ground water

Historical Note/

Luna B. Leopold—Pioneer Setting the Stage for Modern Hydrology

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> What is not seen is the important water that is out of sight—called ground water because it is in the ground. It is convenient to refer to surface and ground water separately. . .even though they are not different kinds of water. Luna Leopold, *Water—A Primer* (1974)

In 1986, during the first year of graduate school, the lead author was sampling the water from a pitcher pump in front of "The Shack," the setting of the opening essays in Aldo Leopold's renowned book *A Sand County Almanac*. The sampling was part of my Master's work that included quarterly monitoring of water quality on the Leopold Memorial Reserve (LMR) near Baraboo, Wisconsin. The Shack was already a well-known landmark, and it was common to come upon visitors and hikers there. As such, I took no special note of the man who approached me as I was filling sample bottles and asked, as was typical, "What are you doing?"

Every field person has a stock answer for non-scientists, which I gave without much thought. The man immediately saw the connection between the surface waters that were of interest to the LMR and the groundwater I was sampling. He followed up with a series of questions that required me to increase the technical level of each response, to the point that by the end of conversation I was asking questions and scribbling answers furiously into my field notebook. After this exchange, I drove to the LMR's Bradley Study Center and ran into Nina Leopold Bradley, the daughter of Aldo Leopold and co-director of research at the LMR. I mentioned that I had just run into the most fascinating man when sampling at the Shack, and Nina replied "Oh, you must have met my brother Luna." I of course knew the name, and was taken aback that he never mentioned it! But, looking back now it seems fitting that it was there, with his help pumping the groundwater I sampled, that I first met Luna Leopold.

Luna Bergere Leopold (1915–2006), the second child of famed environmental pioneer Aldo Leopold and his wife Estella, is best known for work on the geomorphology of rivers. However, this landmark work can overshadow his interest in and appreciation of all aspects of hydrology. As the book *Water—A Primer* illustrated, a recurring theme resonated throughout Luna's career: the interconnectedness of water, all water. Luna's view of groundwater, and its place in the entire hydrologic system, is the focus of this historical note. We believe that such an interdisciplinary view of groundwater remains essential in connecting groundwater science to contemporary societal concerns such as ecohydrology, adaptive management, ecosystem services, economic tradeoffs, resilience, sustainability, water policy, and water ethics. As such, Luna's thinking over the last half century is vitally important today as the journal *Ground Water* looks ahead to its next half century.

From the earliest steps in his career, Luna Leopold demonstrated a fascination with hydrology, an understanding of basic hydrological connectivity, and an appreciation of the role of science in informing resource management and stewardship. When he was still a teenager, Luna went to work in the field in Coon Valley, Wisconsin, site of the nation's first watershed-scale soil and water conservation project. The project, in western Wisconsin's Driftless Region, was organized under Hugh Hammond Bennett's leadership, through the U.S. Department of Interior's Soil Erosion Service (later the USDA Soil Conservation Service (SCS), now the Natural Resources Conservation Service). Aldo Leopold served as an adviser to the project, and emphasized the need to integrate all aspects of land management—soil and water conservation, wildlife, forestry, agronomy, economics—in reversing the degradation of watershed quality, function, and productivity (Leopold, 1935).

Leopold also contributed two sons to the effort. Luna's older brother Starker focused on incorporating early game management techniques. Luna was assigned

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"The Shack" at the Leopold Memorial Reserve, Baraboo, Wisconsin, in October 1986 (top) and with an ATV mounted hydraulic push rig in April 2001 (bottom). The pitcher pump discussed in the text is located in the left of the pictures (under bucket in bottom photograph.)

(with his father's encouragement) to work on the hydrological aspects of what was then a highly erodible and flood-prone watershed. As Coon Valley's farmers began to adopt new soil and water conservation techniques, and as the young workers of the Civilian Conservation Corps went to work planting trees, fencing off steep slopes, and installing check dams, Luna was at work along the streambanks. There, no doubt, pieces of the watershed puzzle began coming together: enhanced infiltration leads to greater groundwater flow, which moderates stream flow regimes, which reduces the risk and intensity of flood events. For the nation, it was the starting point in a revolutionary new approach to conservation on working landscapes. For the new SCS, it was the testing ground for its critical mission. For Coon Valley's residents, it was the beginning of a startling transformation that would play out in the decades to come: from a flashy stream in a destabilized valley to a groundwater-dominated watershed that can now support thriving trout populations.

