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WATER QUALITY

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SECOND EDITION

THE WATER QUALITY HANDBOOK

By David Beeman and Paul Songer
with Ted Lingle
Specialty Coffee Association of America

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David Beeman, Founder
The Water System Group
dba, Cirqua Customized Water

Paul V. Songer, President
Songer and Associates, Inc.

Ted Lingle, Executive Director
Coffee Quality Institute

Edited by Laura Everage

Specialty Coffee Association of America
330 Golden Shore, Suite 50
Long Beach, CA 90802
www.scaa.org

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FOREWORD

“Ninety-eight percent of every cup of coffee is water. The taste of the coffee, therefore, is directly related to the taste of the water used to brew it… Some mineral content (”hardness”) in the water is actually desirable.”

– Kevin Knox and Julie Sheldon Huffaker
Coffee Basics, a Quick and Easy Guide

“Water is the most important variable in the preparation of Coffee and the least understood it can act as the catalyst that brings it all together or a barrier that stops it. Understanding how and why this occurs will give you an invaluable tool in your quest for that perfect cup.”

– Skip Finley
Cirqua Customized Water, Technical Service Director

In the coffee business, water can be our best ally or our worst enemy. Water can add to, or subtract from, the quality of a cup of well prepared coffee, a quality brew that reflects the true origin of the beans and allows all the subtleties to stand out. It is important to acknowledge the effect water can have on the performance and longevity of brewing equipment.

This work aims to provide a basic understanding of water, assistance in finding the most economical way to treat water, and the assurance that what you have done in water treatment is working. In the process, the hope is that you will come to view water as one of the most controllable aspects of a quality extraction.

This handbook, which represents the combined efforts of Paul Songer and David Beeman, was produced under the direction of the Technical Standards Committee of the Specialty Coffee Association of America.

– David Beeman

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The specialty segment of the coffee business has always been about exceeding expectations of consumers through noticeably higher quality. Just *passably good* is not enough to ensure the repeat purchases that are the basis of any brewed coffee or espresso business.

The challenge is that there are so many individual factors that affect the flavor of the beverage. Here we deal with one immensely complicated, but important aspect. We have done our best to provide detailed information without becoming overly technical.

A great many people helped to make this effort possible. Darrin Daniel helped edit my side of the contribution; Dan Cox allowed me valuable work time to meet with David and to write my portion of the handbook during my time at Coffee Analysts in Vermont; and Ted Lingle provided extensive resources, editing assistance, and valuable feedback. I would also like to give a particular thanks to the Technical Standards Committee for their additional research and revisions, as well as to all Cup of Excellence participants for keeping the quality ideal foremost, which is why most of us are on this path in the first place.

Thanks to Lawrence A. LeBlanc, Ph.D., who is now Research Assistant Professor in the Department of Food Science and Human Nutrition in the University of Main, for reading over the early drafts and correcting my chemistry. Please keep in mind that a lot has happened since then and any mistakes are probably mine rather than his.

Finally, thanks to my old friend Ric Rhinehart for continuing to push to get this into print, and to Laura Everage for finally getting it all together in the form you see here.

An amazing aspect of this industry is how it is constantly evolving. The innovations that are eventually adopted by the larger part of the industry usually come from the group up, from small business people that have insight, and then work their butts off to make their inspiration a reality, rather than some grand scheme imposed from above. Hopefully, this assemblage of information can help all developing coffee businesses in some way.

– Paul Songer

INTRODUCTION

When coffee professionals discuss the process of brewing coffee, the merits of certain key variables–bean, roast, grind, brew temperature, and brewer–are always touched upon. Unfortunately, one of the most important variables, water, is often left out of that discussion. Given that a cup of coffee is made up of 98.5% of water, and typically 95% of the espresso beverage, it is important to understand that water is an essential variable–and the quality of this variable is even more important. Water used for brewing coffee must meet the high standards required for proper extraction of the flavors and aromas inherent in a Golden Cup, the Specialty Coffee Association of America's certification of high-quality, freshly brewed coffee.

Municipal water authorities are challenged to supply the community with a safe source of drinking water and to deliver it at a consistent volume and pressure. Because they consistently meet this difficult challenge day in and day out, most consumers take for granted the quality of available water. Water delivered to homes and businesses throughout a region meet specific safety standards for consumption, however, municipal water authorities do not address the quality of water from a flavor perspective. Because only 0.5% of tap water is consumed, maintaining the flavor quality of drinking water is not a high priority for municipal water authorities. In fact, because of the increasing demand put on an already scarce resource, current trends in the water treatment industry are to conform to a commercial-grade standard of tap water that does not take into account aspects of flavor. As a result, consumers are expected to treat the water they drink, or purchase bottled water for their at-home and on-the-go demands.

The value of coffee depends on the flavor found in the cup; and the quality of the water used can either enhance or detract from that value. Therefore, formulating a dedicated approach to water quality standards is a key component in maintaining consistent coffee quality. Adherence to water quality standards not only improves beverage quality, but it also reduces the need for brewing and espresso equipment maintenance, thereby eliminating down time and frequent equipment repairs, resulting in a cost savings for café owners. Taking into account these savings, there is no denying that the installation of properly designed and maintained water treatment systems is an investment that will ensure efficient, consistent operations.

Of course, attaining the water quality capable of producing a Golden Cup presents numerous challenges. The first step in meeting that challenge is to be aware of a simple concept: Water quality varies greatly from one location to another. It is a simple concept to comprehend, yet a complex concept to implement because it involves chemistry, thermodynamics, and physics. But, by understanding this challenge, one can gain a better understanding of the problem.

The second challenge is determining the water quality available, and what level of quality is desired for a specific location. The final challenge is wading through the numerous water treatment products in order to find the one that most appropriately meets one's needs.

This handbook is designed to provide the reader with the information necessary to overcome these challenges so that one may make intelligent, informed, and cost-effective decisions regarding the testing and treatment of water.

The first chapter, Water Fundamentals, offers a brief description of terminology and a discussion of water itself. The second chapter, A Detailed Look at Brewing Coffee from the Perspective of Water, describes the attributes of coffee and how the brewing process can be affected by the quality of the water. The final chapter, A Strategic Approach to Water Quality, outlines six steps for dealing with water quality issues. This chapter includes sections on basic research, parameters of quality brewing water, testing the water, comparing test results to standards, determining problems and potential solutions, and selecting water treatment dealers.

To determine ideal parameters of water for brewing, as presented in Chapter 2, information from The Coffee Brewing Center and other research was reviewed. However the bottom line is coffee flavor. Therefore, in order to understand the importance of water chemistry and its effects on taste and aroma, six members of the SCAA Technical Standards Committee participated in a blind taste test at the SCAA lab in Long Beach, California and confirmed research results. Some of the results are presented in Chapter 3. While this cannot be considered a statistically valid test, it indicates the importance of different aspects of water quality.

David Beeman, Founder
The Water System Group
dba, Cirqua Customized Water

CHAPTER 1

Water Fundamentals

In the United States, coffee drinkers consume more than 18 million bags, or approximately 2 billion pounds, of coffee each year. Assuming that each pound of coffee is prepared with approximately 3 gallons of water, slightly more than 6 billion gallons of water are required annually to quench the U.S. population's thirst for coffee. Because brewed coffee is comprised mainly of water, it has a direct influence on the quality of brewed coffee. Therefore, water must be fully understood to ensure the best possible beverage is brewed.

Pure water is a simple combination of two gases: hydrogen and oxygen. When they unite, these gases form the familiar liquid we know as water. Water can also take on other physical forms when temperature is either elevated or decreased. For instance, when the temperature drops below 32ºF (0ºC), it solidifies as ice, and when the temperature rises above 212ºF (100ºC) at sea level, water becomes a gas, in the form of steam.

One rarely encounters water in its pure form. Typically it contains many chemical compounds in an infinite variety of combinations and concentrations. Some of these materials, if present in relatively large amounts, can cause unusual tastes, odors, and colors. They are referred to as dissolved (soluble) materials, because on a molecular level, they are structurally part of the water. It often takes extreme methods of filtration to separate them.

Water may also contain undissolved (insoluble) materials suspended in the solution. These may include living organisms, such as bacteria or molds that may, or may not, be visible to the naked eye. Insoluble substances may also include non-living materials, such as fine dirt and sand.

To ensure water used for human consumption is free of any harmful living or non-living matter, municipalities are charged with the responsibility of removing the undissolved (suspended) material, as well as chemically treating the water intended for human consumption in order to destroy any harmful living organisms that it may contain.

When this handbook refers to *quality* of water, the word addresses parameters that have been determined to have an affect upon flavor and/or machine operation (referred to as secondary standards in municipal water tests).

Water is more complex than it first appears, and contains varying amounts and types of other chemicals. The mineral balance contained in water interacts and reacts chemically and physically with ground coffee to produce the resulting extraction. Unsuitable water chemistry can over-extract or under-extract dramatically altering flavor and aroma characteristics. Changes in water composition will alter the flavor of coffee as much or more than water temperature variations or equipment quality. Besides affecting flavor, unnecessary equipment failures and malfunctions can result from poor water quality.

When water and coffee come into contact with each other, water dissolves soluble substances in the coffee to reach physical and chemical equilibrium. These reactions affect the flavors extracted during the brewing process. The art of coffee brewing is in controlling the variables; and water quality must be controlled, and held in balance, in order to achieve a flavorful beverage. If one component of water (such as hardness) is removed, the equilibrium of the water is altered and different flavors will result from brewing.

Regional Differences

The U.S. Department of the Interior considers water a valuable natural resource, and has compiled information about all of the principal water supplies used by more than 2,300 of the country's largest cities and towns. Table 1, which shows several examples of chemical analyses of water supplies found in several U.S. cities, illustrates the wide variation in chemical composition that can occur. As can be seen, each water supply is unique in its composition due to the different soil it comes in contact with, as well as the different municipal treatments applied.

Table 1

ANALYSIS OF WATER SUPPLIES USED BY LARGE CITIES IN THE UNITED STATES

Component	City											
	Boston	New York	Chicago	Los Angeles	San Francisco	Indianapolis	Cleveland	St. Louis	Kansas City	Galveston	Sarasota	Pittsburgh
(Fe) Iron	0.10	0.03	0.09	0.04	0.02	0.11	0.12	0.01	0.01	0.00	0.56	0.30
(Ca) Calcium	4.0	13.0	39.0	25.0	1.1	67.0	39.0	23.0	75.0	30.0	14.0	60.0
(Mg) Magnesium	0.4	4.3	10.0	5.0	1.4	20.0	7.3	9.7	22.0	9.7	0.3	18.0
(Na) Sodium	1.8	3.0	3.3	34.0	0.4	6.2	8.7	33.0	59.0	351.0	530.0	49.0
(K) Potassium	0.7	1.4	0.7	4.0	—	1.6	1.3	33.0	5.6	351.0	16.0	49.0
(CO_3) Carbonate	0.0	0.0	0.0	2.0	0.0	0.0	0.0	13.0	0.0	0.0	0.0	0.0
(HCO_3) Bicarbonate	7.0	36.0	132.0	138.0	7.0	206.0	103.0	20.0	237.0	336.0	161.0	17.0
(SO_4) Sulfate	5.6	20.0	23.0	23.0	1.6	67.0	30.0	109.0	172.0	1.0	817.0	248.0
(Cl) Chloride	3.4	5.8	7.2	17.0	1.0	10.0	20.0	17.0	29.0	422.0	168.0	58.0

[1]All data given in ppm

Source: Coffee Brewing Center Publication No. 6

Some local water supplies have high levels of certain mineral ions, which can have a direct affect on the flavor of the water (and hence the coffee), how the coffee brewing process progresses, and the functionality of the brewing equipment. For example, salt-water intrusion into the water supply in Galveston, Texas gives it more than 400 mg/L chloride resulting in unbalanced, salty and bitter tasting coffee. In Sarasota, Florida's water, there are 800 mg/L sulfates, which usually results in noticeably bad odor. Deep wells in Michigan and certain arid geographical areas have more than 1,000 mg/L minerals, creating a high alkaline taste that is considered dry, chalky, and even bitter.

Standards for Drinking Water

Virtually all of the water (99%) flowing out of municipal taps is used for general purposes, including watering lawns, washing clothes and dishes, disposing of waste, and fighting fires. Less than 1% is destined for consumption in foods and beverages. The Safe Drinking Water Act ensures public health protection by requiring public water systems to comply with health-based standards, monitoring and reporting requirements. The U.S. EPA, individual states, and local municipalities then work together to make sure that these standards are met with consistency. However, with so much water literally being poured down the drain, it is not economically feasible for local municipalities to use treatments that produce top-quality drinking water that also has ideal flavor.

To qualify as safe to drink, according to the U.S. Public Health standards, water must be clear, odorless, and tasteless. It must be free of bacteria and contain less than 0.2 mg/L of copper, 0.3 mg/L of iron, 250 mg/L of sulfates, 250 mg/L of chlorides, 100 mg/L of magnesium, and 1,000 mg/L of total dissolved solids. The standards also specify there be no more than 10 mg/L alkalinity (with no caustic alkalinity) and less than 50 mg/L of sodium or potassium alkalinity.

While the standards may be considered acceptable for general use, it does not necessarily make the best coffee. Municipal water carries tastes and odors that can become objectionable when used for food or beverage preparation. Further, certain substances that naturally occur in water have an effect on the brewing process. These are discussed in the following section.

Solubility and the Mechanisms of Dissolving

Before delving into how water dissolves various substances, a little chemistry review may be necessary. These basic concepts will be useful in understanding the brewing process and the effect that water quality has on that process.

Types of Chemical Bonding

Molecules are made up of atomic building blocks. The atoms are bonded into compounds by two main methods, covalent and ionic. In covalent bonding, the atoms share an electron, while in ionic bonding the compounds stay together in solid form because their atomic constituents have an electrical charge. An example of a covalent bonded compound is sucrose (table sugar). Even when dissolved in water, the sugar molecule maintains its shape. Conversely, when ionically bonded compounds are dissolved in water, they usually (depending on the strength of the bonds) separate into their constituents. For example, when common table salt (Na+Cl-) is dissolved in relatively pure water, it separates into Na+ and Cl- ions.

It is important to note that in order to remain in solution, all ionic substances must be in balance. That means that there must be the same number of negative charges and positive charges.[1]

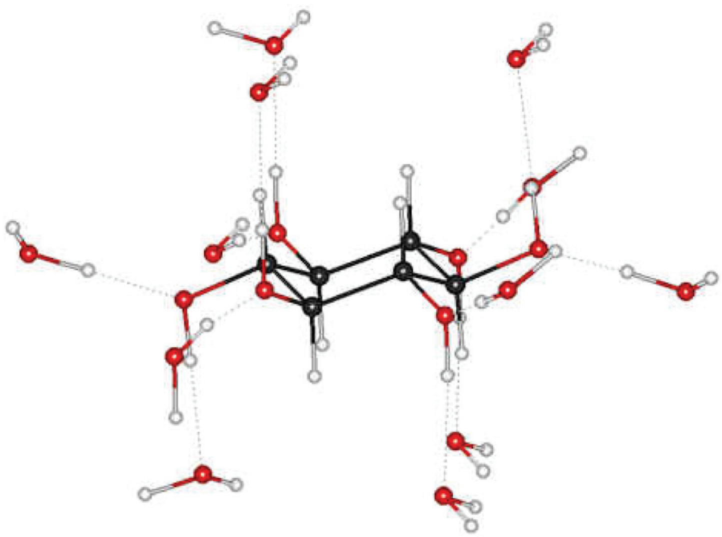


Fig. 1: *A sugar molecule surrounded by water molecules*

Acidity, Alkalinity, and pH

As mentioned previously, water is H_2O. It is covalently bonded, but also can dissociate ionically into H+ or OH-. If there is a higher concentration of H+ ions, the solution is acidic, and if there is a higher concentration of OH- ions, the solution is alkaline. If the solution is in balance (all H+ and OH- atoms are in balance), it has a pH of 7.0. If the solution is acidic, its pH is below 7.0; if it is alkaline (basic) the pH is above 7.0.[2]

Referring to the previous remarks, one may wonder how the substances stay in balance in solution if a high pH solution has a higher concentration of H+ ion. If one stirs in citric acid ($C_6H_8O_7$, or H+ and $C_6H_7O_7$-), one of the hydrogen atoms dissociates from the compound, making the solution acidic because of the H+ ion but in balance due to the $C_6H_7O_7$-.

The *strength* of an acid is its tendency to dissociate (divide into an H+ ion with an associated negative ion) in solution.[3] A strong acid in coffee is phosphoric acid (contributing to the perceived high acidity in Kenya coffees), while a weak acid is chlorogenic acid, which tastes more bitter than acidic due to its tendency not to dissociate.

1 Pauling L, General Chemistry, New York: Dover Publications, 1970. p. 148 & 172.

2 Ibid., 426; 483-484.

3 Ibid., 481.

Solubility

How quickly, or whether, a compound will dissolve in water is referred to as its *solubility*. Many substances, like the stainless steel metal in a spoon, will not dissolve easily, but can do so, however slightly, given enough time under the proper conditions. Few substances are known that are completely insoluble.

When discussing coffee, solubility is the ability of substances, including the soluble solids, liquids, and gasses contained in ground coffee, to dissolve into a medium–in this case, water. Water is a particularly good solvent because it has a high di-electric constant. This is a complicated way of saying that it dissolves other electrically charged compounds. For example, salt (a combination of Na+ and Cl- ions) dissolves easily in water, but such a salt does not dissolve well in non-polar solvents such as gasoline or alcohol. The larger component (water) is called the solvent, and the remaining components are called the solutes.[4] The solubility of a substance can either increase or decrease with higher temperature, which is why particular temperatures are recommended for coffee brewing.[5]

To accurately describe a substance's solubility, one must consider three conditions: the amount of solvent, the amount of the solute, and the temperature of the solution. Different compounds will dissolve at different temperatures and at different rates, depending on their properties. Some solutes will not dissolve unless they reach high temperatures, while some will partially dissolve at that same high temperature. Still others will dissolve completely and immediately at low temperatures. The rate of solubility refers to how quickly the dissolving process occurs when the substance is brought into contact with a liquid. Some actions, such as pulverizing (grinding), stirring, and heating, can speed up the process. The art of brewing is properly managing this solvating process, and the quality of the water is a major factor in this control.

Additional Properties of Water

Water has properties unique to solvents. Both its boiling point and melting point–the temperature at which water moves from liquid to gas, or from solid to liquid, respectively–are relatively high. Water's density increases upon heating, and its volume shrinks upon melting. These distinct properties are a result of the attraction between water molecules, and is a process that is referred to as *hydrogen bonding*.

As seen previously, water is comprised of two hydrogen atoms covalently joined with one oxygen atom. Besides being joined on an atomic level, water molecules also can be joined on a molecular level. The oxygen atom is highly electronegative, resulting in the two hydrogen atoms clustering to one side of the water molecule. The result is a charged molecule with a negative charge on the oxygen side and a positive charge on the hydrogen side (see Figure 2). A polar bond forms between water molecules as the positive hydrogen attracts the negative side of the oxygen (or other polar molecules). This is called a *hydrogen bond*.

