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# Groundwater Treatment Before Use in Aquaculture

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One of the most important factors to consider when developing an aquaculture facility is water quality. This factor can even influence what species should be cultured. The primary source for water used in aquaculture is groundwater accessed through local wells. By using well water, aquaculture producers avoid the costs and chemical additions associated with using treated municipal water.

Before subjecting aquatic animals to groundwater, aquaculture producers should assess the water quality and address any problems identified. The water-quality parameters that can harm aquaculture species include carbon dioxide ($CO_2$), hydrogen sulfide ($H_2S$), and unionized ammonia ($NH_3$). High concentrations of these substances may be toxic to the culture species and reduce the potential of an aquaculture facility's success.

Other parameters, such as alkalinity and hardness, may have a preferable range for the culture species. Maintaining the species within this optimal range will significantly improve production. Aquaculture managers must understand common water quality parameters in groundwater and know effective ways to manipulate them to meet the needs of their production facilities.

## Dissolved gases

Groundwater often contains dissolved gases such as hydrogen sulfide, carbon dioxide, and nitrogen gas, which can be toxic to aquatic animals. Measuring these parameters will help you decide how best to reduce or eliminate them. Conversely, low levels of dissolved oxygen will need to be increased to support aquatic animals.

### *Hydrogen sulfide*

Hydrogen sulfide ($H_2S$) is a gas often present in groundwater. It is produced under conditions of very low oxygen (*anaerobically*), when bacteria use sulfate as an energy source and produce $H_2S$ as the byproduct. The amount of decaying organic matter near the groundwater source often determines the level of $H_2S$ in the water.

Hydrogen sulfide can also occur within an aquaculture system. A good example is in a pond where the water has become layered (*stratified*) by changes in temperature. Because the water at the bottom of the pond has limited access to the surface, it contains less oxygen. The water's lack of oxygen encourages the production of $H_2S$.

Any detectable amount of $H_2S$ can harm and even kill many aquatic animals. $H_2S$ essentially makes the animal unable to breathe. Therefore, it should be removed completely from the water. $H_2S$ has a characteristic "rotten egg" smell and if this odor is detected, the gas should be dealt with immediately.

Although $H_2S$ is toxic to fish even at low levels, it evaporates readily (is relatively *volatile*) and is easy to remove (*degas*). A simple methodology for degassing $H_2S$ is to pump the water into the air as it enters the pond (Fig. 1). The water splashing onto the pond surface—coupled with aeration inside the pond—is typically enough agitation to release the toxic $H_2S$ gas into the air.

Instead of degassing the $H_2S$, some flow-through tank systems are designed to reduce the water flow into the tank. The reduction in water flow dilutes and degasses some of the $H_2S$ that enters the tank. However, this technique is not advised, for two reasons:

- The concentrations of dissolved gas may fluctuate, which could at times expose the aquatic animals to more $H_2S$ and for longer periods.

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- As bacteria consume the $H_2S$, they create an off-white "slime" (Fig. 2), which can increase system maintenance and stress the culture species unnecessarily.

High concentrations of $H_2S$ may require more intensive degassing, which is discussed below in the "Packed column degassing" section.

## Carbon dioxide

In aquaculture systems, carbon dioxide ($CO_2$) is produced primarily from the breathing (*respiration*) of aquatic organisms. In groundwater, $CO_2$ may also be produced from plant respiration and the oxidation of organic carbon. Because $CO_2$ can dissolve in water, it may build up in groundwater over time. High concentrations of $CO_2$ in water need to be reduced before any aquatic animals are exposed to it.

Depending on the organism and the length of exposure, high $CO_2$ concentrations can harm and even kill aquatic animals. High $CO_2$ levels can lower blood pH in aquatic animals, which decreases the amount of dissolved oxygen that the animals' blood absorbs and delivers to body tissues, regardless of the dissolved oxygen (DO) concentration in the water. To further compound its effect, $CO_2$ also influences pH and alkalinity. Generally, as $CO_2$ increases, pH and alkalinity decrease. Conversely, as $CO_2$ decreases, pH and alkalinity increase.

These specific interactions are discussed further in Southern Regional Aquaculture Center (SRAC) publication No. 464, *Interactions of pH, Carbon Dioxide, Alkalinity and Hardness in Fish Ponds.*

Because changes in one parameter affect the others, all need to be monitored closely. Although some aquatic animals can acclimate to elevated $CO_2$ over time, it is ideal to maintain a concentration below 15 mg/L (ppm).

