of algal blooms is the risk of an "algal crash" triggered by such factors as temperature or barometric pressure. When an algal bloom collapses, the dead algal cells settle to the bottom of the pond, adding to the sediment oxygen demand. If the bloom crash is severe, the oxygen supply can be quickly depleted, placing your koi in danger unless back-up aeration is available. Additionally, as the dead algal cells rupture, they release organic nitrogen and phosphorus back to the water, adding to the system nutrient load. Bacteria convert these components back to inorganic elements, which are then available to be recycled and the bloom cycle continues.

The main problem with filamentous algae is that strands separate from the attached surface and end up clogging the intake screen of the pump. This is not detrimental, but does become a maintenance problem.

Controlling Algae

Effective control of algae requires that a koi pond be viewed as an ecosystem and be managed to keep the system in balance. Perturbations in the system lead to die-off of the algae and subsequent water quality upsets.

Filamentous Algae. Attached filamentous algae can be controlled by several mechanisms including shade, feeding strategy, chemicals, and the addition of algae eaters. When constructing your koi pond, you should consider its location with respect to shading. Placement of the pond in an area that will provide some level of shade will reduce the amount of direct sunlight, which will decrease the photosynthetic activity of algae. This may not provide a complete solution to algal growth, but will definitely help. If the pond has already been constructed, anything that can be done to create shade over the water will help reduce algal growth.

Careful selection of a feeding strategy will provide a dual service to a koi pond. First, the nutrients added to the water will be reduced, decreasing the amount available for uptake by algae. Secondly, feeding the koi short of satiation will prompt them to continually graze on the attached algae as a food source.

[1]There are many commercial algaecides available for killing algae, including Cutrine Plus™, Aquatrine™ and Weedtrine-D™. Algaecides work mainly by inhibiting photosynthesis and altering nitrogen metabolism within the algal cell. The pond's response to chemical additions is usually very rapid; however, most treatments require repeated applications. The active ingredient in each treatment is copper, which is toxic to fish at elevated levels. Therefore, when applying algaecides, you must strictly adhere to the directions to minimize impact on the fish. The authors do not recommend using chemicals of any sort in your koi pond.

Where legal, the addition of a plecostomus (Figure 3.1) to your pond will provide a biological control method for attached algae. The plecostomus is an algae eater native to the Amazon River basin in South America. It is compatible with koi and grows to about one foot in length. Being from South America, the plecostomus cannot survive cold temperatures and must be removed from your pond prior to winter.

Planktonic Algae. Planktonic algae can be controlled by biological (plants), physical (shade, ultraviolet radiation), or chemical (algaecides, ozone) methods. The level of control depends on the selected method or combination of methods. One of the simplest ways to reduce the growth of algae is by locating the pond in a shaded area or providing for shade if the pond is in a sunlit area. If you locate your pond under trees, you must regularly remove the leaves that fall into the water because they will add to the oxygen demand of your system. Reduced sunlight decreases the amount of energy available to drive photosynthesis, thereby reducing the synthesis of new cell matter. Additionally, shade helps to maintain cooler water temperatures and dampen the extreme temperature fluctuations that may otherwise occur. Another method of producing shaded pond conditions is through the use of dyes such as Aquashade™ or Blue Veil™®. These dyes are mainly inert and absorb sunlight, thus reducing the amount available for algal uptake. They do impart a blue or green tint to the water, however.

Plants can be used as both a biological and physical mechanism of algal control. Like algae, plants take up nutrients and carbon dioxide and convert them to new cell matter. This is not recommended, however, as an effective method for controlling algae. In fact, using aquatic plants as a mechanism for nutrient uptake involves a delicate ecological balance. Plants, just like algae, will die off because of perturbations within the system. Once this happens, the plants must be harvested before they decompose and release stored nutrients back to the water column. Using plants as a physical control may be more feasible. Placing plants in your pond reduces the amount of surface area exposed to sunlight. There are several plant varieties that are compatible with koi.

