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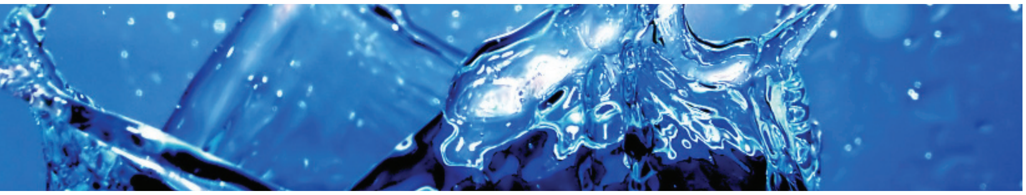
WATER TESTING



WATER QUALITY EVALUATION FOR OPTIMUM VISUAL APPEARANCE AND EASIER MAINTENANCE

Summary: Water quality has more meanings in the 1990s than in previous decades. Users now need to be concerned about water quality of the runoff and deep percolation water from the landscape site as well as the water quality of the irrigation water used on site. Due to drought and keen competition for water supplies, it is now necessary to use sources of water with high concentrations of potentially troublesome constituents than previously. New types of skilled management techniques are necessary to get the full advantage from the use of municipal reclaimed water and other sources of water for irrigation. To salinity and boron problems of yesteryear are now added new problems of phosphorus, nitrogen, certain heavy metals (especially nickel, copper, chromium, lead and zinc), pathogens and some organic substances. These extend the meaning of water quality. More than ever, users need the help of a qualified laboratory for safe and effective water management.

The Wonderful Uniqueness of Water

Oxygen is the most abundant element on earth; almost half of the weight of the earth is oxygen (47%). The majority of it is found combined with hydrogen to form water. Three-fourths of the surface of the earth is sea water with an average depth of about 13,000 feet with 360,000,000 cubic miles of water unfit for human and most plant needs. Annually, about 80,000 cubic miles of water are evaporated from the oceans, and about 15,000 cubic miles are evaporated from the lakes and land surfaces of the world. Total precipitation on the land surfaces is about 24,000 cubic miles of water where runoff and seepage through the soil is about 9,000 cubic miles of water. The annual flows of rivers in the USA are approximately 385 cubic miles or 1.3 billion acre feet.

Besides being ubiquitous, water is indispensable for life. An average person requires 5.5 pints of water a day to maintain the 71% water content of the body. Plants are less efficient with water needs; an average tree requires about 40 to 50 gallons per day to maintain a moisture content from 40 to 50%. Herbaceous plants and grasses contain 80% to 90% water and require an average of 60 gallons of water to produce one pound of dry matter.

Water is unique in its properties. Water swells when it freezes. It freezes lakes from the top down and not from the bottom up; it heaves soil and gradually wears down mountains. Water's boiling point and melting point are extremely high compared with other molecules of similar size.

Water has a high cohesion or surface tension causing it to bead up. This property allows for its capillary rise or wicking action. Water flows through the soil as a liquid or vapor to plant roots to replenish the moisture depleted by the roots. Water moves up into the shoots of plants from the roots probably by capillary rise as it flows through the narrow passageways in the stems or trunk. Another remarkable property is its adhesion or wetting ability. Water will wet soil, cellulose, cotton, and other biological materials. These two properties of cohesion and wetting ability allow water to be stored in the fine capillaries of soil holding it against the force of gravity. In addition, water evaporates slower than other liquid substances with the same size molecule.

One of the most extraordinary properties of water is that of a solvent. Water is known as a polar chemical, meaning that one end of the molecule has a slight positive charge while the other end is slightly negative. This fact makes it an outstanding solvent which dissolves most inorganic chemicals or salts, and organic compounds containing oxygen or nitrogen such as sugars, alcohols, acids etc. Water is the medium in which all cells metabolize energy sources such as sugars and fats or produce energy storing compounds such as sugar in photosynthesis.