When pumping water directly to a pond, be mindful of $CO_2$ entering it. If the pond is uncovered, it is likely sufficient to allow the natural biological processes of the pond coupled with aeration to reduce the $CO_2$ concentration. However, if the pond is covered or enclosed with no outlet, $CO_2$ can become trapped, reenter the water, and increase $CO_2$.

If you are pumping water to tanks, first reduce $CO_2$ to ensure optimal health of the animals and the systems. The target concentration will vary because some species and life stages are more sensitive to $CO_2$, and the objectives of aquaculture systems differ. More intensive degassing is typically required to reduce $CO_2$ and is discussed in the "Packed column degassing" section.

**Figure 1.** Groundwater enters a Florida ornamental fish pond directly from a well. The water is pumped into the air as it enters the pond to create more surface area of incoming water and to encourage splashing at the pond's surface. This action is usually enough to degas hydrogen sulfide ($H_2S$) present in groundwater for extensive pond aquaculture.

**Figure 2.** If left untreated, water containing hydrogen sulfide ($H_2S$) may create a "slime" that can compromise aquatic animal health and create system maintenance issues.

## Nitrogen gas

As a part of the denitrification cycle, bacteria convert nitrate to nitrogen gas ($N_2$). At the surface, $N_2$ is readily transferred to the atmosphere. However, well water is typically drawn from deep underground, where the pressure is much greater. This higher pressure "pushes" any gases present into solution—that is, the pressure causes the gas to dissolve into the water. As the water is brought to the surface and the pressure drops, the gases will begin to come out of solution.

If the water comes in contact with animals before an adequate degassing period, the unpressurized $N_2$ will form bubbles in the animals' bodies and disrupt their bodily functions. This is called *gas supersaturation* or *gas bubble disease,* which can kill aquatic animals.

Other gases such as oxygen can also be responsible for gas supersaturation, especially in aquaculture systems where pumps and pipes can push oxygen into solution. However, for aquatic animals exposed directly to groundwater, gas supersaturation is most often caused by $N_2$, as it is inert and the animals' bodies cannot expel it. $N_2$ must be degassed from the water before it is exposed to aquatic animals.

Although the process is similar to that used to reduce $CO_2$ and $H_2S$, more intensive degassing is typically required for $N_2$. See the "Packed column degassing" section.

### Dissolved oxygen

The dissolved oxygen (DO) concentration in groundwater can be low because the water has limited contact with the atmosphere. Typically, if $CO_2$ and $H_2S$ are detectable in the water, its DO concentration is likely low. However, DO may be low even when the water has no detectable $CO_2$ and $H_2S$. Furthermore, the DO concentration often is outside the preferred range for aquaculture production (that is, at or near 100 percent saturation). Because DO is essential for life and therefore aquaculture, it must be increased before using the water for aquaculture purposes.

Fortunately, oxygen can often be added to the water by implementing the same measures as for reducing $CO_2$, $H_2S$, and $N_2$. Afterward, adequate DO concentrations can be maintained through aeration, the rates of which will depend on the culture species and the amount of biomass being produced in the aquaculture production facility.

### Packed column degassing

The best method for degassing any dissolved gas is to install a packed column, which is a highly efficient aerator consisting of a tall, vertical container filled with packing media, leaving space for the water to become agitated (Fig. 3).

The device creates tiny streams and drops of water that trickle down through the media, increasing the ratio of surface area to water volume. Air is also injected into the bottom of the packed column to create a countercurrent of air to the falling water drops. The process extracts dissolved gases from the water and adds dissolved oxygen to it.

The need for degassing will vary depending on the source water, location, and demand. For more details on packed columns, see SRAC Publication No. 191, *Design and Construction of Degassing Units for Catfish Hatcheries.*


**Figure 3.** A degassing unit on a Florida ornamental fish farm. The pipe on the left brings water to the top of the unit, and the air pump at the bottom supplies air into the unit. Water drops down the unit as air is pumped upward, creating a countercurrent exchange and drawing unwanted dissolved gases from the water.

Implementing degassing into treatment techniques will adequately reduce undesirable dissolved gases while simultaneously increasing the needed DO. The treated water can then be pumped to a holding tank or directly to aquatic animals in either a recirculating or flow-through aquaculture system.

