House Ag. & Natural Resources
February 14, 2012
Attachment 1

# 1 A Historical Perspective

In humid regions, primitive humans paid little attention to water. always present and, like air, was taken as a matter of course. Ho in semiarid and arid regions, the occurrence of water controll activities of humans. Villages were originally built on perennial st or around water holes. Our early movements consisted chiefly of tions to perennial water in the dry season and ventures into new pastures or hunting grounds in the wet season.

Primitive humans learned to dig for water, possibly by observing the actions of wild horses and wolves in search of water. As soon as we learned to domesticate and rear cattle and sheep, the water well became the most important possession.

The Bible described many incidents illustrating the importance of groundwater supplies to the tribes of Israel. Abraham and Isaac were renowned for their success at constructing wells. The Father of Modern Hydrology, O.E. Meinzer once said that the twenty-sixth chapter of Genesis read like a water-supply paper. Most people recall from the Old Testament how the Jews suffered for want of water in their 40 years of wandering in the deserts. To quell a near revolt by his people, Moses smote a rock with his rod and a fountain of water burst forth.

The ancient Greeks in the early seventh century BC told the story of Tantalus, Zeus' favorite mortal son who stole the ambrosia and nectar from the gods that gave the gods endless lives. Tantalus tried to share the heavenly food with mortals to give humans immortality. Zeus punished Tantalus by hurling him to Tartarus, a prison of darkness where Tantalus currently stands, trapped in the pool of water that is chin-height. He cannot drink it, though, for anytime he lowers his mouth to take a drink, the water recedes. The ancient Greeks knew the value of water, for Tantalus was sentenced to an eternal life of thirst, the most terrible punishment available. Hence, the word, tantalize.

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*Modern Groundwater Exploration: Discove Water Resources in Consolidated Rocks Using Innovative Hydrogeologic Co Testing, and Management Methods*, by Rol
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The Romans depended on many shallow wells and springs before they built their first aqueduct in 312 BC. The soil was so rich in springs and underground streams that wells could be sunk successfully at any point, and the average depth necessary was only about 5 m. Such wells were common from the earliest period, of the Roman Empire Excavations in the Roman forum have uncovered more than 30 wells dating back to the Republic.

The drilling rather than digging of artesian wells in France and Italy began in the twelfth century and created considerable popular and scientific interest on the occurrence of underground water. The art of drilling and casing wells was actually invented, perfected, and extensively practiced by the ancient Chinese. They used bamboo poles and patience to penetrate hundreds of feet. Wells were started by the grandfather and completed by the grandson.

The most extraordinary works of ancient humans for collecting groundwater are the qanats and karezes of the Persians and Afghanies. The qanats and karezes are tunnels that connect the bottoms of shafts, which were dug by humans working as moles over long periods of time and are conspicuous over all the high central valleys of Iran. Thirty six of these tunnels supplied Teheran and the highly cultivated tributary agricultural area.

In ancient times, springs were considered the miraculous gifts of the gods; they wrought miracles and consequently were places where temples were built. These superstitions continue today with those who optimistically overestimate the therapeutic value of medicinal springs.

Prior to the latter part of the seventeenth century, it was generally assumed that the water discharged by the springs could not be derived from the rain, first because the rainfall was believed to be inadequate in quantity and second, because the Earth was believed to be too impervious to permit penetration of the rain water far below the surface. With these two erroneous postulates lightly assumed, the philosophers devoted their thought to devising ingenuous hypotheses to account in some other way for the spring and stream water.

Two main hypotheses were developed: one to the effect that sea water is conducted through subterranean channels below the mountains and is then purified and raised to the springs and the other to the effect that in the cold dark cavern under the mountains, the subterranean atmosphere and perhaps the Earth itself are condensed into the moisture. The sea water hypothesis gave rise to subsidiary ideas to explain how the sea water is freed from its salt and how it is elevated

to the altitude of the springs. The removal of the salt was asc processes of either naturally occurring distillation or filtration.

