THE UNIVERSITY OF GEORGIA
COOPERATIVE EXTENSION
Colleges of Agricultural and Environmental Sciences & Family and Consumer Sciences

Water Quality Assessment

The University of Georgia
The Greenhouse*A*Syst Publication Series
A Program Designed To Assess and Manage Issues
Involving Our Natural Resources and Environment

Table of Contents

The University of Georgia

The Greenhouse*A*Syst Publication Series

A Program Designed To Assess and Manage Issues Involving Our Natural Resources and Environment

Home*A*Syst is a national program cooperatively supported by the USDA Cooperative State Research, Education and Extension Service (CSREES), USDA Natural Resources Conservation Service (NRCS), and U.S. Environmental Protection Agency (EPA).

This publication follows the Farm*A*Syst/Home*A*Syst (FAS) grower self-assessment model of dividing farming management into a series of issues, dividing each issue into categories, including educational materials, and following up the self-assessment with the development of action plans to address the key areas of concern. Universities that have *A*syst publication series include Oklahoma, Kansas, Texas and Wisconsin. New series have recently been successfully developed at major universities including Orchard*A*Syst, and Food *A*Syst.

The Greenhouse*A*Syst publication Series has been developed to assist greenhouse owners with the task of assessing three management issues: Water management, Environmental Risk and Business Profitability. To date, 6 publications in this 12-part series are being reviewed and 6 more are being developed.

The Greenhouse*A*Syst series of publications is a confidential self-assessment program you can use to evaluate your greenhouse business for risks associated with water management issues. Armed with facts and figures, you will then be able to reevaluate your management strategies and determine ways to conserve water and minimize those risks. By following the guidelines, you will be able to establish a formal company-wide water conservation plan. Implementation of this plan will facilitate more efficient use of resources and impart significant savings in water use, fertilizer and pesticides.

This bulletin will also help you establish a water conservation document you may find useful if and when state or local water authorities develop policies or implement water restrictions. Most water authorities are favorably impressed with businesses that have developed water conservation plans.

Greenhouse*A*Syst risk assessment consists of a series of questions that will walk you through the considerations to be taken into account while evaluating your business. In order to gain the full benefit of the Greenhouse*A*Syst program, we recommend that you use all 12 publications in the series in the following order.

Risk Area	Greenhouse*A*Syst Publication	Suggested Order
Water Source and Expansion	Available	1
Delivery and Technology	Available	2
Water Management	Available	3
Water Quality Assessment	In production	4
Water Recycling/Pollution Prevention	In production	5
Water Regulations/Company Policy	In production	6
Fertility Management	In development	7
Operation Safety and Biosecurity	In development	8
Shipping, Transportation, Material Handling	In development	9
Greenhouse Energy Utilization	In development	10
Time and Labor Management	In development	11
Greenhouse Maintenance	In development	12

Water Quality Assessment

Publication #4 in the Series

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What Can This Bulletin Series Do for Me?

In most greenhouse operations, water quality is not a management issue, though it should be. Most businesses test their water supply at the time of purchasing the business and infrequently thereafter, usually right after a serious problem has developed. Water quality can change due to weather conditions such as flood or drought, development of land in nearby areas, earthquakes, and rural development via subdivisions or industry. Water quality issues go beyond what is coming from the water source. The type of fertilizer you add can also affect the quality of water coming out the end of the hose. Knowing what is in your water from the source is important. Knowing what you are putting in your water, however, is also important. This section will help you determine your water quality and help you develop a management plan to monitor your water quality.

The purpose of this section is to help you determine the risks associated with water quality and the benefits of regular water quality assessment

How often do you test your water supplies?

Since water quality does fluctuate in many systems, testing twice a year is good, four times a year is best.

Do you understand the results of water quality test reports?

If you have to ask someone else to interpret the results, it is probably time to relearn the importance of each test value provided and what it means to your company.

Do you keep long-term records of those tests?

Keeping long-term records can provide valuable information on subtle but important water quality trends. Water quality can change due to local construction, prolonged drought, suburban encroachment and shifts in water movement due to minor earthquakes.

Do you filter your raw water supply before it enters the greenhouse?

The longevity of pumps, emitters and filters may depend on it.

Have you adjusted your fertility and pesticide applications in relation to your water quality?

Water hardness and pH can dramatically affect how soluble your pesticide is and how effective the active ingredients are.

Would water quality intervention practices improve your crop quality?

If the soil tests show pH shifts substantially over time or if chronic nutrient deficiencies occur, adjusting your base-line water quality may improve the quality of your plants significantly as well as reduce losses.

Water Quality Management

Water Quality Monitoring and Record Keeping

Water quality monitoring and record keeping is a chore that many growers find difficult to find time for, however, record keeping is the best way to catch a problem before it becomes an economic liability. Time spent keeping good records of your operational activities is well worth it in the money, time and energy saved from averting disasters to your water supply which is the life blood of your operation. When you do not have information on the water use and the water quality of your operation's resources, you take unnecessary risks. Monitoring and record keeping for water quality are not expensive, and the records can be simple and easy if they are a planned part of production management. Water monitoring and record keeping chores are minimal for municipal and groundwater sources. Knowing the water quality of a water source is important not only for the health of the crops, as well as choice of fertilizer and pesticide formulations.

Water from municipal systems usually has consistent chemical concentrations controlled by the water treatment processes. However, in years where water supplies run short, the water quality may change due to the concentration changes of the utilities source water. A public water supply facility may find it necessary to purchase water from different sources, which means different source water for their customers.