A **recirculating aquaculture system** (RAS) should have a degassing component built into the system design. Although treating groundwater eliminates or reduces undesirable dissolved gases, $CO_2$ will increase in the system over time as a byproduct of the animals' metabolism, which is the natural processes by which their bodies change food into energy or use it to make cells and tissues. $H_2S$ and $N_2$ are less likely to reappear in an aquaculture system, but they still might be added by anaerobic metabolism and denitrification of nitrate, respectively. Therefore, it is preferable to implement degassing into each RAS.

**Flow-through aquaculture systems** may not need additional degassing measures beyond what is provided by aeration. However, you will need to monitor dissolved gas concentrations routinely.

## Dissolved ions

Many dissolved ions are present in groundwater. Because some have been studied extensively, their effects are better understood. For others, we are just beginning to ascertain their effects on aquaculture production and culture species.

Nitrogenous waste products such as unionized ammonia need to be reduced as they are produced by aquatic animals. Other parameters, such as alkalinity and hardness, need to be measured because some culture species prefer differing concentrations. For optimal aquaculture production, monitor the amount of these ions in the groundwater.

### Nitrogen

Nitrogen takes various forms in water. Total nitrogen is a measure of both organic and inorganic forms of nitrogen found in water:

- **Organic forms** of nitrogen include amino acids and proteins. They are relatively harmless.
- **Inorganic forms** of nitrogen include ammonia (unionized and ionized), nitrite, nitrate, and nitrogen gas (see the section on dissolved gases). Some forms of inorganic nitrogen can harm aquatic animals and decrease aquaculture production.

Within aquaculture production systems, ammonia is typically produced from animal waste, uneaten food, and decaying plants. However, groundwater can also contain ammonia before it is introduced into an aquaculture system. Ammonia is often recorded as total ammonia nitrogen (TAN), which constitutes both the toxic unionized ($NH_3$, or ammonia) and nontoxic ionized ($NH_4^+$, or ammonium) forms. The proportion of ammonia present increases as the pH and temperature increase.

For details on how to calculate the portion of ammonia in TAN, see Publication FA16, *Ammonia in Aquatic Systems,* published by the Electronic Data Information Source of the University of Florida Institute of Food and Agricultural Sciences (UF/IFAS EDIS).

## Biofiltration

The use of living organisms to remove contaminants from water is known as *biofiltration.* A biofilter is a bed of media such as clay, plastic, or rock, where microorganisms attach to the media and via natural processes detoxify harmful materials in the water flowing through it. Biofiltration can be used to remove nitrogenous waste products such as ammonia and nitrite from groundwater. Although groundwater can contain nitrate, it is typically low enough that it is not considered harmful to aquatic animals or aquaculture production.

The amount of biofiltration needed is dictated by:

- The amount of ammonia and nitrite in the groundwater
- The aquaculture system design (flow-through, RAS, or hybrid)
- The animal species

In a flow-through system, even low levels of ammonia in groundwater can cause chronic problems for aquaculture production. These levels may not cause mortality, but they could inhibit the animals' growth and reproduction while reducing their resistance to stress and impairing the system's overall performance.

In RAS systems, low levels of ammonia in groundwater will likely be dealt with by the systems' biofiltration components before negative effects arise. However, if ammonia concentrations in groundwater are high enough, they could compromise production regardless of the type of aquaculture system used.

Biofiltration techniques for groundwater are similar to those in RASs. For ease of water manipulation, install a holding tank. The size of the holding tank will depend on the available space, expected daily water use, and biofiltration measures needed. A holding tank allows time for the groundwater to be treated before it is used in aquaculture. It also provides a reservoir of treated water in case problems arise and access to the groundwater is limited.

**Figure 4.** A moving bed reactor in a marine ornamental aquaculture production system.

If ammonia levels are relatively low (0.2 to 0.5 mg/L TAN) and contact time is long enough, a simple solution is to create a moving bed reactor (MBR) within or in addition to the holding tank (Fig. 4). If heavy aeration is used to move the media within the MBR, take care to prevent air bubbles from entering the water pump intake and causing gas supersaturation. This problem can be prevented through careful system design and light aeration and water flow to move the beads in the MBR.

