Water and energy are twins. In many parts of the world, supplies are decreasing as demands are increasing. Wise management — starting with education — is the answer to this potential problem.

Water and Trees

By Dr. Alex L. Shigo

Water as snow adds beauty to these beech leaves. As snow melts, the water seeps slowly into the soil and run-off is minimized.

Water, water, everywhere, but only 0.05 percent to drink! Oceans cover 71 percent of the earth's surface, but ocean water is too salty for people and trees. Many plants and a few species of trees do live in salty water. The salty water makes up 97 percent of the earth's water. Of the remaining fresh 3 percent, 75 percent is in ice at the poles. The rest can be used for drinking. However, most of it is inaccessible groundwater. We are back to 0.05 percent available to us from lakes and streams.

We not only drink it; we wash in it, flush it, and use it for irrigation of grass, crops and trees as if it will never run out. In many places in the world, it has run out. As trees were cut the land heated. No clouds formed. No rain fell.

Water, trees and life

Arborists know about water best by its amounts in extremes: too much, too little. Too much brings floods, or when frozen, breakage. Too little brings droughts. Amounts of precipitation are out of human control. Humans do bring on tree problems when they water too much, or forget to water.

Stress is a condition where a system begins to operate near the limits for the way it is designed. Water is an essential for all life systems to survive. When too much or too little water is present, the tree system begins to operate near its limit for survival. Stress. Water-caused stress is a major predisposing factor for a long list of tree problems that could end in death. Root

A Plea for Modern Arboriculture

Years ago I predicted that in the 21st century, arboriculture would begin to split as more arborists moved from old arboriculture toward modern arboriculture. Old arboriculture will not go away. It is, and will be for many years, the dominant force for tree care.

New people are coming on the scenes, and the scenes, or demands of the marketplace, are changing rapidly. Survival of any individual or system depends directly on their ability to adjust to changes. The rate of adjustment defines the winners. Some arborists believe that chemistry is not arboriculture, and that it has no place in arboriculture. A few teachers have told me they do not use my book, *Modern Arboriculture*, because it contains some very simple chemistry, which is not arboriculture. Many teachers do understand chemistry but their schedules do not allow time to teach it. But, what about the arborists who are sick and tired of the same old stuff? They want something new and better. It will take time to bring modem arboriculture into full bloom. A better understanding of tree biology and chemistry is the basis for modem arboriculture. Sad, but biology and chemistry still frighten many people.

Here I give a brief glimpse of water, one of the most essential substances for trees and for all living things. To be an arborist and not have some understanding about water is unthinkable for me. I'm sure some arborists will not read this article. I'm also sure that others will not only read it, but chew it and study it. If you want more of this stuff, I should be pleased to give it. If not, so be it. I respect trees and arborists. I believe they deserve and need something new and better, not the same old stuff.

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Water is held in clay soils. This can be very beneficial when in moderate amounts, but when too much water saturates the clay, problems start – usually root rots.

problems are at the top of the list. Insects and fungi are easy to see and they will always be there. Fighting secondary agents of tree problems has become the primary role of many people.

Water as a liquid dissolves many substances essential for the life of trees. Water transports the substances throughout the tree. Water is essential for photosynthesis and its end product, glucose. As bound water, it acts as a storage product. The way water changes from free to bound, and back again, is one the wondrous processes of nature.

What is water?

Water is a substance in which two hydrogen atoms bond in a unique way to one oxygen atom, hence, H_2O. The unique bonding is so spectacular that water takes on fascinating characteristics. It is the only substance on earth that occurs naturally as a liquid, gas or solid.

All water on earth originally came from rocks. As the extremely hot, young earth began to cool, gases such as oxygen and hydrogen escaped from rocks. They collected above the earth, and as some oxygen and hydrogen bonded, the rains came.

Your basic atom

Atom was the name given to the smallest bit of matter. The word means uncuttable. Of course we know now that atoms can be reduced or cut further.

There are 92 naturally occurring kinds of atoms. In elaborate laboratories, scientists have increased that number to 110, as of this writing.

An atom contains at least one central, positively charged body and one circling, negatively charged body. Every atom is unique in that the number of positive charges normally equals the number of negative charges. The positive bodies are protons, and the negative bodies are electrons. The circling nature of the electrons is often referred to as a negative cloud. All atoms except hydrogen have at least one neutron in their nucleus. The neutron has mass, but no charge. The hydrogen atom has one proton and one electron, but no neutron.

If the nucleus of an atom could be enlarged to about the size of a dime, the circling cloud of the electron or electrons would be nearly the size of a football field. Think about it. A half-inch cube of nuclear material would weigh about 10 million tons. The figures lose their meaning because it is difficult for our minds to grasp these facts. In the end, we must remember the energy and matter are concepts, and that they are interchangeable.