For normal or average weather conditions, testing of water from the municipal water supply once a year for chemical constituents should be sufficient, but in drought years or when the water treatment plant institutes new treatment methods, additional water testing may be needed. If your primary water supply is from a public water system, keep in touch with the manager there, so you can be aware of changes that could affect your operation.

Some municipal systems are "flushed" annually, which could affect water quality. Ground water sources also need to be monitored regularly, because long-term weather changes may affect well water quality.

Surface water sources will change with the seasons with climatic conditions and with upstream land use changes. Water quality testing for surface water sources should be carried out at least four times a year. Samples should be taken at least once each season to assess these seasonal water quality changes. March, April and May (spring) stream flows are high and chemical constituents in ponds and streams are more dilute. June through September (summer), stream flow fluctuates according to weather, with a marked decrease in flow in the hottest weeks of summer. October through February (fall and winter), water levels start out low and increase with rainfall. Monitoring for water quality may need to be more frequent in spring and summer if stream flows rise or fall to a great extent in a season. Then in fall and winter, the water flows usually gradually increase and checking the water quality once or twice during this part of the year may be needed.

Surface water monitoring should not only be planned for seasonal and climatic variations. It also depends on your cropping schedule. Frequency of water monitoring also should be tied to the crops being grown and whether they are being established or are filling out. Plants are most sensitive to water quality when germinating or developing first roots for a cutting or tissue culture. It is while the first roots are developing that a plant adjusts to the water quality it is provided or is killed by toxic concentrations. In general, once a healthy root system is established, plant sensitivity to poor water quality decreases. Different plant materials, however, have different sensitivities, and this needs to be taken into consideration for each kind of crop.

Monitoring runoff water quality leaving the production area may be needed if the area is near a stream or other water body. Issues of runoff water monitoring are discussed in publication #5 of this series.

Collecting a Water Sample

For collecting a water sample for laboratory chemical analysis, use a clean, carefully sealed plastic container. Avoid glass containers because they can contaminate the water sample with boron. Similarly, metal caps may cause metal contamination.

Allow water to run for 5 minutes to clear the lines so the sample is taken "fresh" from the source and not from water that has been sitting in the pipes. Rinse the container two or three times with the collection water and collect approximately 16 oz. Mail the sample within 24 hours. When sending a water sample to be tested in a laboratory, preserve it so it will accurately reflect the chemical content at the time the sample was taken. Refrigeration may be necessary to slow down microbial activity until the sample is shipped. Consult the laboratory for requirements of handling and collection for a particular chemical to be tested.

Quality of Supply Water

Eliminating Suspended Solids — Filtration

Municipal water supplies can pick up particles as water flows through the delivery pipes. Ground water can be relatively free of particles or it can have large quantities of sand and/or silt that can enter greenhouse irrigation supply as water is pumped from the aquifer. The particulates from municipal sources and ground water will wear down nozzles and clog emitters and negatively impact irrigation uniformity.

Filtration of the water supply increases the lifetime of your irrigation components while keeping the efficiency and uniformity of irrigation application optimum. A filtration system removes sand, silt, plant material, algae and other materials suspended in the water. No matter what the source of water, some filtration is needed. The kind of filtration needed depends on the water source and its characteristics.

For municipal sources, screen filters are usually adequate. Place the filter just upstream of the backflow prevention device but before any fertilizer or acid injector. The frequency with which the filter should be cleaned depends on the water source and the amount of water flowing through the filter. Cleaning should take place when pressure drop across the filter has increased by 3 to 5 psi. The area of a filter screen should be determined from the flow rate going through the filter. For every 200 gpm of flow, there should be 1 square foot of screen area.

For irrigation systems with micro-irrigation or drip components, a 200 or finer mesh size is recommended. For overhead sprinklers only, mesh size should be about 1/6th the size of the smallest orifice in the system. The smallest orifice in a sprinkler system is usually the sprinkler nozzle, but may be an orifice within a control valve.

Mesh screen size numbers indicate the number of wires per inch. They can be made of stainless steel, polyester or nylon. The larger the screen size, the smaller the screen opening. Size of opening for different mesh screen sizes is provided in Table 1.

Table 1. Mesh screen size conversion to opening size in inches

Mesh Screen Size	Inches
20	0.0330
50	0.0132
100	0.0059
150	0.0044
200	0.0029

Example for Mesh Size Selection:

Given that the smallest sprinkler nozzle size on the system is a 3/32 inch (0.0938), what mesh screen size would work best? 3/32 divided by 1/6 is 0.0156, which equals the screen size needed. The 50-mesh screen is the best choice as it is the next smallest size for the calculated screen opening needed.

For properly developed wells that do not pump much sand, mesh screens may be the only filtration needed, but many wells tend to pump measurable amounts of sand, and if significant sand is pumped the mesh screen will clog too quickly and another kind of filter may be needed. If most of the particles to be filtered are sand size (0.01inch or larger), a sand separator filter would prevent the sand from getting into the irrigation system. A sand separator works by swirling the water, creating a centrifugal force that separates the water to the outside of the column. Heavy particles settle out and fall into the bottom of the column and get left behind. Sand separators can remove up to 98 percent of particles larger than the equivalent of 200 mesh screen. The sand separator is sized according to the flow rate of the system.

Filtration of surface water is quite different because, with surface water, you are dealing with organic materials that you do not have with well or municipal water. Organic matter in water has very different characteristics than the particulates of rust or sand encountered with well water. Organic matter may condense and clog the mesh screen.

For filtering organics out of water, the first consideration is the flow rate. When the flow rate into the system is less than 50 gpm, a cartridge filter will clean out the organics. Cartridge filters are made up of a rigid porous media such as nylon, cotton, fiberglass or other synthetic material. Any materials suspended in the water are filtered out by the cartridge. However, cartridge filters must be replaced periodically.

