INTRODUCTION

Many years ago, in an alpine meadow high in the Montana Rockies, I kneeled beside a creek to take a drink. The creek was fed by snowpack in a pass above me and flowed with water so clear that every pebble on the bottom showed with the kind of magnified clarity you expect to see only with fine optical equipment. I leaned over to drink and was startled when my face plunged into icy water. The water was transparent as air, hardly more than a disorganized shimmering of light and shadow, and I could not see where atmosphere ended and water began until I crashed the boundary. It was the clearest stream I had ever seen, and the sweetest tasting. I drank my fill, then lifted water by the handful and watched it run through my fingers. It was like coming face to face with the origin of the word *purity*.

This book was written with that stream in mind.

Earth is a water planet—about 70 percent covered with it. We inhabit islands of rock and soil surrounded in all directions by water. It permeates the ground, the atmosphere, and every living thing. We humans are mobile reservoirs of it, carrying it everywhere we go. We never seem to get enough of it. When we vacation we travel almost automatically to oceans, lakes, and rivers. For recreation we swim, fish, raft, canoe, sail, surf, ski, or scuba dive. We relax by taking hot baths or showers. When we need time to reflect and replenish, we prefer to go to places where we can watch waves or current or falls.

Yet, in spite of water's central role in our lives, we have treated it poorly. For most of the history of civilization we have dumped our wastes into the nearest water, leaving our fouled trails behind. In these relatively enlightened times we like to think we're too smart to urinate in the well, but the evidence doesn't support it. We still contaminate with waste, still deplete rivers and aquifers to over-irrigate our crops, still flush fertilizers and pesticides into every waterway. As of 2014, more than a billion people lack access to safe drinking water, and every day six thousand children die of waterborne illnesses. It's clear that our water resources will continue to be tested. And it's increasingly crucial to remember how fragile those resources are and how much they need to be protected and conserved.

For about half of every year I can step outside my house and see water in its solid, liquid, and gaseous forms. That it can be found in all three forms at once so impressed the Greek philosopher Thales that he decided water was the fundamental element of the universe, more essential than fire, air, or earth. All matter, he argued, must be composed of water because anything that was not made of it was born in it or changed by it.

We sense something of Thales's esteem when we see in a single day—sometimes in a single glance—a stream, a field of snow, a frozen lake, dripping icicles, a sky obscured with clouds. If we live in a place where water is abundant, it's possible to see it in all its forms and begin to take it for granted. But we do so at our peril.

It's my hope that this book will serve as a reminder that water is a wonder -- the most wonderful substance on earth -- and that it is absolutely essential to the survival of all living things.

Chapter 1

THE CYCLE OF WATERS

I was hiking across snow-covered meadows in January when I found a stretch of East Creek I had never seen in winter. It was small, three or four feet wide, and made even smaller where snow had drifted beyond the banks and built canopies over the water. The effect was startling, the structure so fragile I hesitated to approach. Water flowed somewhere beneath the snow—I could hear it, like a stream in a grotto—but I had to lean out carefully from the bank before I could see that the creek was clear and quick, with a bottom of bright gravel.

Near the water, a line of tiny icicles clung to the snow like drops frozen to the beard of an arctic explorer. As I watched, a drop formed, paused for a moment on its tip of ice, then fell into the creek. I imagined the molecules within that drop unfurling and drifting downstream and joining the Boardman River, then flowing through riffles and pools and impoundments to West Bay. From the bay they would drift north up Lake Michigan to the Straits of Mackinac, pass beneath the bridge, then make slow progress south the length of Lake Huron. They would enter the St. Clair River and pass through

Lake St. Clair to the Detroit River, then cross shallow Lake Erie to the Niagara River. They would become airborne at Niagara Falls, settle as mist in the rapids below, and tumble downstream to Lake Ontario. They would drift eastward to the outlet of the lake, downstream past the Thousand Islands, and into the broad St. Lawrence, passing Ogdensburg and Trois-Riviéres and Québec City until finally they merged with salt where all river journeys end. I focused again on the creek, bewitched by water, pleased with the tidiness of its complete world. Then something cool and wet touched my cheek and I looked up: snowflakes.

