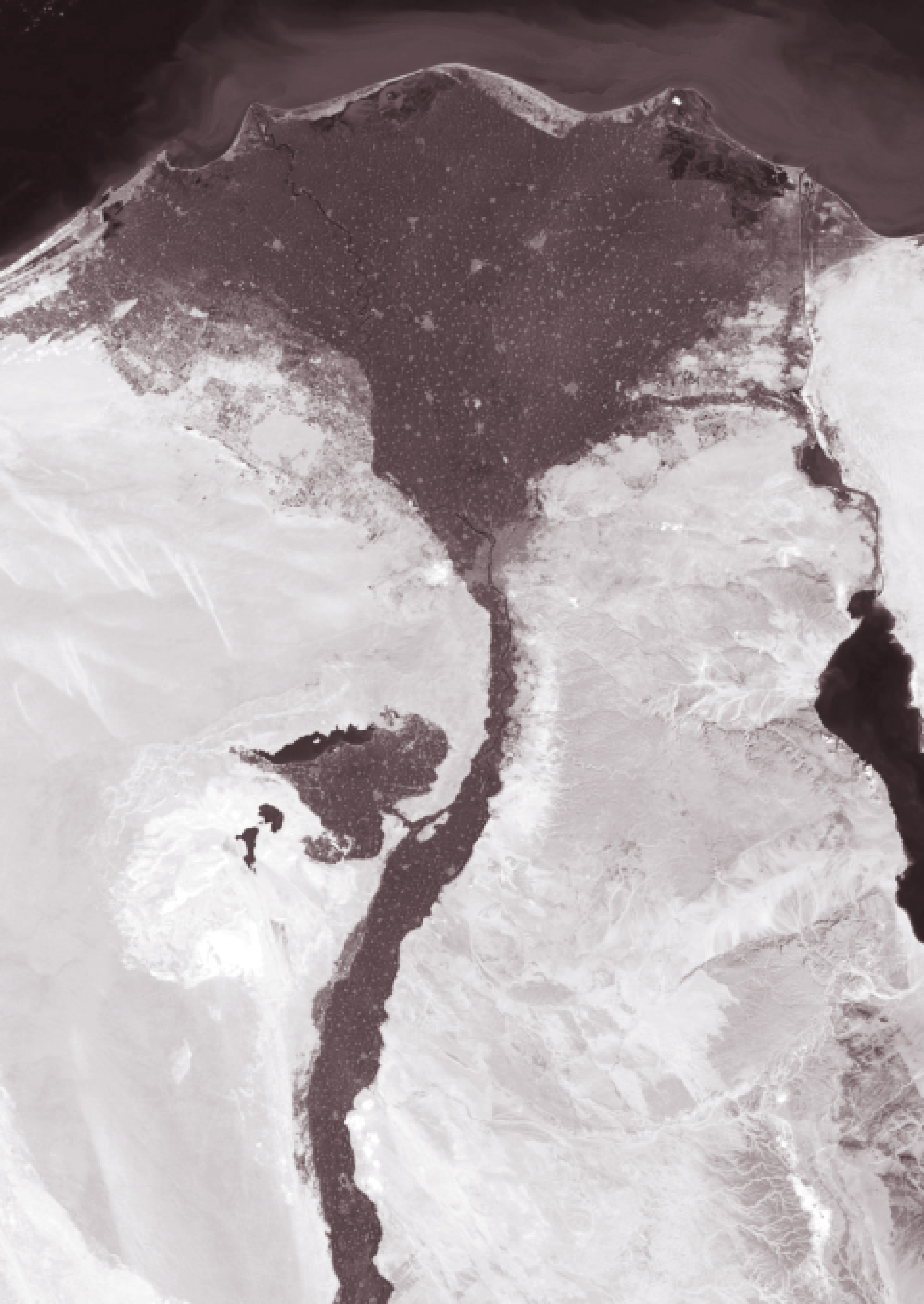

QUEST FOR WATER

Summoning the Expertise—and the Will—to Exploit the Middle East's Underground Reserves

By Farouk El-Baz

Arab countries lie within a band roughly between fifteen and thirty degrees north of the Earth's equator. This desert belt stretches for eight thousand kilometers, from the coast of the eastern Atlantic to the Arabian Sea. It encompasses the Great Sahara of North Africa and the desert of the Arabian Peninsula. In this region, only three major rivers, the Nile, Tigris, and Euphrates, supply narrow strips of land with year-round water. The rest of the region must depend on groundwater resources.