Beginning with the middle of the sixteenth until the close of enteenth century, numerous publications appeared that cc discussions of groundwater, but the two ancient or classic hypotheses chiefly occupied the field, although an infiltration was explained in 1580 by Bernard Palissy. In the later part of enteenth century, Perrault, Mariotte, and Halley abandoned tl ries of the past and actively undertook experimental work to de the source and movements of groundwater, and thus was b science of groundwater. Perrault made rainfall measurements three years and roughly estimated the area of the drainage basi Seine River above a point in Burgundy and of the runoff from th basin. He computed that the quantity of water that fell on the basin as rain or snow was about six times the quantity discharged by the river. Crude as his work was, he definitely demonstrated the fallacy of the old assumption of the inadequacy of the rainfall to account for the discharge of springs and streams.

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Mariotte computed the discharge of the Seine at Paris by measuring its width, depth, and velocity at approximately its mean stage and by doing so verified Perrault's results. About the same time, Halley made crude tests of evaporation and demonstrated that the evaporation from the sea is sufficient to account for all the water supplied to the springs and streams, thus removing the need for any other mysterious subterranean channel to conduct the water from the ocean to the springs.

Centuries were required to free scientists from superstition and wild theories handed down from earlier generations regarding the unseen subsurface water. To a certain extent, we still live at a time when great misunderstanding if not superstition exist with regard to the occurrence and movement of groundwater. The elementary principle that gravity controls motions of water underground as well as at the surface is still not appreciated by all engaged in the development of the world's vast groundwater supplies.

Many people still believe that the magical forked witch stick is able to point to underground water streams and will actually twist in the hands of the operator in its endeavor to do so.

These popular superstitions are examples of the ability to believe without the foundation of facts, and this peculiar ability exists in the minds of both educated and uneducated men and women. Inasmuch as the movements of underground water cannot be observed at the surface, they have been subject to wild speculation. Even an American

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judge in a court case once ruled that "percolating water moves in a mysterious manner in courses unknown and unknowable."

Little by little in the last decades of the twentieth century, groundwater hydrologists dragged the water supply fraternity and the public at large kicking and screaming into a twenty-first century. Now groundwater resources are appropriately valued as often the best hope for enabling society and commerce to move forward unhindered by water shortages. Forty-seven percent of the U.S. population now depends on groundwater for its drinking water. In the Asia-Pacific region, 32% of the population is groundwater dependent; in Europe, 75%; in Latin America, 29% and in Australia, 15%.

The authors of this book played their role of ardent enthusiastic scientists during this period battling ever-present opposition to belief that significant quantities of groundwater supply could be sustained. Although we approached success in our efforts, it was still a small victory as our intent has been to reveal to the world the vast quantities of groundwater yet hidden deep within the Earth, often beneath arid lands. Thus far, there has been little confidence in our conceptual model or paradigm.

We have long believed that a planet whose surface is covered by water should not be facing water shortages. Admittedly, 97% of the Earth's water is too salty for humans and agriculture, and glaciers and ice caps put another significant portion out of reach. But we have long believed that a significant portion thought to be out of reach under the ground is not.

Energy-intensive desalting of seawater is currently too expensive except in wealthy but dry areas near seacoasts. Our fresh surface water has been allocated in most of the developed world, with Canada being a rare exception.

Although humans have learned well over the past century to conserve water in such that water use per person has actually declined, the addition of the final two billion people on the planet in the next 40 years before its population stabilizes (in accordance with most sound demographic projections) will require considerable additional water supplies. If we fail to develop additional water supplies, international strife will remain. Half of our continental land lies within river basins shared by more than one country. Multinational water claims have not and likely will not provoke war, but local and regional conflicts have occurred over inequitable allocation and use of water resources. International diplomacy commonly encourages opposing countries to cooperate, but not always before lives are lost. Most recently, apartheid battles in South Africa in 1990, Iranian and Iraqi disputes in 1991, and intrastate conflicts in India in the mid 1990s cost thousa lives.

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There has been an explosive development of groundwater in major deserts of the world in the last half of the twentieth centu liminary results of activity in the Sahara and throughout the A Peninsula substantiate the occurrence of vast amounts of water beneath desert lands. This development is due to efforts of groun geologists and engineers, well construction crews, and political who had the courage to launch the investigations against ac water resources paradigms.