More about hydrogen

Hydrogen is the most abundant atom in the universe. Because of its abundance on the sun, there is life on Earth. On the sun, the heat and pressures are so great that hydrogen atoms are fused to form helium atoms. In this fusion process, some matter is converted to enormous amounts of energy. The energy radiates from the sun as light. Chlorophyll in trees and other green plants traps some of the light energy that is ultimately used to form glucose. Carbon dioxide and water are key players in this process. This may be why water is often called the substance of life.

Hydrogen starts the many events that lead to water, energy and life. Hydrogen is a unique atom because it normally does not contain a neutron. To understand the ways of hydrogen's single proton and electron is to understand much about chemistry, life and, here, trees.

The single electron rotates about the proton in a cloud that is commonly called a ring. The single ring of hydrogen could accommodate two electrons. But, if it did, this would unbalance the charges, and this won't happen unless something forces it to. Normally the number of protons equals the numbers of electrons.

Models have been developed for atoms so that discussions about them could be easier. In the models, the first ring could have two electrons, and the second ring eight electrons. Of course the "real" nature of the atoms are replete with exceptions and strange characteristics. However, with water and hydrogen and oxygen, most of the model terms are applicable.

More about oxygen

Oxygen has eight protons and eight neutrons in its nucleus, and eight electrons in two rings. The first ring is saturated with two electrons and the second ring has six. It can hold eight electrons.

We breathe oxygen so it can combine with hydrogen "left over" from our energy-yielding processes. When it does connect or bond with hydrogen, we breathe it out as water vapor. It seems that we just cannot get away from water and life, and in this case, our own life.

Water is also essential for the life of trees, and trees provide arborists with the means of their life and business.

Oxygen is a product of photosynthesis. We say oxygen is given off to the air. In the process of photosynthesis – where carbon dioxide and water are the ingredients – the power for the process comes from the hydrogen in the water. In a sense, water is split, or to be even more precise, the protons and electrons of the hydrogen atoms are separated. After many chemical processes, oxygen is released.

Oxygen becomes very essential in respiration. In this process, the energy stored in glucose is released to do the work of life. The products of respiration are carbon dioxide and water. Back to water again.

The processes of photosynthesis start with carbon dioxide and water, and, in the end, the processes of respiration end with the release of carbon dioxide and water. In all of this, the power of the sun is used to make life on Earth possible. Oxygen, carbon dioxide and water are the actors. They start and they finish still being the same actors ready to act again and again for continued new life.

Now if all of this does not "grab you" then there is no hope!

Bonding patterns

Atoms bond with other atoms to form dogs, cats, humans and trees. All life forms are made up of atoms bonded in unique ways, often in the form of electrically neutral molecules.

The strongest bonds are called covalent. With these bonds, two or more atoms share electron fields by actually penetrating one another's fields. The next level of bonding is called ionic. Each atom or group of atoms here has a positive or negative charge. Such atoms or groups are called ions. Because unlike charges attract, ions of unlike charges bond, but do not penetrate each other's electron field. We commonly call many of these ion combinations "salts." Common table salt is really a crystal made up of sodium ions bonded to chloride ions. Table salt is not a molecule. When the crystals are poured into water, the ionic bonds separate. The same processes operate for commonly used fertilizers. They are salts. In water, their bonds are released.

In the third type of bonding, the atoms or groups come fairly close together, but do not touch. This bonding pattern is the weakest, yet this pattern is the major one that holds you and trees together. On a relative numerical basis, consider the holding power of these bonds to be about two or three; on the same scale, the covalent holding power between two nitrogen atoms in the air is about 190.

Yes, life forms are held together by these relatively weak bonding forces. If this were not so, processes of breakdown and buildup would not work. No recycling. No new life.

This third type of bonding brings us back to water, and its ingredients – oxygen and hydrogen. The third type of weak bonding is called hydrogen bonding. Because it is so important, some additional details should be given.

Hydrogen bonds

Hydrogen bonds are the unique features of water. In summary, oxygen has two positions for additional electrons in its second ring. Hydrogen has one electron in its single ring, but the ring can accommodate two electrons.

Two hydrogen atoms bond with a single oxygen atom to form a molecule called water. Each hydrogen atom bonds on the second ring of the oxygen atom where there is a place for them. When the hydrogen atoms bond with the oxygen atom, a strange partnership takes place. Each hydrogen atom now has two electrons in its ring and the oxygen atom has electrons filling the two available positions on its second ring. Add to this the fact that the hydrogen atoms and the oxygen atom now have their rings saturated, yet the positive and negative charges of the molecule are balanced! What a process!