The Arab desert belt is among the driest regions of the world. The Great Sahara constitutes the largest and driest stretch of land on Earth, extending nearly six thousand kilometers from east to west. In its eastern part, the received solar radiation is capable of evaporating two hundred times its actual rainfall. This measure of dryness, the Aridity Index (AI), for the rest of the Arab deserts varies from 100 to 50. By way of comparison, the driest place in North America is Death Valley in California; its AI is 7.

The hyper arid conditions in most of the Arab lands necessitate dependence on groundwater resources. The quest for water is an urgent priority for people and policy makers alike in the countries of the Arabian Gulf region, for one example. These countries are endowed with plentiful oil resources, which are used among other things for local sea-water desalination to produce water for human consumption. Agriculture, however, must depend on groundwater, and population growth has exacerbated the scarcity of water.

◁ Image of Egypt taken by a Moderate Resolution Imaging Spectroradiometer from NASA's Terra satellite, Feb. 5, 2003. *Jacques Descloitres/MODIS Rapid Response Team/ NASA/GSFC*

A Plentiful Resource

The Earth is aptly called the Blue Planet because water covers over 70 percent of its surface. Views from space clearly depict continents as islands floating in a vast sea. The salt water in the oceans and seas constitutes 97 percent of all water on Earth. Tangible, visible fresh water bodies constitute a negligible fraction of the store of sweet water in the remaining 3 percent. Polar ice masses and mountain glaciers contain nearly 70 percent of all Earth's fresh water. Groundwater represents the remaining 30 percent, while surface water amounts to less than 1 percent of fresh water resources. This means that there is thirty times more water beneath the ground than in the fresh water of all the rivers, fresh water lakes, and swamps on Earth.

There is little question, then, that we must ponder where these invisible water resources are hidden in order to wisely locate, use, and manage them. In the Arab region, groundwater is both more prevalent and more extensive than generally believed, particularly in sand covered deserts far from population centers. However, it is important to note that such water accumulated during wetter climates in our geological past. This means that they are being infrequently replenished today, and must be properly managed to ensure sustainability.

There is a common misperception in the Middle East that groundwater resources are limited and undependable. This belief arises in part because too many wells are drilled within close distance of each other and, in most cases, are drilled to the same depth. Another reason for the misperception is that water is typically pumped at rates that are much higher than the mobility rate of water through the pore spaces in the host rock. The practice of unregulated water extraction has led to the notion that groundwater resources have been depleted in much of the Arab region. However, the resources are there but they must be mapped thoroughly, used wisely, and managed properly.

The groundwater story begins when rainwater accumulates on the Earth's surface. The driving force for its movement into the ground is gravity, which causes water to move from higher to lower elevations. Water moving beneath the surface is protected from the heat and evaporation caused by solar radiation, and will remain trapped in the fabric of the rock for thousands of years. During its journey, water will move through primary porosity (the open spaces between grains of soft sedimentary rocks) and/or secondary porosity (the faults and fractures in any rock type). Many people erroneously believe that water beneath the surface takes the form of underground lakes and rivers. In fact, the water in the ground exists mostly in pore spaces between rock grains.

Rock composed mostly of adjoining sand grains, sandstone, and others, such as limestone, have irregular yet connected pore spaces that allow water free passage. Water percolates through such rocks to move from higher to lower areas. Sandstone is generally salt free, and its confined water remains sweet and drinkable for thousands of years. On the other hand, limestone rocks contain soluble chemicals and passing water dissolves the salts and in some cases, the dissolution of salts within the host rock renders its water reserves saltier than that of the sea.

Vast groundwater basins may be up to hundreds of meters in capacity as is the case of the Nubian aquifers of North Africa, and the Empty Quarter basin of the Arabian Peninsula. Here and there, such extensive, seemingly horizontal sandstone aquifers are interrupted by non-porous rock masses, including igneous and volcanic rocks.

The direction of surface water runoff depends on topography; the greater the degree of tilt, the faster the runoff. However, the pattern usually depends on the orientation of faults and fractures in the surface rock. As surface water denudes the rock to establish an easy passageway, a drainage pattern emerges. The pointed tips of the often V-shaped pathway intersections indicate the direction of downward water flow. As such, dry *wadi* patterns indicate topography at the time of formation. Therefore, the analysis of patterns visible on land from running surface water is essential to the prediction of groundwater accumulation sites.

Pictures from Space

The modern search for groundwater has been aided immeasurably by satellite technology, but signs of the resource have always been apparent. Sparsely populated areas in the Middle East have depended for generations on water that percolated through fractures from higher topography to exit in the form of springs, or oases. These are called *wahat* in North Africa, *oyoun* in the Eastern Mediterranean, and *aflaj* in southern Arabia.