For Luna, the experience provided essential early lessons in the role of water in landscapes, and the role of the scientist in public service and in the public arena. Surface water and groundwater in any given place are essentially connected. Landscapes change. Human actions can lead to degradation—and could also promote rehabilitation and restoration. Different disciplines had to come together, and work together, to diagnose and solve environmental problems. The private sector and the public sector (in the form of the government's agencies) could and should come together to realize outcomes that serve the common good.

These early lessons would stay with Luna throughout his career. Late in his life, he recalled, "In 1932, I saw the deep gullies, the degraded hardwoods, the up-and-down cultivation on the hills... Now, after 70 years, Coon Valley is as good an example as we have that proper land management can solve many of the problems of water quality" (Novak, 2002). More personally, Luna's immersion in the waters of Coon Creek would lead him to continuing work with the SCS in the late 1930s, as he completed a degree in civil engineering at the University of Wisconsin in Madison.

Hudson and Cragwall (1996) describe the next stages of Luna's professional development. During World War II, Luna enlisted in the U.S. Army Air Force and joined the Army Weather Service, where he was tasked with predicting weather in the South Pacific in support of the war effort there. During this time he developed his scientific acumen on the job, earning a M.S. degree in physics-meteorology from the University of California in 1944. After the war he worked for the U.S. Bureau of Reclamation in Washington, D.C., then with the private sector Pineapple Research Institute in Hawaii. A chance encounter in Hawaii resulted in an offer to work for the United States Geological Survey (USGS), which Luna accepted. His first duty station was in Los Angeles, in 1949. The next 8 years show him publishing scientific papers, obtaining his Ph.D. degree from Harvard with renowned geomorphologist Kirk Bryan (who was himself affiliated with the USGS Division of

Unsustainable soil erosion that a young Luna would have seen in the Coon Valley, Wisconsin, area at the outset of the restoration work that he performed with his father Aldo Leopold in the 1930s, under the auspices of the Soil Conservation Service. (Photo from http://tucsi.tu.org/Images/ColdwaterFishes/DABT/HistoricErosion_small.jpg.)

Luna Leopold's agency portrait taken during his years at the U.S. Geological Survey. (Photo from U.S. Geological Survey.)

Ground Water), moving to Washington D.C., and being promoted to high-levels of USGS management (in a non-conventional and historically accelerated manner for the USGS). This managerial fast-track culminated with Luna being named to lead all USGS water programs in 1957.

Luna's years at the head of the USGS Water programs (1957–1966) are now viewed as a time of profound change, both within the USGS and throughout the field of hydrology (Hudson and Cragwall, 1996). Indeed, Hudson and Cragwall chose the time of Luna's tenure as head of the USGS water programs as the sole period covered in the official USGS Water Resources Division history, Volume VI, *The Years of Change*. They provide an in-depth and fascinating view of the times in which the journal *Ground Water* began. That story is by necessity greatly condensed here. In 1957, the USGS comprised much of the body of hydrologic knowledge, and institutionally divided the world into separate fields of Surface Water, Ground Water, and Quality of Water. The job classification of "hydrologist" did not exist within the U.S. government. Technical training was *ad hoc* due to the dearth of graduate programs and hydrology courses. Consequently, there were no uniform standards by which to judge academic proficiency. There were no journals devoted to the science of hydrology. By the time Luna stepped down in January 1966 to focus on research, all this had changed.

In 1957, newly minted USGS Chief Hydraulic Engineer Leopold brought with him a conviction that "water on and beneath the Earth's surface and the quality of both were interdependent parts of one water-resources system" (Hudson and Cragwall, 1996). Leopold believed, moreover, that the USGS and the field of hydrology had to change to reflect this reality.

He also recognized that hydrologic research was critical in meeting the needs of water-resource planning. In retrospect, one could see such strong views as a logical outcome of his experiences in Coon Valley working with his father—work that required an integrated and holistic view of land, and one that combined disciplines to research, implement, and disseminate new land management practices. This approach became manifest within the USGS. Luna instituted the most comprehensive restructuring of USGS Water Programs in the history of the agency, an effort that culminated with the combining of the three separate branches of USGS water programs, located in separate offices in most states, into a single office for the state.