The hydrogen bonds between water molecules cause the melting and boiling points of water to become relatively high compared to other solvents, such as alcohols or hydrocarbons. The interaction between the water molecules due to hydrogen bonds is similar to how a magnet is attracted to some metals, and is attracted, or repelled, by other magnets. This tendency of attraction or repulsion is referred to as *polarity*.

Water is a polar solvent, having negative and positive sides (Figure 2). Conversely, a non-polar solvent is one in which the molecule is symmetric in structure, and where there is an equal sharing of electrons between the atoms, and no attraction or repulsion occurs (Figure 3).

4 Ibid., 449.

5 Ibid., 450.

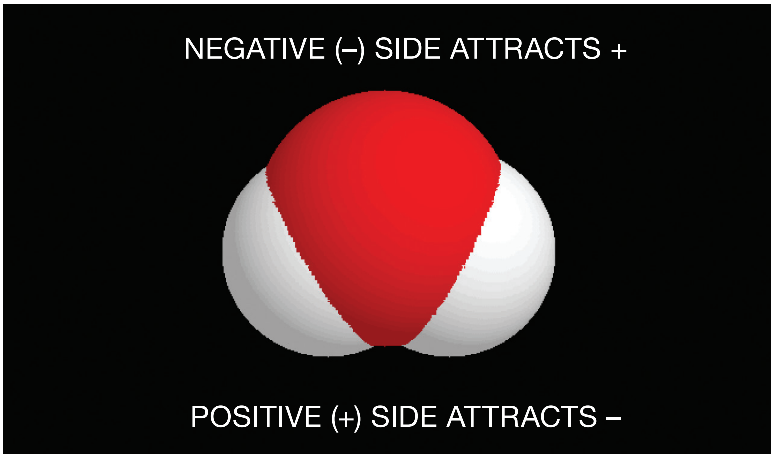


Fig. 2: *The water molecule, H_2O, with polarity marked. The hydrogen atoms are gray, the oxygen atom is red.*

All polar molecules have a positive and negative orientation, which affects a solute's ability to dissolve. Polar substances will more easily dissolve in polar solvents, and vice versa. However, polar substances take longer to pair up because the negative side of the polar molecule must contact the positive side of the other molecule, which happens only 50% of the time.

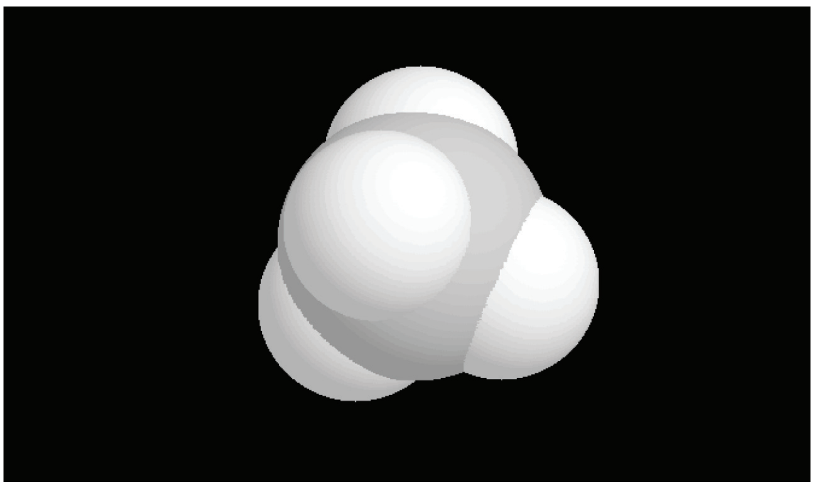


Fig. 3: *Methane, CH_4, a non-polar molecule. The hydrogen atoms are symmetrically arranged around the carbon atom. As a result, no hydrogen bonds are formed with other methane molecules and the substance has a low boiling point. However, in its liquid form it is capable of dissolving compatible substances much more quickly than a polar molecule such as water.*

The Structure of Water

We rarely think of liquid as having a structure, because in the liquid state, the molecules are constantly in motion, depending on the gravity or pressure. But at the molecular level, water molecules form clusters as the result of hydrogen bonding. These mini-structures are continually moving and changing in form. They are especially active when water is heated and the structures that are formed are further influenced by the presence of other charged compounds and the pH of the liquid.

Due to hydrogen bonds, water can behave as if it is a large aggregate composed of multiple sets of hydrogen and oxygen atoms. The shape of these aggregates determines the polarity of their contact with the solutes they touch, the speed with which they are hydrolyzed (dissolved), and, hence, the final flavor of the brew. These aggregates change according to temperature, pH, and the presence of various substances.

When pure, water molecules come together in a variety of structures. These range from simple 4-molecule structures (Figure 4), to various shapes and combinations (Figure 5), to complex 280-molecule structures (Figure 6).

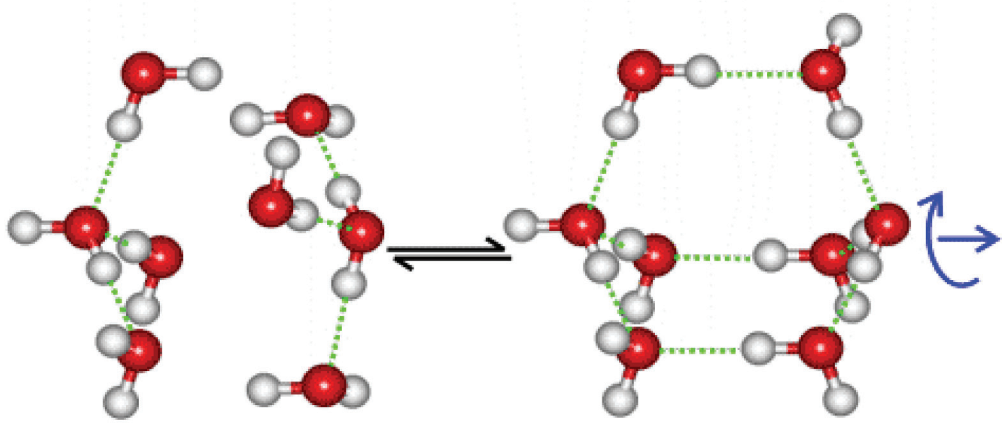


Fig. 4: *Four water molecule clusters arranging themselves into 8-molecule clusters.*

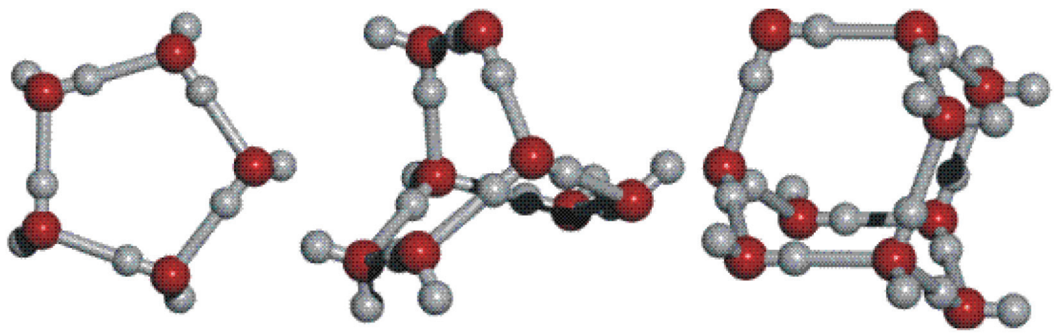


Fig. 5: *Various configurations of water molecule clusters.*

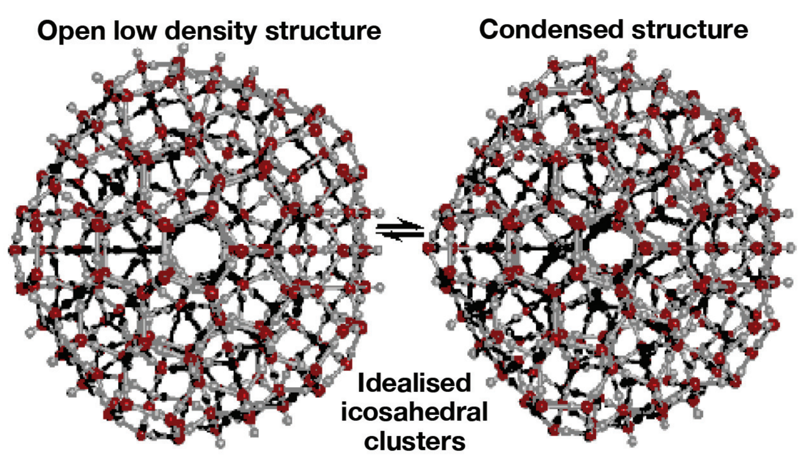


Fig. 6: *Two complex water molecule structures. The structure on the left has less density than the one on the right due to the arrangement of the molecules.*

As water is heated, the water molecules gain energy and break some of the hydrogen bonds. This enables the water to hydrate other chemicals. The size of the structures decrease as the number of structures increases, allowing more charged sites to be exposed and more material to be hydrolyzed. This is another reason why temperature is important when brewing. When substances other than water are present—which is the case for virtually all natural and tap waters—these well-ordered structures change considerably and affect the extraction process.

Individual Characteristics of Water

Water is arguably the most recycled substance on the planet. Whether it is from the ocean, rain, glaciers, rivers, lakes, or underground caches, the history of a water supply defines its quality. Just like any traveler, as water takes the journey from place to place, it gathers a number of souvenirs. What it gathers, as can be seen in Table 1, can be different from one location to the next. And those souvenirs are likely to produce significantly different water quality.

A water supply is typically classified by its source. Surface water is contained in rivers, lakes, reservoirs, and other open supplies. It is subject to runoff, sources of surface pollution, and the direct infusion of rainwater. Ground waters are contained within the earth, such as springs or aquifers. Each source tends to have associated chemistries, which manifest themselves in these characteristics of water.

The major issues for coffee brewing that can be measured are Total Dissolved Solids (TDS), the carbonate system, and the chlorine-based oxidizers used to ensure safe drinking water. The chemistry of these three aspects is discussed in some detail here. There are some specific common problems that are also discussed in other chapters.

Total Dissolved Solids

The amount and nature of solids already dissolved in water are referred to as Total Dissolved Solids (TDS). The source of the water supply chiefly determines the type and concentration of TDS.

Ground water cached in underground aquifers or dispersed throughout a soil may have a high concentration of minerals, depending on the composition of the aquifer, of the soil, or rock, in which it is resting. Limestone, for example, will dissolve easily under acidic conditions and create calcium-infused (hard) water, whereas granite will not. In soil, the biological metabolism of various microorganisms can also contribute carbon dioxide, again lowering the pH and giving the water the capacity to dissolve minerals.

On the other hand, surface water (sources from rivers and lakes), which typically has less contact with soil and minerals, usually has lower TDS. However these water supplies rarely originate from natural sources that are unaffected by human activity. A variety of conditions can change the TDS in a water source from day to day. For instance, acid rain from air pollution results in lower pH and higher mineral contents in poorly buffered lakes. Industrial and agricultural wastes can add still more solids to the surface water supply. Although municipal water treatment eliminates most, but not all, of this activity, water may still carry musty-smelling products of lichens, moss, and molds, as well as the nitrogenous products of mammals or fertilizers added to soils in agricultural areas.

Surface water from rivers and lakes is often recycled multiple times. Municipalities take water in for their use and discharge treated water. Further downstream (in the case of rivers), the next municipality will do the same. Municipalities on lakes may be recycling their own discharge, as well as that from other municipalities bordering the lake. A single municipal use of water treated and discharged into a lake or river usually adds to the total dissolved minerals. All of these conditions change the TDS from day to day and location to location.

A water source is considered safe and meets current requirements if it has less than 1,000 mg/L TDS. If dissolved solids are present in high concentration, the flavor potential of the coffee being brewed will not be fully realized. This is because water will have less capacity to solubulize flavor-producing substances. Further, the type and concentration of these substances will affect the hydrodynamic dispersion of water as it penetrates the bed of coffee and the individual grind particles. As a result, both dwell time and the level of extraction are affected. In the tests detailed in Chapter 3, it was found that a TDS of 120-150 mg/L brewed a beverage of noticeably higher quality than a beverage brewed with a 300 mg/L.

Some ions and compounds have a greater effect on extraction during coffee brewing than others. One study compared the extraction levels of coffee solids based on the individual mineral compounds dissolved in distilled water. It found that extraction ranged from 1.04 % of coffee TDS using calcium chloride to 1.29 % using sodium bicarbonate.[6] Calcium binds with the negatively charged soluble organics and carbohydrates in the solid coffee. Sodium has a significantly lower positive charge, resulting in very little binding or even dispersion of the soluble coffee compounds. The phenomenon is similar to what can be directly observed by how hard water containing calcium forms a soap scum in a bathtub. The calcium binds with the soluble soap compounds forming (precipitating) the (solid and less soluble) soap scum ring. When the water is softened, exchanging sodium ions for the existing calcium ions, the soluble soap compounds remain soluble and flow down the drain, leaving no soap scum ring in a tub but making the water saltier.

Other dissolved solids have other effects on brewing. The presence of bicarbonate tends to expand the coffee particles and accelerate extraction.[7] While the bicarbonate is expanding the coffee particle, the calcium is binding to specific substances, creating a unique flavor that would not have happened during brewing with another water chemistry.

Measuring TDS provides an overall picture of the amount of dissolved solids present in a water supply. Increases in the ionic loading (TDS) of the water supply will limit the level of soluble compounds that will be extracted from the coffee. The higher the level of TDS in the water, the lower level of soluble flavor compounds. One of the primary goals of water treatment must be to limit the level of TDS to an acceptable level.

TDS is not the whole story, however. To determine the quality and nature of coffee flavor that will be extracted, testing of the water for specific instances of certain chemicals is recommended.

The Carbonate System

In natural waters, the carbonate system[8] refers to many factors pertaining to acids and bases, such as buffers, total alkalinity, pH, and certain metals, especially calcium (Ca+) and magnesium (Mg+), all of which are interrelated when it comes to water quality. This system is referred to as the *carbonate system* because these acids, bases, and other ions originate from carbon dioxide (CO_2) dissolving in water (to form carbonic acid). When using these characteristics to assess the quality of water for brewing, the entire system, including individual measurements and their interactions must be taken into account. For example, calcium present in water will have a greater tendency to deposit scale on coffee brewing equipment if there is a high total alkalinity, or if pH is also present.

As rainwater falls to Earth, it dissolves carbon dioxide in the atmosphere and develops a low (acidic) pH. Air pollution can further lower pH even more. After falling through the atmosphere, the water disperses over the earth's surface and permeates through the soil and around mineral formations. Acidic water tends to dissolve the minerals it comes in contact with, raising the pH of the water and dissolving minerals to keep the solution in balance. Conversely, absorption of carbon dioxide present in the soil can lower the pH. In the case of ground water located far below the surface, by the time the water arrives at an aquifer or saturates the earth, its pH is higher and it contains considerable dissolved mineral content.

Acidity and alkalinity within the context of the carbonate system: If H+ and OH- ions are out of balance in a solution, it becomes either an acid (when there is an excess of H+ ions) or a base (when there is an excess of OH- ions). Higher concentrations of either of these ions will increase rates of reaction in different ways during brewing.

6 Pangborn RM, Trabue IM, & Little AC, "Analysis of Coffee, Tea, and Articially Flavord Drinks Prepared from Mineralized Water," Journal of Food Science, Volume 36(2), 1971. p. 358.

7 Rivetti D, Navarini L, Cappuccio R, Abatangelo A, Petracco M, & Suggi-Liverani F, "Effects of Water Composition and Water Treatment on Espresso Coffee Percolation," (Proceedings of the Colloquiem of the Association Scientifique du Café, Paris, 2001).

8 Snoeyink V, and Jenkins D, Water Chemistry, USA: John Wiley & Sons, Inc., 1980. p. 156.

Not all acids or bases dissociate immediately in a solution. Naturally occurring solutions like water and coffee contain a variety of compounds, including ionically bonded substances in different strengths.

One can neutralize a base or an acid by adding its converse acid or base. For example, a solution with a high pH (a greater concentration of the OH- ion) can be neutralized by adding an acid. The H+ in the added acid and the OH- already in solution combine to form a water molecule (the TDS is also increased due to the associated negative ion from the acid).

There are usually many different acids, bases, and salts present in a solution. If a weak acid (or base), one that does not dissociate easily, is present along with a strong acid (or base), only the strong acid (or base) will dissociate. If one attempts to neutralize such a solution by adding the converse acid or base, the stronger acid (or base) will be neutralized, but the weaker acid (or base) may dissociate and the pH will not change.

The pH is a measurement of the concentration of H+ or OH- ions in solution at a certain point in time. Due to the presence of other un-dissociated ionically bonded structures in the solution, one may need to add a greater amount of the converse ion to measurably lower the pH. Measuring pH in a liquid can be compared to measuring a room's temperature. One can measure how hot or cold the room is at a certain point in time, but the temperature won't tell you how much heat would be necessary to make the room warmer. Similarly, measuring the pH will not reveal how much correction will be necessary to attain the target pH (how much acid or base should be added). The measure of the amount of correction that will be needed is referred to as *total acidity* or *total alkalinity*. Most important when dealing with municipal waters is total alkalinity.

Total alkalinity measures the water's ability to neutralize acids. The associated ions consist of hydroxide (OH-), carbonate (CO_3, with two negative charges), and bicarbonate (HCO_3-). The pH and alkalinity act in opposition to affect the relative acidity of a solution. Using the comparison of heating a room, you could attempt to lower the pH of a liquid by adding an acid, which is similar to raising the temperature of a room by turning on the furnace. However, the added acidity would be consumed by total alkalinity just as the heat which is initially generated, is absorbed by the volume of cold air in the room before any warmth is felt.

The presence of these ions has a dramatic effect on coffee brewing. The alkalinity and reserve total alkalinity neutralize the acids of the coffee as well as causing expansion of the coffee particles.

In tests using different combinations of water qualities, coffees brewed with water containing carbonates were the most bitter, had the highest pH (were most alkaline), and tasted flat.[9] Water containing higher amounts of carbonates also increased dwell time significantly.[10]

Hardness relates to the presence of calcium and magnesium in the water. Water with a high concentration of these metals is referred to as hard because of the mineral and scale deposits that can result. In extremely hard water, other metals are also commonly present. In addition, extremely hard water indicates the presence of positively charged ions (or captions) and an equal amount of negatively charged ions (anions) comprising of chlorides, sulfates, carbonates, and bicarbonates that are dissolved in solution. The anions are responsible for total alkalinity carbonate and bicarbonate (in which case the measure is of temporary hardness, or sulfate (permanent hardness).

Due to the interactions of the carbonate system and other ions, scale can form on brew machinery, especially in areas that experience temperature changes, such as spray heads and heating elements.