If the watering system has a flow rate greater than 50 gpm, then a media filter designed for filtering organics is necessary. Media filters are tanks filled with sand, fiberglass or crushed granite. The water flows through the media, which captures particulates and organics. The particle size of the media determines the size particles that will be filtered.

Tanks can be made of carbon steel or stainless steel. The carbon steel tanks are suitable in most cases but may corrode under certain conditions. The stainless steel tank does not corrode but is more expensive.

Media filters are generally more expensive but can capture both organic and inorganic contaminants smaller than 200 mesh, and they have a greater filtering capacity. Have at least two media filters in tandem so that, once one filter loses its filtering efficiency, it can be cleaned by backwashing while the second filter is filtering water. Additional filter tanks can be added if increased filtration capacity is needed. The size and number of filters needed depends on the flow rate and the amount of material that must be removed to filter the water. The recommended sizing for media filters is 15 to 25 gpm per square foot of filter area. If the water has 100 ppm sus-pended material or more, lower flow rate to filter area ratio is needed to prevent over-frequent back flushing and high-pressure losses in the tanks. In conjunction with the media filter, it is good to have a screen filter downstream to trap any media that slips out of the media tanks. Where sediment load is high, it may be a necessary to pre-screen just upstream from the media tanks with a sand separator.

Finally, when withdrawing water from a surface source, it is desirable to keep large particles out of the pump. To do this, a suction screen filter at the upstream end of the intake pipe is recommended. This filter has a mesh size of 30 or less and may even be a perforated screen rather than a woven screen. The screen surrounds the area outside the intake pipe and the filter uses rotating water jets inside the screen for self-cleaning. Pressure for the cleaning jets comes from the discharge side of the pump.

Chemical Constituents

pH and Alkalinity

A pH reading is a measurement of the acidity or basicity of a solution and indicates the concentration of hydrogen ions. The pH range is 0 (most acid) to 14 (most basic). The recommended ranges of irrigation and substrate solution pH depend on the crop grown, but it is generally 5.4 to 7.0 for the irrigation water and 5.2 to 6.3 for the substrate solution.

Alkalinity is a total measure of the substances in water that have “acid-neutralizing” ability. Two ways to think of alkalinity are that it is the buffering capacity of water and/or that it is like lime in the water. Alkalinity is attributed mostly to calcium and magnesium carbonates and bicarbonates, which are major components of limestone. Alkalinity should not be confused with pH. While pH of a solution is the concentration of hydrogen ions and measures the strength of an acid or a base, the alkalinity reflects the solution’s power to react with acid and keep the solution pH from changing. The alkalinity, then, indicates how well a solution is buffered. Alkalinity sounds very much like “alkaline” but beware because they are **not** the same thing! Alkaline is a term applied to solutions with a pH higher than 7.0.

Alkalinity and pH can be tested in-house using various kits or samples of the irrigation water can be sent to an analytical lab and a complete test of water quality obtained. The alkalinity level has far-reaching implications because of its strong effect on the substrate pH. Of two water sources, one with a pH of 9.0 and alkalinity of 50, and the other with a pH of 7.0 and alkalinity of 300, the first will raise substrate pH very little, while the second will cause a much higher rise in the substrate pH.

Since carbonates and bicarbonates are the major components of water alkalinity, most laboratories equate total carbonates [TC = carbonates (CO_3^{2-}) plus bicarbonates (HCO_3^-)] with alkalinity. Other laboratories assume that bicarbonates are the sole contributors to alkalinity. Alkalinity is expressed as parts per million (ppm), milligrams per liter (mg/L), or milliequivalents per liter (meq/L) of equivalent calcium carbonate or bicarbonate alone. Various sources prefer to use one or another of these units, and unless you are familiar with the conversion factors, it could be rather confusing.

$$50 \text{ ppm } CaCO_3 = 50 \text{ mg/L } CaCO_3 = 1 \text{ meq/L } CaCO_3 =$$
$$61 \text{ ppm } HCO_3^- = 61 \text{ mg/L } HCO_3^- = 1 \text{ meq/L } HCO_3^-$$

In the aquifer, water comes in contact with the rocks and dissolves some of the component minerals. The longer the duration of contact, the more minerals are dissolved. (This is why, after prolonged periods of drought, the alkalinity of a well may rise and the opposite may occur during rainy periods.) When the calcium and magnesium carbonates and the calcium and magnesium bicarbonates are dissolved, they dissociate as calcium (Ca), magnesium (Mg), carbonate and bicarbonate ions:

$$Ca^{2+} + Mg^{2+} + HCO_3^- + CO_3^{2-}$$

The substrate pH rises because the carbonate and bicarbonate ions react with the substrate acidity (H^+) to form carbonic acid, which in turn converts to water and carbon dioxide.

$$HCO3^- + H^+ \quad H_2CO_3 \quad H_2O + CO_2, \text{ and,}$$
$$CO_3^{2-} + 2H^+ \quad H_2CO_3 \quad H_2O + CO_2$$

In these reactions, the acidity (H^+) and the carbonates and bicarbonates are consumed. The loss of hydrogen ions in the substrate causes a higher pH level. This is the mechanism through which alkalinity in the water affects the substrate pH.

