Rethinking Groundwater Supplies in Light of Climate Change: How Can Groundwater be Sustainablly Managed While Preparing for Water Shortages, Increased Demand, and Resource Depletion?

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Abstract

Although 70% the Earth's surface is covered by water, freshwater makes up only 3% of the total water on the planet. Most freshwater is stored as ice in glaciers and polar ice sheets. Although humans rely heavily on freshwater from streams, rivers and lakes, this water amounts to only 0.02% of all water on Earth. By far, most liquid freshwater is stored in aquifers as groundwater. Even so, groundwater makes up only 1% of all water on the planet.

As climate change progresses, groundwater reserves will become increasingly important. There is mounting evidence that water tables are falling around the world. Surface water resources are also showing signs of stress. However, groundwater is harder to manage and protect than surface water since it is hidden from sight. A new effort is needed to put groundwater systems under the management and protection of special agencies specifically created for the job. Groundwater districts, authorities, commissions and similar designations should be established for significant groundwater systems around the world. Management authorities can provide equitable administration of intra-state, inter-state and international aquifer basins using sound scientific research and management plans, implemented by professional staffs. The management agencies can conduct studies, prepare management strategies, quantify the resource, determine equitable distribution of the water, and establish safety margins for allocations in anticipation of climate swings like severe drought. The needs of humans are balanced against the needs of other stakeholders such as the ecosystem and its inhabitants as allocations are made. Groundwater may be the water of last resort in the future. Strong management and protection of important groundwater sources will become increasingly critical as communities across the U.S. and the world work toward sustainable use of all the earth's natural resources.

Signals that a World Water Crisis is Developing

The *Intergovernmental Panel on Climate Change* (IPCC) has noted, in increasingly strong language, that the water sources (rivers, lakes, and bores/groundwater) humans have relied upon for millennia may disappear or be radically different in the future (Bates 2008; Gupta 2007; Lean 2007; Watson et al. 1997).

The predicted changes address where water is located, in what form water is stored (ice vs. liquid) and in what amount will water be available. The natural conditions related to these changes include:

- shifts in precipitation patterns; some areas receiving more rain, others receiving less;
- shifts in storm frequency (fewer) and intensity (more intense) (Chang 2008);
- loss of ice stored as glaciers and as polar ice formations (Revkin 2008);
- loss of inland river flow due to reductions in winter storms, spring snow melt and runoff; and
- drop in groundwater levels due to reduced recharge (less rain over recharge areas) and increased pumpage from aquifers (Bates 2008; Rogers 2008).

Although public and regulatory attention is slowly exerting pressure to make public water supply systems more efficient, meaning they waste less water, and more conservation minded, are these efforts missing the bigger picture of overall freshwater availability, now and in the future? According to Peter Rogers, P.E., of Harvard University (2008), "the world's demand for freshwater is currently overtaking its ready supply in many places and this situation shows no sign of abating."

Reminder of World Water Resources

It is worth remembering how the earth's water is distributed across the planet. Of all the water on earth, 97 per cent is held as saline water, primary in the earth's oceans, and is unfit for use by most terrestrial plants and animals, including humans. Only 3 per cent of the earth's water is freshwater and of this, 2 per cent is stored as ice in continental glaciers and the polar ice caps. Thus, only 1 per cent of the earth's total water is readily usable by humans. Most of the 1 per cent is stored as groundwater. Surface water (streams, rivers and lakes) makes up only about 0.02 per cent of all water (USGS Water Basics).

Climate Change Is Already Affecting Freshwater Resources

Some of the most important glaciers around the world are in retreat. For example, glaciers in the Himalayas, the Tibet-Qinghai Plateau, Alaska and Canada, Greenland, South America and Switzerland are melting faster than most climate models predicted.

"Yao Tandong, one of China's leading glaciologist, believes that at currents rates, two thirds of the Tibet-Qinghai Plateau glaciers could disappear by 2060" (Brown 2008 4). The Greenland glaciers are melting so rapidly that they are triggering localized earthquakes as the crust adjusts to the loss of billions of tons of ice that is "breaking off and sliding into the sea." (Brown, P. 2007).