To raise the profile of hydrology as a distinct science, the USGS developed and shepherded through a new civil service job classification, "hydrologist." And, on March 21, 1963, Luna Leopold became the first "Chief Hydrologist" of the USGS. In 1967, he became the first hydrologist inducted into the National Academy of Sciences. Luna directed the USGS to assist in developing hydrology-focused undergraduate and graduate degree programs to address the need for more and better hydrologic research. This effort included programs at Iowa State University; Colorado State University; Georgia Institute of Technology; the Universities of Arizona, California, Michigan, Illinois, Wisconsin, and New Mexico; California Institute of Technology; Johns Hopkins University; Harvard University; and Stanford University (Abrams and Simpson, 1996). Thus, the actions of this first USGS Chief Hydrologist were in many ways defining the role of the modern, multifaceted, problem-solving hydrologist for the first time—a role that was needed then, and no less now, to inject hydrologic principles into debates about the future of our rapidly changing world.

Although Luna and the USGS were encouraging universities in this direction, one of the best known programs that directly resulted from this effort came about more serendipitously: the hydrology graduate program at the University of Arizona began with discussions in a bar at the Denver airport (Simpson, 1986). At that bar, waiting for a plane, sat the chair of the University of Arizona geology department along with several USGS personnel, including Luna and Walter Langbein. In the course of the conversation, the USGS men asserted that the country needed "a university program in hydrology that will teach groundwater and surface water as an integrated discipline." The department chair said that he agreed, but that such an undertaking would require help from the USGS. "You got it," Luna replied. A program was outlined then and there on the back of an envelope, a program which included contributions by a number of Luna's USGS colleagues, most notably Herb Skibitzke, John Ferris, Alfonso Wilson, Nick Matalas, Jose da Costa, and Tom Maddock. It is notable that the first groundwater hydrology degree resulting from this airport bar agreement was granted to Jay Lehr, who in turn served as editor of the journal *Ground Water* for 25 years.

Though recognized for his work in river geomorphology, Luna was well aware of groundwater being of critical importance to hydrology. In a comprehensive 1964 article in the journal *Science*, "Ground Water in North America," Harold Thomas of the USGS and Luna laid out themes that still resonate today. As they describe it, groundwater is a national resource abundant enough to cover the United States to a depth of 10s of meters if uniformly distributed. But groundwater is not uniformly

Luna Leopold continued to teach in the field as in this U.S. Fish and Wildlife Service documentary. Note the USGS insignia on his jacket years after he had left the Survey, a symbol of the connection he felt to the agency even after his departure. (Photo from http://stream.fs.fed.us/news/streamnt/apr95/apr95a1.htm.)

Luna Leopold (3rd from left) visiting the USGS Wisconsin Water Science Center in 2002. The combining of USGS efforts involving groundwater, surface water, and water quality into single state offices was one controversial change that Luna instituted during his time as Chief Hydrologist for the USGS. Lead author is in front to the right of Luna.

distributed, nor uniformly potable. They define the term *ground-water conservation*, and state that the groundwater resource is different from other renewable resources due to the inherent characteristics of groundwater systems, whose timescales (from decades to centuries) limit renewability. As a consequence, local pumping can exceed local sources of water, and cause serious problems of resource over-exploitation and depletion. Perhaps most interesting, in retrospect, is the authors' explanation of the potential misuse and overextending of O.E. Meinzer's "safe yield" concept, where "the aggregate of pumping has reached a steady state after inducing all possible recharge and eliminating as much as possible of the natural discharge—in other words, an ultimate condition" (Thomas and Leopold, 1964).

Their discussion of the effects of wells covers the history of well hydraulics, transient and steady-state conditions, and the importance of changing technology (such as high-capacity turbine pumps), as well as the promise of groundwater modeling in addressing the complexity of well interference. Problems of over-pumping—water quality, seawater intrusion, streamflow depletion, and land subsidence—are all described, as well as mitigation approaches such as artificial recharge. The importance of saline and brackish water as a groundwater resource is listed—a topic that is increasingly important again in 2012. They discuss contaminant transport and its potential use as a groundwater tracer, along with attendant observations regarding the use of groundwater systems for disposal of soluble wastes. They highlight the importance of groundwatershed-scale management, and the connection to scientifically based legal frameworks such as water rights. In its breadth, the article covers topics dear to Luna: the importance of conservation; the need for basic and applied research; the interaction between groundwater and all other things of the land, including people. In many ways, it stands as a compact textbook of groundwater issues, published at a time before general groundwater textbooks existed.

