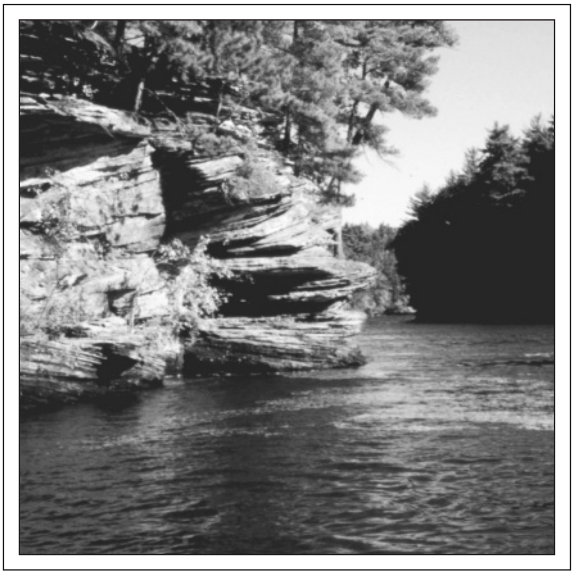

2

A Water Science Primer

Randy Hunt

The water must be confused by so much advice.
Aldo Leopold, *A Sand County Almanac*

When drinking water, think of its source.
Chinese proverb

Liquid water is what makes our planet unique and is essential for life as we know it. Ancient civilizations were located on the banks of rivers or near seacoasts. Civilizations flourished with adequate water supplies, and then crumbled when water supplies failed. Water itself is an amazing molecule. Known as a universal solvent for its ability to dissolve many solids, it exists in three different forms—ice, liquid, and vapor—at temperatures experienced by life on Earth. Aquatic life in Wisconsin would be very different if water did not have one unique property: its solid form (ice) is less dense than the liquid from which it forms. As a result, ice floats and protects the underlying water from the cold atmosphere above. If this were not the case, our lakes would freeze from the bottom up and everything living within the lake would be entombed in ice every time the temperature fell below 32°F.

Water science is vital to our understanding of this resource. Water has been studied for centuries, with the first measurements of precipitation recorded around 2,500 years ago. The first aquaduct and canal projects date back to the ancient Egyptians, about 5,000-5,500 years ago (Dingman 2002). But water was often mysterious to the ancients. During the time of Plato and Aristotle there was much debate on where the water in the rivers comes from (Deming 2002). Now we know that there is a global water cycle in which water evaporates from the oceans, falls to the earth as snow and rain, moves back through our aquifers (the upper parts of the Earth that hold and transport water) and rivers, and returns to the atmosphere and oceans.

While much has been learned that is useful for understanding the waters of Wisconsin, common myths and misunderstandings about water persist. The purpose of this article is to review the basic principles that govern water and to provide perspective on both the science and myths surrounding this all-important resource.

The Four Misconceptions Regarding Wisconsin's Waters

A great Wisconsin naturalist, James Hall Zimmerman ("Jim Zim" to his students), distilled observations from his four decades in the field into four misconceptions about our wetlands. These myths apply equally well, however, to all of Wisconsin's aquatic systems.

Misconception #1: ***"All Wisconsin's Waters Are Alike"***

For practical purposes, we group our waters into just a few categories. For example, regulatory activities often assume that all waters of a given type are similar. In reality, the sources of water, and the associated vulnerability of an individual lake, river, wetland, or aquifer, differ greatly. For example, there are over one hundred types of wetlands in the United States, and fourteen wetland types in Wisconsin alone. Some are fed primarily by rain (bogs); some have significant groundwater sources (fens). Some have important stream inputs (floodplain forests); others do not (low prairie wetlands). Lakes, streams, and aquifers also have different conditions as a result of their varied sources of water. Cold-water trout streams are associated with higher groundwater inflows; warm-water streams often are derived from surface-water sources. Deep clear-water lakes often are fed by groundwater. Deep aquifers supply water derived from storage or leakage from overlying rocks, while shallow aquifers supply water derived from precipitation that infiltrates the ground and other water sources (streams, lakes, and wetlands). How any given water resource responds to stress (for example, a nearby pumping well) depends on the sources of water.