Chemical control of algae can be accomplished using algaecides or ozone. Another form of chemical treatment is ozonation, which employs one of the most powerful oxidizing agents available. As a disinfectant, ozone is three to five times more effective than chlorine for bacterial

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[1]Use of these product names does not imply endorsement by the authors. They are only used as examples.
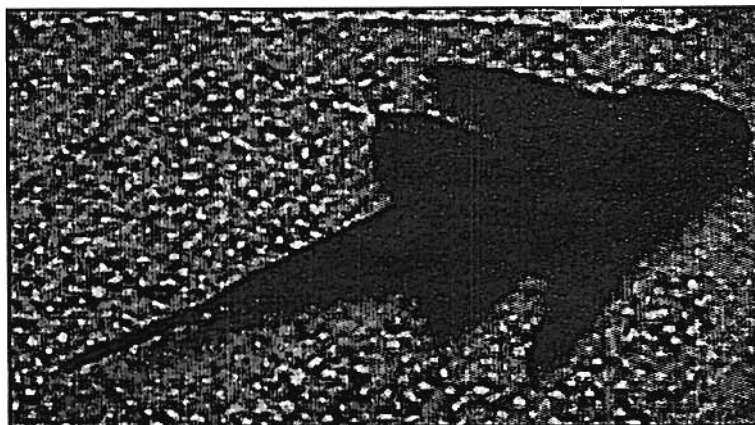
Figure 3.1. Attached algal growth can be controlled by the addition of a plecostomus to your koi pond during the summer months (where legal).

and viral treatment. Ozone, an unstable pale-blue gas that contains three atoms of oxygen, kills algae by rupturing the cell wall. It is produced naturally in the atmosphere by electrical discharges in the presence of oxygen and is associated with a fresh, pungent odor after rainstorms. Ozone can be generated using either ultraviolet or corona discharge methods, with corona discharge being more efficient. During the process, either pure oxygen or dried air is injected into the generation unit where the oxygen molecules (O_2) are excited to the proper energy level to produce ozone (O_3). While this high energy content makes ozone a very powerful oxidizing agent, it also results in a very unstable configuration. Therefore, ozone must be generated on-site, which increases its cost. Ozone has many advantages, including: (1) rapid reaction times, (2) short contact time requirements, (3) oxygenation of the water, and (4) production of very few by-products. However, ozone is very dangerous and must be used with great caution. Ozone is toxic to aquatic life, so ozonation should not take place directly in the same pond with the fish. Residual ozone must be removed through either heavy aeration or contact with activated carbon prior to returning the water to the pond. A good rule of thumb to

follow is that if you can smell the ozone produced by a treatment unit, you are in trouble.

The last, and perhaps the most effective, method of algal control is ultraviolet radiation. Ultraviolet radiation works by penetrating the cell wall of the algae. Once inside, the radiation is absorbed by nuclear materials including DNA and RNA, which either prevents reproduction or causes the cell to die. UV radiation has many advantages that make it a very attractive option for algal control. First, it is a physical treatment, so it does not change the water chemistry of your pond. Second, it is very easy to install. Third, the treatment takes place outside the koi pond, away from the fish. Last, since it is a physical method, it has no effect on the koi in the pond. The bead filter/UV light combination has proved to be a powerful agent in controlling algal blooms if operated properly.

Bead filters will not control algal blooms in ponds exposed to strong sunlight. They are effective at removing suspended particles as small as 10 microns, but cannot harvest the small, fast-growing 5-10 micron algae. To overcome this

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problem, bead filters are often operated with an ultraviolet light (UV). The sizing of a UV light is critical to its success at combating planktonic algae. The pond's volume must be turned over more rapidly than the algae can grow, i.e., the pond turnover rate must be greater than algal net specific growth rate. During the hot summer months, many algae that inhabit koi ponds can divide every six to twelve hours. Consequently, the UV unit must be sized to process the entire pond's volume at least two to four times a day to put a dent in the algal population.

Proper selection of a UV light must be based on the unit's light intensity output and its design flow rate. Most hobbyist units are rated for 15,000 or 30,000 μwsec/cm^2 at their design flow rates. The killing power requirements for microalgae are 30,000 μwsec/cm^2 or greater. Thus, if a UV light is rated at 15,000 μwsec/cm^2 at 120 gpm, and you want to increase the intensity to 60,000 μwsec/cm^2 to ensure successful removal of algae from your pond, the flow rate should be decreased to 30 gpm. This increases the length of time the algae are exposed to the UV light, thus, increasing the exposure intensity. UV lights are a physical disinfection mechanism and are effective only on algae that actually pass through the UV unit. UV lights do nothing to address the attached filamentous algae growing on the side walls of the pond.