There is much more to this story of water. Oxygen "accepts" the electrons of the hydrogen atoms, but it pulls most of their electron clouds deep into its atom. Another way to say this is that the electrons of the hydrogen atoms spend much more time deep inside the oxygen atom's ring than they do rotating about the protons in the hydrogen atoms.

The hydrogen protons as a result are near the outer edge of their ring, with very little electron negative charge about them. The protons, being positive, exert their charges out from their position on their rings.

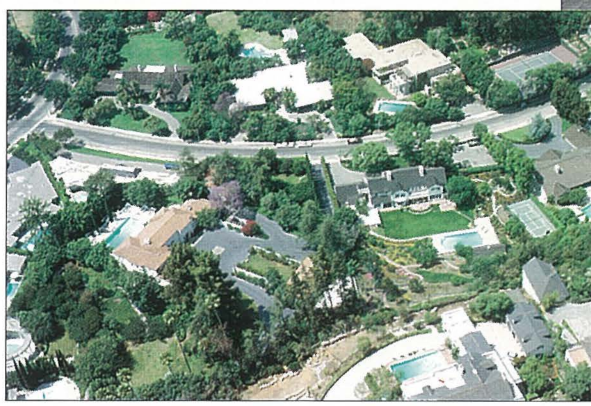
And, because the oxygen has absorbed most of the negative charges of the electrons of the hydrogen atoms, the side opposite the hydrogen atoms becomes weakly negative. So now one part of the water molecule has two weak positive points and the opposite side two weak negative points. Such a molecule is called a dipole. Water is a dipole.

Here is another way to view the water molecule. Imagine oxygen as a large clear ball. Now, mark four points on the ball all equidistant from each other. Make two points red and two green. Next, move the green points slightly away from each other, and move the red points slightly toward each other the same distance that you moved the green points. The two green points have weak negative charges, and the two red points have weak positive charges. The red points are positions where the hydrogen atoms are bonded to the oxygen. The exact points of red are the positions where the protons reside and are producing the weak positive charges. If you can imagine this three-dimensional model of water in your mind, many fascinating characteristics of water become easy to explain and understand.

Cohesive water

Water forms drops as it rains and falls on leaves and needles. If water is poured on a smooth glass surface, mounds will form. If you pour alcohol on the same surface, no mounds will form. Why? The answer: water has an abundance of hydrogen bonds; alcohol does not.

Water and trees were both at the Khyber Pass many years ago, I have been told. Now, neither are present. The question is, what part did the removal of the trees play in this problem?



Water is used in abundance to maintain lawns, gardens and trees in some of the driest parts of the world.

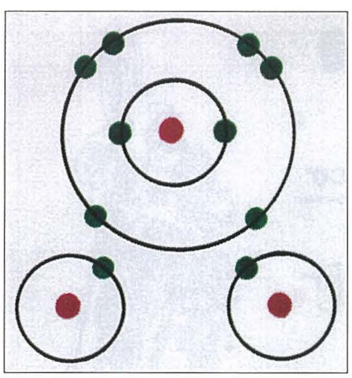


Figure 1: Oxygen, above, has eight electrons in two rings, and eight protons and eight neutrons in its nucleus. Shown here are two-dimensional diagrams for three-dimensional atoms and molecules. All diagrams are from models and the nucleus and electrons are greatly enlarged. (Red = Positive; Green = Negative) The hydrogen atoms, below, each has a single proton and single electron in one ring.

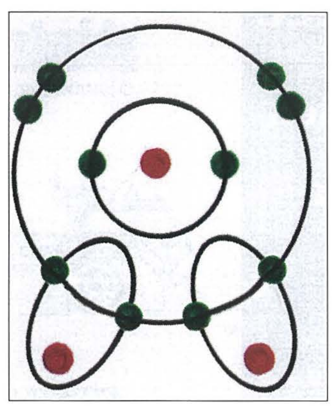


Figure 2: Water forms when two hydrogen atoms bond with an oxygen atom. Weak positive charges extend from the protons in each hydrogen atom, and two weak negative charges extend from the opposite side of the molecules.