Several factors make water development programs in arid feasible:

(1) The deserts offer uncrowded space
(2) Favorable climate for nearly year-round crop growth
(3) Large areas of reasonably good soils and food-fiber requirements for persons in mineral and petroleum resource industries in desert areas.

Throughout most of the world, aquifers have not been regarded as true water resource reservoirs. Rather, they are simply viewed as holding tanks for annual contributions of what is unfortunately thought of as safe yield. The annual increment of groundwater is skimmed off the top when the basin below is depleted in any significant way. But in fact, the surface-water reservoir that remains full is obviously as poorly managed as that which remains empty; so too is the groundwater reservoir poorly managed when it is not allowed to rise and fall in contrast to the vagaries of the natural cycle and the demands of the human population.

Good water management is the optimum manipulation of the available water resource to serve the greatest common good. It includes the coordination of both the natural aspects of the hydraulic cycle and every artificial operation that can be performed upon it, save, in most cases, the drastically expensive and uneconomic interbasin transfer of surface water.

The concept of the hydrologic cycle has become so generally accepted that it is difficult to appreciate the long history that lies back of its development and demonstration, from the dawn of history until comparatively recent times, barely a quarter of a century ago. The central concept in the science of hydrology is the hydrologic cycle, a convenient term to denote the circulation of the water from the sea, through the atmosphere, to the land

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back to the sea by overland and underground routes and in part through re-evaporation and transpiration from vegetation, lakes, and streams. It involves the measurement of the quantities and rates of movement of water at all times and at every stage of its course through multiple reservoirs, from a height of 15 km above the ground to a depth of some 5 km beneath it. The reservoirs include atmospheric moisture, oceans, rivers, lakes, icecaps, soil, and groundwater. The transport mechanism from one physical state or aquifier to another is either gravity or solar energy over periods that range from hours to thousands of years.

The pioneer of intensive groundwater investigations was Germany's Adolph Theim who introduced field methods for making tests of the flow of groundwater and applied the laws of flow in developing water supplies. Under his influence, Germany became the leading country in supplying its cities with groundwater, and it still derives over 80% of its needs from wells.

Because we can see surface waters and because such tremendous amounts of money have been spent in building visible dams, levees, artificial reservoirs, aqueducts, and irrigation canals involving surface water, it is openly natural that we tend to think of that water as the major source of the world's needs. Actually less than 3% of unfrozen fresh water available at any given moment on our planet Earth occurs in streams and lakes. The other more than 97%, estimated at eight trillion acre-feet, is underground.

The total amount of water on our planet has almost certainly not changed since geological times. Water can be polluted, abused, and misused, but it is neither created nor destroyed; it only migrates.

Groundwater is tracked by remote sensing and tracer techniques, but the water movement is exceedingly difficult to follow. It is known that groundwater migrates slowly. Sometimes groundwater moves only a few millimeters a day, although occasionally it is a few meters per day. Near the water table, the average cycling time of water may be a year or less, whereas in deep aquifers, it may be as long as thousands of years. It is easier to measure water tables. Through test wells and controlled pumping, it is not difficult to measure the recharge rate and flow behavior around a particular site. The difficulty comes in sensing movement in the aquifer as a whole. Water can be stored in the pores of rocks, but it can also be stored in cracks and fractures, and sometimes these fissures can provide conduits to allow water to travel quickly and over great distances.

No one knows how many unexplored and unexploited aquifers exist, but the amount of water stored in them is thought to be considerable. This is the focus of this book, to help exploration geologists around the

globe to uncover vast stores of water yet undiscovered. Wate
ration companies have not yet made a major impact on tl
markets of developed countries, but they would not be a bad
adventurous investors.

Water exploration must tie itself to the many great advanc
by the petroleum industry, which long ago tied itself to comput
nology. The petroleum industries need for processing power
tiable, and it has resulted in many computer technology a
Today we stand on the launching pad to a journey into high
ogy groundwater location and development whose foundat
been laid for us through advances in petroleum and other
explorations. The oil industry itself has been a driving force in t
puter industry where Texas Instruments began as a company in 1930 known as Geophysical Service. Seismic imaging now available for groundwater studies led to the development of computer programs to assess sound waves generated in rock to infer the nature and location of rock layers capable of trapping oil. From initial two-dimensional images, computers ultimately were taught to process gigabytes of data that would result in three-dimensional images.