Water Hardness

The calcium and magnesium ions dissolved in the water constitute the **hardness**. Hardness is a measure of the combined content of calcium and magnesium in water. Hardness is expressed as parts per million (ppm), milligrams per liter (mg/L), or milliequivalents per liter (meq/L) of equivalent calcium carbonate. As you might expect, hard water would **generally** be associated with high alkalinity, but not always. If there are high levels of calcium and/or magnesium chloride in the water, then the water may not have high alkalinity even though it would be considered "hard." In this case, you have to measure the level of chloride, as it may pose potential problems.

Pure distilled water is said to be very soft because it does not contain any dissolved minerals. Likewise, rainwater is soft because it contains very few minerals. However, soft water does not always lack minerals. Highly mineralized water sources where sodium is the main cation are also said to be soft.

If you have hard water, you need to look at the levels of Ca and Mg and the ratio between them. Proper balance should be 3 to 5 parts Ca to 1 part Mg, if expressed in meq, or 5 to 1 if expressed as ppm Ca and Mg. Calcium levels higher than these can interfere with the uptake of magnesium, causing magnesium deficiency in the plant. If you have hard water with high levels of Ca and Mg, it may be wise to lower the amount of limestone added to the growing substrate. Make sure you monitor the substrate pH to make sure it is in the proper range. The most common problem is a low level of magnesium relative to calcium. This problem can be corrected with an occasional application of a magnesium source, such as magnesium sulfate (Epsom salts).

Bottom line on the water pH, alkalinity and hardness: Consider a high water pH (over 7.2) a warning to look at the alkalinity level. Hardness can be used only to estimate alkalinity. A specific test for alkalinity is required.

Not all water sources have high mineral content and high alkalinity. In fact, if you have very pure water and especially if you are using acidic fertilizers, the substrate pH may gradually decrease over time. This may affect the availability of nutrients and cause micronutrient toxicities in susceptible crops. For this reason, some growers who use water with very low levels of carbonates and bicarbonates add potassium bicarbonate ($KHCO_3$) to increase water buffering capacity. An analytical laboratory can tell you how much potassium bicarbonate is needed based on the pH and alkalinity of the existing water source. The actual amount of potassium bicarbonate injected into the irrigation water should be based on considerations such as crop species, substrate type and fertilizer used. Do not use baking soda (sodium bicarbonate), because sodium readily builds to toxic levels. Suggested minimum alkalinity levels range from 0.66 to 0.8 meq/L for plug production and from 1.2 to 1.98 meq/L for plants in 6-inch pots.

Correcting High Alkalinity

What level of alkalinity should you consider "best"? Precise upper critical alkalinity level is very specific to cropping characteristics. Excessive alkalinity will cause a substrate pH to rise to an unacceptably high level by the end of the crop cycle.

Three factors decide the upper critical alkalinity level: the length of the crop period, the plant-to-substrate ratio, and the upper substrate pH level that the crop can tolerate. Water alkalinity causes substrate pH to increase over time as more water is added with each irrigation. The longer the crop cycle, the higher the pH can get. A short-term crop may tolerate a high alkalinity level in the water, while a long-term crop may not. Also, the smaller the growing container and the larger the plant shoot, the faster the changes in pH can occur. This situation develops in plug production, where the seedlings are grown in very small volumes of soil. As the shoots grow, they use large quantities of water. If the irrigation water has a high alkalinity level, the substrate pH can quickly rise, because there is little substrate to neutralize the carbonates and the bicarbonates. Lastly, crops that need low substrate pH for normal growth will not tolerate high alkalinity.

Alkalinity levels up to 2 meq/L (or 1.5 meq/L for plug production) will probably be safe for most crops. If the alkalinity levels range from 2 to 3 meq/L, consider adding less lime to the substrate and/or using acid fertilizers. Acid injection is required if the alkalinity levels are above 3.0 meq/L. If the alkalinity levels are higher than 8 meq/L, consider treating your irrigation water by reverse osmosis. The precise quantities of acid to add can be determined using an alkalinity calculator developed by researchers at North Carolina State University and Purdue University and can be found on the following website:

www.ces.ncsu.edu/depts/hort/floriculture/software/

The acids most commonly injected into irrigation water to neutralize water alkalinity are sulfuric acid and nitric acid. Citric acid and phosphoric acid can also be used, but they are more expensive. The amount of acid required takes into account the water pH and alkalinity. There are several considerations when deciding which acid to use — safety, cost and nutrients. Citric acid is the least hazardous, while nitric acid is caustic and can produce dangerous fumes.

For all acids, avoid skin and eye exposure and wear acid-resistant eye wear, gloves and an apron. When mixing acid, ALWAYS add acid to a larger volume of water and NEVER add water to concentrated acid.

Citric acid is safer and easier to use, but it is the most costly. Citric acid is used mainly in pesticide sprays and in fertilizer stock solutions rather than to neutralize irrigation water. Sulfuric and nitric acids are less expensive than phosphoric and citric acids. Three of the four acids normally used to correct alkalinity will also add plant nutrients to the irrigation water. Nitric acid adds nitrogen, phosphoric acid adds phosphorus, and sulfuric acid adds sulfur. When designing your nutrition program, take into account the quantities of nutrient supplied with the acid and reduce accordingly the amount of fertilizer that carries this nutrient.

Citric acid does not add nutrients. Sulfuric acid is a good choice for correcting alkalinity in irrigation water and is readily available from auto supply stores as a common battery electrolyte product, Qual®.

Salinity

Salinity is the total quantity of dissolved salts in the water. Since all salts are charged ions, the solution they are dissolved in conducts electricity when an electric current is applied to it. To measure salinity, we obtain a measure of the electrical conductivity or EC of the Total Dissolved Salts (TDS). The higher the EC, the more salts are dissolved. There is no indication, however, of which salts are present. A common conversion factor derived from the average of many water samples is: 1 mmhos/cm = 640 ppm TDS. The soluble salt level should ideally be less than 0.75 mmhos/cm for plug production, less than 1.0 mmhos/cm for other greenhouse crops, and less than 2.0 mmhos/cm for nursery crops.