Misconception #2: ***"Our Waters Can Stand Alone"***

When one looks at a lake, river, or wetland, one can see that a transition zone separates drier upland areas from water in low areas. Some water bodies even appear to have edges, almost as if they are isolated from the surrounding landscape. In reality, water bodies are connected to the larger landscape through overland flows during snowmelt and heavy rains, and by the less visible groundwater system that underlies the land. Many animals, from macroinvertebrates to frogs to ducks to moose, depend on both water bodies and their associated uplands during different parts of their life cycles. Thus, what happens on the land, even if that land is not directly adjacent to the water body of interest, can still have important effects on the quality of our waters. This connection is why we often hear about the need to protect and manage Wisconsin's waters by watersheds or water basin. This connection is also one of the reasons that wetlands are often called the "kidneys of the landscape." Wetlands take pulse inputs (water, sediments, nutrients, contaminants) from within the basin and either trap or transform the inputs, or release them to the system downstream at a much-reduced rate. Thus, when we lose wetlands in a basin, it is like losing our kidneys—with no access to dialysis!

Misconception #3: ***"Wisconsin's Waters Do Not Change Over Time"***

We might expect that our waters are essentially unchanged since the glaciers receded 10,000 years ago. But this is not the case. Natural erosion and deposition have cut some valleys deeper while slowly filling other lakes and wetlands. Water levels in a lake, stream, or wetland also vary naturally from year to year due to changes in annual precipitation. In some cases these changes are important for animals that use the water. For example, invertebrates, frogs, ducks, and other organisms require a certain range of water levels (and often multiple water bodies) to survive, especially as drought and flood cycles alter the characteristics of a given water body. Human activities have perturbed many of these natural processes. Stormwater systems can "short-circuit" water that would have infiltrated into the ground and discharged to nearby streams, lakes, and wetlands. Pumping and diversions can lower water tables to the point where springs disappear. Development along lakes and rivers can affect the amount of water, sediment, and nutrients that the water receives. Thus, our waters do change, and we have some say in how they will change.

Misconception #4: ***"Our Waters Function the Same Regardless of Impacts"***

We use water in multiple ways, and our engineering technologies allow us to modify natural water flows to do so. What is less well appreciated is that, in diverting, ponding, pumping, and using water, we affect the functions of our natural system. One cannot expect a wetland to support rare and endangered species if its sources of water are significantly changed by stormwater addition or nearby high-capacity pumping. The water quality of a deep clearwater lake will change in response to added nutrients from failing septic systems. Trout streams cannot support trout if the groundwater supply is limited by pavement and storm sewer interception in the basin, or if sediments from improper land management cover the gravel spawning beds. Although the loss of function in water systems due to a given stress is often poorly understood, we should expect to see impacts from that loss.

Six Scientific Misunderstandings

These four misconceptions go hand in hand with *scientific* misunderstandings about Wisconsin's waters. Our discussions about the future of our waters will be most productive if we free ourselves of these misleading notions.

Misunderstanding #1: *"We Have All the Water We Could Ever Need"*

From space one can see that the majority of the Earth's surface is covered by water. The volume of water on the Earth is estimated to be about 330 million cubic miles—enough to cover the entire Earth's surface to a depth of 1.5 miles (Schlesinger 1991)! But, as might be expected, not all of the water is suitable for human consumption. The breakdown of the Earth's water supply is as follows:

Saline water in oceans	97.20 %
Ice caps and glaciers	2.14 %
Groundwater	0.61 %
Surface water	0.009 %
Soil moisture	0.005 %
Atmosphere	0.001 %

(Fetter 2001)

Of these, usually only groundwater and surface water are considered suitable for human consumption. Even though the global percentage of these waters is low, they still comprise a large quantity of water.

In Wisconsin we receive about 31 inches of precipitation a year—some 29 *trillion* gallons of water—falling as snow and rain (WDNR 1999). So why do we hear about possible water shortages in our water-rich state? Most of this water (around 75%) is transferred back to the atmosphere by evaporation and plant transpiration before it makes it to groundwater or surface water (WDNR 1999). A significant amount of this water does eventually make it to groundwater and surface water bodies, but the issue of availability is more subtle: water supply problems are typically not *statewide* problems but rather *local* supply problems. That is, the flow of water in the natural system cannot in some cases keep up with the local demands placed upon it; our ability locally to extract water exceeds the natural replenishment. And water cannot easily be transported around the state to meet shortages. So although we do have an ample amount of water in our state, we can still experience water shortages locally.