Water Carries Nutrients to Plants
Water is the medium in which mineral salts dissolve in the soil and are transported to the roots. As the relatively large volume of water is transpired though the leaves of plants, the salts are passively transported to the plant roots. The water adjacent to the roots, therefore, could be of low quality if not properly managed because of the removal of the moisture by the roots. When the ratio of the external concentration ions outside the roots to the internal concentration is large, ions leak into the roots. Healthy roots can discriminate within limits and keep certain ions from being absorbed.

Some nutrients are bound to the soil particles and are present in the soil moisture at very low levels while other nutrients are soluble at various concentrations in the soil water. Less soluble minerals dissolve as they are being depleted from the soil solution and move by diffusion to the roots which actively absorb them while consuming metabolic energy. As the root system becomes more developed, more nutrients can be absorbed from a larger volume of soil.

Roots actively transport nutrients across membranes against concentration gradients and into the roots by various means which require the metabolism of energy-containing compounds. The flow of salt into the roots can be independent of water flow, especially if there is no leakage. Metabolic needs require oxygen which must be present in the roots. Low oxygen levels are the cause for some of the poor plant growth in soils which are insufficiently aerated. The metabolism of dicot plants generally acidifies the soil releasing minerals while moncot plants instead produce transport molecules to dissolve minerals which then diffuse back to the roots.

Water Quality
Water quality used to mean how much salt and how much boron and occasionally how much bicarbonate was in the irrigation water. Today, there are expanded meanings for water quality, and we not only need to consider the effects on plant growth but also on the environment and the potability of water. One relatively new problem is that fresh water supplies are stressed to the limit (due to drought and increasing populations) and there is need for use of lower quality water including municipal waste water for irrigation. These require a more extensive look at water quality. There is much concern about nitrate and phosphate in the runoff water. For example, the characteristics of water that impart poor quality include the osmotic concentrations of dissolved substances as well as the concentration of individual substances which may be nutrients and/or substances which can result in specific toxicities. All need to be known and understood.

In arid and semi-arid areas, water quality needs to be carefully considered. Due to high temperature and low relative humidity, water evaporation is high. Salts are then concentrated in the remaining moisture. Warm soil surfaces especially with wind lose moisture from the soil; water then moves up to maintain an equilibrium of soil moisture. As this water moves to the soil surface through the capillary rise in soil, it brings salts to the surface. A higher level of salinity is deposited on the surface by the evaporating water. Besides the salts present in the soil, irrigation water may have high levels of total dissolved salts which add to the problem. One acre foot of Colorado River water has about

1 1/2 tons of salts. Annually, eight tons of salts could be added to each acre under irrigation. This is about 400 pounds of salt for each 1,000 square foot area. This salt must be removed and any negative conditions must be corrected. The water quality will determine the level of needed management to control the soil conditions and the plant palettes suitable for the conditions.

Soils with poor physical structure, such as those which have a surface crust, or which are compacted, or which have poor drainage, need better water quality than the soils with better properties. The poorer soils lose more water due to evaporation resulting in higher salinity levels and, at the same time, do not have sufficiently good leaching to remove the excess salts. Soils with good physical structure such as 50% compaction or less, 20% or more pore space when at maximum water holding capacity, and drainage rates of well over 2 inches per hour support the growth of plants better and can tolerate lower water quality in terms of osmotic concentrations. Soil conditioning in the soils having low soil organic matter (less than 5 to 7 percent) is needed for the best responses to fertilization and irrigation. In the last 10 years, new soil conditioners have been developed for imparting excellent soil physical properties. They are quite valuable for land reclamation and for removing excess salinity from soil and to maintain good drainage and aeration.

The amount of water needed for plant growth is variable and depends on water quality. Plants not stressed are more efficient is their use of water. Proper nutrition enables an increase in water-use efficiency. Less water is needed for the same amount of biomass production.

Salinity as an Osmotic Problem

Salinity is a qualitative term used for the state of saline water or saline soil that contain various amounts of salt. A salt is the combination of a cation (a positively charged metal ion) with an anion (a negatively charged ion such as ionized acids). For example, sodium bicarbonate and sodium hydroxide or lye react with hydrochloric acid forming sodium chloride or table salt. Many salts are possible such as sodium sulfate and calcium salts. As the salt level increases in water, the water molecules are held more firmly preventing the diffusion of water from the external solution into plant roots (this phenomenon is called osmosis). When the level of salinity is too high, the water is unavailable for the plantings and the water is unsuitable. Organic molecules such as sugar or the alcohol mannitol cause osmotic problems also.