Additional holding tanks after the MBR can also help degas any gas supersaturation that may have occurred. If space is limited, a more compact biofiltration component can be used, such as a bead biofilter or fluidized sand bed. Plumbing a loop from the holding tank through the small biofiltration component and back to the holding tank allows ammonia concentrations to be reduced within a more compact area.

For more details on biofiltration components, see SRAC Publication No. 453, *Recirculating Aquaculture Tank Production Systems: A Review of Current Design Practice.*

## pH

pH is represented as a scale of numbers from 0 to 14. A pH of 7 is considered "neutral" and anything below 7 is "acidic" and anything above 7 is "basic." Since pH is measured on a logarithmic scale, there is a ten-fold difference between each increment. For example, a pH of 6 is ten times more acidic than a pH of 7.

Most aquatic animals function within a pH range of 6 to 9. However, some species prefer more acidic or basic water, particularly during breeding. Because the pH of groundwater can vary, determining its value is key to developing a functional aquaculture facility. Furthermore, pH interacts with other parameters such as $CO_2$ and alkalinity and also determines the toxicity of ammonia and some metals.

For more details on these specific interactions, see SRAC No. 464, *Interactions of pH, Carbon Dioxide, Alkalinity and Hardness in Fish Ponds.* Techniques for adjusting pH are discussed in the "Softening/hardening" section.

### *Alkalinity*

The alkalinity of groundwater is directly influenced by the bedrock and soils it has come in contact with. Alkalinity is the amount of bases—mostly carbonates and bicarbonates—in the water. Alkalinity is also defined as the amount of hydrogen ions that the water can absorb, or *buffer,* before the pH begins to drop. Typically, alkalinity is measured and expressed as the carbonate portion of calcium carbonate ($CaCO_3$), but other factors such as dissolved gases, phosphorus, and nitrogen may also influence it. For further details on these specific interactions, see SRAC No. 464, *Interactions of pH, Carbon Dioxide, Alkalinity and Hardness in Fish Ponds.*

A desirable alkalinity range for fish culture is between 75 and 200 mg/L (ppm) $CaCO_3$. However, this may vary with culture species and production cycle. Techniques for adjusting alkalinity are discussed in the "Softening/hardening" section.

### *Hardness*

Like alkalinity, hardness of groundwater is directly influenced by the bedrock and soils it has come in contact with. Whereas alkalinity is the amount of bases in the water, hardness is the measure of the divalent ions in the water. These divalent ions are typically represented by calcium, magnesium, and in some cases other elements like iron.

Calcium and magnesium are not only essential for fish growth, but they also help prevent the loss of salts, such as sodium and potassium, from fish tissues. Some hardness, particularly in the form of calcium, is required for optimal fish growth. Similar to pH and alkalinity, the desirable amount of hardness required will depend on the culture species and production cycle. However, for most fish, a hardness of between 100 and 250 mg/L (ppm) $CaCO_3$ is preferred.

Iron may also contribute to the hardness of groundwater. Unlike calcium and magnesium, excessive levels of iron can reduce aquatic animal production and increase aquaculture system maintenance. Concentrations below 0.1 mg/L (ppm) are likely not an issue for the culture species. Higher levels of iron can lead to system maintenance issues, potentially leading to system component malfunction. Elevated iron concentrations may also worsen the animals' preexisting health issues.

Other trace elements, such as zinc and copper, also need to be considered when evaluating hardness, as they can be toxic to aquatic organisms and compromise overall health and aquaculture production.

For more information, see SRAC No. 464, *Interactions of pH, Carbon Dioxide, Alkalinity and Hardness in Fish Ponds.* Techniques for adjusting hardness are discussed in the "Softening/hardening" section.

### *Salinity*

Salinity is the concentration of salt in the water. Salinity can be influenced by several factors including evaporation, precipitation, runoff, leaching from bedrock, and proximity to coastal waters.

Sodium chloride, or common table salt, is usually the compound measured in salinity. Small amounts of salt are often added to freshwater aquaculture systems as a common treatment for fish parasites and to reduce osmotic stress. Osmotic stress causes water to flow into or out of cells in ways that disrupt cell functions. Both sodium and chloride are essential elements for fish growth and are found in most waters.

However, elevated salinity can harm some freshwater fish. If salinity from a freshwater well is high, it can indicate that saltwater is entering the groundwater. High chloride concentrations may be caused by industrial and agricultural wastes entering the groundwater.