Water supplies must also be understood in the context of current and future water use. Human beings require less than a gallon per day to live. Our personal water usage in Wisconsin is greater than this basic requirement, about 63 gallons per day for each person (WDNR 1999). If energy, industrial, and agricultural uses are factored in, our per capita usage approaches 260 gallons per day (Fetter 2001). When all this water use is added up, Wisconsinites use 1.45 *billion* gallons of water each day (WDNR 1999). What do such large numbers mean? To give just one example, about 1,400 gallons of water are required to produce one fast-food meal of a quarter-pound hamburger, fries, and soda (WDNR 1999). More positively, the demand for water has stabilized in recent years. Although water use increased continually until around 1980, since then national demand has been stable due primarily to water conservation measures, including low-flow plumbing fixtures and power plant water recycling (Wood 1999). With recognition of water's multiple uses and the demands of an increasing population, water quantity issues will likely continue to be a topic of debate in the future.

Misunderstanding #2: *"Water Doesn't Move"*

Water moving in a river or stream is easy to see. It is less obvious that all water—including lake water and groundwater—moves. This movement follows from the well-established scientific principle that water moves from high to low energy. In Wisconsin, groundwater generally moves from higher areas in the landscape toward lower areas containing streams, rivers, and lakes, or toward low areas created by pumping. Surface waters flow "downhill" (downstream) unless captured by a municipal or irrigation water intake.

While all water moves, it does not all move at the same rate. Whereas water in a stream can move at speeds of a foot or more per second, a speed of a foot *per day* is considered fast for groundwater flow. In fact, some shallow groundwater in the red clay areas of northern Wisconsin has been there since the time of the glaciers—10,000 years ago (Bradbury et al. 1985)! This suggests an important point about Wisconsin's waters: the rate of natural replenishment, and associated vulnerability, is different for different water resources. Our water has a "memory" of the past, and will remember what we do in the future. A stream may "remember" a chemical spill for a week to a month, a lake might remember a spill for a year to tens of years, but a groundwater system might remember a spill for hundreds to thousands of years. Thus, water is not a nonrenewable resource like oil and gas, but neither is it a completely renewable resource like solar energy (Alley et al. 1999). Slow rates of groundwater replenishment also have real-world consequences. For example, groundwater carries into central Wisconsin streams nitrates that were likely applied as fertilizer in the basin decades ago (Kraft 2002). Best management practices involving nitrate application in the basin today are not expected to be evident in the stream for years to come.

Misunderstanding #3: "Our Water Comes from Canadian Underground Rivers"

One of Wisconsin's great natural scientists, T. C. Chamberlin of the University of Wisconsin, stated in 1883 that "the idea that there are vast subterranean channels or caverns in which artesian water flow like a river has been long since abandoned. These are matters of common scientific knowledge" (Chamberlin 1883). However, this misunderstanding is surprisingly resilient. In fact, most of the groundwater we use does not come from "underground rivers" or distant sources, but from areas close to the wells that pump it. The importance of local effects also holds true for surface water; that is, the quality of surface-water supplies is controlled by the quality of the surface-water body from which it is pumped. Thus, what we do on our land determines the quality of our water.

Misunderstanding #4: *"Surface Water Can Be Treated Separately from Groundwater"*

Discussion and management of water is commonly separated into groundwater and surface-water components. In reality, however, nearly all surface-water features interact with the groundwater system. Groundwater and surface water do not exist as separate components, but form a continuum in our landscape extending from areas where the water is below the ground to areas where the water is above the ground. Water is thus linked across time and space. Most surface water can be thought of as a visible expression of the groundwater system; conversely, much of the groundwater system can be thought of as a hidden supply for the surface-water system. Due to this interconnection, any discussion about water must include both the groundwater and surface-water components.

Misunderstanding #5: *"Water Can Be Used without Any Effect"*

A basic principle of water science is that water cannot be created or destroyed; water flowing into a system must either flow out of the system or be stored within the system (as represented by an increase in water levels). This system response is like a household financial budget. A household budget has given inflow (i.e., salary and interest) and outflow (mortgage, groceries, car payment, etc.). The differences between inflow and outflow are made up by changes in the bank account balance. Similarly, a lake or aquifer has a *water* budget consisting of a set of inflows (precipitation, groundwater flow, inflowing stream water) and outflows (evaporation, plant transpiration, water flowing out to the groundwater system or through a stream). Any imbalance is offset by a change in lake or aquifer storage, as indicated by changes in lake or aquifer water levels.

The upshot of this principle is that there is no "unused" water; all water is used by something or someone. Actions that remove, redistribute, or transform water affect the natural system—that is, decreasing the amount of water normally flowing to a lake will result in less water in the lake and lower lake levels. A dam holding back water to generate energy changes the natural ebb and flow of the river, which in turn affects all the plants and animals that depend on that natural cycle. Removing water from a groundwater system in an area that supplies water to a spring will reduce spring flows.