The level of salinity increases in soil after irrigation with water containing salts. The water evaporates from the soil, and water is transpired from the soil through the plants. Both processes concentrate the remaining salts. Soil salinity increases with depth in the soil. At deeper depths in the soil more water has been removed by transpiration of the shallow and deep roots leading to increased salinity.

Plants vary in their ability to resist the osmotic aspect of salinity. Chart I gives the effects of salinity on a few common plants. The more sensitive plants start responding adversely to salinity in the soil of 1 millimho/cm (a measure of the ability of water to conduct electricity which in turn depends upon the salt concentration) by decreasing their growth. Plant problems start occurring with water containing about 0.75 millimho/cm. Above 3 millimho/cm the problems become severe. The degree of the problems depends upon the soil conditions and plant conditions. Healthy roots can restrict the flow of passive movement of salts into the plant. Application of water in excess of water loss from evaporation and transpiration (ET) to well drained soil will leach excess salts below the root zone. Methods for calculating the leaching fraction (the fraction of water needed in addition to the ET requirements) to keep excess salts out the root zone have been developed to guide the needed application of excess irrigation water. **(See Chart I)**

Beans and strawberries are affected by salinity levels over 1 millimho/cm. All turf grasses can grow with salinity of 4 millimho/cm. Highland Bent and Kentucky Blue grass are the least tolerant. Alta Fescue is able to tolerate 7 and Creeping Bent can tolerate a salinity of 10. These levels of salinity decreased the growth 25%. Germination is more salt sensitive than is the vegetative growth. Lower levels of salinity are needed for germination.

Symptoms of excessive salts are leaves with necrotic or dead tissue on the margins or tips. The plants often extrude excess salts at the tips which causes tip burn and kills the tissues. Interestingly, some desert xeric plants actually thrive on low and medium amounts of salinity. Such plants can be used where problem waters and soils indicate.

Chart I
Tolerance of Plants to Salinity (Millimho/cm)

Threshold level	Level of salinity where growth begins to decrease	for 50% Reduction
strawberry	1.0	2.5
bean	1.0	3.7
grape	1.5	6.7
plum	1.5	4.3
orange	1.7	4.8
tomato	2.5	6.5
tall Fescue	3.9	10.5
perennial ryegrass	5.6	10
bermudagrass	6.9	16

(under otherwise good soil conditions)

Salinity and Permeability of Soil

Soil crumbs are cemented together with agents made from salts. If water contacting the soil has a very low salinity, i.e. rain or runoff water from snow pack off of mountains, the cements are dissolved causing the soil crumbs to disperse. This seals the soil and prevents water recharge into the root zone or rhizosphere. At salinity levels of less than 0.2 millimho/cm, this problem is severe in many soils. Salinity levels can be increased. In some cases, calcium sulfate salt known as gypsum is injected into irrigation water from a slurry tank to increase the salinity. Calcium is needed also for good water permeability.

Permeability of Soil Affected by Sodium

Well drained, productive soils have low levels of sodium bound to the clay particles (called exchangeable sodium since it can be made to dissolve). When the exchangeable sodium level increases due to irrigation with high sodium/low calcium water, the clay particles become dispersed and possess poor physical properties. Some clays swell when wet especially in the presence of sodium. And when the particles swell, the pores in the soil are narrowed causing a decrease in water percolation. The alkalinity increases from dissolved carbon dioxide which is produced from the roots and microorganisms (bicarbonate and carbonate are produced). Since the soil becomes sealed, the carbon dioxide is trapped and kept from escaping as a gas. Leaching is reduced keeping the alkaline bicarbonate and carbonate present. If the problem is not corrected, the soil can become alkaline. In this condition, the soils turn black from the soil organic matter which dissolves. Sodic soils or soils containing high levels or sodium have a sodium adsorption ratio (SAR which is a modified ratio of sodium to the sum of calcium and magnesium). Irrigation water containing an SAR of 3 to 5 or more significantly increase this problem. Frequently, an adjusted SAR is used. Since the bicarbonates and carbonates precipitate the calcium and magnesium as limestone and magnesium carbonate, the SAR is altered to reflect the decreased concentration of calcium and magnesium. Excellent soils contain about 70% calcium and 15% magnesium with only a few percent sodium. Sodic soils contain 15% or more sodium.