The plant root cells absorb water as a result of the differences in osmotic pressure between the cell contents and the soil solution. Whenever the salinity of the soil solution is near or greater than that of the root cell contents, plants are unable to take up sufficient water to maintain growth. Nonfertilizer salts tend to accumulate in the growing medium since they are not removed or used by the crop. Therefore, water with high salinity of non-nutritive elements may require leaching to reduce salt buildup in the media.

High levels of salts also can accumulate in the plant tissue and cause burns. Salinity is one of the most difficult problems to correct. In serious cases, finding an alternative source of water may be the only answer. However, proper management can reduce the effects of moderate salinity of irrigation water.

Soluble Salts

The growing medium should provide sufficient drainage and thus be easily leached and reduce the potential for the accumulation of soluble salts. If the salt hazard is high, approximately 15 to 20 percent more water than the container can hold should be applied at each irrigation. Growing media should not be allowed to dry out if salt levels are high. The concentration of soluble salts in plant tissues increases as moisture levels decrease. Growing media is usually formulated from materials such as perlite, vermiculite and pine bark, which do not contain excessive amounts of salts.

Salinity caused by high levels of sodium is especially hard to correct. Sodium toxicity, whether due to root absorption or foliar absorption of sodium, is expressed as marginal leaf burn on older foliage. Sodium is another salinity factor which, if found in high levels, could reduce water movement into the plant and retard growth. It could also interfere with the uptake of nutrients and thus lead to various macro- and micronutrient deficiencies. Sodium levels are reported as the **Sodium Adsorption Ratio (SAR)**. SAR reflects the amount of sodium in relation to the amounts of calcium and magnesium present in the water and helps determine if the sodium is the dominant cation. SAR levels higher than 4 meq/L could result in excessive amounts of sodium absorbed. This situation could be alleviated by adding calcium. It is recommended that water containing more than 3 meq/L sodium should not be used for overhead irrigation because of the danger of excessive foliar uptake of sodium and leaf margin burn.

Chloride is the final salinity factor of concern. Similarly to sodium, high levels could interfere with the water absorption and cause wilting and stunted growth. Chloride can accumulate in leaf tissues, resulting in leaf burns. Chloride could become a problem if levels are higher than 2 meq/L.

Macro- and Microelements

Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S) are macroelements that are essential for plant growth. In moderate levels they will not create any production problems. However, their levels in the water should be evaluated as an indicator for potential water contamination and in relation to the nutrition program. An excess of these elements can be harmful, especially when additional amounts are being added through a fertilizer program. Often the excess of macroelements in the irrigation water is the result of contamination. It also may be the result of using recycled irrigation water to which fertilizer had been added.

If water tests show more than 10 ppm of nitrogen or 1 ppm of phosphorus, there is a strong possibility that the water has been contaminated with a fertilizer, detergent or other contaminant. Acceptable levels of various nutrients and other water quality parameters are listed in the Appendix.

Aluminum (Al), boron (B), copper (Cu), fluoride (F), iron (Fe), manganese (Mn), molybdenum (Mo) and zinc (Zn) are microelements that also are essential for plant growth. Among the micronutrients, boron and fluoride could pose problems. Boron-sensitive crops could show toxicity symptoms if levels are above 0.5 ppm. Fluoride in levels higher than 1 ppm pose a special problem to sensitive crops in the Liliaceae, Agavaceae and Marantaceae families.

An excess of micronutrients can be corrected in two ways: by reducing the amounts being added in fertilizers, and by raising the pH level of the growing media solution. Higher pH levels will make these nutrients less available to plants.

Iron and Iron-Fixing Bacteria

In some areas, irrigation water containing excess iron and/or iron bacteria can cause problems such as unsightly brown stains or bluish sheen on foliage and flowers. As little as 0.3 ppm iron in the water could lead to deposits if overhead irrigation is used. Iron problems can come from two sources: well water that contains iron, and iron-fixing bacteria in water storage basins. Iron is a common element in many soils. Consequently, iron-fixing bacteria have existed in our waters for over a million years. Iron-rich fill material or bedrock can create an iron bacteria problem whenever it is located near water. In general, wherever there is oxygen, water and iron, there is a potential for an iron bacteria problem.

Iron bacteria "feed" on iron (Fe). Unlike most bacteria, which feed on organic matter, iron bacteria obtain their energy from oxidizing soluble ferrous iron (Fe^{2+}) into insoluble ferric iron (Fe^{3+}). The ferrous iron precipitates out of the water as a rust-colored deposit.

This process can occur simply by exposing iron-rich groundwater to the atmosphere. Orange or brown slime (precipitate) and oily sheens are often the first indication that these bacteria are present. Unlike oily petroleum sheens, the iron bacteria sheens break apart when they are disturbed. The orange or brown slime may be collected in a jar and analyzed microscopically at an analytical lab to identify the bacteria type. A relationship may exist between iron problems and hot weather. The iron in the water comes out of solution through the oxidizing process that has a higher rate in warm air. Under such conditions, the iron is already precipitated out of the water by the time it hits the leaf surface and is deposited there.