According to Chris Rapley, leading expert for the British Antarctic Survey, "the ice is moving faster both in Greenland and Antarctica than the glaciologist had believed would happen" (Brown 2008 4). Recently, "the Markham Ice Shelf, a sheet of ice that had been attached to Ellesmere Island in the Canadian Arctic for 4,500 years, broke loose and disintegrated over a few days in August [2008], scientists reported," in September (*New York Times* 2008).

The loss of major continental ice formations is important for many reasons. One reason important to humans is that the melting water drains a significant amount of fresh water to the oceans. Excessive melting represents a disruption of the normal snow and melt cycles that have historically provided water to some of the world's major river and groundwater systems. "The glaciers in the Himalayas and on the Tibet-Qinghai Plateau feed all the major rivers of Asia, including the Indus, Ganges, Mekong, Yangtze, and the Yellow Rivers. It is the water from these rivers that irrigates the rice and wheat fields in the region" (Brown 2008). It is possible that the Ganges River could become a seasonal river in a matter of decades (ibid).

With the melting ice will come a rise in ocean levels. Early climate change predictions had estimated sea level increases in the range of up to 1 meter by 2100. More recent predictions are address the possibility of the full loss of the Western Antarctic Ice Sheet which could increase sea level rise by 5 meters and the loss of the Greenland glaciers which could add another 7 meters to the world oceans, totaling a combined effect of 12 meters (39 feet) (UN Environmental Programme 2007). The key question remains the time frame in which the ice loss will occur.

At the same time that ice is melting and running into the oceans, water tables on every continent are falling (Brown 2004). Aquifer systems, where groundwater is stored, are being depleted by heavy use and/or by a loss of recharge water from such important processes as the snow/melt cycle.

Some of the world's largest cities are heavily dependent on groundwater. For example, Beijing, China; Buenos Aires, Brazil; Dhaka, Bangladesh; Lima, Peru; and Mexico City, Mexico all rely on groundwater for drinking water and related water needs (Srinivas, H.). Regional aquifers are also in decline. The Nubian Sandstone Aquifer System beneath the Sudan, Chad, Libya and Egypt is being depleted, in part by a major pumping project by Libya (Brown 2008). Large aquifers in the western and southeastern U.S. are experiencing withdrawals in excess of the recharge rate. The result is the progressive drop in water table elevations.

Problem Areas: China and USA

China's groundwater situation is deteriorating rapidly. China is heavily dependent on groundwater which constitutes a third of its freshwater resources. "Nearly 70 per cent of all drinking water and 40 per cent of agricultural irrigation uses groundwater," according to the World Watch Institute (Zhan 2006). China's groundwater is not evenly distributed. Most of the groundwater (67.7%) is located in the south and only about a third (32.3%) is in the arid northern portions of China (Zhan 2006).

Part of the groundwater problem is that groundwater pumpage has been growing along with the economy. Over the last 20 years, groundwater withdrawals have increased by 2.5 billion cubic meters annually (*China Daily* 2003).

In addition to declining groundwater supplies, China is experiencing the related problem of ground subsidence where heavy over-pumping has occurred. About 50 cities in China have reported sinking ground. The cities of Shanghai, Tianjin and Taiyuan have reported the worst subsidence, where each has experienced drops of more than two meters in elevation since the early 1900s (Zhan 2006). In response to this serious situation, China has started a subsidence monitoring network located in the two major subsidence areas, the Yangtze River Delta and the North China Plains (*China Daily* 2003).

The extensive subsidence is expanding so much that it may soon cover the whole Yangtze River Delta, according to a report in *China Daily* newspaper (2003). Shanghai may be the worst hit. "According to the Shanghai Geological Research Institute, excessive groundwater pumping contributes to 70 per cent of Shanghai's surface subsidence, with the remaining 30 per cent created by the physical weight of skyscrapers" (ibid).

The subsidence problems of Shanghai have been compounded by sea level rise and global warming. The city has "suffered direct economic losses of 290 billion yuan ($35.1 billion US) in the last 40 years from destructive tidal waves, floods and other surface-subsidence-related disasters. The most recent accident was the cave-in at the city's No. 4 subway on the banks of the Huangpu River in July[2003].... Several nearby buildings tilted as a result" (ibid).

Sea level rise at Shanghai has been set at 115 mm in the past 30 years according to the State Oceanic Administration's 2007 sea-level monitoring report. One hundred and fifteen mm is about the length of half a chopstick (*China Daily* 2008). The report also noted that Shanghai will face additional trouble providing fresh water to its 20 million residents due to saltwater intrusion.