Bicarbonates

Bicarbonates and carbonates precipitate some of the micronutrients rendering them unavailable to plants. Iron deficiency is common because of this effect. Symptoms are yellow leaves with green veins. New growth is more affected than older growth. Bicarbonates also have a physiological affect on the roots reducing nutrient absorption. Problems start at around 75 parts per million. If it exceeds 150 parts per million (2.5 milliequivalents per liter), the water is probably not suitable. The problems are less severe if the water is applied by flooding because foliar absorption is more of a problem than root absorption. The bicarbonates and carbonates can be reduced in the water by treatment with gypsum to precipitate them or with sulfuric acid to neutralize them.

Salinity and Specific Ion Toxicities

Liebig's old law of the minimum is not always correct. This law states that the most toxic constituent limits plant growth such as the weakest link of a chain determined the force needed to break it. The law implies that the factor in most limitation needs correction before responses to other factors are obtained. More recently, it has been determined that this is not correct in many cases. The toxicity effects are accumulative. For instance, if two factors were to lower the growth potential to 80 percent each, the overall effect would be 0.8 times 0.8 or 0.64 of optimum. Correction of both factors per the "Law of the Maximum" would give a response showing a 36% adjustment. The response is the synergistic and exceeds the sum of the individual responses if each were correct separately. All limiting factors due to poor water quality need to be considered in concert for the best growth improvement.

Chloride

Chloride at levels in water of less than 100 parts per million will be suitable for all needs. More of a problem occurs with sprinkler irrigation due to foliar absorption. Severe problems occur at levels over 350 parts per million in the soil solution because of root absorption. Chloride can lower the availability of nitrate uptake due to competition of the roots for uptake of ions.

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Sulfate

Plants are comparatively insensitive to sulfate toxicity. When the level is about 3,000 parts per million of sulfate, plant growth would be adversely affected.

Boron

Boron is an essential element but the range between ideal and toxic concentrations is small. In general, the plants tolerant to boron are not also tolerant to salinity as shown in Chart II. Levels less than 0.5 parts per million are essential for plants sensitive to boron. For semi-tolerant plants, levels up to 1 part per million are allowable. For tolerant plants, 2.5 parts per million are satisfactory.

Sodium

Sodium is an essential nutrient for

several plants species adapted to saline soils. Sodium has a sparing effect on potassium deficiency for other species. When potassium is low, sodium may substitute for some of the growth requirements. For other species, sodium is deleterious and can be toxic if excessive. This specific ion effect is independent of the associates anion and related to the sodium concentration in the leaves.

Metals - magnesium, lithium, zinc and heavy metals

Magnesium is essential for growth but sometimes its presence in water can cause problems. If the proportion of magnesium is higher than the calcium, then magnesium can induce a calcium deficient. Lithium is not essential but is present in arid soils. At levels over 3 parts per million, toxicity can occur.

Zinc as well as other heavy metals are also toxic. They effect the uptake of the essential micronutrients and can cause induced deficiencies. In addition, higher levels will cause general toxicity reactions.