9 Pangborn, et al., 357.

10 Gardner DG, "Effect of Certain Ion Combinations Commonly Found in Potable Water on Rate of Filtration through Roasted and Ground Coffee," Journal of Food Science, Volume 23(1), 1958. p. 78.

Chlorine and Chloramines

The primary purpose of municipal water systems is to prevent waterborne illness. Most substances that control the safety of the water supply, however, destroy coffee's flavor and aroma. Chlorine and chloramines (the compound formed by chlorine and ammonia) are oxidizing substances that destroy harmful pathogens. However they also affect coffee flavor by prematurely oxidizing aromatics and oils. Because chlorination is standard in all municipal water supplies, removing these substances is necessary for the finest brewed coffee flavor.

Free chlorine refers to chlorine available in the ionic form that oxidizes most easily and is most volatile. *Total chlorine* includes free chlorine and other chlorine-based substances, some of which are added to maintain chlorine levels throughout the water delivery system. Both free and total chlorine have a deleterious effect on coffee flavor, however, it is free chlorine that has the most reaction in coffee brewing.

Other Potential Water Quality Problems

Depending on the source of the water supply, other problems can arise. Iron is common and will cause coffee to look slightly green.[11] Hydrogen sulfide, which can also be oxidized, is a gas that causes water to smell like rotten eggs. Chloride and sulfate in high concentrations can make water taste salty and cause gustatory imbalance in brewed coffee.

11 Lockhart EE, Tucker CL, & Meritt MC, "The Effect of Water Impurities on the Flavor of Brewed Coffee," Journal of Food Science, Volume 20(6), 1955. p. 603.

CHAPTER 2

A Detailed Look at Brewing Coffee From The Perspective of Water

As seen in the previous chapter, the subject of water is quite complex. Brewing coffee and dissolving favorable flavor substances into a liquid adds to this complexity. Knowledge of what occurs during the brewing process is useful in making decisions regarding the water quality necessary to brew coffee. In the first section of this chapter, the flavors of brewed coffee are examined, followed by an assessment of the brewing process itself, including the effects that water quality will have on the final flavor of the brew. Finally, some examples are provided to illustrate how water of a certain quality can affect the final brewed coffee beverage.

Flavor Attributes of Brewed Coffee

Whether green, roasted, or liquid, coffee's flavor potential is constantly changing. As a result, when conducting a chemical or sensory analysis, coffee must be considered as a moving target. One's impression of coffee at one point will not match one's impression at another point. This fickleness makes coffee one of the most challenging beverages to measure, chemically or organoleptically, with accuracy or precision.

Brewing is the final step in the long process of producing the perfect cup of coffee that begins with the farmer and progresses through roasting and grinding. It marks the moment of truth when the uniqueness of growing conditions, the hard work and dedication of the farmers, and the skill of the roasters come together, but which cannot be realized unless the coffee is brewed using pure, untainted water.

As water represents the vast majority of the beverage, it is important to understand the interaction between water and specific flavor-producing substances found in the coffee bean. Which flavor components are ultimately extracted will depend upon the quality of the solvent (the water), the solute (the coffee), and the temperature and other conditions under which the brewing process occurs.

The coffee liquor is comprised of liquids (including oils), gasses, and partially dissolved solids. Some substances emerge from the liquid surface as aromas, while the more solid substances often sink to the bottom of the cup. This process can be observed when a paper filter has not been used, because a light layer of oil appear on the liquid's surface, along with an accumulation of solids that are apparent once the cup is finished.

The flavor-producing compounds found in brewed coffee have their own individual properties that may evolve once in a solution. These compounds must be viewed as individual entities as well as how they work with, or against, other compounds present. These various compounds can accentuate, contrast, or conceal one another's flavors. Understanding this essential concept will explain why certain minerals in water affect the overall flavor profile of the brewed coffee.

The flavor of coffee is an extremely complex balance of several individual flavor qualities and sensations. Many of the flavor compounds that are appreciated in the beverage would be unacceptable in isolation, or in too great a concentration. In most sensory literature, taste qualities are classified according to how they are perceived by the human body. Olfactory sensations, perceived by the olfactory lobe at the top of the nasal cavity, are classified as aromas when they originate from a food and are meant to be consumed, and fragrances, or olfactory sensations from non-foods that will not be consumed. Gustatory sensations are perceived by the taste buds on the tongue and around the mouth. Physical mouth sensations such as body, smoothness, and temperature are tactile senses arising from nerves that are sensitive to texture and pressure. The trigeminal nerves sense pungency and are responsible for the fact that we can experience hot peppers, cool mint, and a tingling sensation in the nose when sniffing certain spices such as black pepper. Other chemicals may create sensations of astringency, the drying of the mouth and tightening of mouth tissues.

The flavor experience of coffee is more than the sum of these categories. Still, the knowledge of these different categories can be useful in discussing how the various flavor components of coffee are extracted during the brewing process and how water quality affects this process and the final flavor of the brew.

Aromas

Aromatics are perceived by the olfactory lobe at the top of the nasal passage. Two passageways lead to the olfactory lobe: the nostrils of the nose, referred to as the orthonasal channel; and a passage leading from the mouth and throat area, called the retronasal channel. The olfactory lobe itself has numerous cilia (small hair-like organs) in a layer of mucous. When a water-soluble aromatic reaches this organ, it is dissolved in the mucous, where the cilia sense the chemical, and a signal is sent to the brain. When one becomes aware of the stimulus, he/she can classify the type and intensity of the smell experienced.

In brewed coffee, the perception of aroma is the result of the aromatics originally present in the ground coffee and what is dissolved into liquid during the brewing process, some of which might not be available from dry ground coffee. Brewed coffee aroma differs significantly from the fragrance of dry ground coffee because a shift in concentrations occurs. Some of the sulphurous, or roasty, aromas that are prominent in ground coffee are not as dominant in brewed coffee. Conversely, some of the aromas that are barely perceptible in ground coffee are key odorants of brewed coffee. The volatility and stability of the compounds also contribute to aroma, such as the fresh-fruit; long-chain aldehyde aromas are delicate and subject to rapid oxidation, while some earthy odorants are highly stable once extracted.

Different aromas have different strengths and their perception may vary according to concentration. One of the most important of coffee's aromas, diacetyl, is pleasantly buttery at the low concentrations found in coffee, but perceived as burnt and sulpherous, or even chlorine-like, in high concentrations.[12] Vanilla aroma is almost always present to some degree in coffee, but is rarely perceived due to the presence of stronger aromas.

Most aromatic constituents can be found in the oils of brewed coffee. The number of aromatics that escape into the atmosphere depends on temperature, the properties of the aromatic, and interaction with the gasses above the liquid surface. Acetic acid (conventionally known as vinegar) is especially active and can be readily perceived in any liquid in which it is present. More volatiles are released from a liquid surface than a solid surface and are transmitted by movement of available gas. When cuppers break the surface of a crust of coffee, the carbon dioxide under the grounds releases aromatics into the atmosphere.

It is possible to detect more than 1,200 aromatic compounds in coffee, making aromas the most variable component of the coffee. These aromas are based on numerous variables such as the origin of the green bean, the species and variety of tree, and the degree of the roast. Because of their great number, aromas are often classified according how they are perceived (such as sweet or earthy) by the olfactory lobe. Together, the various descriptors create an aroma profile for the particular coffee.

Certain acids also contribute to brewed coffee aroma, and include those acids responsible for the unpleasant fermented aroma and flavor.[13] An acid is considered an aroma if perceived by the olfactory lobe. The most important aromatic acids include lactic acid (responsible for the sour taste and smell of yogurt, sour cream, and buttermilk) and acetic acid (vinegar). Water with high pH or total alkalinity will directly affect these aromas.

12 Flament I, Coffee Flavor Chemistry, New York: John Wiley & Sons, Ltd., 2002. p. 135.

13 Bade-Wegner H, Bendig I, Holscher W, & Wollmann R, "Volatile Components Associated with the Over-fermented Flavour Defect," (Accociation Scientifique Internationale du Café, Paris; 17th International Scientific Colloquium on Coffee. 1997), 176-182.

The aroma profile of a cup of brewed coffee is affected by grind, water, heat, and time. These variables affect the amount of aromatic compounds being extracted, and in what quantities. The perception and enjoyment of the aroma profile then depends upon the balance of these many constituents.

Gustatory Sensations

There are much fewer compounds affecting gustatory perception than there are aromatic compounds. These sensations are perceived by our taste buds in very different ways. Further, these compounds also interact with the brain at different rates and in different patterns. Early in their training, professional cuppers gain knowledge that some parts of the mouth, palate, and tongue are more sensitive to certain stimuli, and that some sensations occur faster than others. How these individual sensations combine to cancel each other out or amplify their mutual effect must also be taken into consideration when examining the flavor of coffee.

When it comes to perceiving aroma, the possibility exists that aromatic molecules will not make contact with the olfactory lobe, or the contact will be too brief to be perceived by the olfactory sensors due to dissipation or breakdown of the aroma. Gustatory sensations are more regular because contact between the liquid and receptor occurs for a longer period (at least a couple of seconds) of time. However, what is perceived depends to a great extent on what has previously been tasted. If a sweet solution has just been imbibed, what is tasted next will not have as great an effect in terms of sweetness. There is also the possibility of over-saturation, especially with the bitterness receptors, because if a molecule is already attached to a receptor, it will not be able to pick up further stimuli.

Gustatory sensors are constantly bathed in saliva, itself a solution containing water, salts, acids, proteins, sugars, and more. This saliva is fed and maintained by the blood, an even more complex solution that is constantly in a state of flux. Further, the chemical state of the saliva will also affect perception.

In discussing gustatory responses, some experts refer to as many as 12 different possible perceptions.[14] However, the most familiar and well-studied gustatory sensations are salt, sour, sweet, and bitter. The sense of taste is referred to as a chemosensory perception because each perceived taste has a particular chemical compound associated with it. For example, the H+ ion is perceived (in the form of the hydronium ion, H_3O+) as sour, while the sucrose atom, a totally different covalently bonded compound, is perceived as sweet. In terms of size, salty tasting ions are smallest, and are therefore more difficult to remove through filtration, followed by sour-tasting substances, then sweet, and finally bitter-tasting substances, which are the largest.

Still larger molecules are tasteless since there are no taste bud receptors capable of sensing them, but they can be perceived as aromatic by the olfactory lobe, viscosity, or as body by the tactile senses.

Acidity, *Acids*, and *Salts*. A major focus of cuppers when evaluating coffee is acidity. In solution an acid is defined as an ionically bonded compound capable of donating a proton (designated H+, a hydrogen atom without its electron) to a water molecule,[15] which forms the hydronium atom, H_3O+. Upon contact with the appropriate taste bud, the hydronium molecule is perceived as sour.

In the previous chapter, liquids were discussed in terms of being acid (having a higher concentration of H+ ions) or alkaline (also referred to as basic and having a higher concentration of OH- ions). The concentrations of these ions in solution are measured as pH. If the pH is above 7 at a temperature of 25˚C, the solution has more OH- ions and is referred to as basic. If the pH is lower than 7, the solution has an excess of H+ ions and is referred to as acidic. (More information on the scale of those measurements is provided in Chapter 3 on page 27).

14 Buffin, *EducVin: Oenoplurimédia, Chaintré, France,* Developing Your Skills as a Wine Taster, 2002, www.oeno.tm.fr, p.29.

15 Pauling.

Also in the previous chapter, we saw that some acids, while capable of dissociating in solution, are more tightly bound together and tend not to dissociate. These are referred to as weak acids. When pH is measured, only the concentration of free H+ ions in solution (i.e. those that have dissociated and given up a proton) are measured. When tasting, one senses not only the dissociated atoms but also other acids that are non-dissociated in the originally ingested solution. Although these are not immediately measured in terms of pH, they dissociate in the mouth upon contact with saliva, or on the tongue itself, and are perceived as acidic. This phenomenon gives certain coffees completely different acid perceptions, and thus, a different taste than other coffees.

Weak acids that do not dissociate in solution can contribute to perceived acidity by dissociating upon ingesting due to mouth pH, which is typically a pH of 6. As H+ forms hydronium and binds to a receptor (taste bud) in the mouth, the balance of the solution is disturbed and more anions (including H+) are released. Acids will either continue to bind to receptors in this way, or be neutralized by salivary bicarbonate, a naturally occurring buffer solution.

For example, citric acid is reasonably strong acid present in all coffees, though it degrades as the coffee roast is darker. Malic acid, like that found in apples, is often present, especially in higher grown coffees, but is a weaker acid than the citric. When one tastes a coffee containing both acids, one first perceives the citric acid and then, as it is neutralized by the saliva, the malic acid can be perceived. The Englehardt and Maier (2001)[16] study found 22 different acids in coffee, and other more recent studies have found many more.

Also present in brewed coffee are ionically bound substances known as salts. Consisting of a positively charged metal and an associated negatively charged anion, these are found in the brewing water and as potassium and other salts in coffee. These contribute to how acidity and the other tastes are perceived. In solution, interaction effects occur when strong acids, weak acids, and salts are all present. Stronger acids ionize readily and delay the ionization of the weaker acids, while the salts present in the waters can inhibit ionization of either strong or weak acids. The greater the difference in the strengths of their ionic bonding, the more this effect comes into play and will affect the flavor of the brewed coffee. This is one reason why the amount of salts present in the water, whether originating form the water supply or from softening, will have a major effect on coffee flavor.

Interactions between acids and bases can affect the perception of acidity in another way. Undissociated weak acids in the presence of a base can form salts, with the remaining OH- and H+ ions combining to produce water. Likewise, if a strong acid ionizes in the presence of a strong base, the dissociated H+ ions combine with dissociated OH- ions to form water. As a result, a hydronium atom is not formed, no change in pH occurs, and the acidity is not perceived. The capacity of a solution, such as coffee, to neutralize acidity is referred to as the buffering capacity. This is determined by measuring the total alkalinity, or concentration of negative ions (anions), which, in turn, helps determine the capacity of a water supply to brew flavorful coffee. Total alkalinity also has a physical effect on coffee bed expansion due to the particle expansion previously noted.

A solution that can remain at a fairly constant pH, despite changes in relative concentrations of specific ions, is known as a *buffer system*. A buffer system either protects against strong acids, because salt is present in a base, or protects against strong bases, because of the reserve acidity in an undissociated weak acid. The balance of all these ions, including those measured by pH and total alkalinity, will affect the perceived acidity in the cup.

As with aromas, the variety and concentration of acids and salts differ according to origin and roast parameters of the particular coffee. For instance, the interaction of phosphoric acid (a strong acid) and potassium (a strong base) appears to be important to perceived acidity.[17] The amount of phosphoric acid appears not only to make a direct contribution to beverage acidity but also binds to the potassium, giving a less salty or rough taste.

16 Engelahrdt UH, and Maier HG, "Sauren im Kaffee" cited in "Coffee: Recent Developments," Eds. Vitzhum OG and Clarke RJ, 2001. Malden MA, USA: Blackwell Science, 2001. p. 23.

17 Clifford M, "What Facors Determine the Intensity of Coffee's Sensory Attributes?," Tea and Coffee Trade Journal, August, 1987. p. 39.

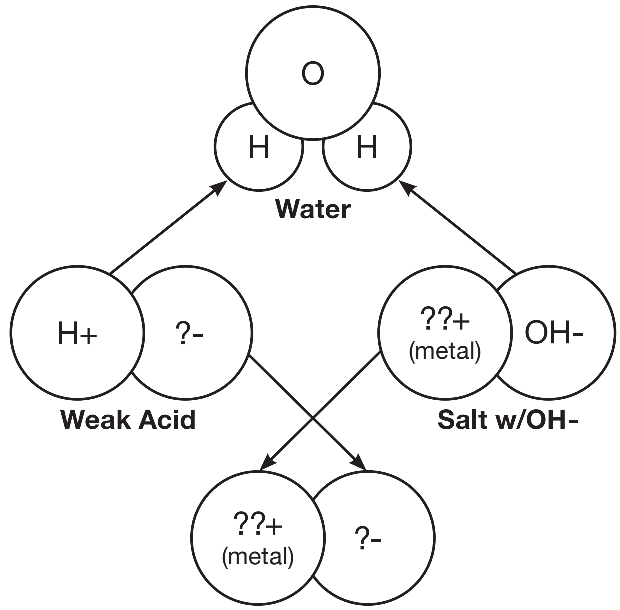


Fig. 7: *Buffer*

Bitterness and Sweetness. The perception of sweetness in foods is mainly due to low molecular weight carbohydrates such as sucrose (table sugar). These not only contribute to the gustatory sensation of sweetness but also can add to the perception of body. [18]

Most of sucrose and other simple sugars originating in green beans are sublimated during roasting (97% in light roasts and 99% in dark roasts), emerging mainly as aromatics, caramelized sugars, and organic acids. This is enjoyed as a subtly sweet gustatory note that is often present, especially in the best coffees.

The caramelization of sucrose that occurs during roasting forms other compounds that will be perceived as a combination of sweetness and sugar-browning aromatics such as caramel. Maillard reactions are more complex sugar browning reactions in which amino acids and carbohydrates combine to form new aromatic compounds. More complex carbohydrates found in the green bean can degrade into simple sugars upon roasting. Some combination of these effects most likely accounts for coffee's sweet taste sensation.

The small amount of sucrose that remains in brewed coffee (between 0.11% and 0.08% dry weight) is below the taste threshold, the level at which most people can perceive. These sub-threshold concentrations of sucrose can improve flavor without directly causing a sweet sensation, but at the same time suppressing to some extent the bitter, acid, and salty tastes.[19] From these observations, it is reasonable to infer that a key function of the sweet compounds in coffee is not to directly impart a sweet taste, but to subtly balance the other gustatory sensations. The maximum extraction of sucrose and other simple carbohydrates, despite their low levels, may be important to brewed coffee flavor and can be affected by water quality.

The most common complaint heard about the coffee beverage relates to bitterness. As with many foods, some bitterness in coffee is desirable—but it should not be overwhelming. Caffeine, bitter tasting in its purified form, was initially thought to be responsible for coffee's bitter taste, but decaffeinated coffees can also taste bitter. Recent sensory studies have shown that caffeine accounts for about 10% of the bitterness perceived in coffee. As in many foods, bitterness affects other gustatory perceptions, accentuating sweet and sour gustatory sensations. Bitterness is

18 Godshall MA, "Role of Sucrose in Retention of Aroma and Exchanging Flavor of Foods," in "Sucrose, Properties and Applications", Eds. Mathlouthi M and Reiser P. Glascow: Blackie Academic and Professional, 1994. p. 251-252.

19 Delwiche J, "The Impact of Perceptual Interactions on Perceived Flavor," Food Quality and Preference, Volume 15(2), 2004. p. 138.

sometimes confused with astringency, described as a mouth-drying sensation.