It is easy to forget that snowflakes and creeks are links in a hydrologic system that circulates water constantly between the earth and the sky. It is a system without beginning or end, a true cycle, and it is complex, covering many possible paths. The system is so extensive that it is proper to label its domain the *hydrosphere*, a watery realm that extends from a dozen miles above the ground to a few thousand feet beneath it and includes all the water in rivulets and rivers, in icicles and polar ice fields, in clouds and desert springs and oceans.

At any moment, a little more than 97 percent of the 326 million cubic miles of water in the hydrosphere is contained in the oceans. The remaining 3 percent is fresh water, about three-quarters of which is locked up in glaciers and ice sheets at the poles. Most of the rest of the freshwater supply is in the ground. Only about 0.036 percent of the earth's water is contained in lakes and rivers, and a much smaller amount—about 0.001 percent—is in the form of vapor in the atmosphere. If all the water vapor were to condense at once and fall as rain it would flood the surface of the planet with about one inch of water. In contrast, if the earth were a smooth sphere and all the water in the oceans could be distributed evenly across its surface, it would be covered to a depth of 8,800 feet.

But of course water is not distributed evenly. Abundant in some places, scarce in others, it moves constantly as solid, liquid, and gas through countless channels within the hydrologic cycle. Every day 210 cubic miles of water evaporates into the atmosphere from the oceans, and another 38 cubic miles enters the sky as evaporation from land and inland waters and as transpiration from plants. An equal amount condenses and falls back to earth as precipitation. Most of each day's evaporation and precipitation takes place over the oceans in a simple exchange between sea and sky. When precipitation falls on land or ice, however, there are many possibilities for sidetracks and delays and the cycle becomes more complicated. A molecule of water might drift to the ground in a snow crystal and become enveloped in a glacier that take hundreds of years to creep through a mountain pass to the ocean. It might descend as rain that soaks into the ground and is picked up by the roots of a tree, is carried to leaves high in the crown, and transpires as vapor back into the air. It might fall during a desert rainstorm and run off into a roaring, clay-colored arroyo that for 360 days each year is a gash of dry sand. It might sink into soil and enter an aquifer. It might be swallowed by animals or piped into septic tanks or treatment plants. It might get sealed inside a plastic bottle and placed on a supermarket shelf. Always, regardless of the paths it follows or how harshly it is used, water completes the cycle from ocean to sky to earth and back to ocean.

The period of the cycle varies greatly. On average, a molecule of water spends only nine days as vapor in the atmosphere before condensing as frost or dew or falling as rain, snow, sleet, or hail. When it finds its way into a river (a typical one, with a current speed of about three feet per second) it stays there about two weeks. If it soaks into the first few feet of the ground it remains for as little as two weeks or as long as a year before it evaporates or is absorbed by plants. If it infiltrates deeper and enters the shallow groundwater supply, it will stay there tens or hundreds of years. If it infiltrates farther yet and enters the deep groundwater it won't come to the surface again for thousands of years. It is likely to stay in a large lake for 10 years, the shallows of an ocean for 120 years, and ocean depths for 3,000 years. If it falls on the Antarctic ice cap it will remain there perhaps 10,000 years before riding into the ocean.

Through all its routes, the hydrologic cycle maintains a broad equilibrium. As fast as water runs into the seas, it returns to the sky to journey through the cycle again. Each year the oceans lose enough water through evaporation to reduce their levels by more than four feet. If the oceans were not replenished, in 4,000 years they would be dry, salt-encrusted chasms. But the lost water is always replaced by rain and snow (enough to return about 3.7 feet to the oceans) and the discharge of rivers (enough to return about 0.3 feet). Likewise, though the land surfaces of earth receive enough rain and other precipitation each year to cover the continents with 29 inches of water, the continents are not constantly flooded because about 17 of those inches return quickly to the atmosphere through evaporation and transpiration and the remaining 12 inches infiltrate the ground or are carried away as runoff into rivers.