Nutrient Balance

Inasmuch as plants respond mainly to the ratio of nutrients, a toxicity or deficiency can result when an element is not in the needed proportion. Some ions in irrigation water can upset the normal balances. Essential trace metals; iron, manganese, zinc and copper; are sometimes difficult to keep in proper proportions. Plants may have iron levels in the leaves reduced with excessively high zinc or copper levels in the soil. Some sources of water can increase the level of these metals in the soil. In addition, nonessential elements can inhibit the uptake of these four essential metals. Soils on the average contain appreciable levels of nonessential heavy metals. Fortunately, the metals are not easily dissolved by water. The more active elements such as calcium, lithium, sodium, etc. will dissolve in the soil moisture readily. The heavy metals do not easily dissolve and the actual available concentrations are much lower than the total concentrations. Acidic conditions, however, will dissolve them. Chart III gives the maximum safe levels of some essential and non-essential elements in water. In addition it lists the maximum levels in general along with the natural abundance of these elements and the ranges found in soils.

Sources of Water Affect Its Quality

Surface waters from rain have less dissolved salts than the water which seeps into the ground. As the water moves through the soil, salts dissolve. Seepage can flow into rivers gradually increasing the salinity of the water downstream. When the Colorado river water gets to Mexico, it is too saline for irrigation. The salinity comes from tributaries which drain large areas. Some low quality drainage water flows into it from farms while flash floods move salt from the desert into the river. In contrast rivers from granite mountains are almost salt free.

Ground water from wells can contain appreciable levels of salts and may have extremely poor water quality from the extracted minerals. Water from deep wells or geologic sources may have good quality while shallow renewable aquifers may have high salts from drainage of irrigated lands. Shallow well water may be unfit for human consumption.

Reclaimed Water

Reclaimed municipal water typically contains appreciable levels of boron probably mostly from borax laundry products. Sensitive plants will be affected. Sodium, chloride, bicarbonate and zinc are other general problems. The bicarbonate and carbonates are the by products of the oxidations of the organic constituents of the waste stream. Nitrogen levels are lowered during this process.

Zinc comes from galvanized pipes in homes etc. The zinc used for galvanization is contaminated with cadmium at about one percent. Recycled water containing industrial waste may have high levels of cadmium and other heavy metals such as nickel, lead and chromium. These severely lower water quality. Micronutrient fertilization problems need to take this into account. High soil pH values and liming of the soils can reduce these potential toxicities. Phosphorus when high in reclaimed water may be applied in excess of plant needs and precipitate the trace

elements. Plants can generally tolerate excess, nonessential elements better than can animals or humans. Water used for produce production should entail a complete analysis of potentially toxic elements. Fortunately, some potentially toxic elements are not translocated from the roots to the shoots in many plants.

A case study of common bermudagrass in Tucson was conducted with reclaimed water by Hayes et al. (Agronomy Journal, Vol. 82, 943-6 (1990)). Turfgrass appearance was better on the average with unfertilized reclaimed water than with fertilized potable water. Iron chlorosis was a problem with reclaimed water when nitrogen was applied due to the lower unavailability of iron caused by phosphorus when the turf demand was increased by the nitrogen. Sodium levels increased in the soil indicating the need for more amending with gypsum and perhaps need for more aerification.

Effect of Soil Types on Allowable Water Quality (Osmotic Quality)

Sandy soils allow the use of lower water quality since the leaching of the salts is rapid avoiding a large increase in soil salinity. Soils with lower percolation rates require better water quality because of the slow rate of leaching.

On the other hand, clay soils buffer or remove from the water undesirable ions. Clays have high absorption of metals which lower the availability and toxicity of metals.

How to use Poorer Quality Water

Some water quality factors can be improved through management practices guided by laboratory analyses. Salinity can not be lowered easily nor can boron or chloride be removed, but sodium problems can be reduced. The effect of bicarbonates and carbonates can be controlled.

Gypsum Requirement

Excessive sodium levels in low quality water, can be solved with the addition of calcium such as from gypsum. The calcium can lower the relative activity of sodium by dilution. Calcium can precipitate the bicarbonates and carbonates as well as supply sufficient calcium for plant needs. The gypsum requirement is the sum of these three needs. For good water quality, none is needed. For poor water quality, gypsum may be needed in the range of several pounds per 1,000 square feet for each inch of irrigation.

The gypsum requirement can be lowered if the bicarbonates and carbonates are removed from the water through acidification such as with sulfuric acid.