Current studies[20] on taste buds hypothesize that a close relationship exists between sweet and bitter taste receptors. These studies suggest that certain compounds have a sweet side to their molecules as well as a bitter side, processing in both the sweet and bitter molecular taste buds. A familiar example is that some sugar substitutes have a definite bitter aftertaste.

Bitter compounds found in coffee include chlorogenic acids, diterpenes, trigonelline, and caffeine. All are water soluble, but most require a longer contact time, greater agitation during brewing, or higher temperature to fully dissolve than acids, salts, and simple sugars. For this reason, the rate of extraction of flavors, which is directly affected by water quality and coffee particle porosity, will determine the balance of tastes in a brewed coffee.

Body and Other Tactile Mouth Sensations

Defined as the perception of heaviness and viscosity in the mouth, body is affected by the amount of solids found in the coffee liquor, other emulsified constituents such as oils, and certain chemical effects in the mouth. Cuppers often evaluate body by moving the tongue against the palate, applying pressure to the liquid against the surfaces of the mouth.

The perception of body in a free-flowing liquid is more the result of the uniformity of size of the particles than the concentrated amount of particles.[21] During brewing, a number of solids become suspended in solution, oils are emulsified, and, in the case of espresso, gasses are extracted.[22] Oils are mainly present in brewed products that do not employ paper filtration, such as French Press or espresso methods. Dissolving of gasses in liquid usually require pressurized extraction, as in espresso methods of brewing, and quickly dissipate or are held in crema by emulsifiers and oils.[23] These oils and gasses contribute to the mouth feel of crema in espresso, but there are differing opinions about their contribution to the overall mouth feel of the liquid.

Recent studies[24] show that there are a more dimensions to the tactile sensation than body. These include the smoothness, syrupiness associated with simpler carbohydrates, and an after-feel sensation. These different aspects are especially important in the appreciation of espresso.

The Trigeminal Sensory System

The trigeminal nervous system is not as familiar to most individuals, but it has been the subject of much recent study in terms of how it affects flavor. These nerve endings exist in both the nasal passages and mouth, and give thermal sensations and pain. At a less intense level, they cause sensations of pungency and tingling.[25] They affect the perception of olfactory and gustatory perception,[26] especially in terms of intensity of flavor.[27] Many of the substances present in coffee can cause this sensation, such as aromatic mercaptans, citric, phosphoric, and quinic acid. However negative this sounds, trigeminal sensations contribute to the satisfaction of many foods, including coffee.

20 Delwiche.

21 Terry Acree, Cornell University, personal conversation.

22 Petracco M, “The Cup,” in “Espresso Coffee: The Science of Quality” Eds. Illy A and Viani R. London: Elsevier Academic Press, 2005. p. 191.

23 Navarini L, Barnaba M, & Suggi Liverani F, “Physiochemical Characterization of the Espresso Foam,” 21st Association Scientifique du Café Colloquium, Montpellier, 2006, p. 320-327.

24 Navarini L, Cappuccio R, & Suggi Liverani F, “The Body of the Espresso Coffee: the Elusive Importance,” 20th Association Scientifique du Café Colloquium, Bangalore, 2004. p. 193-203.

25 Bryant B and Mezine, I. “Pungency and Tingling: Sensations and Mechanisms of Trigeminal Chemical Sensitivity,” in “Chemistry of Taste: Mechanisms, Behaviors, and Mimics,” Eds. Given P and Paredes D. Washington DC: American Chemical Society, 2002. p. 202.

26 Delwiche, 137–146.

27 Silver WL and Maruniak JA. “Trigeminal Chemoreception in the Nasal and Oral Cavities,” Chemical Senses, Volume 6(4), 1981. p. 295-305.

The phenomenon of astringency is a special case. Astringency refers to a puckering, drying, or rough feeling in the mouth that is the result of a lack of saliva. The compounds responsible for this sensation precipitate proteins, especially those in saliva.[28] While most often thought of as a tactile (physical) sensation, it has a direct effect on perception of tastes and aromatics.[29]

When considering water for brewing, one must seek to balance all of these aspects into a satisfying beverage. Some aspects present in water, such as salt, will have a direct effect and can throw the beverage out of balance. Other water constituents affect what is extracted from the solid coffee particles, ensuring extraction (of sugars), over-extraction (of bitter components), or neutralizing (alkalinity combining with acid) flavor attributes. To delve further into the process of creating a satisfying coffee beverage, the process of brewing itself is now examined.

The Brewing Process

The brewing of coffee should be considered from two aspects: physical and chemical. The physical aspects include the effects that water will have on the coffee grounds themselves (such as expansion), the amount of solids dissolved (as the result of temperature, stirring, etc.), and the physical actions that take place as the water passes over or the amount of time the water is in contact with coffee grounds. The chemical aspects include the actual flavors, tastes, and aromas of coffee that are dissolved into solution. These will result in the flavor attributes of the coffee liquid that will be appreciated (or rejected) by consumers.

Brewing procedures differ in their use of pressure, methods of combining water, grounds, and methods of separating grounds from the liquid. Brewing methods can be roughly divided into four categories: those in which the grounds are never separated from the liquid (Turkish, Greek, Russian, and Middle East preparations); those in which the coffee and water are put into contact for a period of time, and then the liquor quickly separated (French Press, vacuum pot); drip brewing where the water is passed over the coffee grounds in a continuous stream, and techniques using pressure such as espresso. These methods mainly differ in the amount of physical action that is involved. (Note: Percolation, or re-boiling, of coffee is not often used within the specialty industry, therefore it is not discussed.) All brewing procedures have the same goal of extracting solids from the coffee into a liquid. And only after the substances present in roast coffee are dissolved into a liquid can they be served and enjoyed.

Physical Action of Brewing

During the brewing process, ground coffee goes through several physical processes that allow the conversion of solid to liquid. The process, described by H.K. Camenga[30] et. al., is summarized as follows:

Initial contact and penetration:

- The water initially penetrates the coffee bed. At this point, some gasses (including carbon dioxide) are displaced from the particles, the particles are moisturized, and the bed of coffee is mixed. If the coffee has been freshly roasted, a considerable amount of carbon dioxide (a by-product of the sugar-browning that takes place during roasting) must be displaced before any water penetrates the coffee particle. Water does not take the path of least resistance through the bed of coffee as might be expected. Instead, it spreads throughout the bed and occupies an ever-increasingly wide pattern. This phenomenon is referred to as hydrodynamic dispersion.[31] The degree of

28 Noble, AC, “Astringency and Bitterness of Flavenoid Phenols,” in “Chemistry of Taste: Mechanisms, Behaviors, and Mimics,” Eds. Given P and Paredes D. Washington DC: American Chemical Society, 2002. p. 192-201.

29 Delwiche.

30 Cammenga HK, Eggers R, Hinz T, Steer A, & Waldmann C, “Extraction in Coffee-Processing and Brewing,” 17th Association Scientifique du Café Colloquium, Nairobi, 1997. p. 219-220.

31 Bear, J, “Dynamics of fluids in Porous Media,” New York: Dover Publications. 1972. p. 579.

hydrodynamic dispersion, responsible for the even wetting of the coffee bed, is a function of any external force exerted (including pressure in the case of espresso), the geometry of the pore system within the coffee particles, interactions between water, the coffee, viscosity and density of the liquid.[32] The evenness of wetting (a function of the spray head design in drip brewing) also affects how quickly the entire bed of coffee is saturated with water. The rate of particle expansion is a function of the density of the particle (dark roasts are less dense and have more porosity than light roast, for example), grind particle size (smaller particles are saturated more quickly), and quality of water. Ions and compounds present in the water used for brewing especially affect the latter.

- The first material to be dissolved is the soluble material on the surface of the coffee particles. How much of this material is available will partially depend upon how recently, and how finely, the coffee was ground. In freshly ground, recently roasted coffee, this is often gaseous carbon dioxide (CO_2). The more volatile aromas—those released immediately after grinding—will potentially dissolve into solution if they are still present.
- The hot water begins to penetrate the coffee particles.
- The particles swell.
- Water-soluble substances within the particles dissolve and, at higher temperatures and/or pressure, normally insoluble substances can dissolve.

Diffusion into liquid:

- The dissolved substances diffuse to the surface of the particle. This is the slowest aspect of the brewing process and will determine the rate of extraction. During this phase of brewing, the movement of dissolved substances to the surface of the coffee particle is affected by both physical aspects such as particle expansion, and coffee bed agitation (which is greater in the case of drip brewing than in French Press brewing), and by chemical aspects of brewing water.

Dissolving into the final coffee liquor:

- The mass of compounds now dissolves from the coffee particles into the surrounding solution, through a process known as convective mass transfer. As substances dissolve, the liquid immediately adjacent to the coffee particle becomes denser and more concentrated.
- This denser liquid further diffuses into the less dense liquid that is moving through, or present in, the bed of coffee.
- The degree of convective mass transfer that occurs is affected by the properties and states (gas, liquid, or solid) of the substances it contacts, the flow, and the pore system through which it takes place. In the case of drip brewing, the mass transfer continues at a greater rate, since the flow of water through the bed ensures that the coffee liquor does not become over-saturated with solids.

In short, brewing washes the various solutes out of the coffee and then diffuses the particles throughout the brewing liquid. The degree of extraction is a function of the amount of time the water is in contact with coffee particles, the temperature of the water (195º–205ºF; 92º–96ºC[33]), and the law of mass action, which can be stated as: The extraction rate decreases as the concentration of solids increases. The highest percent of solutes are extracted earliest in the brew cycle. Water with too many dissolved solids (a high TDS) already present will not have as great a tendency to pick up

32 Ibid, p. 580-581

33 Specialty Coffee Association of America, *Coffee Brewing Handbook*, First Edition, 2010.

coffee flavor substances. This is why the previous discussion of Total Dissolved Solids (TDS) is important to understand, as it is a major issue in determining the quality of water for brewing. During the initial contact and penetration phase of coffee brewing, the rate at which the water penetrates the bed particles is affected by water's structure—a function of both temperature and TDS.

Along with this physical action of extracting coffee solids into solution, there are some chemical aspects of water quality, which affect the flavor and rate of extraction.

Chemical Aspects

When the solvent (water) passes over the solute (ground coffee) at a certain temperature, the following processes take place on a chemical level:

- The most polar compounds, including ionic salts and acids, are dissolved into solution. How much, and which ones are extracted, depends primarily upon solubility of the particular compound and temperature of the water. The temperature of the water must be high enough to overcome the ionic bonding and the tendency of water molecules to orient themselves around the charged particles. It has often been observed that when the brew water is not hot enough, the acidity of brewed coffee is muted. As noted previously, in some cases, acids and bases combine to produce a neutral salt and water. The presence of certain ions in the brewing water will affect this process and the resulting flavor.
- Polar compounds which are covalently bonded, such as sugars and other carbohydrates, are then extracted. Again, adequate heat is needed to dissolve the molecules from their sites on the coffee particle. The presence of certain minerals ions (especially calcium) in the water will affect this process and alter the extraction process to a degree where minute changes in mineral content can have a pronounced flavor change in the coffee that is brewed.
- Larger molecules which are not as soluble—including bitter tasting compounds such as chlorogenic acids and trigonelline, and compounds contributing to mouth feel such as complex carbohydrates and oils–begin to dissolve into solution.
- Other solid suspensions, gasses (in the case of espresso), and liquids are extracted into solution. Solubility of solids increases with temperature. The amount of solids extracted into the liquor will depend on the method of brewing, ranging from paper filtration (least amount of suspended solids) to Turkish brewing (greatest amount of suspended solids). Solubility of gasses decreases as temperatures increases, but under pressure, such as during the espresso method of brewing, gasses will dissolve.
- Other than water, liquids of different miscibility, including oils and waxes, combine as the result of both temperature and pressure. Because oil and water do not emulsify easily, oils, which contain many aromatic substances, are retained to a certain degree in the grounds.
- At extreme high temperatures, normally insoluble substances, such as cellulose and other complex carbohydrates, will hydrolyze and suspend in the liquid.

These chemical processes can be correlated to sensory effects, the taste of the brewed coffee. For example, from a gustatory standpoint, the first substances extracted consist of the ionic substances and include stronger acids, salts, and bases. This will result in perceptions of sour and salt. The most polar and volatile aromas will also be initially extracted.

The sugars and carbohydrates extracted in the second stage above, modulate the effects of the ionic substances previously extracted. The amount of the polar compounds extracted will depend upon the available heat and the amount of substances already dissolved. If the solution is saturated, either because of the amount of solids in the water or the amount of polar substances already extracted, fewer of these polar compounds will be extracted, resulting in under extraction.

The other substances that will be extracted, including oils and dissolved cellulose (the complex carbohydrates that form the cell wall of the coffee bean) which affect the perception of body, depend upon the dwell time (the time of contact between coffee and water), temperature, and (in the case of espresso) pressure. The oils contain many aromas. Too much hydrolysis of complex carbohydrates will take place if excessive temperatures or pressure, coupled with extended dwell time, occurs.

The swelling of individual coffee particles is partially a function of the amount of bicarbonate atom present.[34] This is measured as total alkalinity (along with other ions). Too much alkalinity can slow the progress of water through the coffee, which may cause over extraction. Water with higher total alkalinity causes the particle to expand more quickly.

Figure 8 (adapted from the Coffee Brewing Chart in the SCAA Coffee Brewing Handbook) illustrates the process of brewing under ideal conditions.

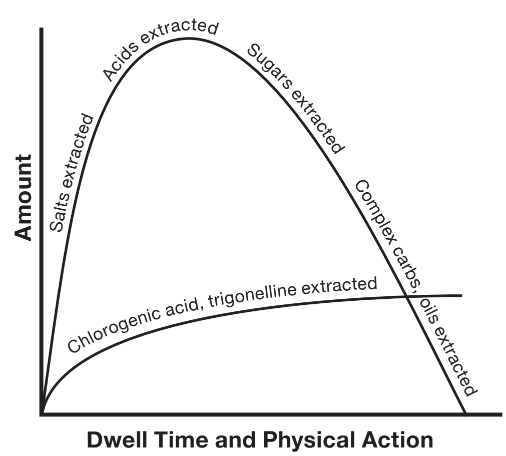


Fig. 8: *Modified Brewing Chart—(showing chemical actions)*

The Interactions of Coffee and Water

At this point we have looked at water quality and the process of brewing. Now we discuss what could happen when coffee is made with poor quality water. Following are some possibilities using some radar charts as illustrations.

In a radar (spider) chart, one starts reading at the top. The flavor attributes are listed on the outside, and the distance from the center indicates the intensity of the particular flavor attribute. The first figure is of a well-balanced, high-quality specialty brewed coffee with good sweetness and medium high acidity.

In *Figure 9*, the coffee is pleasant because it is dominated by the aromatics, sweetness, and acidity, with medium body. The salt/potassium aspects and bitterness are present, but at levels that do not dominate the overall flavor profile.

However, if one brews with water containing high TDS, the flavor profile of the coffee significantly changes, as illustrated in *Figure 8*.

34 Rivetti D, Navarini L, Cappuccio R, Abatangelo A, Petracco M, & Suggi-Liverani F, "The Effect of Water Composition and Water Treatment on Espresso Coffee Percolation," 19th Association Scientifique du Café Colloquium, Trieste, 2001.

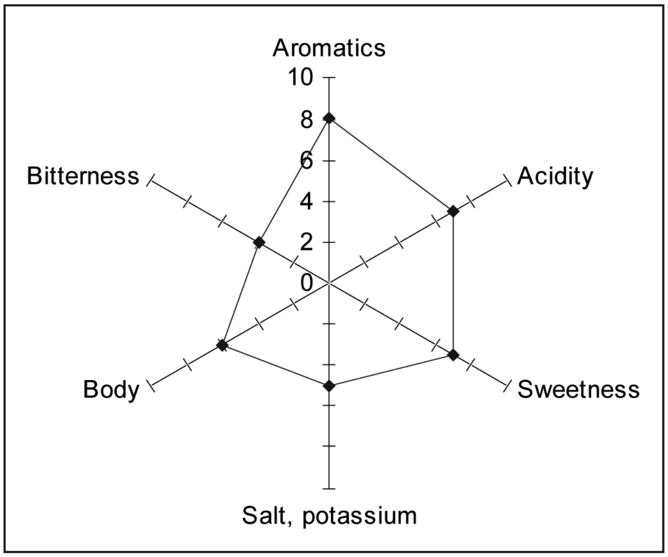


Fig. 9: Ideal Water Quality

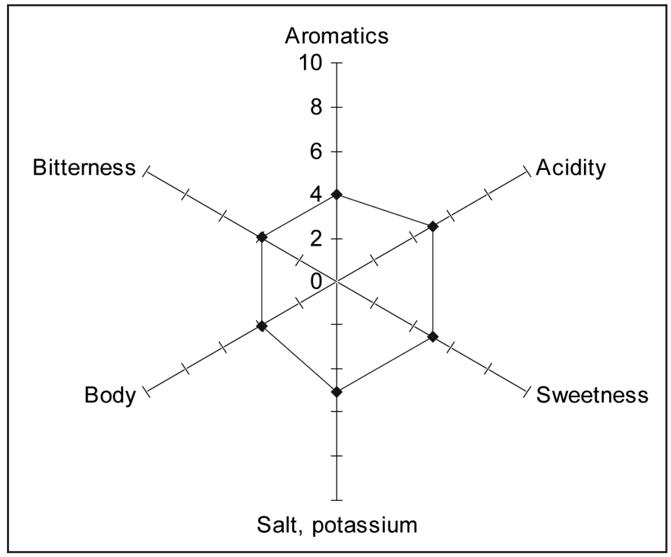


Fig. 10: High TDS Water

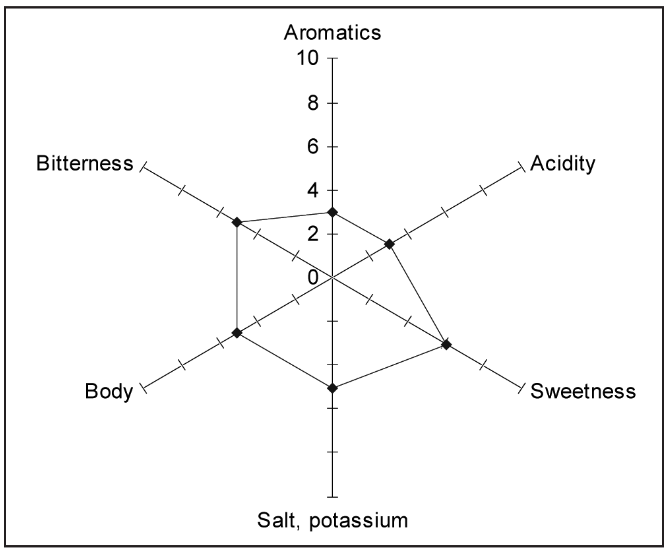


Fig. 11: High pH (or Total Alkalinity) Water

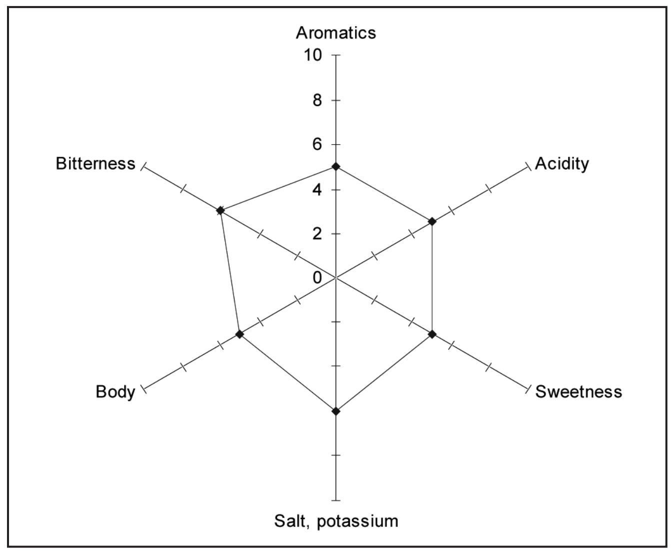


Fig. 12: Salty or Brackish Water

In *Figure 10*, not as much flavor is extracted; in particular, the preferred flavor components. The salts, which dissolve easily (additional salt may be present in the brewing water itself), completely dissolve and the bitter aspects solubulize more as a result of dwell time and action, but the aromatic, acidity, and sweetness attributes have not dissolved.