Since UV lights work by emitting radiation that penetrates the cell walls of the algae, it is customary to place the unit after the solids removal device. Solids in the water decrease the efficiency of the UV unit because the particles provide a hiding place for the algae, away from the harmful rays emitted by the UV light. In koi ponds, the UV light may be placed in a parallel flow pattern with the bead filter. The clear water conditions in the pond produced by the bead filter assure enough light penetration, and effective disinfection can be obtained by direct flow through the UV light. This permits the UV light to be placed on a pump feeding the waterfall, for example, while the bead filter is operated on its own pump on the other end of the pond. One note on operation: so long as the pond is clear, the UV light does not need to be in operation. However, if the UV is on, you must assure that water is continuously flowing through it to prevent damage to the unit.

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Acclimation - The process of establishing a healthy bacterial film in a biofilter.

Activated Carbon Column - Usually used as a polishing process for already treated water; used to adsorb dissolved organic (color causing) compounds and to neutralize ozone prior to returning the water to the culture unit.

Aerobic - In the presence of free molecular oxygen.

Aeration - The addition of oxygen to water, usually through blown air, u-tubes, pure oxygen injection, or cascades.

Aggregation - Clumping together.

Airlift Pump - Consists of a vertical tube with an aerator (airstone or diffuser plate) placed inside the tube, near the bottom. Airlift pumps can be used to pump water (in which case, the tube extends above the water surface) or they can be used to mix and transfer oxygen. In the latter case, the tube remains submerged below the water surface.

Alkalinity - The ability of water to resist pH change upon the addition of acids.

Anaerobic - In the absence of free molecular oxygen.

Aquaculture - The culturing of aquatic organisms (finfish, bivalves, crustaceans, etc.).

Backwashing - The process of cleaning the media in a filter by hydraulic, pneumatic, or mechanical agitation.

Biochemical Oxygen Demand (BOD) - A measure of the amount of oxygen-demanding material in water. BOD is an indirect measure of the amount of biodegradable organic matter in recirculating systems.

Bioclarifier - A filtration unit that provides both solids removal and biological treatment of the water.

Biofilm - A thin layer of bacteria that coats the media in a biofilter.

Biofloc - Clusters of heterotrophic and/or nitrifying bacteria that can form large visible particles in the water.

Biofouling - Biological growth on the components of the culture system in contact with water and inside the pipes. If left unmanaged, could completely clog pipes and cause system shut-down.

Biofiltration - The use of bacteria, fungi, or algae to remove dissolved wastes from water.

Biomass - The weight of biofloc, plants, or fish being measured.

BOD - Biochemical oxygen demand.

Broodstock - Adult organisms used for reproduction and refinement of genetic lines.

Carbonate Alkalinity - The level of alkalinity attributed to the bicarbonate and carbonate ions.

Carbon Dioxide - The metabolic end product of respiration and a normal component of all natural waters. The equilibrium concentration is 0.53 mg/l; however, most intensive recirculating systems exhibit supersaturated levels (20-50 mg/l) that depress pH.

Chemical Flocculation - A process used to remove fine suspended solids and colloidal particles by inducing the chemical formation of flocs that entrap small particles as they form or sink.

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Clarification - The removal of particulate solids from water, usually by settling or filtration.

Clarifiers - Tanks or filters specifically designed to remove suspended solids.

Closed Recirculating System - A system with little or no inflow or outflow of water, equipped with a treatment train (solids capture, biofilter, aeration, degasifier, foam fractionator, etc.) for the complete reconditioning of the water.

Colloids - Very small particles that exhibit characteristics intermediate between suspended solids and dissolved chemical compounds.

Culture Unit - The physical container in which the organisms are held during the culture period; can be tanks, raceways, or trays.

Degasification - The process of stripping supersaturated gases (usually carbon dioxide or nitrogen) from the water.

Denitrification - An anaerobic biological process; the conversion of nitrate to nitrogen gas which readily escapes from the system water.

Density - Loosely used to describe the population of fish (or animals) per unit volume (pounds of fish per gallon) or per area (crabs per square foot) that a system supports.

Diffuser - Usually a piece of perforated pipe designed to distribute flows and reduce velocities at the point of water injection.

Disinfection - The selective destruction of disease-causing organisms.

Dissolved Gas - The amount of gas contained in a liquid; usually expressed as mg/l.

Effluent - Flowing out of, i.e., the pump's effluent is the water discharged from the pump.