Electrical conductivity, or specific conductance, is a measure of the water's ability to conduct electricity. Electrical conductivity is related to the salt content of the water. The higher the salt content, the higher the electrical conductivity.

Electrical conductivity and salinity measurements can also be used to understand the system's total dissolved solids (TDS) level, which is the measure of all dissolved constituents in water. Techniques for adjusting salinity are discussed in the "Softening/hardening" section.

### *Softening/hardening*

Depending on the culture species or production phase, you may want to reduce the water's alkalinity and hardness. Water softeners and reverse osmosis (RO) units are commonly used equipment to remove bicarbonates, salts, and other ions from the water (Fig. 5). They can reduce and in some cases totally remove most ions. Although pH may be reduced indirectly, softeners and RO units do not lower it directly. These units cannot reduce dissolved gases either, including $CO_2$.

Further reductions in pH may require the addition of an acid (such as muriatic acid), which may be practical only

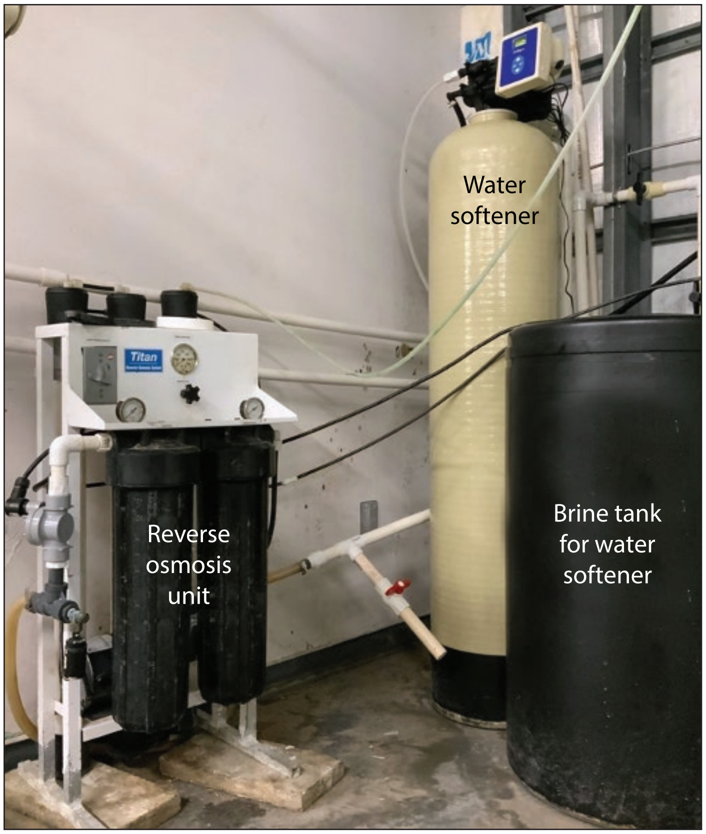


**Figure 5.** Reverse osmosis unit and water softener components at the Tropical Aquaculture Lab of the University of Florida Institute of Food and Agricultural Sciences. After the water passes through these components, it is stored in a 1,500-gallon storage tank for later use.

on a small scale. If needed, the softened water can also be mixed with treated, non-softened groundwater to reach the desired ion concentration. This scenario is ideal when a specific production cycle is targeted for a short time, such as during breeding. If mixed water is needed daily, greater coordination of mixing softened and non-softened water will be required.

Conversely, raising pH will require simply adding the desired ion to the water. Adding bicarbonate to the water will increase alkalinity and, to some degree, pH. To effectively raise pH, add hydroxide to the water. Similarly, adding calcium or magnesium will raise hardness, and adding salt will increase salinity. These chemicals are often available combined, such as in calcium carbonate, which will raise both alkalinity and hardness.

## Integrated groundwater treatment system

Water preparation methods will vary depending on culture species, production phase, aquaculture systems design, and overall facility production goals. Some parameters, such as $H_2S$, will need to be eliminated regardless of culture species. Other parameters, such as hardness, may need to be adjusted only slightly, if at all, regardless of the production system.

Groundwater parameters may also fluctuate over time, culture species may change, and/or production system may be improved. Regardless, you will need to monitor and maintain groundwater parameters continually to create an efficient groundwater treatment system.