Water (as seen in *Figure 11*) used for brewing has high (alkaline or basic) pH and/or high total alkalinity, it directly affects the acidity of the brew.

In *Figure 11*, the aromatics are low due to the elimination of acetic acid and other aromatic acids. This results in a brew with low acidity. The sweetness is still present, but the balance of the profile tends towards the salt/potassium and bitter side of the chart.

If a salty water (*Figure 12*) is used, the balance again changes.

Figure 12 is not as out-of-balance as some of the previous charts, but the acidity and aromatics are not perceived as clearly as the salt/potassium attribute. The result is a coffee that is more bitter than sweet and acidic.

Effects of Water Quality on Brewing Equipment

Many coffee vendors originally consider water quality as the result of equipment problems. They notice significant buildup of white solids on their spray head or, worse, the espresso machine or brewer clogs up and ceases functioning.

The dissolving of calcium and magnesium in natural waters makes water hard, and this is responsible for scaling, liming, and other undesirable mineral deposits on brewing equipment.

These dissolved substances can deposit scale on metal surfaces when water is heated and then cooled, as when water emerges from the spray head of a brewer. These deposits occur when Negatively charged bicarbonates lose a hydrogen atom and combine with calcium or magnesium to form a chalky scale. Oxidation of dissolved silicon or sulfites can also cause silica or calcium sulfate (respectively) to grow on metal surfaces under these conditions and form a much harder and more insoluble compound. As these compounds grow, they restrict flow through spray heads and plumbing, and coat thermostats and auto-fill sensors, causing them to fail. The coating of the heating elements and tanks make heating less efficient. This affects brewer operation and, in turn, the flavor of the brew, along with leaving scale and lime deposits in boilers, tanks, and heating elements, preventing efficient heating of the water and blocking water flow during brewing.

However, one does not want to remove all of these hard chemicals from coffee brewing water. Calcium, when balanced with bicarbonate, sulfate, or chloride in the water, chemically reacts with the beans to create favorable flavor extraction. Excessive calcium is what causes scale build up in equipment. But a balance in the relationship between quality of coffee flavor and equipment maintenance must be determined.

Hardness, and the resulting scale, is not only caused by calcium. Magnesium can also cause scaling and have a negative effect on coffee flavor, as does silica, which does not affect flavor, but can be difficult to remove if allowed to build up.

The tendency of a water supply to form scale is a function of its hardness chemicals, total alkalinity, and pH, discussed previously as the carbonate system. The Langelier Index can be used to compute the tendency to scale or corrode (in the case of acidic waters). This Index takes into account all measurable aspects of the carbonate system, including pH, calcium hardness, total alkalinity, and temperature to determine the likelihood of corrosion or scale formation. By computing this result, one can reasonably predict the physical effect that the existing quality of water will have on equipment. The mathematical concepts behind the index are beyond the scope of this text, but an index calculator can be found at http://www.csgnetwork.com/langeliersicalc.html.

Use of the Langelier Index is necessary because different aspects of the carbonate system influence the tendency to develop scale in different ways. For example, water with a pH range between 7.0 and 6.5 will result in lower scale formation in any piece of brewing equipment, especially espresso machines due to the pressure applied during brewing. A range of pH values of 7.5 to 8.5, which are more commonly found in tap water, will tend to produce more scale.

Different combinations of carbonate system aspects have different effects on equipment. Water with 120 mg/L of hardness, low alkalinity, and a pH of 7.0 will not produce scale to the same extent that water with 7 grains of hardness, high alkalinity, and high pH will. Hardness above 170 mg/L will cause scale build up to occur rapidly, while hardness below 17.1 mg/L with not allow a desirable level of extraction. Commercially softened water, with a calcium level of 0 mg/L, will not produce any scale, but the lack of calcium makes it inappropriate for brewing coffee beverages.

The differences just described could be the difference between servicing an espresso machine every 6 to 12 months and servicing it every month. Brass pumps will often corrode under these conditions, and a switch to more expensive stainless steel pumps will be necessary.

One must keep in mind that the existence of scale does not always indicate carbonate system interaction as mentioned, silica, which is typically present in a much lower concentration than hardness, will scale to the same extent as calcium hardness regardless of pH and alkalinity.

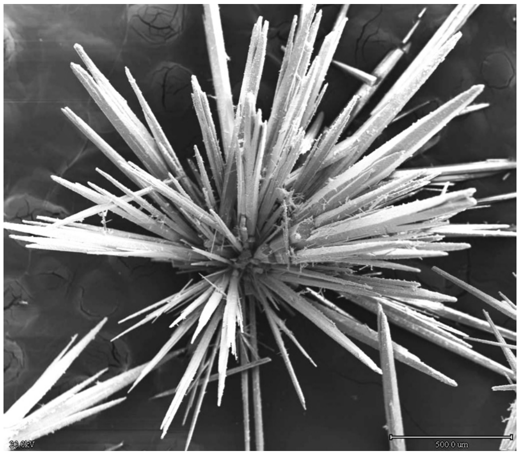


Fig. 13: *Scale scraped from the inside of a coffee brewer. Scale forms faster after an initial seed deposit has formed. Even after an appliance has been descaled, the microscopic particles, or irregular surfaces and seeds, left behind accelerate the re-development of scale; it may be best to replace the part.*

Scale is not the only problem that can occur in equipment as the result of water quality. Under acidic conditions, severe corrosion in stainless steel brewers, solenoid valve problems, and brown/black deposits in brewer is can be noticeable usually above the water line. Lab analysis of corrosion material showed high concentration of chlorides, iron and nickel.

The cause of this frequent and service-intensive problem is rarely in the natural waters themselves, though some acidic waters do exist under special conditions. The culprit is usually acid flux used in the soldering of copper pipe joints. The problem manifests itself 6 to 18 months after equipment is in use. Hydrochloric acid from flux used in copper pipe joining attaches to the chromium oxide coating of stainless steel slowly eating it away resulting in corrosion.

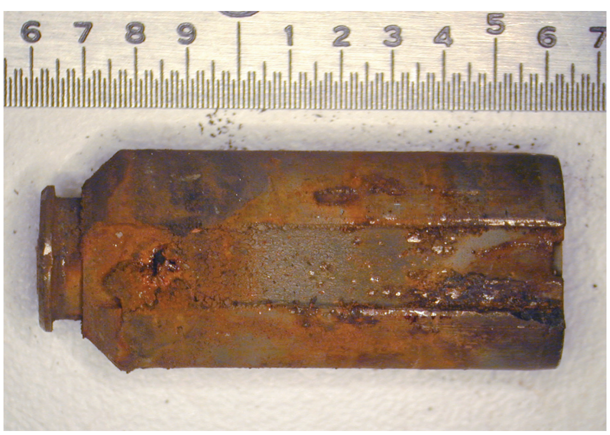


Fig. 14: *Solenoid piston in coffee brewer. Corrosion was initiated by acid flux used in copper pipe joining, not the water. Notice severe pitting where chromium oxide coating of stainless steel part has been eroded exposing plain steel allowing corrosion to take place. Defect was detected 6 months after installation. Corrosion of this type will manifest 6 to 18 months after installation.*

Water can be a problem on a number of levels. In the final chapter, we look at another important issue: how water quality affects brewing equipment. More important, we look at the water tests and corrections that can be undertaken to brew the ideal cup of coffee.

CHAPTER 3

A Strategic Approach to Water Quality

Determining water quality and addressing solutions can be daunting. Not only is water a complex subject, there are a multitude of products are available, all promising to correct any water problems one may have. The key is to decide what level of water quality is necessary for your business, and make a commitment to achieving it.

In a tasting conducted by the Technical Standards Committee of the SCAA, coffee was brewed with different levels of TDS to determine if significant flavor differences existed and how much difference actually existed. Table 2 presents results of a blind test isolating TDS as a key variable. The same coffee, grind, and brewer were used and the same standard combination of minerals was used. The only difference was the concentration of the minerals in the brewing water. The first tasting was conducted using three water samples: one contained TDS at a level of 45 mg/L, one at 150 mg/L, and one at 450 mg/L. The coffee that was brewed with 150-mg/L water was chosen as far superior by all who judged the coffee.

Table 2
Effects of TDS in Water on Extractable Compounds and Effect on Coffee Tasting

Cupping Taste Test	Dissolved Solids in Water	Tasting Judging
1	45 mg/L	Little body; tart taste
2	150 mg/L	Rich, piquant, rounded taste
3	450 mg/L	Imbalance of acidity and body, aroma off, harsher finish

A second tasting was conducted using 125 mg/L, 150 mg/L, and 175 mg/L samples to determine if minor variations in water quality would have an effect on flavor and extraction. The minor changes in the TDS of water were unanimously discernable by the panel. Acid and body balances were perceived to be off at both 125mg/L and 175mg/L TDS, and the 150 mg/L TDS brew was rated superior.

When tasting water alone, rarely is one able to discriminate a level of 25 mg/L difference in the water. Knowing this, it is then notable that the difference was so readily discernable to all participants. This supports the idea that the minerals as measured by TDS in the water play a primary role in producing the ultimate cup.

Units of Measurement

To this point, we have dealt with the water from molecular standpoint in order to understand how it affects the flavor of coffee during brewing. When making decisions about corrections to be made, we need to define the standards of measurement that one might encounter when dealing with water products, interpreting water test reports, and relating to plumbing issues. The following are the basic water measurements:

- **Units of Concentration and Size:** The concentration of substances dissolved in water is provided in milligrams to liters, abbreviated as mg/L, which is equivalent to parts per million. In some cases when evaluating test results, other standard measures are given by testers, most commonly *grains* (referring to grains per gallon, or gpg; 1 gpg = 17.1 mg/L). The actual particle size that a filter can remove is usually given in *microns*. This refers to a particle that will not pass through an opening of one micrometer. A filter that can filter 1 micron would be able to filter out tobacco smoke.

➥ **Delivery Volume and Pressure:** In mechanical terms, the *amount* of water refers to the delivery volume, while the *pressure* refers to the force (rate of flow) at which it is delivered in pounds per square inch (psi). When filling a 1-gallon vessel, it takes longer if the pressure is lower. Pressure is influenced by the diameter of pipe, the length of the pipe, and any resistance to flow, such as a partially clogged filter.

➥ **Total Dissolved Solids (TDS):** The standard measurement for TDS is made in either mg/L or ppm (parts per million), which is the same measurement and requires no conversion. A conductivity meter is used to measure the ionized solids already dissolved into the water to be used for brewing based upon their electrical charge. This measurement provides an overall view of the concentration of dissolved solids. Other more specific measurements may be taken to determined exactly which ions are present. Positively charged ions are referred to as cations, whereas negatively charged ions are referred to as anions. Recall from Chapter One that these must be present in the water in a balance (the same amount of positive and negative ions will be dissolved). Following is a list of the most commonly found dissolved solids in water that one may encounter in a water test report.

Cations	Anions
Calcium Ca++	Bicarbonate HCO_3–
Magnesium Mg++	Chloride Cl–
Sodium Na+	Sulfate SO_4–
Iron Fe++	Nitrate NO_3–
Manganese Mn++	Carbonate CO_3–

➥ **pH:** In the first chapter, we defined pH as the measure of acidity and alkalinity. The pH measurement is the negative logarithm of the hydrogen concentration on a scale from 0 to 14.0. A pH value of 7.0 is neutral, while a pH of 9.0 is 100 times as alkaline as pH 7.0, and 1,000 times as alkaline as pH 6.0.

The pH is an indicator of the balance of the solution and will determine the effects of other water constituents. For example, a water supply with high pH and the presence of calcium is more likely to scale than a supply with low pH and a same amount of calcium. While pH is important from a water quality standpoint, it is one of the most difficult to control. The pH of a solution is difficult to directly manipulate without adding TDS, but removal of other components will change the balance of the water and this is usually reflected in a change of pH.

➥ **Total Alkalinity:** This is the measure of the concentration of negative ions (anions) in the supply, and is a measure of the ability of the water to neutralize acids. This includes the acids of coffee which affect flavor.

A small amount of limited total alkalinity is necessary in the brewing process, because it allows absorption of water by the coffee particles. In excessive amounts, alkalinity will affect both the rate of extraction and the actual flavor extracted.

A step-by-step Approach to Achieving Quality Brewing Water

To avoid overspending on products that will not address the existing issues with water, the following six steps should be followed.

1. Conduct basic research on water quality and establish real world standards
2. Test water at each location, since they can vary significantly
3. Compare test results to the SCAA water quality standards
4. Select solutions to the specific problems that have been found
5. Assess water related equipment and plumbing parameters
6. Select a water treatment dealer

Each of these steps is discussed in the following sections.

1. Basic Research and Establishing Standards

As seen in Chapters 1 and 2, water makes up 95% or more of the coffee beverage, its chemistry has a direct effect on the flavor extracted, and it has an effect on the functioning of brewing equipment. If these concepts are understood, a good foundation exists for further investigation. However, deeper research is beyond the ability and resources of most coffee brewing businesses.

Before determining which water correction is necessary, one must have measurable standards for comparison. Water and coffee has fortunately been a subject of research for some time. Beginning in the 60's, the Coffee Brewing Center[35] conducted several tests regarding water quality and coffee brewing. The SCAA has continued to take up the challenge, and has refined the work of the CBC to create the current Standards for Coffee Brewing Water.

Here the standards and how they were developed are discussed.

Developing standards for TDS: When considering the level at which impurities in the water will react adversely with coffee's flavor, it is important to view their concentration in relationship to the concentration of coffee flavoring materials. For example, a coffee beverage containing 1% of coffee and 99% water has a concentration of 10,000 parts of coffee flavoring materials for each 1 million parts of water. If the coffee was brewed with water containing 100 mg/L total dissolved solids, the resulting mixture of dissolved solids to coffee flavoring material is 100 to 10,000–or 1%. Depending on the type and nature of the dissolved solids, a 1% concentration is high enough to affect the coffee's flavor, even though the concentration level in the water (100 mg/L) produces no detectable odor or taste. This is in addition to the chemical effects that the TDS can have upon coffee brewing as detailed in the previous chapter.

The Coffee Brewing Center's extensive consumer studies established taste thresholds for both water and coffee containing the minerals most commonly found in municipal drinking water. The chart below shows the point at which the average person begins to detect various minerals. See Table 3, page 27.

It was concluded that if the total concentration of dissolved solids of all types is below 200 mg/L, brewing coffee should not be a problem—unless the mixture of dissolved solids also contains iron.

Iron as a major problem: Preparing coffee with water that contains iron at concentrations as low as 10 mg/L yields a beverage that stands out not because of flavor changes, but for changes in color or appearance—particularly when cream is added. Although the concentration in the water is extremely low, the iron combines with the phenols in the

35 Coffee Brewing Center, Water Composition and Coffee Brewing, 1967, CBC pamphlet #31, New York.

coffee extract to produce greenish (iron-like) colors. Differences are detectable even at 1 mg/ levels of concentration. At levels ranging from 4 to 7 mg/L, some question of acceptability arises. At levels exceeding 7 mg/L, one can readily perceive a definite and unpleasant greenish cast.

Developing standards for the carbonate system: More than any other group of compounds normally found in municipal water supplies, carbonates and bicarbonates slow the flow of water through the coffee bed—especially when their concentration exceeds 100 mg/L (*Table 4*). As seen in Table 5, the greatest change of the flow rate occurs at the beginning of the brewing cycle, and decreases as the concentration of carbonate-bicarbonate compounds increases (See *Table 6*). The retarding effect can be so great that it prevents the water from passing through the coffee bed within an acceptable time. In these instances, the coffee brewing system requires the addition of a water bypass device.