The problem with such figures is they make the hydrologic system appear more orderly than it is. Local and seasonal variations in rainfall can cause floods or droughts so destructive they make the concept of aquatic equilibrium ludicrous. As climate changes over millennia, the distribution of water changes with it, transforming a lush forest into the Sahara, shrinking an inland sea the size of Lake Michigan into Great Salt Lake. But when water no longer falls on the Sahara, it is because it is falling more heavily elsewhere. All the amounts average out because, strictly speaking, there is no way to take water away or add water to the cycle. Virtually the entire supply circulating through the ground, on the surface, and in the air has been here since the infancy of the earth.

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Wherever we intercept the water cycle, it seems complete. Rain appears to be an isolated phenomenon, the oceans are full and permanent, a snowbound creek is a settled feature of the landscape. It takes a broad view to see the whole system at work.

That broad view is a relatively recent accomplishment. The Greeks and others in ancient times wondered much about the origin of springs and rivers but only flirted with the idea of a water cycle. Those who debated the source of rivers usually divided into two camps. Some took the side of Plato, who argued that water from the ocean was carried to the Underworld by the River Styx, where it was filtered of its salt and divided into small streams that returned to the surface as springs. Others sided with Aristotle, who proposed that fresh water was formed when air and earth combined in caverns deep underground, creating new water that later found its way to the surface.

Later, the Roman philosopher Seneca compared the waters that circulate through the oceans and cavities beneath the land to the closed system of blood that circulates through the veins, arteries, and cavities of the human body. Yet neither Seneca nor most other observers in the Mediterranean region recognized that rain and snow were the source of springs and rivers. Rain was intermittent, after all, and fell in quantities that seemed insufficient to feed mighty rivers like the Nile or the Rhône.

About 100 B.C., the Roman engineer Marcus Vitruvius Pollio proposed a cyclical nature for water that was unique in giving precipitation a role. In a section of his *De architectura* describing techniques for drilling wells, he stated matter-of-factly that the source of groundwater was rain and melted snow that had infiltrated the earth. He also explained that water on the surface is changed to vapor by the sun and rises into the sky to become clouds, which eventually collide with mountains and break open, causing rain to spill out.

Such a revolutionary notion was slow to be accepted. For centuries the popular imagination seems to have been stirred most by Plato's model of water entering the earth through caverns beneath the oceans, where it was filtered of salts before finding its way by mysterious processes to the surface. In the Middle Ages it was thought that the oceans did not overflow because all their excess water drained away into a reservoir at the center of the earth, which became the source of springs, rivers, ocean currents, and tides. Water gushed to the surface the way blood gushed from an open wound, defying gravity because it was powered by heat within the earth, or by magic, or by some undiscovered law of physics. By the seventeenth century, the popular concept of the "living earth" was used to argue that water in the ground was a byproduct of the planet's respiration. To explain the baffling but easily observed fact that groundwater existed far above the surface of the sea, some scholars proposed that the curvature of the earth actually placed the ocean's center of gravity far above the land, so that the emergence of springs at even the highest elevations was caused by nothing more complicated than water seeking its natural level. Even clues in the Bible and other sacred texts were overlooked. The observation in Ecclesiastes that "all the rivers run into the sea; yet the sea is not full; unto the place from whence the rivers come, thither they return again," has rarely been interpreted as natural history.

In an era when most people in western Europe believed that surface water originated from the oceans or was manufactured magically in the center of the planet, Leonardo da Vinci (1452-1519) proposed that clouds, "the begetters of rivers," were part of a worldwide cycle of waters. In his notebooks he wrote:

> You can well imagine that all the time that Tigris and Euphrates have flowed from the summits of the mountains of Armenia, it must be believed that all the water of the ocean has passed many times through these mouths. And do you not believe that the Nile must have sent more water into the sea than at present exists of all the element of water?
> Undoubtedly, yes. And if all this water had fallen away from this body of the earth, this terrestrial machine would long since have been without water. Whence we may conclude that the water goes from the rivers to the sea, and from the sea to the rivers, thus constantly circulating and returning, and that all the sea and the rivers have passed through the mouth of the Nile an infinite number of times.