Recommendations for removing iron are to aerate water in a holding pond, which allows the iron to precipitate before it reaches the plants. If iron-fixing bacteria are present, however, this measure may not be sufficient. Some growers have been able to reduce the problem of iron deposits by adjusting the irrigation intake location. The intake should be located 18 to 30 inches below the surface to avoid pulling in the oily surface sheen, at least 18 inches deep to prevent "vortexing" from the surface, and should be up from the bottom to avoid pulling up iron sediment. The next step is to install a basin aeration pump, which helps precipitate the iron, thus reducing the food source for the iron bacteria.

Problems caused by iron-fixing bacteria also could be corrected by injecting chlorine in the water in conjunction with an irrigation filter. Chlorine acts as a catalyst to instantly precipitate iron, which then can be captured in a filter. Chlorine has an oxidizing effect that also changes the chemical form of iron, making it less harmful and eliminating iron deposits on the surfaces being irrigated. The chlorine must be in contact with irrigation water for one minute to be effective. To accommodate the chlorine injection, the irrigation system needs retrofitting, which may require storage tanks, swirl chambers or extra loops in the irrigation lines. Two forms of chlorine can be used: gas or liquid. Gas is the most efficient and effective but is also hazardous. Liquid chlorine injection is safer. A filtering system that removes organic residue will reduce the amount of chlorine required.

Greenhouse*A*Syst Risk Assessment of Water Quality

Instructions for Completing the Risk Assessment

For each subject given in the left-most column, read through each column and then select the description that best describes your operation. Do not rate practices that do not apply to your operation. Record the risk rating value in column 6 (the right-most column), and then calculate the overall risk rating for this section at the end of each section. We will use these ratings to assess the overall water related risk of your operation at the end of the document.

	Low Risk 4	Low-Moderate 3	Moderate-High 2	High Risk 1	Rank Your Site
Water quality records	Have written records of water quality testing. Testing at least once for each production cycle.	Have written records of water quality testing. Testing at least twice a year.	Have written records of water quality testing, but test less than twice a year.	No written records of water quality measurements.	
Filtration	Filtration systems for all water supply sources are appropriate to the source.	Only water supply from surface water sources is filtered.	All water sources are filtered except the public water supply source.	Source waters are not filtered before going into the irrigation system.	
Groundwater or public water source sand filtration	All water sources from wells or public system are filtered for fine particles.	--------------------	Groundwater supply water is filtered but public water supply is not filtered.	None of the groundwater and public water supply sources are filtered.	
Water supply quality — pH	pH of water supply is consistently between 5.5-6.5.	pH of water supply occasionally is less than 5.5 or greater than 6.5 from a surface water or recycle source.	pH of water supply is not consistent due to differences in various sources.	--------------------	
Water supply quality — electrical conductivity (EC)	EC of water supply is always below 1.0 millimhos/cm.	EC of water for plugs, seedlings and small pots is always less than 1.0 mmhos/cm with any higher EC water used on larger plants.	EC of water supply is usually greatr than 1.5 mmhos/cm.	EC of water supply is usually greater than 2.0 mmhos/cm.	
Substrate solution pH	Substrate solution pH is between 5.2-6.3 or a value that is best fo the particular crop throughout crop production cycle.	Substrate solution rises above 6.3 or falls below 5.2 by the end of the crop production cycle.	Substrate solution pH is below or above 5.2-6.3 at the initial propagation phase of production.	No measure of substrate solution pH is taken.	

	Low Risk 4	**Low-Moderate 3**	**Moderate-High 2**	**High Risk 1**	**Rank Your Site**
Correcting high alkalinity	Alkalinity is low in irrigation water or is controlled with fertilizer injection.	Alkalinity can be above 3 meq/L occasionally with no acid injection and the crop cycle is less than 4 weeks or container to plant size ratio is large.	Alkalinity is above 3 meq/L with no acid injection, and crop production cycle is greater than 4 weeks or plug production.	Alkalinity is not measured.	
Hardness — Ca to Mg balance	Water supply water has 30-50 ppm carbonate and/or bicarbonate.	Water supply has enough [Ca + Mg] to make it hard, but the Ca to Mg ratio is in a proper balance of 3-5 ppm Ca to 1 ppm Mg.	Water supply has enough [Ca + Mg] to make it hard and the Ca to Mg ratio is not in balance.	No measure of hardness to identify problems.	
Sodium adsorption ratio	SAR <4 meq/L and sodium ions <3 meq/L	SAR >4 meq/L or sodium ions >3 meq/L with irrigation system other than overhead sprinkler.	SAR >4 meq/L or sodium ions >3 meq/L with overhead sprinkler irrigation.	No measure of sodium to determine SAR.	
Iron bacteria	Low iron content in water supply.	High iron content with good filtration system and disinfection of irrigation water.	High iron content and disinfection without adequate filtration to remove iron precipitate.	High iron content of water supply with no method of control.	

Ranking Totals	÷	Total Areas Ranked	=	Water Quality Risk Rating
___________	÷	_______________	=	___________________

Summarizing, Evaluating Your Greenhouse*A*Syst Assessment Results and Identifying Action Steps

The purpose of this section is to help you summarize your overall risk to your business from water related issues.

Once you have filled out the seven sections of risk assessment, you may summarize the results in the table provided below. This will allow you to easily see what areas your company needs to reduce risk in and where you need to make improvement. An overall risk value for the company is the last step in the process.

STEP 1.
Identify Areas Determined to be at Risk

Fill in this summary of your Greenhouse*A*Syst Assessment for Your Operation.