In 1985, more than a day of computing time was required to analyze a square kilometer of subsurface structure; by 1995, computers could do it in 10 minutes, and the cost to survey 10 km$^2$ dropped from millions of dollars to tens of thousands of dollars.

Concurrently, computer-assisted drilling technology advances include saw drill bits that have direct sensing tools to evaluate physical channels, and electrical characteristics of what they were drilling through while transmitting their exact location to the surface and enabling the implementation of immediate course corrections. In some ways, it is truly amazing that this book is only being written at the beginning of the twenty-first century. Advances to be described in the following chapters regarding groundwater development were recognized in the parallel fields of geologic science and engineering, more than two decades ago. This is why, with the exception of water every mineral resource on Earth has become less and less expensive than it was in our youth. Technologic- and knowledge-based advances have reduced the costs of location, development, and refinement of every other mineral in the Earth, without exception.

Mines and oil fields once abandoned have been reopened for redevelopment of formerly uneconomic resources. Groundwater, however, has been saddled with a century old paradigm. We place a straw in only the upper portion of our water-fi
deeper regions because of our ina

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tures. Or we are misguided by beliefs that recharge could not continuously replenish the deeper portions of that or any aquifer. So leave it there lest we become dependent on a nonrenewable resource. A similar philosophy would have left us in the Stone Age, never to develop an Iron Age or use any other minerals in the Earth's crust.

At the same time, commitments are being made by the United States and other governments that could severely damage independent efforts to discover the realities of deep groundwater environments. For example, in recent years, the U.S. Environmental Protection Agency and similar agencies worldwide not only missed an ideal opportunity to advance the understanding of deep groundwater resources, but delayed its advancement by demanding instant competence of an unprepared scientific community. In addition, U.S. EPA spent billions of dollars on groundwater "cleanup" and "protection" without first performing the due diligence required to critically evaluate the actual knowledge base. The origins of this unfortunate situation are of recent vintage. In the 1980s, it was disconcerting for exploration scientists to observe the U.S. Congress balk at a request from the world's preeminent institution of basic geological research and knowledge, the U.S. Geological Survey, for modest funding to update decades-old, low-resolution, pre-space-age geological maps (upon which groundwater studies are usually based); and it was even more bewildering in the 1990s to witness Congress funding a multi-billion-dollar nationwide groundwater cleanup effort without benefit of the requisite knowledge base they failed to develop a decade before.

Spending those billions of dollars have not only failed to advance the knowledge base about deep groundwater, but also have induced a surfeit of numerical models largely based on anachronistic concepts of groundwater occurrence. Such elegant, but ill-conceived models have been combined with sophisticated computer visualization programs and published as factual representations of global groundwater occurrence in professional journals and the popular press, leading engineers, economists, and political leaders to premature and erroneous conclusions regarding groundwater balance and the Earth's fresh water balance as well.

# 2 Megawatersheds—A New Paradigm

ALEXANDER RAYMOND LOVE
Founding Executive Director, Partnership to Cut Hunger and Pov
Africa

> "The originator of a new concept . . . finds, as a rule, that it is much more difficult to find out why other people do not understand him than it was to discover the new truths."
>
> —Herman von Helmholtz

In 1875, a 17-year-old German student had just graduated from Gymnasium and was about to enter University. Intrigued with his early studies of physics, he had decided to pursue it as a career. He thus approached the head of the physics department at the university for advice. The professor was not encouraging. "Physics is a branch of knowledge that is just about complete. The important discoveries, all of them, have been made. It is hardly worth entering physics anymore."

The attitude of the professor was probably representative of the prevailing wisdom in "Newtonian or Classical" physics in 1875. It represented a plateau of knowledge that had been reached in the nearly two centuries since the early discoveries of Sir Isaac Newton. Little did the professor realize that the field of physics was on the verge of a major new age of discovery and development, one that would reshape the study of physics and profoundly impact on world development.

The professor, of course, also had no way of knowing that the student, Max Planck, would ignore his advice and go on to become a world famous physicist. Planck would introduce the quantum theory and help usher in the new age of physics with the publication of his

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