If degassing and biofiltration are both necessary, implement them in a single groundwater treatment system. The water can be pumped directly from the well through the degassing units, which will then empty into the MBR and/or holding tank (Fig. 6). From there, the water can be pumped from the MBR/holding tank to any additional holding tanks or directly to the aquaculture production systems.


**Figure 6.** Two different setups showing the combination of degassing units and holding tanks, which could also include biofiltration. At top, pipes take water from the degassing units to the storage tank. At bottom, the water falls directly from the degassing units (blue barrels) into the holding tanks below.

Most often, water softening or hardening is performed after degassing and biofiltration. However, site-specific needs may arise, requiring it to occur before these activities. Also, the softening or hardening step usually does not require that all the water be treated. In such cases, it is ideal to pump water from the degassing/biofiltration treatment system to the softening/hardening system and then to a holding tank for storage until needed. If the groundwater has high levels of iron, you may need to remove the iron before degassing and biofiltration occur. Fig. 7 shows the basic flow of water that may occur within a facility.

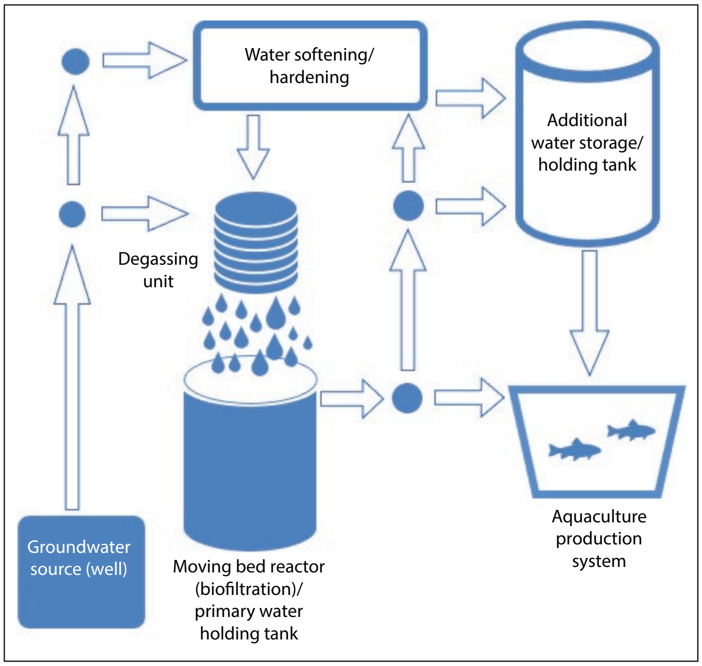


**Figure 7.** A schematic diagram showing potential groundwater treatment scenarios and water movements before supplying aquaculture production systems.

**Table 1:** Common water quality parameters in groundwater, their preferred range for aquaculture production, and mitigation strategies used to adjust them. These are general guidelines, and species-specific requirements should be identified for each culture species.

| Parameter | | Preferred concentration/ range | Mitigation strategy |
|---|---|---|---|
| Dissolved gas | Carbon dioxide | < 15 mg/L | Degassing |
| | Hydrogen sulfide | 0 | Degassing |
| | Nitrogen gas | < 110% total gas pressure | Degassing |
| | Dissolved oxygen | 4–8 mg/L (80–100%) | Degassing/aeration |
| Dissolved Ions | Unionized ammonia | < 0.05 mg/L | Biofiltration |
| | Nitrite | < 0.10 mg/L | Biofiltration |
| | pH | 6–9 | Softening/hardening |
| | Alkalinity | 75–200 mg/L $CaCO_3$ | Softening/hardening |
| | Hardness | 100–25 mg/L $CaCO_3$ | Softening/hardening |
| | Salinity | Species-specific | Softening/hardening |

## Conclusions

Appropriate water quality is one of the most important aspects of an effective and lucrative aquaculture production facility. Understanding the water quality of the groundwater is the first step in determining the measures needed to provide the culture species with an optimal production environment. Water quality will also dictate what species may be best to culture for the specific aquaculture facility.

Because water quality tends to fluctuate over time, you will need to monitor groundwater quality parameters consistently and understand the treatment techniques available. The system must be designed properly and techniques implemented before subjecting the culture species to groundwater (Table 1).

## Suggested reading


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