Like many of Leonardo's insights, this one was so contrary to popular opinion that it made no impact during his lifetime. Not until the middle of the seventeenth century were the first scientific tests of the hydrologic cycle as we know it undertaken. Two French scientists, Pierre Perrault (1608-1680) and Edmé Mariotte (1620-1684), working independently of one another, measured the precipitation that fell within the drainage basin of the Seine River and found that it was more than enough to account for the amount the river discharged into the English Channel. About the same time, British scientist Edmund Halley (1656-1742), who is best known for discovering the comet that bears his name, calculated the amount of water that evaporated from the Mediterranean and concluded that it was approximately equal to the amount that flowed into the sea from its tributaries. Unlike many of the scientific discoveries of the era, those early models of the hydrologic cycle were given approval by the Church because a self-contained system of water could be explained by the Christian doctrine of the Great Divine Order, in which all of nature was created for the use and delight of mankind. What, it was reasoned, could be more delightful and useful than a closed system of constantly renewed water?

People intuited a cycle of water and gave expression to it in their mythologies and legends long before scientists tested, described, and named it. To the early Greeks, the earth was surrounded by Oceanus, a vast and endlessly flowing river that was represented circling the land like a snake with its tail in its mouth. Classical Eastern cultures portrayed most of their sacred waters flowing in circles. The ancient Egyptians saw a river running through the heavens, with the sun and the moon riding the current around the earth every day and night. In many mythologies rivers issue from the earth, the mother who gives birth to generation after generation of living things. The cycle of waters is paralleled with cycles of birth and death, with the cycle of the seasons, the sun and moon, and day and night. All things come and go, then come and go again, and the waters always run.

In the folklore of the Great Lakes region Paul Bunyan organizes a log drive on Round River, a waterway that flows into itself and circles in a continuous loop somewhere in the woods of northern Michigan or Wisconsin. In most versions of the legend, Paul Bunyan leads a crew of lumbermen who cut and stockpile a winter's worth of logs on the banks of the river, then in the spring ride the logs downstream toward Lake Michigan, trusting that a sawmill will be found along the way. After two weeks Bunyan and his companions float past an abandoned camp that looks suspiciously like the one in which they spent the winter. Two weeks later, when they pass the camp again, they realize their log drive can never end.

Such circularity speaks partly of the seasonal aspects of lumbering, a job that must have seemed endless to lumbermen who cut and drove logs year after year in forests most people thought could never be depleted. But the legend also gives voice to the self-contained and cyclical world of nature. To conservationist Aldo Leopold the tale of Round River was a parable for the biosphere—the flow of energy from soil to plant to animal and back to soil—and an argument for a sound conservation ethic. In Leopold's view we are circling in a perpetual stream of land, water, and life, and every part of it is critical to the fertility and health of the whole. Central to that flow of energy and life is the hydrologic cycle.

In "The Round River Drive," a rhymed version of the Paul Bunyan tale written in 1914 by a poet named Douglas Malloch, Round River is located in "section 37" (a fallacious site, since townships consist of 36 sections) in the woods of northern Michigan, "...west of Graylin' 50 miles." It happens that I've lived most of my life in northern Michigan, almost precisely 50 miles west of Grayling. Many of my favorite streams are located there, including the small one I came across that January day when the banks were dripping with icicles. I've explored the region in all seasons and have yet to come across a river that flows in a circle, without source or conclusion. If that is a failure, it is a failure of imagination, not discovery. In the larger context there are no beginnings or endings. Snowflakes fall into creeks that flow into oceans that rise to the sky. Every drop of rain carries a bit of sea. Every river is a round river.