In some cases, water is known to follow such fractures for extended distances and release water for long periods of time. For example, Bir Zamzam is an open well near Mecca in the Hijaz Mountains of western Saudi Arabia. It receives its water, via fractures in the surrounding rocks, from seasonal rainfall or snowmelt—as it has done for thousands of years. The water level may increase or decrease occasionally, but the flow of its highly prized water is constant.

Pearl divers in the Gulf, in fact, benefited from this phenomenon for centuries. Prior to the modern oil era, the economy of the region depended on harvesting pearls from the sea. Rainwater from the Hijaz Mountains also found its way through fractures in the rock to exit at the bottom of the Gulf, a distance of nearly one thousand kilometers. To obtain drinking water supplies during their hunt in the sea, a pearl fishing party would send a diver carrying a rock—for fast descent—tied to a rope. The diver would locate the fresh water emanating from the bottom of the otherwise highly saline Gulf water and fill a goat skin *girba*. When finished, the diver would signal by tugging the rope and would be pulled back to the vessel. The process was repeated until the party had enough drinking water for their pearl-foraging mission.

Until recently, no one had established a plausible explanation as to the source of the fresh water springs on the Gulf floor. Most experts had discounted the distant Hijaz Mountains as its source, suggesting instead that the water must have seeped from nearby rocks. However, the latter are composed mostly of limestone, which contains, as mentioned, salts and so the groundwater in these rocks is rather saline.

The Hijaz theory gained tangible support after field exploration of the environmental effects of the Gulf War of 1991. My own observations of the desert surface of Kuwait suggest that the whole area is basically the dry delta of an ancient river. The surface was covered by round cobbles, pebbles, and grains made of the igneous and volcanic rock found in the Hijaz Mountains. This led me to map the "Arabia River," a passageway of surface water from the Hijaz all the way to western Kuwait, a distance of 850 kilometers. The theory being that if surface water made the journey along a fracture that crossed Arabia from west to east, then similar cracks in the subsurface could do the same. These findings were established not only by field observations but also via essential satellite images.

The Arabia River case illustrates how, for every surface feature that we can distinguish in the arid lands of today, there is the backstory of how, when, and by what mechanism it was created. The variety of such features makes it essential to study, in detail, the entire surface of the desert in order to be able to understand its history. Thus, the study of landforms over vast areas of the Arab region requires a bird's eye view and satellite images are the best source of information on desert regions, especially for groundwater exploration.

Imaging the Earth from space has progressively advanced over the past forty-five years. In the mid-1960s, photographs were taken by the astronauts on the Gemini, Apollo, Skylab, and Apollo-Soyuz missions using hand-held cameras with color film. Ancient rocks, with much iron and other dark elements appeared brown, limestone looked bright, sands appeared golden yellow, and ocean currents became discernible. And so we began to map Earth's hard to reach regions based solely on views from space.

The detail of images from space depends, of course, on the altitude of the spacecraft; the lower the orbit, the higher the resolution. It also depends on the focal length of the camera lens; the longer the length, the greater the detail. In the first satellite images, a whole town appeared as a dot. Today a car can be clearly identified in high-resolution images.

Digital imaging from space allows the use of filters to separate the reflected light into various wavelengths. For example, when certain bands of Landsat are used, they become equivalent to visible light. These multi-spectral bands could be combined with an infrared band, or a thermal band that measures differences in the temperatures of rock, soil, and sand.

There is the promise of expanding efforts to utilize satellite imaging for groundwater discoveries in the Middle East. In the past few years, several Arab countries have launched imaging satellites. Saudi Arabia was the first, followed by Egypt, which operates a multi-spectral imaging system with 7.8 meter ground resolution. Algeria is planning one and the United Arab Emirates is also considering one such project.

A combination of all available satellite image data is ideal for investigating the probability of groundwater concentration in the Arab desert. These data include:

1. Multi-spectral images that clearly depict the surface features and allow the deduction of their geologic history.
2. Thermal images that show the location of rainwater accumulation just below the surface, which may replenish groundwater aquifers, as well as seepage of groundwater into the sea along coastal zones.
3. Radar waves that penetrate sand cover to reveal buried river courses.
4. Elevation data that depict the direction of surface water flow in the past as well as in the present.

The correlation of such data using Geographic Information System (GIS) methods allows us to define the best way to locate and utilize groundwater resources.