Table 3

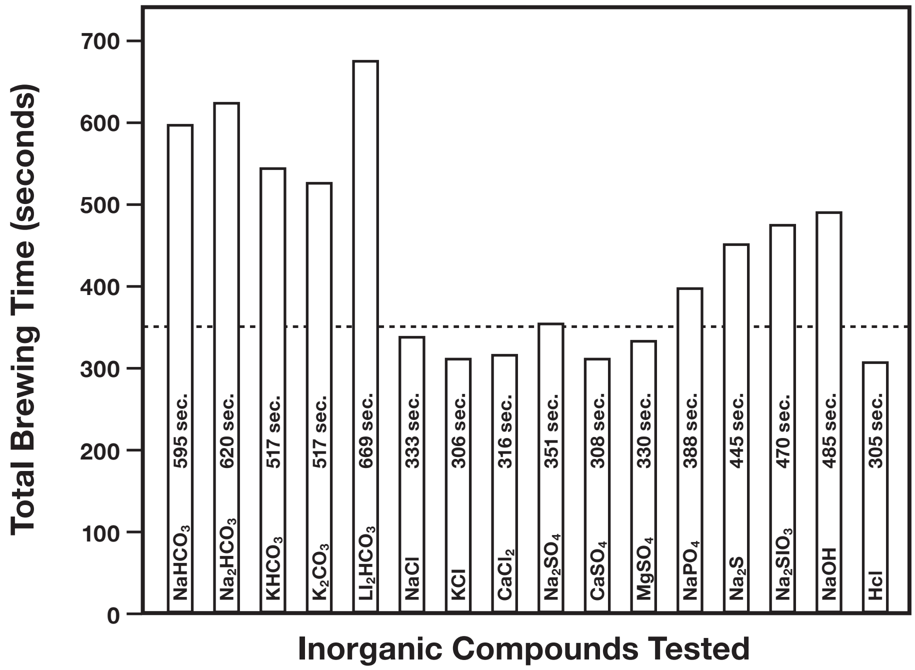
Threshold Concentrations of Ions in Water Solution and Concentration in Coffee Beverage

Ion	Threshold in Water ppm	Concentration Detectable in Coffee Beverage ppm
$NaHCO_3$		
Na+	290	377
HCO_3^-	770	1000
Na_2CO_3		
Na+	34	96
$CO_3^=$	44	125
Na_3PO_4		
Na+	75	—
$PO_4^=$	105	—
NaAc		
Na+	140	—
Ac–	360	—
NaCl		
Na+	135	258
Cl–	210	400
KCl		
K+	340	410
Cl–	310	450
KAc		
K+	680	—
Ac–	1020	—
$CaCl_2$		
Ca++	125	300
Cl–	222	530
MgSO		
Mg++	100	200
$SO_4^=$	400	800
$Fe(SO_4)_3$		
Fe+++	10	10
$SO_4^=$	25	25

Source: Coffee Brewing Center Publication No. 6

Table 4

BREWING TIMES OF 400 PPM OF VARIOUS INORGANIC COMPOUNDS IN DEIONIZED WATER

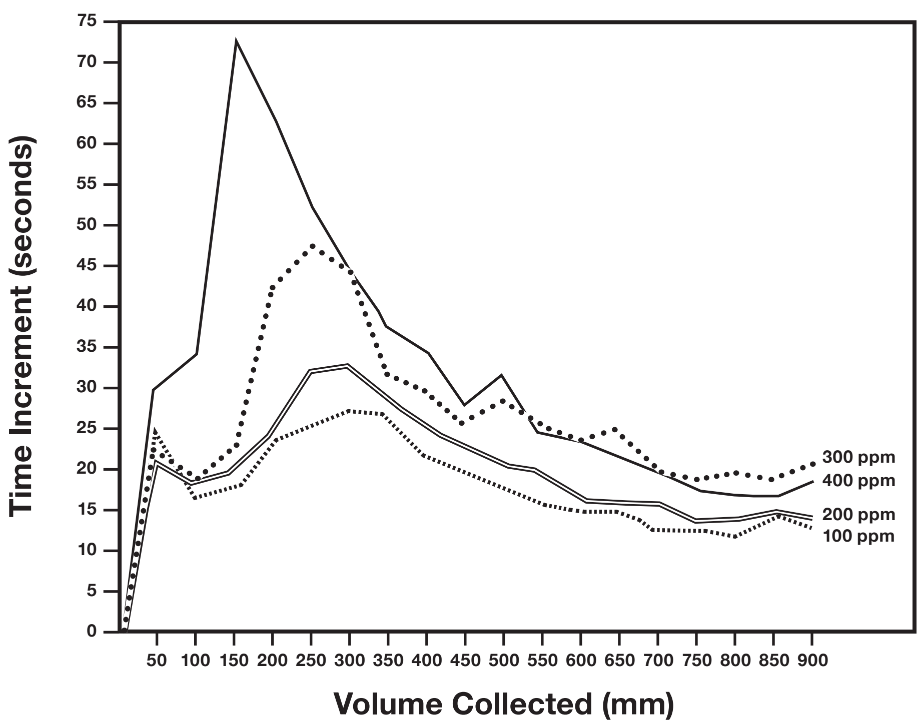


Note: Reference line at 350 seconds is brewing time using pure deionized water

Source: Coffee Brewing Center Publication No. 31

Table 5

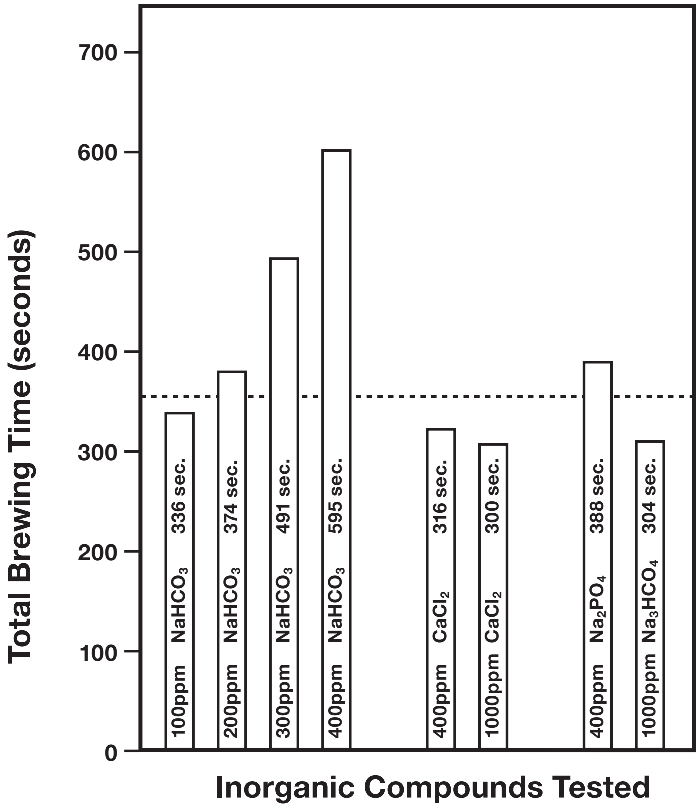
THE EFFECT OF VARYING THE SODIUM BICARBONATE CONCENTRATION ON THE BREWING RATE



Source: Coffee Brewing Center Publication No. 31

Table 6

Effects on Total Brewing of Varying Concentrations of Compounds in Solution



Note: Reference line at 350 seconds is brewing time using pure deionized water

Source: Coffee Brewing Center Publication No. 31

The flow-rate problem through the bed of coffee is further compounded if the water has been treated by a zeolite water softening system, the most common type of water softening system, and which is required to be regularly recharged with salt. Through ion exchange, this process replaces the minerals in the water—principally calcium and magnesium—with sodium. When combined with the bicarbonates already in the water, the sodium bicarbonate forms a shiny, slimy material that binds the coffee particles together and blocks the passageways through which the water would normally flow. As shown in Table 7, this extends the brewing time, thereby causing over-extraction of the flavoring material and leading to excessive astringency and bitterness. As a result, brewing coffee or espresso with softened water is not recommended.

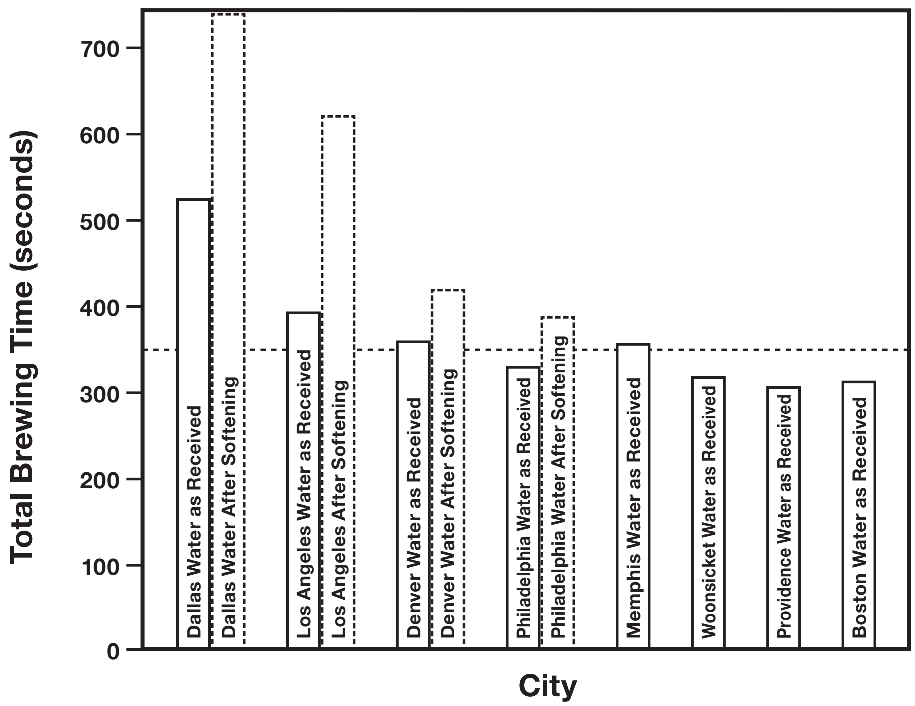
Developing standards of sodium-potassium content: At low concentrations, these salts actually add to the perception of sweetness in the brew. However, as their concentration increases, the sodium tends to increase the perception of sourness in the fruit acids present in the beverage. At the same time, the potassium increases the perception of the bitterness in the phenolic compounds present in the brew. Fortunately, few municipal water systems are plagued by excessive concentrations of either sodium or potassium, but it can be found in coastal water supplies and some ground water supplies.

Developing standards for pH: Pure water has a pH of 7.0, with an equal number of hydrogen and hydroxide ions present in the water. Chemically, it is neutral, acting neither as an acid nor as a base.

As the pH measurement of the water decreases below 7.0, it shows an increase in the presence of hydrogen ions, which lead to aqueous solutions that have sour tastes. In addition, when water becomes a weak acid due to an excess of hydrogen ions, it tends to increase the water solubility of other compounds. As the pH measurement of the water increases above 7.0, it shows an increase in the presence of hydroxide ions, which at high levels lead to aqueous solutions that have bitter tastes. When water becomes a weak base because of an excess of hydroxide ions, it tends to reduce the acidity of aqueous solutions through the formation of salts.

Table 7

Effects on Zeolite Softening Process on the Total Brewing Time of Carbonate Hard Waters



Note: Reference line at 350 seconds is brewing time using pure deionized water

Source: Coffee Brewing Center Publication No. 31

Developing standards for odors: This one was simple. Never use water with a detectable odor for coffee brewing. Detectable odors usually can be traced to the presence of hydrogen sulfide (the rotten-egg like aroma), chlorine (the cleaning-solvent like aroma), or ammonia (the uric acid like aroma). Different odors in water also may be the result of decaying organic material.

Hydrogen sulfide, a problem in some southern states, is easily detectable at low levels of concentration—0.05 mg/L in water and 0.12 mg/L in coffee. In general, water containing hydrogen sulfide can be treated by adding chlorine to oxidize the hydrogen sulfide, before it is used to brew coffee.

Because it is easy to use, readily available, inexpensive, and effective, chlorine is commonly used by municipalities to kill any bacteria present. Considered the standard water disinfectant, more than 96% of people living in municipalities have access to water treated with chlorine. When properly treated, the chlorine completely oxidizes as it attacks the bacteria and leaves no residue. Most municipalities, however, over-chlorinate the water to make certain it cannot transport infectious bacteria—and to meet the chlorine residual standards required by law for purification and safety of potable water supplies. Consequently, residual chlorine in municipal water supplies is a common problem when brewing coffee.

By itself, chlorine has a low taste threshold concentration for both water (5 mg/L) and for coffee (100 mg/L). The chlorine from the water often combines with the phenols from the coffee to create chlorophenol. This compound has a highly objectionable, medicinal taste that can be detected at a very low level of concentration (0.001 mg/L) in the coffee beverage. Chlorine must be removed by some type of activated carbon filter prior to coffee brewing.

Table 8

Threshold Concentrations of Selected Odor-Producing Chemicals

	Compound	Threshold in water ppm	Threshold in coffee brew ppm
Odor-producing chemicals	Ammonia	34.0	140.0[1]
	Chlorine	5.2	108.0
	Chlorophenols		
	ortho -	0.006	0.001
	para -	0.9	3.60
	para -	1.35[2]	1.33[2]
	Hydrogen sulfide	0.05	0.12[3]
	Phenol	60.0	105.0
Detergent: water softeners	Calgon	200.0	935.0
	Disodium dihydrogen versenate	120.0	825.0
	Tide	12.0	100.0
	Trisodium phosphate	225.0	1,550.0

[1] Color change prevented use of higher concentrations.
[2] Tap water substituted for redistilled water in water solution and coffee brew.
[3] Losses by volatilization made higher levels difficult to measure.

Source: Coffee Brewing Center Publication No. 38

It is important to note that, although not directly related to water quality, cleaning compounds that are used on the brewing equipment and coffee cups can accumulate and form insoluble proteins in the brew. If these compounds are not thoroughly rinsed off, they will dissolve into the coffee beverage as it is brewed and be found in the beverage that is served. Some compounds such as alkyl sulfonate, found in many dishwashing detergents, have unpleasant tastes that become detectable at concentrations above 100 mg/L.

The standards listed below, the result of testing at the former Coffee Brewing Center[36], cover the most important issues in producing good coffee. These standards have been adopted and added to by the Technical Standards Committee of Specialty Coffee Association of America in DATE. (As with many quality control procedures, an ideal target level and a range of levels for each parameter are specified.)

For a superior quality extraction of coffee solids, the brewing water should have these characteristics:

- Odor free;
- Clear color;
- Free of chlorine, iron, and sulfur compounds;
- TDS level of 150 mg/L;
- Calcium Hardness of 3-4 grains (51 mg/L to 68 mg/L);
- Total Alkalinity at or near 40 mg/L;
- pH of 7 to 8
- Sodium level of 20 mg/L.

………………………………

36 Ibid.

These are the target standards. For practicality, a wider range in the brewing water's TDS and total alkalinity, as shown in Table 9, will still allow for adequate extraction of coffee solids.

Table 9

Water Quality Parameters for Superior and Adequate Brew of Coffee

Water Quality Parameter	Superior Brew	Adequate Brew
Odor	Clean/Fresh	Clean/Fresh
Color	Clear	Clear
Chlorine	0 mg/L	0 mg/L
TDS	150 mg/L	75-250 mg/L
Calcium Hardness	3 to 4 grains or 51 mg/L to 68 mg/L	1-5 grains or 17 mg/L to 85 mg/L
Total Alkalinity	At or neat 40 mg/L	10-100 mg/L
pH	7 to 8 pH	6.5 to 7.5 pH
Sodium	10 mg/L	Less than 30 mg/L

Source: SCAA Technical Standards Committee, 2009

The parameters listed above should be tested in all situations. These cover TDS, the carbonate system parameters, and the most common problems. However, other water quality problems that require additional testing may also exist. Additional water quality considerations are summarized in Table 10.

Table 10

Additional Potential Testing Parameters

Parameter	Comments
Iron	Fairly common, can give coffee a green tint and bitter/metallic flavor, water may be rusty colored.
Sulfates	Sulfates dissolve quickly in water and give an obviously bad odor to the water. Sulfates are found to a certain extent in all waters, and in high concentrations in industrially polluted areas, which can emit a medicinal taste. High concentrations usually indicate extreme hardness, and can result in a laxative effect.
Silica	Not common, however creates hard, glassy scale that is difficult to remove. Levels below 5 mg/L will reduce equipment maintenance.
Manganese	Usually found in conjunction with iron, with similar effects, however, manganese is more difficult to remove. Levels as low as 0.05mg/L may cause staining and odor issues.
Nitrate	Usually found in shallow wells, however intrusion has become more widespread due to excessive uses of fertilizer in certain agricultural areas. Does not have a known direct effect on coffee flavor, however usually indicates high TDS.
Phenols	The result of industrial pollution, phenols give water a medicinal taste and odor when chlorinated.

2. Test the Water at Every Location

Water quality is highly variable from location to location. When the mineral content in water (TDS) was tested, in locations in New York and Vermont, tap-water mineral content ranged from 10 to 20 mg/L. Seattle registered about 45 mg/L in the city and up to 450 mg/L outside the city, whereas Southern California ranges from 250 mg/L to 750 mg/L—and sometimes higher. With the mineral content of water varying considerably from place to place, one might consider the question, What is the natural mineral content of water? For this, we turn to the Columbia Glacier in Alaska, which is a source considered a baseline for pure water. Samples taken from below the surface of the glacier have a mineral content was found to be 5mg/L.

Not only does water at individual locations vary in its mineral content (as measured by TDS), but that content can vary from season to season. Even within municipalities, different systems may serve locations in immediate proximity, depending on the distribution pipes and city treatment plant locations. Different supplies will have different problems, depending upon the original source of the water, the municipal treatment used, and the distribution systems.

Since water quality can change over time, regular testing must take place for effective comparison to standards and to determine consistency. When obtaining water samples for testing, collect water from the same location each time. Be aware that the time between collection and testing can affect results. For example, chlorine will evaporate relatively quickly and hydrogen sulfide may oxidize and form a residue that will not be identified in most instances, meaning that these tests must be performed immediately or the results will be inaccurate.

The first test is the simplest: Sniff, taste, and visually examine the water. This is best done formally, with a group of at least four persons. Take notes on any particular flavor or odor qualities observed, such as saltiness, bitterness, metallic tastes, or chalkiness. It is beneficial to compare the taste of the tap water under consideration with a bottled water of known good quality (select one that is as close to the standards listed above as possible). This first test may provide some clues as to the type of water problems that are present, however further testing will still be necessary to precisely determine quality.

A wide variety of water-testing options, with various levels of accuracy, is available. The SCAA water-testing kit provides a means of testing the basic parameters. A pool supply store will also have equipment to conduct simple tests for alkalinity and hardness. Your city's water provider will have information that includes an analysis of the local tap water. You can also contact a local water quality laboratory or university facility for a more detailed analysis. Many water filtration dealers also offer free testing, however the results may be designed to steer you toward their products.

3. Compare Test Results to Standards

Once water analysis results are received, they should be compared to the standard parameters discussed above. Regard a water supply as a potential source of brewing problems if it has any of the following characteristics:

- ➡ The presence of odor
- ➡ The appearance of turbidity (suspended matter), cloudiness, or discoloration;
- ➡ A total dissolved solids content above 200 mg/L or less than 20 mg/L of dissolved solids;
- ➡ Demineralized or reverse osmosis water;
- ➡ A carbonate-bicarbonate alkalinity above 100 mg/L;
- ➡ A combined calcium and magnesium content above 100 mg/L;
- ➡ Combined sodium-potassium content above 50 mg/L; and
- ➡ Acidity (pH) below 7.0 and alkalinity (pH) above 8.0.

4. Select Solutions to the Problems and Selecting a Water Filtration System

Many problems can be solved quickly with a minimum of filtration. Other specific problems will require special solutions. For instance, in some cases with very poor water, it may be less expensive to use bottled water than to correct existing water. The main point to consider is whether the water can be brought into the standards recommended by the SCAA (see page 32).

Common General Solutions

Particulate Filtration: The solution is determined by the size of the particles to be filtered. If severe turbidity is present, filters of various ratings can be placed in a series, from coarsest to finest filtration. A 5-micron filtration will normally provide clear water, however, if cysts such as Giardia are known to be present, finer filtration will be necessary. Filtration below 5 microns may clog quickly and filter components will need more frequent replacement. Physical filtration of this kind is also used after the oxidation-reduction process for the treatment of iron and manganese tainted waters.

Micron Ratings for Sediment Filters: Micron is a unit of length equal to one micrometer, or one-millionth of a meter. It is used as a measurement reference, or size for the removal of unwanted physical particles such as dirt, sand and rust. Micron ratings for filters vary from 75 microns to sub-micron sizes. The most common size is 5 microns, which aids in the removal of problem-causing physical particles. Further, sub-micron rated filters are mandated for removal of cysts such as Giardia and Cryptosporidium.