Luna's commitment to the role of science in informing public policy would become even more apparent as the dramatic advances in environmental policy began to unfold in the late 1960s and 1970s. While still serving with the USGS, Luna contributed importantly to the evolution of environmental assessment protocol (most notably in developing new methods of analysis to gauge the impacts of a planned airport near Florida's Everglades). Well recognized by then as a leading scientific authority, Luna was dedicated to such public outreach and communications work, even as he found himself involved regularly in contentious policy issues at the intersection of hydrology, conservation, politics, and economics. In 1966, the Time-Life Science Library published the book *Water* (Leopold and Davis 1966). He wrote *Water—A Primer* in the wake of the passage of the Clean Water Act in 1972 (using the pronunciation "primmer" to reflect the intended meaning of the volume as an elementary textbook). These volumes underscored his feeling that policy makers and citizens alike required a broader and stronger foundation of basic hydrologic understanding in order to make sound water resource management decisions.

In 1972, Luna transitioned from the USGS to the University of California-Berkeley's Department of Geology and Geophysics and Department of Landscape Architecture. In this position, Luna carried forward his own wide-ranging research and became an influential teacher and mentor to the next generation of hydrologists. His involvement at the interface of hydrology and public policy never waned. In his own work, Luna carried forward his father's "land ethic," embracing the waters fully as a part of "the land community" and emphasizing our conservation responsibilities.

In an important and hard-hitting 1990 paper, "Ethos, Equity, and the Water Resource," Leopold (1990) wrote: "The proliferation of public agencies dealing with water has led to a disassociation of their policies, their procedures, and their outlook from the operational health of the hydrologic system. Everything one entity does

Research involving groundwater-surface water interaction and its effects on denitrification of Wisconsin River (background) floodwater on the Leopold Memorial Reserve, Leopold's family land in 2001. The work shown in the figure is in support of a Master's level graduate student at the University of Wisconsin, and illustrates the 21st Century applicability of Luna's ideas of water as a single resource and the importance of holistic research approaches.

affects many other entities, yet each entity operates as if it alone is the flower facing the sun. There is no guiding belief, no ethos involving the natural world. . . . [Resource] management is stressed by a plague of special interests, a disdain for equity, and as a result, the public is the continual loser." This was a statement of a scientist who understood the connectivity that was at the heart of his science, and of his ethics as well.

The last time we saw Luna give a public address, he was speaking as Honorary Chair of the 2002 Waters of Wisconsin conference (WASAL, 2003a,b). This multi-day gathering brought together a varied audience of hydrology professionals, agency scientists and officials, tribal members, academics, non-governmental organizations, and members of the general public interested in the sustainability of the whole of Wisconsin's aquatic ecosystems and resources. Luna was 87 years old at the time, and his health was declining, such that it was not certain he would be able to attend, much less address, the conference. On the last day of the conference, however, using a walker to reach the podium, he did speak. He told a story of work he had done for the U.S. Army after World War II, work that involved the installation of hand pumps—not unlike the one at the Shack—to supply water in developing countries. He explained that in these communities it was not uncommon for the women and children to travel miles to carry water for their families. He then related the joy he saw on the faces of the people when the miracle of groundwater spilled across their hands, clean and accessible. Choking up near the end of his remarks, he made a strong case for water, all water, regardless of location or place in time, forming connections with and between all things. "We have to teach the general public to appreciate water—clean water—both in quality and quantity," he said. "We can't take it for granted" (Novak, 2002).

This holistic view of water, and people's relation to water, holds true today just as it did in Coon Valley in the 1930s, during times of war in the 1940s, in the midst of the environmental movement of the 1960s and 1970s, and in the 1990s as debates over ethics and the role of the government and special interests intensified. But more importantly, this view provides a strong foundation for the future of hydrology as the journal *Ground Water* looks to its next 50 years.

> Water is the most critical resource issue of our lifetime and our children's lifetime. The health of our waters is the principal measure of how we live on the land.
>
> Attributed to Luna Leopold

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