Back to our ball model. You can bond one water molecule with another molecule, or even bond four molecules with one molecule. However, you cannot have one water molecule bond its two positive sites with the two negative sites on another water molecule. Remember, the red dots are closer together than the green dots. You cannot fit two red dots over two green dots. Back again to four on one. It is possible for four molecules of water to align themselves in such a way that they bond one of their dots with a dot of a different color on the ball. As each molecule moves into position where its positive site bonds with a negative site of another molecule, an active dance goes on. If you can imagine it, every water molecule is "trying" to bond with another. The problem starts for the molecules when bonding partners position their other sites too close to similarly charged sites on the molecules. Remember, unlike charges do attract, but like charges repel. And, because the hydrogen bonds are such weak bonds, it does not take much to knock them apart. So, the wild dance goes on as molecules vie for positions only to be knocked out of place again and again.

The significance of this process for life and for trees specifically cannot be overrated. Cohesion makes it possible for water to cling within vessels and tracheids. The cohesive feature gives us raindrops and water as a liquid at temperatures below 100 degrees Celsius. Many liquids, alcohol included, form few hydrogen bonds. Ammonia, which weighs the same as water on a chemical scale, is a gas at normal temperatures—again because its molecules do not bond together as water molecules do.

Water from liquid to ice

As long as the dance goes on, liquid water exists. As temperatures begin to decrease, the pace of the dance decreases until, at 4 degrees Celsius, everyone gets a last chance to pick a bonding site. Because many of the molecules that would normally be in the middle of the group now move to outer positions to find a bonding partner, the volume or space occupied by the dancers increases. We say that as water's temperature drops near 4 degrees Celsius, expansion takes place. As water expands, bottles or even large rocks can be broken. The power of expanding water has been used by humans down through history. As a result of further cooling, the dance stops, as every molecule has a position. We call this state ice. Because ice is less dense than an equal volume of water, it floats – all because of hydrogen bonds. Some people have said that hydrogen bonds (icebergs) caused the sinking of the Titantic. Yes, water can be good, and it can be bad!

Bound Water

How do trees stay alive in areas of the world where winter temperatures are far below freezing? How do trees store water?

Every arborist needs to know something about those two questions, mainly because many of the major cities of the world are in areas where winters are cold. The simple answer again is hydrogen bonds. Let me explain.

Trees are made up mostly of cellulose. Cellulose is made up mostly of glucose units bonded in ways that cause the units to twist as a rope does. Water plays an important role here, but the details go far beyond the scope of this article. Suffice it to say, the removal of a water molecule between two glucose units results in the cellulose pattern. The twisting takes place because the glucose units must be in a very precise position to enable the water molecule's removal. My only point here is that water does play a major role in the formation of cellulose. The free water becomes available then to the tree.

Cellulose has many oxygen and hydrogen units as part of its makeup. In a sense, the oxygen-hydrogen units "stick

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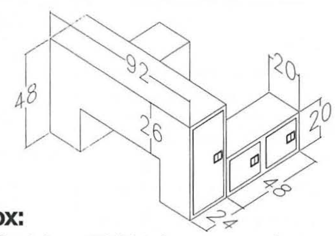
A. General:
1. All G-60 Galvannealed Material (zinc coated, resists rust)
2. All Wiring in Conduit
3. Sealed Lexan Lens Lights Meet FMVSS 108 Specifications
4. Anti-Sail Mud Flaps
5. Hoist with Power Take Off
6. Trailer Light Connector, Six Pole
7. Pintle, Pin, or Pintle/Ball Combination Trailer Hitch with Tow Hooks
8. Bodies: Mounted, Undercoated, Chemically Degreased, Coal Tar Epoxy Coating inside Chip Box, Primed and Painted
9. Stainless Steel Hinge Pins with Grease Zerks
10. Weatherproofed Tool Boxes
11. Chipper Air Exhaust Vents

B. Overall Body Dimensions:
Length: 168”
Height: 72” (Inside)
Width: 92”

C. Chip Box Material: (Galvannealed)
1. Floor: 10-ga. plate
2. Sides & Front: 12-ga. plate
3. Top: 14-ga. plate
4. Tailgate: 12-ga. plate with tubing frame (270° swing)
5. Runners: 8” structural channel
6. Cross Members: 3” structural channel
7. Rear Vertical Support: formed 1/4” plate
8. Rear Horizontal Support: 4” x 4” x 1/4” square tubing

D. Tool Boxes: (14-ga. Galvannealed)
1. **Underbody Tool Boxes:**
   (two) 48” long x 20” high x 20” deep



2. **“L” Cross Box:**
   24” long x 92” wide x 26” high across chassis rails
   Door: 24” long x 48” high; six rope hooks, stationary shelf and water cooler holder
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E. Optional
1. **Tool boxes and Step-Type Rear Bumper**
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out" from the glucose – now cellulose – molecule. Because each oxygen has a weak negative charge, the site could be a potential bonding site for a positive charge from a hydrogen atom that is part of water. The story continues with the same theme. As liquid water comes in contact with cellulose, some of the positive sites on the water molecule bond with the negative sites on the oxygen atoms that are part of the cellulose. A hydrogen bond again. As more liquid water comes into the same area, the water begins to bond with other water molecules as it normally does. Remember: Cellulose – especially cellulose in the middle layer of the second wall of fibers – is made up of many "ropes" of cellulose with some spaces in between. The water molecules with their hydrogen bonds soon start filling all the empty spaces. As the molecules of water squeeze into every available space, spaces soon become saturated. This point is called the fiber saturation point of wood, which is the point where all available spaces are taken by water.