Case Studies: Egypt and Sudan

Egypt and Sudan are two examples of locating previously unknown groundwater resources using satellite images in the heart of the eastern part of the Great Sahara. Although the Sahara is now dry and is subject to the action of strong winds from the north, archaeological evidence indicates that it hosted much wetter climates in the past allowing rainwater to accumulate in depressions and seep through the substrate to form the Nubian aquifers. These aquifers were confined to two distinct basins—rather than the one vast layer extending from Chad to the Mediterranean Sea as has been previously postulated.

In southwest Egypt, a three-hundred-kilometer flat and sand-covered area straddles the border between Egypt and Sudan. This region is called the Great Selima Sand Sheet, with the Selima Oasis on its eastern border. This oasis is a prominent way station on the *Darb El-Arbain* (the forty-day trek) of camel caravans from Darfur in northwestern Sudan to the Nile valley in Egypt. Faint drainage lines that led to the sand sheet from the west and its general setting suggested the potential of groundwater accumulation within the basin, although there was no tangible evidence of water.

In 1980, the Egyptian government planned to establish a military base in southwest Egypt. As a science advisor to President Anwar Sadat, I completed a survey of Egypt's Western Desert. The survey proved that sand in the vast dunes originated from water and was deposited in topographic depressions during previous wet climatic eras. The sand was later shaped into dunes during dry episodes. However, neither the transportation pathways nor the depositional basins could be seen in early satellite images, and the theory lacked tangible evidence.

In November 1981, during the first flight of the Space Shuttle Imaging Radar mission, the instrument was aimed at a flat region in northwest Sudan. Its imagery revealed sand-buried courses of river channels just south of the border of Egypt. I then postulated that the flat area in southwest Egypt—part of the Great Selima Sand Sheet—was one depression where water collected during past humid episodes.

The site was approved for groundwater exploration wells in 1982. However, when the strategic need for the military base ended, so did the interest in the wells. I continued to campaign for test wells to evaluate the groundwater potential of the region. It took thirteen years before testing finally began, and proved the existence of sweet water in vast amounts. Water showed up at one hundred meters below the surface and rose to twenty-five meters below the ground under its own pressure. The water had only two hundred parts-per-million salts, which made it sweeter than that of the Nile River.

In 1995, the Egyptian government offered a number of ten-thousand-acre plots to agricultural endeavors in order to develop the land. Today, 750,000 acres utilizing nearly one thousand wells are actively producing wheat, chickpeas, peanuts, and other crops at considerable profit. The proven water reserves in the region would support agriculture over at least 150,000 acres for one hundred years. Since then, my team has mapped five main stream channels emanating from the Gilf Kebir highlands in southwest Egypt that fed rainwater there in the past. The accumulated water in the depression seeped into the porous sandstone substrate as groundwater and this suggests that the resource might be even greater than estimated.

The second case is just south of the Egyptian border in the Darfur region of northwestern Sudan. This arid home of the Fur tribe is presently divided into three governorates: north, west, and south. (It is now being considered for division into four governorates.) The governorate of North Darfur in particular hosts an environment typical of the eastern Sahara of North Africa: the farther north one goes, toward Egypt and Libya, the greater the aridity.

A mountain range, Jabal Marra, straddles the three governorates. It does receive some annual rainfall, particularly at the end of summer, but severe droughts over the past two decades have caused population migration along the fringe of the Sahel belt of North Africa. Competition for the meager water resources in the Darfur region contributed to the conflict there as farming communities settled around wells that were considered to belong to nomadic populations. The latter inflicted much damage to the numerous farms and caused the severe humanitarian crisis. Darfur is yet another example of the desperate need for additional water resources.

Interpretations of space-borne data were then conducted at the Boston University Center for Remote Sensing and resulted in the identification of horizontal lines at an elevation of 573 meters above sea level in northern Darfur. Detailed geologic analysis of these discontinuous lines confirmed that they were remnants of shorelines of an ancient mega lake.

Modeling of the ancient lake basin showed that at its maximum extent, the lake had occupied an area of about 30,750 square kilometers, the size of Lake Erie in North America. It would have contained approximately 2,530 cubic meters of water when filled. The enormity of the lake's size and the topographic setting of the area suggest that this lake was formed during wet epochs, when rain was plentiful, over a protracted period of time. And, just as in the case of the basin to the north in southwest Egypt, much of the rainwater would have seeped into the substrate to form groundwater.

After completing the mapping of the lake boundaries using the space data, I conveyed the outcome to officials of the Sudanese government, prompting them to launch the "One Thousand Wells for Darfur" initiative. The map survey was also conveyed to and welcomed by officials in North Darfur, as well as at the United Nations.