Eutrophication - An accelerated increase in the productivity of a water body caused by excessive overloading of nutrients (phosphorus and nitrogen); results in massive algal blooms and crashes; decreases stability of the ecosystem.

Exotic - A species not native to the area where it resides or is cultured.

Expandable Granular Bioclarifiers - Fixed-film filters in which the filtration bed remains packed during normal operation and is expanded or fluidized to backwash.

Fingerling - A juvenile fish usually less than seven inches in length.

Fixed-Film Process - The biological treatment process in which the bacteria responsible for the conversion of organic and nitrogenous matter to stable end products grow attached to some inert media (sand, beads, limestone, etc.).

Flange - A circular flat collar that is attached to the end of a piece of pipe or equipment to facilitate a water-tight attachment with bolts.

Flow-Through System - A system with continuous inflow and outflow of water; wastes are flushed from the system with the water, thereby, requiring little or no internal reconditioning.

Fluidized Bed - A filter in which the filter medium is not fixed, but is rather expanded because of the flow rate; most commonly used for high-rate nitrification.

Foam Fractionation - Also called protein skimming; the removal of dissolved organic and fine particulate matter through agitation of the water with air bubbles. The matter adsorbs to the bubbles and forms a foam that can be easily removed from the system.

GPM - Gallons per minute.

Granular Filters - Filters containing a filter medium consisting of granular materials such as sand, beads, activated carbon, etc;

Head Loss - The pressure drop between two points within the system; can be measured in units of length (ft.) or pressure (psi).

Heterotrophic - A classification of bacteria that extract carbon used as an energy source from the breakdown of organic matter.

Heterotrophs - See Heterotrophic.

High Density - Also referred to as intensive culture; the raising of organisms at densities above those found in nature; requires supplemental feeding and intensive water reconditioning.

Hydraulic - Of or related to the behavior of fluids.

Hydraulic Conductivity - The amount of flow through a given porous media area per unit time.

Hydrostatic Pressure - The pressure equivalent to the depth of water at the point of measurement.

Influent - Flowing into, i.e., the filter's influent is the water flowing into the filter.

Influx - Inflow.

Inland Production Strategies - Movement of culturing practices away from the bays, lagoons, and open waters to land-based facilities.

In Situ Strategies - Movement of culturing system into the natural aquatic environment, taking advantage of the food and waste purification capacities of the water.

Ion - An atom or molecule that has lost or gained an electron so that it exhibits a positive or negative charge.

Low Head Centrifugal Pump - A pump commonly used in the swimming pool and sauna industries to move water by centrifugal force (moving away from the center of axis) created by a propeller and shaft contained within the pump.

Loading - A term used to express the relative amount of waste that a filter or system must process.

Manifold - A section of pipe used to collect or distribute waters to or from several locations.

Mass Transfer Rate - The rate at which a gas transfers into solution (in this case, into the water column); expressed in mg/l·s; rate is dependent on the solubility of the gas, temperature, and saturation and actual concentration of the gas in solution.

Mg-N/l - Milligrams of nitrogen per liter.

National Pipe Thread - Standardized tapered thread used for both galvanized and plastic plumbing fittings.

Nitrate - The nitrate ion, NO_3^-, is a stable nitrogen form produced as an end product of the nitrification process widely used as a fertilizer for plants. It is not toxic to most fresh water and marine species at concentrations of the order of 100 mg-N/l.

Nitrification - The process of converting ammonia to nitrate through the actions of bacteria.

Nitrifying Bacteria - The group of bacteria that convert ammonia nitrogen to nitrate nitrogen. *Nitrosomonas* converts ammonia to nitrite, while *Nitrobacter* converts nitrite to nitrate.

Nitrite - The nitrite ion, NO_2^-, is an intermediate product formed in the nitrification process. It is highly toxic to a wide variety of freshwater and marine species in concentrations of the order of 1 mg-N/l.

Nitrogen Gas (N_2) - The end product of denitrification. High concentrations of nitrogen gas can cause nitrogen gas bubble disease in fish.

N.P.T. - National Pipe Thread.

NTU - Nephelometric Turbidity Units.

Open Recirculating System - Modified flow-through system equipped with solids capture and/or biofilters to minimize water or heating demands.

Organic Compound - A compound containing carbon.

Organic Loading - The amount of organic waste applied to a filter usually expressed in terms of pounds of feed per cubic foot or more precisely pounds of BOD per cubic foot.