Risk Area	Greenhouse*A* Syst Publication	Overall Risk Rating
Water Source	Bulletin 1274	
Delivery and Technology	Bulletin 1275	
Water Management	Bulletin 1276	
Water Quality	Bulletin 1277	
Water Recycling/ Pollution Prevention	Bulletin 1278	
Legislative Awareness/ Company Policy	Bulletin 1279	
Total Overall Risk Level for Water (Average of 6)		

* Bulletins are all Georgia Cooperative Extension bulletins; visit http://www.caes.uga.edu/publications/

Low risk practices (4s) are ideal and should be your goal. Low to moderate risk practices (3s) provide reasonable results and protection. Moderate to high risk practices (2s) provide inadequate protection in many circumstances. High risk practices (1s) are inadequate and pose a high risk for causing environmental, health, economic or regulatory problems.

High risk practices, rankings of "1," require immediate attention. Some may only require little effort to correct, while others could be major time commitments or costly to modify. These may require planning or prioritizing before you take action. All activities identified as "high risk" with a ranking of "1" should be listed in your action plan developed from this assessment. Rankings of "2" should be examined in greater details to determine the exact level of risk and attention given accordingly.

STEP 2.
Determine Your Overall Risk Ranking

This value provides a general idea of how your water use practices might be affecting your efficiency of water use and your understanding of proper watering practices and maintaining good water quality in your operations and impacts to surface and groundwater.

Water Use Risk Ranking	Level of Risk
3.6 to 4.0	Low Risk
2.6 to 3.5	Low to Moderate Risk
1.6 to 2.5	Moderate Risk
1.0 to 1.5	High Risk

This ranking gives you an idea of how your water use practices might be affecting your business success and conservation of water. This ranking should serve only as a very general guide, and not as a precise diagnosis since it represents the average of many individual rankings.

STEP 3.
Transfer Information on Risk to a Formal Plan for Improving Your Water Management and Use Practices

From the results of this assessment and after studying the provided guidelines and facts section, outline a plan of changes you want to incorporate into your operations with a timetable on when you will achieve these changes. A plan can always be amended and changed due to new information, but if you do not make a plan with the new knowledge about your own practices that you have gained, then odds of follow through with real changes is unlikely. The plan outline can be as brief or as detailed as you want to make it. Be sure and note where you need to gather more information or consult with someone in your plan so that you will take action only after careful consideration of complex issues.

STEP 4.
Develop A Formal Action Plan

Simply put, assign specific staff to accomplish specific tasks in a known period of time. If more information is needed to make appropriate decisions, delegate specific fact-finding tasks to personnel best suited to accomplishing the task. Set goals and time lines based upon realistic expenditures of time and resources. Have each individual task written up for the entire team to assess and put into the larger context of the company. A formal action plan form is provided in the Appendix.

STEP 5.
Develop a Company Water Use and Monitoring Policy

The final step in this process is to sit down with your management team and decide how to address your plans. The best method is to establish company water conservation/use policy. By doing so, every new and existing employee will be able to learn and follow your expectations for water management. By developing a policy document, you are also showing legislators and regulators that your company is serious about water management. Such documents will greatly improve how your business is viewed in the community.

STEP 6.
Implement the Policy

Your policy document stands as a symbol of your commitment to resource preservation. Consistent implementation will yield greater profits and better relations with your community.

Contacts and Information Sources

Organization/Individual	Responsibilities	Address	Phone Number
Georgia Department of Agriculture, Pesticide Division	Questions regarding anti-siphon requirements for irrigation systems.	Agriculture Building 19 Martin Luther King Jr. Dr. Atlanta, GA 30334	404-656-4958 www.agr.state.ga.us
Geologic Survey Branch Environmental Protection Division	Regulations concerning water well drinking standards.	Georgia DNR 19 Martin Luther King Jr. Dr. Suite 400 Atlanta, GA 30334	404-656-4807 www.state.ga.us/dnr/environ — Geologic Survey Branch
Department of Biological and Agricultural Engineering, University of Georgia	Questions related to well-head protection or ground water on a farm.	Extension Unit Landrum Box 8112, GSU Statesboro, GA 30460	912-681-5653 www.bae.uga.edu
Drinking Water Program Environmental Protection Division	Questions regarding public drinking water.	Georgia DNR 205 Butler St SE Floyd Towers East, Ste. 1152 Atlanta, GA 30334	404-651-5157 www.state.ga.us/dnr/environ — Water Resources Branch
Safe-Drinking Water Hotline U.S. Environmental Protection Agency	General drinking water questions. 8:30 a.m. - 5:00 p.m. EST	401 M Street SW (Mail Code 4604) Washington, DC 20460	1-800-426-4791 www.epa.gov/safewater
U.S. Environmental Protection Agency	General drinking water questions.	U.S. EPA Region IV 61 Forsyth St SW Atlanta, GA 30303	404-562-9424 www.epa.gov/region4
Water Protection Branch Environmental Protection Division	General water quality questions.	Georgia DNR 4229 International Parkway Suite 101 Atlanta, GA 30354	404-675-6240 404-675-1664 www.state.ga.us/dnr/environ — Water Protection Branch
Pollution Prevention Assistance Division	Pollution prevention references	Georgia DNR 7 Martin Luther King Jr. Dr. Suite 450 Atlanta, GA 30334	404-651-5120 1-800-685-2443 www.p2ad.org
Robert A. Aldrich and John W. Bartok Jr.	Greenhouse engineering. NRAES-33	National Resources Agricultural and Engineering Service. 1994	
Karen L. Panter Steven E. Newman Reagon M. Waskom	Pollution Prevention for Colorado commercial greenhouses. SCM-206.	Colorado State University Cooperative Extension	
Sharon L. Von Broembsen Mike Schnelle	Best Management Practices (BMPs) for nurseries to protect water quality. E-951, *Water Quality Handbook for Nurseries.*	Department of Entomology and Plant Pathology Oklahoma State University Cooperative Extension Service	http://zoospore.okstate.edu/nursery/recycling/shy.html