So why doesn't every water-use activity result in substantial degradation of our waters? There are two reasons. First, the magnitude of the stress may be so much smaller than the natural supply or variation that there is no noticeable effect on the natural system. Second, the stress may cause reconfiguration in the water flow such that it "steals" water from other sources in the system. For example, municipal and industrial pumping in Dane County over the last fifty years has lowered groundwater levels, but these declines are not as large as those measured elsewhere in the state. This is because pumping has captured groundwater that formerly flowed into Lake Mendota and surrounding streams (Hunt et al. 2001).

The ability of natural groundwater and surface-water systems to redistribute water illustrates a common misconception regarding the concept of a water budget. Indeed, water science has tried during different times in its history to address what has been called the "water budget myth" (Alley et al. 1999). The misconception is that the amount of water available for use by people is equal to the amount of replenishment over a given area. For example, one may hear that, because the rate at which precipitation enters the groundwater system is ten inches per year over a countywide area, our pumping can be equivalent to ten inches per year from that county's groundwater without ill effect. However, natural hydrologic systems are dynamic and interconnected. They respond to pumping by reducing the amount of water available for rivers, streams, springs, lakes, and wetlands, taking water from other sources (either inside or outside of the basin), and taking the water out of the system storage. None of these effects can be directly calculated by a predevelopment water budget. In order to assess the effects of water withdrawals, a more holistic view of the water system—groundwater and surface water—is needed.

Misunderstanding #6: *"The Past Can Predict the Future"*

In the past, we could stress our aquatic systems without seeing a noticeable change in the quality of the water resource. But *cumulative* effects, such as the same stress applied later in time to an already stressed system, can have a much larger impact. Imagine a boxer who can take a punch in round 1 and still be standing, but when hit with the same punch in round 15 is knocked out. The cumulative effect of all the previous punches reduces the resiliency of the boxer.

Watershed resiliency is similar in that watersheds respond differently to changes in the amount of lake and wetland area, depending on how much they have to lose. One Wisconsin study suggests a 10% reduction in lake and wetland area results in about 10% greater flood flows and erosion when the watershed starts out with 40% lake and wetland area. That same 10% reduction results in flood flows and erosion increasing by 250% to 500% when the watershed started out with only 10% of its area containing lake and wetlands (Novitzki 1982). Thus, a system's response to stress depends on the original condition of the system. These effects are cumulative, and how systems responded to the stresses of our ancestors may not give us a good indication of how they will respond as we and our descendants stress them.

We also know that some disturbances, such as the introduction of exotic species, cause major effects immediately (Turner et al. 2003). Invasive species can change the character of aquatic ecosystems, as well as their suitability for recreation or drinking water (Carpenter 2003). The past is not always a good indicator of the future when it comes to exotic species, because we often have no frame of reference to understand how the system might respond to the invasion. In many cases, the introduction of non-native or "exotic" species was unintentional; the organisms hitched a ride in the ballast of ships (zebra mussel and lamprey) or hid in imported products (Asian longhorned beetle) (USFS 2003). Other times, exotic species were purposefully released with the thought that they would improve our waters.

Often, however, these "improvements" to the natural system have had the opposite effect. Carp, for example, were added to our lakes in the late 1800s but are now considered an undesirable rough fish, affecting lake water quality by uprooting aquatic plants and stirring up the sediments. In the 1930s, aggressive strains of European reed canary grass were planted for pastures and for streambank erosion control. Reed canary grass has since spread widely into our native sedge meadows and marshes and now dominates over 100,000 acres of Wisconsin wetlands at the expense of native vegetation (Maurer et al. 2002). Purple loosestrife was planted as a garden flower but escaped to overtake many of our wetter wetlands. Rusty crayfish was introduced as a fish bait and has become a problem species in many of our lakes. When it comes to exotic species, the past does not always give us a clear view of the future. It is clear, however, that the campaign to halt the spread of these invasive species will consume much of our energies in the future. That campaign may ultimately decide the state of the waters of Wisconsin that we leave for future generations.

Over many decades, water science has helped to dispel these misconceptions and misunderstandings about water. A scientific framework helps to define what is achievable and provides a firm foundation from which to examine the past, present, and future of the waters of Wisconsin. Of course, this discussion will entail more than just science. Indeed, as Loren Eisley once noted in *The Immense Journey*:

"If there is magic in this world it is to be found in water."

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