Carbon Filtration: The amount of carbon, and size of the filter needed depends upon the level of chlorine and the amount of water that must be treated. The main concern of sizing of the filters is one of contact time, that is, how much contact occurs between the water and the carbon. Larger capacity filters allow greater volumes and higher flow rates of water to be treated. Commercial businesses requiring large volumes of filtered water should realize that residential units (especially those sold by private distributors) seldom have adequate capacity for commercial use.

Carbon filtration is the most extensively used filtration method and offers a variety of options, from block carbon to granular and powdered carbon on a septum. However useful carbon filtration may be, it does not solve all water quality problems and in some cases can create its own problems. While carbon will remove most off-flavors and tastes, hydrogen sulfide (rotten egg smell) will quickly build up and cause other problems dealing with your equipment and taste of coffee or tea. Since the oxidizing ability of chlorine is removed, bacteria can build up within the filter. There have been no studies to date that the bacteria is harmful, however it does damage the equipment in addition to the taste of coffee.

Sizing decisions should be made on the basis of capacity of the filters–for instance, how many gallons of water can be treated, and at what rate before replacement? If paying for service calls, sizing a system that allows for longer life can be cost effective. Before purchasing any type of equipment, it is recommended to ask if the dealer provides a service program. This will avoid any down time and will keep the system in good running condition. A system will only be beneficial with the proper service maintenance program. One final consideration is that all carbon filters must be maintained or replaced regularly. The amount of water that can be treated by a certain amount of carbon depends on the type of filter and the quality of the water.

Water Softening: Water softening systems have been manufactured to minimize the hardness ions, calcium and manganese, through ion exchange in which the sodium ions replace the hardness ions. This method should only be used when equipment maintenance is the primary concern. For example, many espresso machine manufacturers will not honor the warranty unless a softener is attached and regularly recharged. High total alkalinity and silica will produce scale similar to typical hardness scale that water softening will not prevent.

The treatments outlined above–if properly designed, applied, installed, and serviced–will provide solutions to most water quality problems. Alternative solutions include:

Magnetic devices: In March 2001, the Water Quality Association reviewed the literature on these devices and came to the conclusion that there was insufficient study done to certify the claims made. The principal behind the use of magnets is that they will impart a chemical change in the calcium carbonate ($CaCO_3$) and alter it to an aragonite ($CaCO_3$) a crystal structure. Because aragonite is same chemical composition, yet a different atomic structure, those who sell the magnets purport that this crystal structure allows the scale to stay in solution (so called soft calcium carbonate) and be washed out of the brewer or espresso machine.

Aragonite is a polymorph of calcium carbonate. Aragonite is unstable at normal temperatures and pressures, therefore in order to keep aragonite stable after the altered effect of the magnet the pressure must increase faster than the temperature. Even if the magnets did achieve some measurable effect on the state of calcium carbonate, the altered state would not survive the rapid heat gain in a coffee brewer or espresso machine.

Chemical additives: Hexametaphosphate, poly phosphate, siliphos and other like-named products will sequester a limited amount of hardness (usually under 17 mg/L), and prevent it from forming scale on machinery surfaces. If the water contains above 170 mg/L of hardness, little benefit can be derived. At a high pH, these chemical additives are even less effective. None of these additives affect silica, which, once built up, cannot be easily removed.

Deionization: Deionization is a complete demineralization of the water using ion exchange, by means of charged resin beads. This resin is the same type used in water softening, with different resins used for anions and cations. Sodium is not used as a replacement in demineralizers. These need to be regenerated off-site frequently. This method is normally used in laboratories where super-pure water must be maintained, and is not recommended for general commercial use. (Resin will smell like dead fish if beads are not regenerated prior to exhaustion.) Electric probes, such as level sensors found in most brewers, will not have the ability to sense the presence of water if the TDS is below 20 mg/L and this type of water is extremely corrosive.

Reverse Osmosis: Reverse osmosis uses semi-permeable membranes and pressure to filter water at the molecular level. Dissolved minerals and ions do not pass through the membrane as readily as water. By continuously flushing the minerals from the membrane, the water produces the low TDS which is desired and the other concentrated minerals are flushed out to waste. This results in considerable water waste. RO is the most technically advanced water quality solution considered in this manual, and the most expensive. However it is often the best, and in the case of salt or potassium, often the only solution.

Since reverse osmosis is one of the most complex and costly systems for water correction, there are a number of parameters that must be considered. This will affect the amount of water that is available for use, the amount of water that is sent down the drain, and the cost of the system.

Operating pressure: Some systems operate on the basis of incoming pressure, however most systems require pumps. The actual pressure required depends upon the incoming pressure of the feed water. The final water pressure delivery may also need to be increased through use of a pump and a pressure tank.

Membrane area: Elevating the pressure is not the only way to increase the supply of water. By increasing the membrane area, the amount of water that can be treated at the same time will also be increased.

Percent recovery: This refers to the amount of water that passes through the membrane and will vary with the amount of TDS, pressure, and temperature.

RO will lower the pH, making the water neutral, and eliminate most minerals. The water emerging from a RO system should be tested in terms of TDS and pH. Reintroduction of minerals is important, as water that has had all minerals removed will not produce a good cup of coffee. Use of reverse osmosis without reintroduction of minerals may also have an effect on equipment. Electric probes, such as level sensors found in most brewers, will not be able to sense the presence of water if it has been filtered to the extent that the TDS is below is below 20 mg/L.

Please note: Reverse Osmosis has the potential to make the water more aggressive, and unless engineered and installed properly, RO will cause corrosion problems in metal pipes due to its concentration of gases. Under no circumstances should Reverse Osmosis be used if galvanized pipes are used, or copper pipe soldered with lead solder.

Solutions to Specific Problems

The Presence of Odor. The most likely odor is that of chlorine, however other odors may be perceived. Most can be removed using carbon filtration. The rotten egg odor is the result of hydrogen sulfide, which can be removed by oxidation-reduction, followed by sediment filtration.

The Appearance of Turbidity (suspended matter), Cloudiness, or Discoloration. The first step is to determine the origin of the suspended matter. A yellowish color may be the result of tannin, which occurs when plant materials degrade, while a more reddish color is often an indication of iron. Tannin, also known as humus, must be handled using coarse granular carbon of a specific size range. Iron is usually treated by oxidation-reduction, followed by sediment filtration. Other suspended matter, dirt, and cloudiness (due to particulates) are usually removed using sediment filtration as the primary treatment. A commonly used filter size for the trapping of particles in water is 5 microns., but keep in mind, the micron rating of the filter is dependant on the size of the particulate to be filtered and a finer particulate filter may be necessary.

TDS is low. Problems found are rarely the result of dissolved minerals. Carbon filtration for taste and odor control and sediment filtration for dirt and particle removal is recommended. Mineral addition, or use of bottled water, is a possible solution for enhanced extraction.

TDS is high. Carbon filtration for taste and odor control and sediment filtration (5 micron) for dirt and particle removal is recommended. In addition, Reverse Osmosis for mineral reduction is needed. RO is extremely effective at removing TDS, but its use may result in a total loss of TDS. The re-introduction of minerals to obtain the optimum TDS level may be required. A sample of water taken from the output of the RO system should be tested for the appropriate level of TDS on a regular basis and necessary corrections applied.

Carbonate System (Hardness, pH, and Total Alkalinity). The type of hardness (magnesium or calcium) must be considered along with the concentration in mg/L. A low amount of calcium hardness (below 50 mg/L) does not require correction, however the same amount of magnesium hardness will have a negative effect on coffee flavor. A higher level of calcium hardness will not have a negative effect on coffee flavor, however it will require more equipment maintenance. The final decision may be based upon computation of the Langelier Index (see page 22).

Other Solutions. For a review of which products will correct the problems found, consult Table 11. If all parameters listed are within specifications, yet problems are still suspected, more extensive testing may be required.

Table 11

Water Quality Problems and Treatment Solutions

Water Quality Problem	Particle Filtration (5 Micron Level)	Carbon Filtration	Reverse Osmosis (RO)	Mineral Addition	Water Softener*	Comments
Odor or off-flavor	No	Yes	No	No	No	Some particulate filtration at the 5-micron level may help extend the life of the filter.
Turbidity, dirtiness	Yes	For Chlorine removal only	No	No	No	If much dirtiness and turbidity are present, a 2-stage filter (a 10 micron filter in line with a 5-micron filter) may extend the life of filters.
TDS low	Yes	For Chlorine removal only	No	Yes	No	Bottle water may be a solution or mineral addition.
TDS high	Yes	For Chlorine removal only	Yes	No unless using RO	Yes or use as pre-treatment for RO	Check water quality after RO.
Hardness scale formation	No	With additive if under 3 grains	Yes	No	Yes	Test for silica if scale is still encountered after treatment with a water softener. Reverse osmosis will be effective at reducing silica levels under 15mg/L. At higher levels, high pressure may need to be applied to the osmotic membranes to achieve the desired removal levels. Check silica levels use softener only if equipment protection is primary concern.
Cloudiness in tea	No	For Chlorine removal only	Yes	No	Yes	Check alkalinity ion exchange will work however quality will suffer.
High Total Alkalinity	No	For Chlorine removal only	Yes	No	No	Causes floaters (white floating discs) in brew tanks. Anion softeners also work. Acts as a multiplier for scale.
Equipment corrosion	No	Yes	Possibly	Possibly	No	Analysis has proven many corrosion problems occur from acid flux left in pipes from plumbing work. Additional analysis is needed. Corrosion manifests 6 to 18 months after installation and is often incorrectly blamed on water quality.

**While water softening may solve the problems mentioned, softened water is not recommended for brewing coffee*

5. Assess Water-Related Equipment and Plumbing Parameters

Having determined which water quality problems exist and what solutions need to be put into place, it is time to begin looking for systems. Different systems will have different parameters and ratings.

In addition to knowing which corrections need to be made, information on how much water must be delivered, at what pressure (usually found on the specification sheets for the brewing machinery), and how many individual taps (brewers, tea machines, espresso machines, and so forth) will be made on the water supply line. If the system has not been appropriately sized, the machine at the end of several taps will not get an adequate amount of pressure when the other machines are operating. At the other extreme, the pressure may need to be restricted on the lower floors of a high-rise.

The goal is to determine the most economical system that will still meet the needs of the business, including any projected expansions. Be sure to ask yourself a variety of questions, including, Are there other noticeable problems, such as scale or corrosion on equipment? How much water is actually used for brewing over what amount of time?

Potential Plumbing (Water Delivery) Problems

A common problem in commercial brewing situations is short pots, referring to brewing less coffee than intended (or variable batch sizes). This is usually due to occasional low water pressure and pressure fluctuations throughout the day, an especially common occurrence in mall locations that have pressure booster systems and undersized lines. Also watch for extremely high-pressure spikes at mall locations and high-rise buildings after normal operating hours, or at certain times of the day. Pressures over 150 psi have been recorded at mall locations on a regular basis, along with high-rise buildings having tremendous fluctuations in water pressure.

Under-sized lines feeding multiple water-using devices can also cause loss of pressure and short pots. This can occur when the ice machine or other appliance draws water off the same pipe as the brewing. Short pots and lack of water pressure can also occur when lines are of adequate size, but the length of the service line is extended to the point that pressure is lost.

As long as the water pressure does not drop below a certain level, a pressure regulator can be installed in the water line. These can limit the pressure, but they cannot pressurize lines. Reducing the pressure to 20-30 psi will usually help correct variability in batch size caused by water pressure fluctuations. However, in some cases if the pipes are not well secured, knocking sounds may be heard due to the restriction of flow at high pressures.

If increased water pressure is necessary, a pump and pressure tank system is indicated. The pump intermittently turns on to maintain a constant pressure in the tank. The size of the pressure tank required depends on the amount of water that will be necessary at any one period of time.

Boil water orders. Under certain conditions (such as natural disasters), health departments may issue special instructions to ensure safety of the water supply. Flooding, earthquake fractures of water and sewer lines, or power failures can cause bacteria. Giardia, cryptosporidium, and bacteria to infect normally potable water. Usage of a NSF 53 certified filter (systems certified for microbiological contaminants) will comply to these instructions. Boil water decrees for bacterial contamination usually result in the closing of the store or boiling water for 10 minutes before use.

Sanitation of water lines after a bacteria-caused boil-water alert is essential when water treatment is used. The city relies on chlorination, typically super-chlorination, in this instance. However, the water provider may not take into effect the function of a carbon filter, or other water treatment device, used at source to remove all chlorine from the water. Because of this, the possibility exists that harmful bacterial contamination could escape chlorination. Therefore, have a procedure in place to ensure sanitization post-filtration.

6. Select a Water Treatment Dealer

Once you have developed a water quality goal, interview several companies that carry the type of treatment equipment desired. Collect specification sheets, take detailed notes, and insist upon a written, signed proposal. Request references from customers in the coffee or other beverage industry. Also inquire about maintenance, including how often it is required, the availability of replacement cartridges or parts, and who provides the service. Then inquire about estimated costs for those procedures. Make sure the dealer knows about your industry and how the equipment will work for you. Visit the company's service center and visit their website to gather more information.

After receiving several proposals, assess how well the proposed systems will meet the goals of water correction for the price. Study the spec sheets and compare the products in terms of capacity, level and types of corrections that will be made with the system, and maintenance costs. If something is unclear, contact the company representative. The response received may reveal much about the service one can expect. Be sure to include maintenance costs in the overall evaluation, and call the references provided.

Look for a water treatment dealer who:

- Provides helpful service. Try visiting the service department, or calling on a Saturday night. The best water treatment system does no good without a service program;
- Quickly and easily provides lab analysis of problem waters or corrosion investigations;
- Is more concerned about your problems than his or her profits;
- Helps keep cost of repairs and replacements down;
- Warranties;
- Technical support;
- Provides the ability to upgrade system with new technology;
- Reasonable cost for replacement parts and filters; and,
- Provides easy access to the system for needed maintenance.

The job is not over once the system is in place. In order to provide the means to brew a better cup of coffee, ideal water standards must be attained and maintained. Regular testing of the water will give a clue as to how much chlorine is being filtered and how long carbon filters will be effective. It is recommended to monitor the water pressure in reverse osmosis systems to ensure that the membranes are not clogged. If the system is being serviced, your service provider should monitor the water pressure.

Water treatment should always include an element of regular service. The ideal dealer will have a service department that is available 24/7, sell and service all types of equipment, and know at least as much about coffee water as you do. When service visits occur, carefully discuss what was done and ask any questions that may come up (such as, will such-and-such wear out if not replaced soon?). If there are noticeable problems (including weird sounds, restricted flow, change in testing parameters), address them as soon as possible.

AFTERWORD

When a customer comes to their favorite coffee shop, regardless of where it is located, they expect the same quality of beverage every time they visit. These expectations can be met with uniform water quality. A properly designed water treatment program should provide the multi-unit owner with uniform equipment maintenance schedules, reducing equipment maintenance and ensuring product consistency over time.

Because water accounts for more than 98 percent of the coffee beverage and typically 95% of the espresso beverage, it can be a significant source of problems. Even water that appears safe to drink, with no apparent tastes or odors, may contain impurities that interact unfavorably with the flavor compounds in the coffee once it has been brewed. In general, assume that the same coffee will exhibit different flavor characteristics when prepared from waters taken from different municipalities due to the variation in mineral content.

Specialty coffee is most appreciated when it is brewed with water of specific mineral content. Finding a source for that water—or creating it through water treatment methods—is not always easy. By combining a basic knowledge of water's effect on the coffee beverage with water testing (and appropriate correction when necessary), one can enhance the flavor of brewed coffee and gain a considerable competitive advantage.

To the extent that the water quality can be improved, the taste of coffee—especially fine specialty coffee—will be improved as well.

GLOSSARY

- **Absolute Filter Rating:** A filter rating indicating that 99.9% of the particles larger that a specified micrometer rating will be trapped on or within the filter. Not a good choice for coffee brewing due to its short usage life and high cost.

- **Absorption:** The physical penetration of one substance into the structure of another, similar to a sponge.

- **Activated Carbon:** A form of particulate carbon with heat-induced, enhanced surface area to increase adsorption of soluble contaminants.

- **Adsorption:** The attraction and adhesion of a gas, dissolved substance or liquid to a surface (like a magnet). For example, Algae blooms, or rapid growth rates, occur in spring when water supplies are warm and cause sudden filtration problems. Cities super chlorinate to kill off algae blooms and leave behind particulate matter from the dead algae that have a large micron rating which plugs the outer surface of sediment filters. Algae will give water a fishy, grassy, musty or earthy odor.

- **Alkalinity:** A measure of the hydroxide ion (OH-) or the ability to neutralize strong acids.

- **Anion exchange:** A process where anion contaminants are removed from a liquid by contacting a synthetic resin that is coated with other anions. Media must be backwashed and recharged (usually with salt) to replace exchanging anions. Similar to standard water softening, but used when negatively charged ions are the problem, such as alkalinity, bicarbonate, sulfate and nitrate.

- **Aquatic Fulvic Acid:** A complex organic compound leached from decaying vegetation. Generally causes the brown color in water. It is most abundant in springtime and after rains.

- **Carbonate system:** In natural waters, this refers to many factors pertaining to acids and bases, such as buffers, total alkalinity, pH, and certain metals, especially calcium (Ca+) and magnesium (Mg+), all of which are interrelated when it comes to water quality. This system is referred to as the carbonate system because these acids, bases, and other ions originate from carbon dioxide (CO_2) dissolving in water (to form carbonic acid).

- **Filter:** A unit process designed to remove particulate matter from a liquid stream.

- **Flow Rate:** A measure of volume of water moving. Pipe diameter along with pressure determines actual gallons per minute flow. Reduced pipe diameter can result in low pressure under flow conditions. (Not to be confused with pressure.) It is possible to have low flow with high pressure and high flow with low pressure depending on the diameter of the pipe and the flow rate.

- **Giardia:** The genus name for a group of single-celled, flagellated, pathogenic protozoans.

- **Giardia lamblia:** The species of Giardia that is a common cause of human diarrheal disease. Removed from water by mechanical filtration below 5 microns, usually a 1 micron filter, that has been certified for its removal by NSF International.

- **Hardness:** is a function of the amount of dissolved calcium salts, magnesium salts and trace amounts of iron and aluminum.

- **Heterotropic plate count (HPC):** A bacterial enumeration procedure used to measure bacterial density in an environmental sample, generally water. Also called standard plate count, plate count, aerobic plate count and total plate count.

- **Hexametaphosphate:** A chemical that is used as a sequestering agent with the chemical formula (MPO_3) 6 Sodium Hexametaphosphate is a polymer with the formula $NaPO_3$, also called sodium polyphosphate, or glassy sodium phosphate; used as a sequestering, dispersing and deflocculating agent.

- **Hydrogen bond:** The attractive interaction of a hydrogen atom with an electronegative atom. In order to create the bond, the hydrogen must be covalently bonded to another electronegative atom.