Oxygen Depletion - The removal of oxygen from the water because of the respiratory activities of the cultured organisms and bacteria, biochemical oxygen demand, and nitrification.

Ozone (O_3) - Oxygen in the molecular form that contains three oxygen atoms; a powerful disinfection agent. It is unstable, thus it must be produced onsite.

Packed Column - An elevated stack of media through which water is cascaded and air blown to facilitate oxygen replenishment or carbon dioxide removal from recirculating waters.

Parasite - An organism that grows on and feeds off another organism but contributes nothing to that organism.

Pathogenic Bacteria - Infectious bacteria that may cause disease.

Phosphorus - A constituent of most feeds currently used within recirculating systems. When discharged in the effluent, it adds to the nutrient loading of the receiving stream and affects eutrophication.

Photosynthesis - The production of organic matter (algae) from carbon dioxide and light.

Phytoplankton (Algae) - Microscopic, unicellular, autotrophic (produce their own food) organisms used as food for a variety of aquatic organisms.

Planktonic - Suspended or swimming in the water column (i.e., planktonic algae).

Pond Culture - The culture of aquatic organisms at low densities in outdoor ponds in which natural purification processes recondition the water.

PSI - Pounds per square inch.

Purging - The removal of a substance from another entity; i.e., nitrogen gas is purged from a recirculating system through gas stripping.

Purification - The extreme case of reconditioning.

Raw Surface Water - Water taken from lakes, reservoirs, bays, lagoons, or the ocean prior to any treatment to make it adequate for use in a culture system.

Recirculating System - A culturing system that wholly or partially reuses water; culture densities are typically intensive.

Reconditioning - Water treatment to restore adequate quality for reused within a recirculating system; encompasses solids removal, nitrification, degasification, and aeration.

Refractory Organics - Organic matter that cannot be broken down by bacteria.

Respiration - The metabolic process by which an organism assimilates oxygen and releases carbon dioxide.

Saturation - The maximum amount of a substance that can be dissolved in a fluid under the given conditions.

Shear Forces - Forces generated by the differential velocities of adjacent bodies of fluids and or solids.

Shut-off Pressure - The maximum pressure a pump can generate when the discharge is closed.

Sludge - A thick, pudding-like mixture of solids and water usually composed of partially decomposed fish feces and bacterial biofloc.

Slurry - A thick, yet fluid, mixture of sludge and water.

Specific Surface Area - The physical area contained on the surface of the media per cubic foot of media.

Substrate - The compound that bacteria convert or consume as their principal energy (food) source.

Surfactant - Surface-active, dissolved organics that are removed during the foam fractionation process.

Suspended Solids - See Total Suspended Solids.

Supersaturated - Concentration of dissolved materials greater than the maximum amount that can be dissolved under given conditions; usually represented as a percentage.

TAN - Total ammonia nitrogen.

Total Alkalinity - The measure of water's ability to absorb acids (hydrogen ions) usually attributed to chemical interactions with the hydroxide ion (OH^-), the carbonate ion ($CO_3^=$), and the bicarbonate ion (HCO_3^-).

Total Ammonia Nitrogen (TAN) - The sum of the concentration of ammonia (NH_3) and the ammonium ion (NH_4^+) expressed in milligrams of nitrogen per liter (mg-N/l). This term is used because the form of ammonia expressed is pH-dependent.

Total Suspended Solids - A measure of the number of particulate solids found in water; usually determined by filtration of a sample through a filter paper with a pore size of about 1 micron.

Treatment Burden - Culture practices that take the organisms out of their natural habitat and put them into an artificial ecosystem, where they lose the natural purification processes associated with the natural habitat. Therefore, the system operator becomes responsible for treating all wastes generated within the artificial culture ecosystem.

Treatment Train - The series of components and processes used to recondition water within a recirculating system.

TSS - Total suspended solids.

Ultraviolet Radiation - A physical disinfection process; the UV energy is absorbed by the genetic material of the organism, preventing it from reproducing.

Water Hammer - A sudden hydraulic force resulting from the momentum of moving water caused by abrupt interruptions in flow (i.e., sudden valve closure).

Waterloss - A measure of the amount of water that is removed from the system or lost to evaporation.

Zooplankton - Microscopic or somewhat larger grazing animals; most feed on phytoplankton and form the second major link in the food chain; used as food for many aquatic organisms.