Leaching Requirement

Unless salts that have been added to the soil are removed, plant growth will decline because of an increase in salinity. Adequate leaching is required to maintain the salinity of the soil at tolerable levels. The amount of leaching increases with poorer soil conditions. The leaching requirement is the percentage of additional irrigation water which should be applied to the site in order to leach sufficient salts to avoid growth reduction of more than 20 percent. It is calculated from the water quality data and the desired maximum level of salinity depending upon the tolerance of the plants. Values can range from a few percent for good water quality to 50 percent for poor water quality.

Leaching of salts requires that water will flow through the soil profile. If the subsoil is not permeable for the salts to move below the root zone, drain line or other procedures are required for plant growth.

Water-soluble polymeric soil conditioner requirement

Highly permeable, well aerated soils are extremely important when marginal-quality water is used. Water-soluble soil conditioners can help create desirable characteristics in soil. Laboratory tests have been developed (see Soil Science, Volume 141, pages 390-394, 1986) to measure the amount of soil conditioners needed to improve the physical properties of soil. If soils are not readily permeable to water, leaching of salts will occur too slowly to be of benefit. A review of the water-soluble polymeric soil conditioners appeared in Soil Technology, volume 3, pages 1-8, 1990.

Analytical Guidance

Water quality assessment with help of a laboratory can properly guide the use of irrigation water. Since soil conditions affect water leaching and changes in water quality, they need to be evaluated through soil analysis. Plant analysis through tissue testing is the third component of the triad of proper site evaluation. The plant is the bioindicator of the overall interactions of the soil chemistry and soil physical limitations. No one of these parts of the triad should be ignored if successful landscapes are to be achieved.

How to read a Water Quality Report plus Definitions of Terms and Concepts

acid - a substance that releases hydrogen ions in solution. The substance which losses the hydrogen ion has a negative charge is called an anion.

acre foot - the water required to cover one acre, 1 foot deep or 325,829 gallons.

anions - negatively charged ions which frequently are nonmetals

base - an alkaline chemical such as sodium hydroxide or calcium carbonate (limestone) which is the opposite of an acid.

cations - positively charged ions which most frequently are metallic ions such as sodium and calcium.

ESP - Exchangeable sodium percentage is the percent of sodium cations (metal ions) which are potentially soluble from the surface of the soil particles compared to all cations. Soils with an ESP of 15% or more are considered to be sodic. Exchangeable cations are those bound to soil particles which can be made to solublize or exchanged by each other.

ET - Evapotranspiration is the sum of the moisture being lost due to evaporation from the soil and by transpiration from the plants.

ions - molecules or atoms which has have positive or negative charge(s).

milliequivalents per liter - a term used to quantify the number of anions or cations in solution.

pH - the measurement of the degree of acidity. The sum of the hydrogen ions and hydroxide ions is 14 when they are measured in negative logarithms using molar concentrations. At pH 7, the hydrogen ions and the hydroxide ions (14-7=7) are equal and the solution is neutral. Acids contain more hydrogen ions than hydroxide ions. Thus acids are solutions having pH values less than 7. Alkaline solutions have pH values more than 7. Moderately acidic solutions are solution with pH values less than 5 and moderately alkaline solutions are those with pH values over 9.

ppm - parts per million. The newer term is milligrams per liter. One liter of water weighs about one million milligrams. One ppm is about 1 milligram per liter (mg/l) of water.

salinity (millimho/cm) - Also known as the electroconductivity or EC. When measured in water, it is called ECw. When measured in a saturation extract from soil, it is called ECe. The measurement is the reciprocal of the resistance of the solution to an electrical current.

salt - the union of an anion or acid and an cation or base such as sodium chloride and calcium sulfate which dissolves in water and release the individual anions and cations

SAR - Sodium Absorption Ratio. It is used as is the ESP to measure the ability of sodium in water to become fixed on the soil surface in soils. The ESP is used only for soil.

sodic - soils with an excessive level of sodium. SAR values over 6 or ESP values of at least 15%

Total Dissolved Solids - The amount of solids dissolved in water. Units are parts per million or milligrams per liter.