- **Langelier Index, or Langelier Saturation Index (LSI):** is the formula for determining whether water will have a tendency to scale or corrode. If you know the pH, hardness, alkalinity and water temperature, one can determine the relative speed with which that water will scale or corrode equipment.

- **Micromhos per centimeter (umho/cm):** A measure of the conductivity of a water sample, equivalent to microsiemens per centimeter. Sometimes used by water treatment personnel to measure TDS. Conversion to mg/L is computed by multiplying the number by 0.5 or 0.6 depending on water source. (Most commonly multiplied by 0.5.) Water with a measurement of 500 umho/cm would have a TDS of 250 mg/l. (500 x .5 = 250)

- **Microsiemens (US):** A unit of conductivity. The microsiemens is the practicable unit of measurement for conductivity, and is used to approximate the total dissolved solids content in water. Do not confuse with TDS.

- **Milligrams per liter (mg/L):** The unit used in reporting the concentration of matter in water as determined by water analysis.

- **NSF International:** A not-for-profit agency providing development of standards, voluntary product testing and certification, formerly called the National Sanitation Foundation.

- **Parts per million (ppm):** A unit of proportion equal to 10-6. This terminology is now obsolete, and the term milligrams per liter (mg/L) should be used for concentrations in water.

- **pH:** The pH is a measurement of the concentration of H+ or OH- ions in solution at a certain point in time. Due to the presence of other un-dissociated ionically bonded structures in the solution, one may need to add a greater amount of the converse ion to measurably lower the pH. Measuring pH in a liquid can be compared to measuring a room's temperature.

- **Polarity:** The tendency of attraction or repulsion of a hydrogen bond. The separation of electric charge leading to a molecule having an electric dipole.

- **Pounds per square inch (psi):** A unit of pressure. 60 psi is considered normal. 20 psi is the pressure point at which equipment function is hampered. 120 psi is usually the maximum rating for a water using device. Not to be confused with flow rate.

- **Reverse Osmosis (RO):** A pressure driven membrane separation process that removes ions, salts, and other dissolves solids and non-volatile organics. Relative micron rating of removal equivalent to .0005

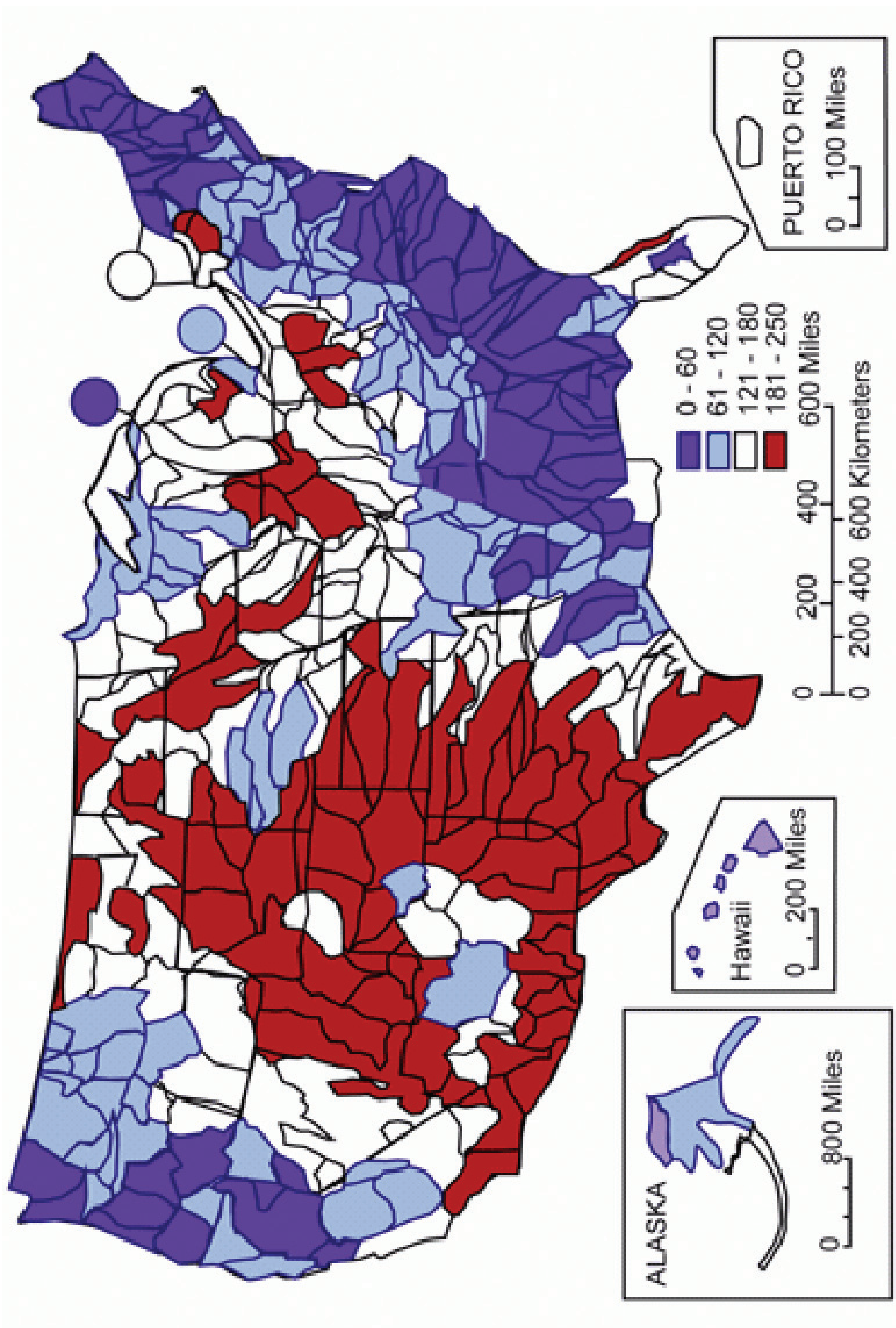
- **Soft water:** A natural water having a relatively low concentration of hardness usually between 0 and 75 mg/L.

- **Softened water:** Any water that has been processed to reduce the total hardness in water to 17.1mg/L or less

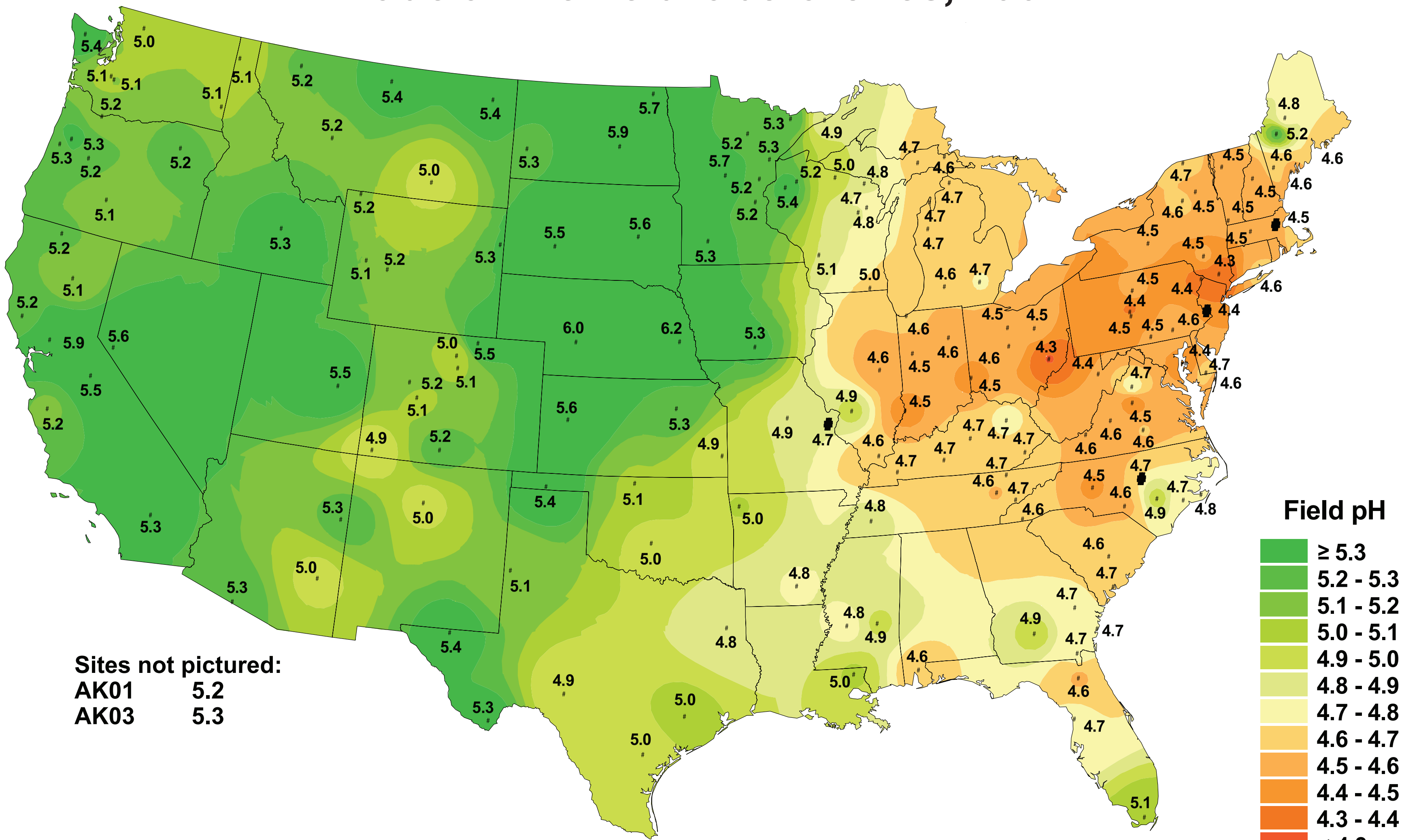
- **Total Dissolved Solids (TDS):** The amount and nature of solids already dissolved in water are referred to as Total Dissolved Solids (TDS). The source of the water supply chiefly determines the type and concentration of TDS.

APPENDIX

CONCETRATION OF HARDNESS AS CALCIUM CARBONATE, IN MILLIGRAMS PER LITER



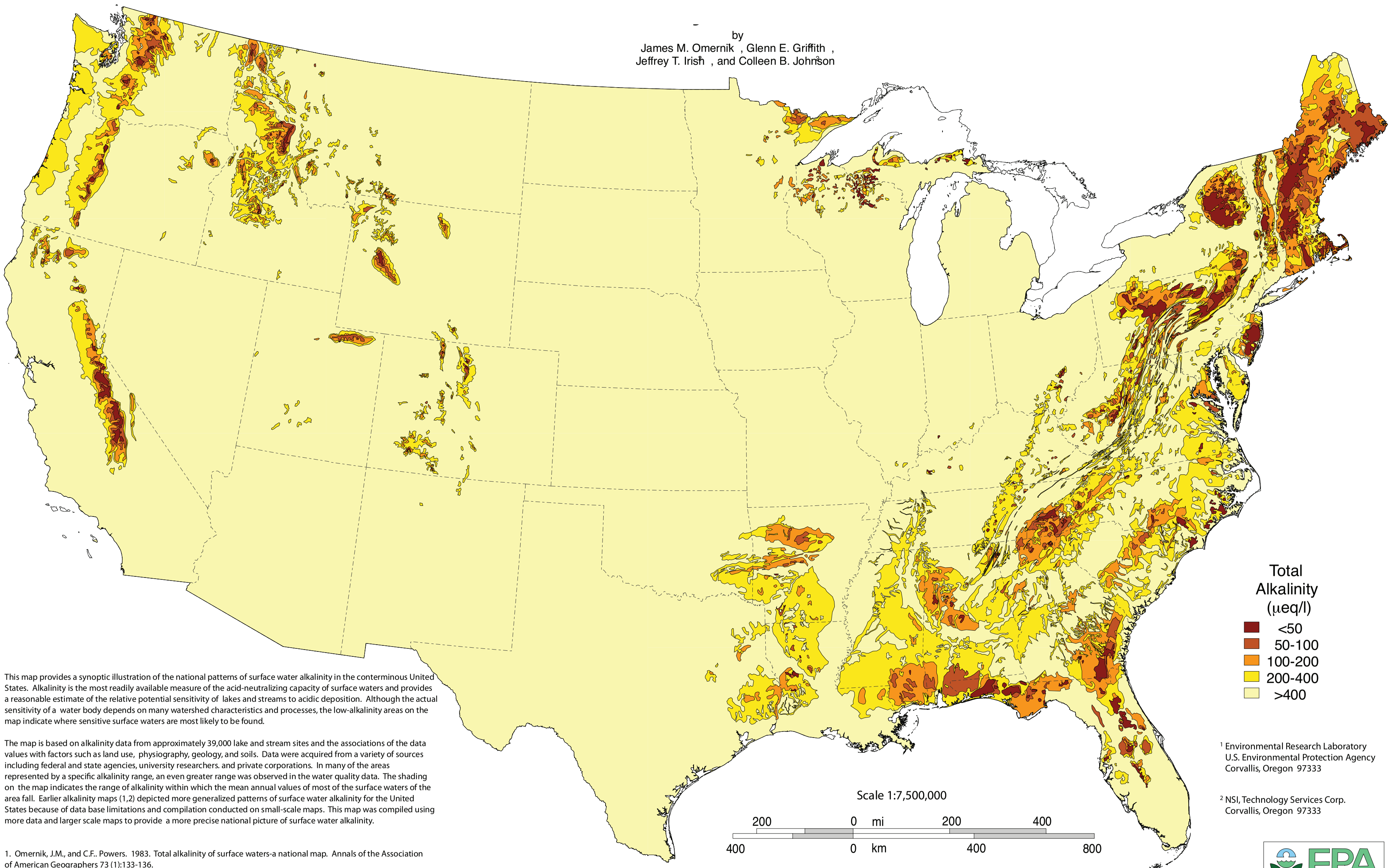
Hydrogen ion concentration as pH from measurements made at the field laboratories, 2004



National Atmospheric Deposition Program/National Trends Network
http://nadp.sws.uiuc.edu

Total Alkalinity of Surface Waters

by
James M. Omernik[1], Glenn E. Griffith[2], Jeffrey T. Irish[1], and Colleen B. Johnson[2]



This map provides a synoptic illustration of the national patterns of surface water alkalinity in the conterminous United States. Alkalinity is the most readily available measure of the acid-neutralizing capacity of surface waters and provides a reasonable estimate of the relative potential sensitivity of lakes and streams to acidic deposition. Although the actual sensitivity of a water body depends on many watershed characteristics and processes, the low-alkalinity areas on the map indicate where sensitive surface waters are most likely to be found.

The map is based on alkalinity data from approximately 39,000 lake and stream sites and the associations of the data values with factors such as land use, physiography, geology, and soils. Data were acquired from a variety of sources including federal and state agencies, university researchers. and private corporations. In many of the areas represented by a specific alkalinity range, an even greater range was observed in the water quality data. The shading on the map indicates the range of alkalinity within which the mean annual values of most of the surface waters of the area fall. Earlier alkalinity maps (1,2) depicted more generalized patterns of surface water alkalinity for the United States because of data base limitations and compilation conducted on small-scale maps. This map was compiled using more data and larger scale maps to provide a more precise national picture of surface water alkalinity.

1. Omernik, J.M., and C.F.. Powers. 1983. Total alkalinity of surface waters-a national map. Annals of the Association of American Geographers 73 (1):133-136.

2. Omernik, J.M., G.E. Griffith, and A.J. Kinney. 1985. Total alkalinity of surface waters. Corvallis Environmental Research Laboratory, U.S. Environmental Protection Agency, Corvallis, Oregon.

[1] Environmental Research Laboratory
U.S. Environmental Protection Agency
Corvallis, Oregon 97333

[2] NSI, Technology Services Corp.
Corvallis, Oregon 97333

EPA
U.S. ENVIRONMENTAL PROTECTION AGENCY
ENVIRONMENTAL RESEARCH LAB - CORVALLIS
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USEFUL TABLES AND EQUIVALENTS

From the National Institute of Standards (NIST)

TABLE 1: SI units

Factor	Name	Symbol
10^9	giga	G
10^{-1}	deci	d
10^6	mega	M
10^{-2}	centi	c
10^3	kilo	k
10^{-3}	milli	m
10^2	hecto	h
10^{-6}	micro	µ
10^1	deka	da
10^{-9}	nano	n

TABLE 2: Temperature Conversions

Convert From	To	Compute
˚C	˚F	˚F = (˚C * 9/5) - 32
˚F	˚C	˚C = (˚F * 5/9) + 32

TABLE 3: Hardness conversion

Hardness designation	onversion to mg/L
Grains per gallon (gpg, or “grains” or “grains hardness”)	mg/L = gpg * 17.1

Table 4: SI standard and book reference conversions

	SI standard		Used in manual (UIM)	Conversion (UIM to SI)	English unit	Conversion (UIM to English)
	Name	*Symbol*	*Name (symbol)*		*Name (symbol)*	
Mass	kilogram	kg	milligram (mg)	1 mg = 10^{-6} kg	ounce (oz)	1 mg = 0.035 * oz
					pound (lb) (16 ounces)	1 mg = 2.2^{-3} lb (1 kg = 2.2 lb)
Length	meter	m	centimeter (cm)	1 cm = 10^{-3} m	inch (in)	1 cm = 0.4 in
Volume	meter^3	m^3	Liter (L)	1L = 1 dm^3 = 10^{-3} m^3	fluid ounce (fl oz)	1 L = 0.3-5 fl oz (1 ml = 0.03 fl oz)
					quart (qt) (32 fl oz)	1 L = 1.06 qt
Mass density		kg/m^3	mg/L	1 mg/L = 10^{-3} kg/m^3	parts per million (ppm)	1 mg/L = 1 ppm
Amount	mole*	mol	*Not referenced in manual; given for purposes of definition*			
Concentration		mol/m^3	mg/L	Depends on molecular weight (mol wt): mg/L = (g/mol wt) / m^3		

**1 mole of a substance is 6.02 * 10^{23} molecules of that substance. The mass of a mole of a certain molecule is referred to as its molecular weight. The different chemicals mentioned are often given “as $CaCO_3$ (calcium carbonate)”, which has a molecular weight of 100.01 g/mol. This means that the value given is calculated with a molecular weight of 100.01 regardless of the composition of those chemicals in solid form.*

TABLE 5: SCAA water quality standards

Water Quality Parameter	Superior Brew	Adequate Brew
Odor	Clean/Fresh	Clean/Fresh
Color	Clear	Clear
Chlorine	0 mg/L	0 mg/L
TDS	150 mg/L	75-250 mg/L
Calcium Hardness	3 to 4 grains or 51 mg/L to 68 mg/L	1-5 grains or 17 mg/L to 85 mg/L
Total Alkalinity	At or near 40 mg/L	10-100 mg/L
pH	7 to 8 pH	6.5 to 7.5 pH
Sodium	10 mg/L	Less than 30 mg/L

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