This is usually the normal healthy condition of trees. When this condition exists, pathogens usually are not able to invade. So, water plays a major role as a preventative against many pathogens.

When water is bonded to the cellulose, the water is called bound water. Because it is bonded to the cellulose, it does not freeze as liquid water does. Remember, the bonding power of the hydrogen bond is very weak. It takes little to pull it apart. The bound water not only prevents freezing and acts to prevent pathogens from invading; the bound water also is a unique way for trees to store water.

Water in its solid form (ice) is a major cause of tree fractures.

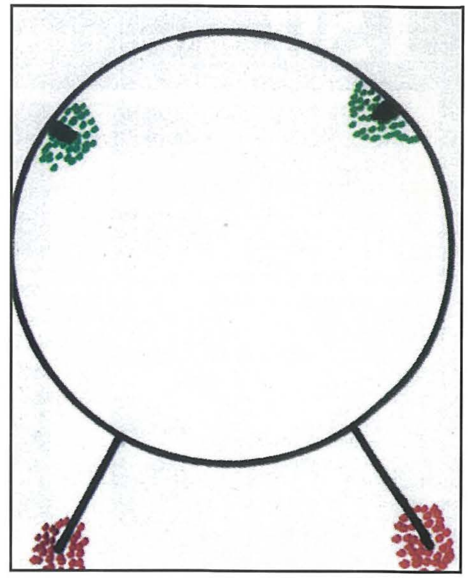

Figure 3: A two-dimensional diagrammatic view shows the negative (green) and positive (red) charges on the water molecule. The negatively charged sites are farther apart than the positively charged sites.

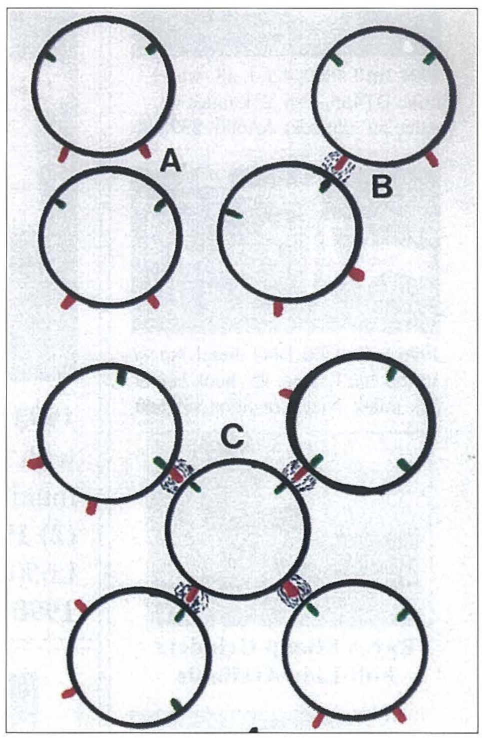

Figure 4:

A: The diagrams of two water molecules show that the two negative and the two positive sites do not align for bonding.

B: One water molecule can bond with another water molecule when opposite charges are in direct alignment.

C: It is possible to have four water molecules bond with one other water molecule when all oppositely charged sites are in direct alignment. When such bonding arrangements bring like charges too close together, the molecules move apart, but only to bond again at different sites. This repositioning of molecules is responsible for water as a liquid.

From flush to free water

Trees store water as bound water and energy in starch and oils. When the flush for new growth starts, some of the stored starch in living parenchyma cells in wood and behind buds is converted back to glucose. Water plays a role here also, because to go from insoluble starch to glucose, a molecule of water must be chemically inserted back into each starch unit. As this process goes on, the glucose dissolves back into the free water. The glucose in the free water brings on a pull force that easily dislodges more stored bound water. In fact, this process triggers the entire process of liquid transport in trees. It starts the pumps. But, that's another story about water.

Dr. Alex L. Shigo is the owner of Shigo & Trees, Associates in Durham, N.H. Special thanks to Dr. Charles Owens, professor of chemistry, for review of this paper and continuing advice on chemistry. TCI