Reagon M. Waskom	Best Management Practices for irrigation practices. XCM 173. August, 1994.	Colorado State University Cooperative Extension
Don Wilkerson	Irrigating Greenhouse Crops. From *Texas Greenhouse Management Handbook.*	Texas Agricultural Extension Service
Don Wilkerson	Treating and recycling irrigation runoff. From *Texas Greenhouse Management Handbook.*	Texas Agricultural Extension Service

Environmental Protection Agency (EPA)
National Service Center for Environmental Publications
U.S. EPA/NSCEP
PO Box 42419; Cincinnati, OH 45242-0419
Phone: 1-800-490-9198 or 1-513-490-8190
M-F 7:30 a.m.-5:30 p.m. EST (www.epa.gov/ncepihom)

Drinking from Household Wells, EPA 570/9-90-013
LEAD In Your Drinking Water, EPA 810-F-93-001
Protecting Our Ground Water, EPA 813-F-95-002
Citizens Guide to Pesticides, EPA

University of Georgia, Cooperative Extension Service
Ag Business Office; Room 203, Conner Hall, UGA
Athens, GA 30602
Phone: 706-542-8999 (http://www.caes.uga.edu/publications/alpha_list.html)

Northeast Regional Agricultural Engineering Service, Cooperative Extension
Cornell University
152 Riley-Robb, Ithaca, NY 14853-5701
Phone: 607-255-7654 (www.osp.cornell.edu/vpr/outreach/programs/ageng.html)

Home Water Treatment, NRAES-48. Includes water-treatment basics, physical and chemical treatments, USEPA Primary Drinking Water Standards and health advisories, and pesticide products that contain USEPA drinking-water contaminants. (120 pp.)

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Appendix A
Nutrient Levels

Recommended upper limits of nutrients and chemical capacity factors for water used for greenhouse crops and for containerized nursery crops. [Adopted from Bailey, et. al., 1999, Horticulture Information Leaflet 557, North Carolina State University.]

Capacity Factor	Upper Limit for Greenhouse Use	Upper Limit for Nursery Use
Substrate pH Factors		
pH	5.4-7.0 is acceptable	5.4-7.0 is acceptable
Alkalinity	2 meq/L	2 meq/L
Total Carbonates ($CaCO_3$)	100 ppm	100 ppm
Bicarbonate (HCO_3-)	122 ppm	12
Hardness (Ca + Mg)	150 ppm $CaCO_3$	150 ppm $CaCO_3$
Salinity Factors		
Electrical Conductivity		
for plug production	0.75 mmhos/cm	-----
for general production	1 mmhos/cm	2 mmhos/cm
Total Dissolved Salts (TDS)		
for plug production	480 ppm	-----
for general production	640 ppm	1280 ppm
Sodium Adsorption	4	
Sodium (Na)	69 ppm (3 meq/L)	69 ppm (3 meq/L)
Chloride (Cl^-)	71 ppm (2 meq/L)	71 ppm (2 meq/L)
Macro elements		
Total Nitrogen (N)	10 ppm (0.72 meq/L)	10 ppm (0.72 meq/L)
Nitrate (NO_3)	44 ppm (0.72 meq/L)	44 ppm (0.72 meq/L)
Ammonium	10 ppm (0.56 meq/L)	10 ppm (0.56 meq/L)
Phosphorus (P)	1 ppm (0.03 meq/L)	1 ppm (0.03 meq/L)
Phosphate (H_2PO_4)	3 ppm (0.03 meq/L)	3 ppm (0.03 meq/L)
Potassium (K)	10 ppm (0.26 meq/L)	10 ppm (0.26 meq/L)
Calcium (Ca)	0-120 ppm (0-6 meq/L) is normal range	0-120 ppm (0-6 meq/L) is normal range
Magnesium (Mg)	0-24 ppm (0-2 meq/L) is normal range	0-24 ppm (0-2 meq/L) is normal range
Sulfur (S)	20-30 ppm (0.63-0.94 meq/L) is suggested for most plants	20-30 ppm (0.63-0.94 meq/L) is suggested for most plants
Sulphate (SO_4–)	60-90 ppm (1.26-1.88 meq/L) is suggested for most plants.	60-90 ppm (1.26-1.88 meq/L) is suggested for most plants.

Capacity Factor	Upper Limit for Greenhouse Use	Upper Limit for Nursery Use
Micro elements		
Aluminum (Al)	0-5 ppm is normal range	0-5 ppm is normal range
Boron (B)	0.5 ppm	0.5 ppm
Copper (Cu)	0.2 ppm	0.2 ppm
Fluoride (F)	1 ppm	1 ppm
Iron (Fe)	0.2-4 ppm	0.2-4 ppm
Manganese (Mn)	1 ppm	1 ppm
Molybdenum (Mb)	-----	-----
Zinc (Zn)	0.3 ppm	0.1 ppm

Action Plan Form

Use this action plan form to organize your ideas and to map out the activities necessary to complete your goals. Be sure to make the time frame realistic. Changes in basic resources take time. Please consult the list of references provided if you need additional information to develop this plan.

Area of Concern	Risk Rating	Planned Action	Time Frame	Estimated Cost

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Bulletin 1277 **August, 2005**

Issued in furtherance of Cooperative Extension work, Acts of May 8 and June 30, 1914, The University of Georgia College of Agricultural and Environmental Sciences and the U.S. Department of Agriculture cooperating.

J. Scott Angle, Dean and Director