Water for the Future

Vast tracts in the Arab region have not been similarly explored for their groundwater potential. This includes the extensive sand covered plains of the Great Sahara and the Empty Quarter of Arabia. Ongoing geological discoveries could make such exploration even more fruitful. For example, there are new indications that desert sands were transported and deposited by running surface water during humid climates that alternated with dry phases in the geological past. The last of the wet phases ended about five thousand years ago. During dry phases, like the present one, the wind acts on the sand deposits to shape desert dunes. As discussed earlier, because desert sands were formed and transported by water, their locations might be underlain by groundwater.

The evaluation of such resources belongs in the policy domain. Government bodies must collect and analyze the required data to regulate groundwater use. It is also essential that the attention of policy makers be sustained in the long term, because data collection and evaluation require a great amount of time. Thus, it is instructive to consider the major issues that require institutional regulation by policy makers. The primary need is to map the boundaries of each groundwater basin or aquifer using all available space images and field-collected data. This should be followed by exploration wells to establish the depth of the groundwater level. In many cases, the water exists in several levels beneath the surface.

Next, modeling should be performed to establish how much water is contained in each aquifer. Data on salinity must be integrated into the models with emphasis on changes over time. In some cases, over-pumping draws water from saline sources and contaminates sweet water. This modeling is essential to establish safe pumping rates to assure sustainability. A glaring example of over-pumping with little or no regulation is that of the Al-Qasim region in central Saudi Arabia. There, unregulated extraction of groundwater for wheat production in the 1980s and 1990s exhausted the resource and led to the abandonment of numerous fields.

Furthermore, regulations are necessary to establish the proper use of the water. In some cases, it is best to use the water for *in situ* agriculture, such as in southwest Egypt. In other cases, the water should be transported to populated areas, such as Libya's "Great Man Made River Project."

In the case of groundwater in desert basins, it is essential that regulations consider the resource fossil water. It accumulated during wet episodes that lasted for thousands of years in the mists of our geological past. It must be remembered that replenishment may occur in some minimal locations along mountain ranges, but the open desert very rarely receives any rainfall, let alone enough to replenish groundwater below. From a policy regulation point of view, this groundwater must be considered a finite resource that will run out in a given period of time.

Clearly, where groundwater aquifers extend beyond national boundaries these extensive areas require study and evaluation to establish regulations for the equitable distribution of water resources. In this case, policy regulations and governance need to be inter-governmental. And it is advisable to collect the necessary information now, to avoid future problems when the available resources will be insufficient to satisfy increasingly desperate needs.

The current major shared groundwater aquifers in the Arab region include:

–The Palestine expanse in Israel and the West Bank;
–The Jordan River system in Jordan, Israel, and the West Bank;
–The Hamad basin in Syria, Jordan, Israel, and the West Bank;
–The eastern Mediterranean system in Lebanon and Syria;
–The Tabuk fracture zone aquifer in Jordan and Saudi Arabia;
–The Selima basin in Egypt and Sudan;
–The Siwa-Jaghboub system in Egypt and Libya.

While the Arab region's groundwater resources remain to be comprehensively charted, the already voluminous literature on groundwater in the region indicates four noteworthy points:

1. Vast areas of the Arabian deserts have not yet been studied or explored.

2. Current water scarcity will be further exacerbated by rapid population growth and increasing water usage.

3. Productive aquifers are being over-drilled and over-pumped with little regulation to assure their sustainability.

4. Aquifers shared by multiple nations have not been quantified for equitable use.

Thus, a major study of the Arab region should be initiated, with the purpose of identifying regions of potential groundwater accumulation. All available data must be collected for each country or region; because using only parts of the data might be misleading. The data should be processed, analyzed, correlated, and updated in an active GIS database. The information within this database should be freely exchanged for the planning of equitable uses of groundwater resources in adjacent countries. And countries should place a high priority on proper utilization of this valuable resource.

In addition, it is essential to construct a complete digital database for currently exploited groundwater resources. The database should be regularly updated based on new findings or more advanced analysis and modeling methodologies. The same should be done for currently shared water resources to establish inter-governmental agreements for utilizing resources that straddle international boundaries.

Data collection should be required in all regions where water might be extracted for human consumption as well as for agricultural or industrial uses: data such as geo-coded locations of the wells, their depth, and the type of host rock; water salinity; pumping rates; and historical illustrations of changes to water levels over space and time. All such data are essential for the proper assessment of actively mined resources and the establishment of a proper water extraction rate to assure the longevity of a given aquifer.

Arabian groundwater resources require more study and better regulation. These objectives need sustained attention by policy makers, who must put their emphasis on long-term sustainable development. Concerted efforts are needed today, so that there is water tomorrow.