China's Agriculture

The agricultural areas of China's north have their own groundwater issues. Growing cities are draining the local aquifers. Shijiazhuang, for example, is an expanding city of 2 million people that relies on groundwater. The water table of the aquifer is dropping about 4 feet a year and municipal pumpage has used two-thirds of the aquifer's water (Yardley 2007). In the past, China has maintained a policy of being self-sufficient in its wheat production, but growing grain uses vast amounts of water, and the agriculture of the northern plains is causing the government to consider how to allocate water among municipal, industry and agriculture uses. Some scientist predict that the aquifers beneath the North China Plain will be drained within 30 years (Yardley 2007).

China and the U.S. both support world-class economies. However, when it comes to water, China has almost 5-times as many people as the U.S. but a much smaller water supply. Worldwide, China has 7 per cent of the world's water resources and roughly 20 per cent of its population (Yardley 2007).

U.S. Agriculture and Groundwater

In the U.S., some of the most productive agricultural land depends on irrigated crops using water from aquifers. However, these aquifers are being "mined" for agriculture at rates that exceed the recharge rate, leading to their depletion.

The Ogallala Aquifer that stretches across the U.S. mid-west, running from South Dakota, down to New Mexico and Texas, is being pumped at many times the natural replacement rate, leading to a drop in the water table of hundreds of feet (McGuire 2001). Lester Brown (2008 69-70) notes that when fossil aquifers like the Ogallala, and the North China Plain are depleted, pumping will cease and so will agriculture.

The connection between water and food is an important one. Average human water consumption is about 4 liters per day in one form or another. By comparison, the water needed to produce our daily food consumption is approximately 2,000 liters or 500 times as much (Brown 2008 69). As for the Ogallala, more than 90 per cent of the water pumped from it is used irrigation. "Crops that benefit from the aquifer are cotton, corn, alfalfa, soybeans, and wheat. These crops provide the Midwest cattle operations with enormous amounts of feed and account for 40 per cent of the feedlot output in the U.S. Since the advancement of agricultural irrigation in the earlier part of the 20th century, the Ogallala has made it possible so that states such as Nebraska and Kansas can produce the large quantities of grain required to feed livestock" (Guru 2000 1)

Nationally, agricultural irrigation is the largest user of water, representing 40 per cent of all freshwater used per year. By comparison, municipal public water supplies use only 13 per cent of the freshwater annually in the US (USGS, Water Q&A).

Sea Level Rise and Aquifers in the U.S.

The most populated areas of the U.S. are along the coastlines: the East Coast (Atlantic Ocean), Gulf Coast (Gulf of Mexico) and the West Coast (Pacific Ocean). Coincidentally, groundwater is an important water source for many coastal communities. These aquifer systems are increasingly vulnerable to climate change-induced sea level rise. A study by researchers at Ohio State University found that "rising sea levels could swallow up to 40 per cent more potable groundwater than previously thought..." (*Times of India* 2007). The Ohio researchers found that "in many coastal regions sea water will leach into the water table and contaminate groundwater well beyond the shoreline... In most studies, people say if the coastline recedes 100 meters then freshwater recedes 100 meters" (ibid). According to Motomu Ibaraki, the Ohio State professor who designed the computer model used in the study, "our study shows that it's going to be extended (up to 40 per cent) more by the mixing process" (ibid). Ibaraki also noted that "the amount of water we have on earth is constant. However, the amount of fresh water we can use is decreasing" (ibid).

The aquifers of Florida which underlie the entire state are being ruined by a combination of drought, over-pumping, contamination and saltwater intrusion (Sutherland 2002). Facing a drought that has extended through multiple years (2000-2008), emergency rules are now in place to limit water use (Florida Department of Environmental Protection, 2008). These rules include limits on lawn irrigation (2-days per week), golf course irrigation limits, prohibitions on withdrawals from certain Lakes, and limitations on diversion of water from certain rivers, many of which are flowing at historically low levels. The State also instituted emergency orders on the standards applied to drinking water quality for total dissolved solids, chloride, sulfate, pH, and sodium that will continue in effect at least until December 31, 2008 (ibid.).

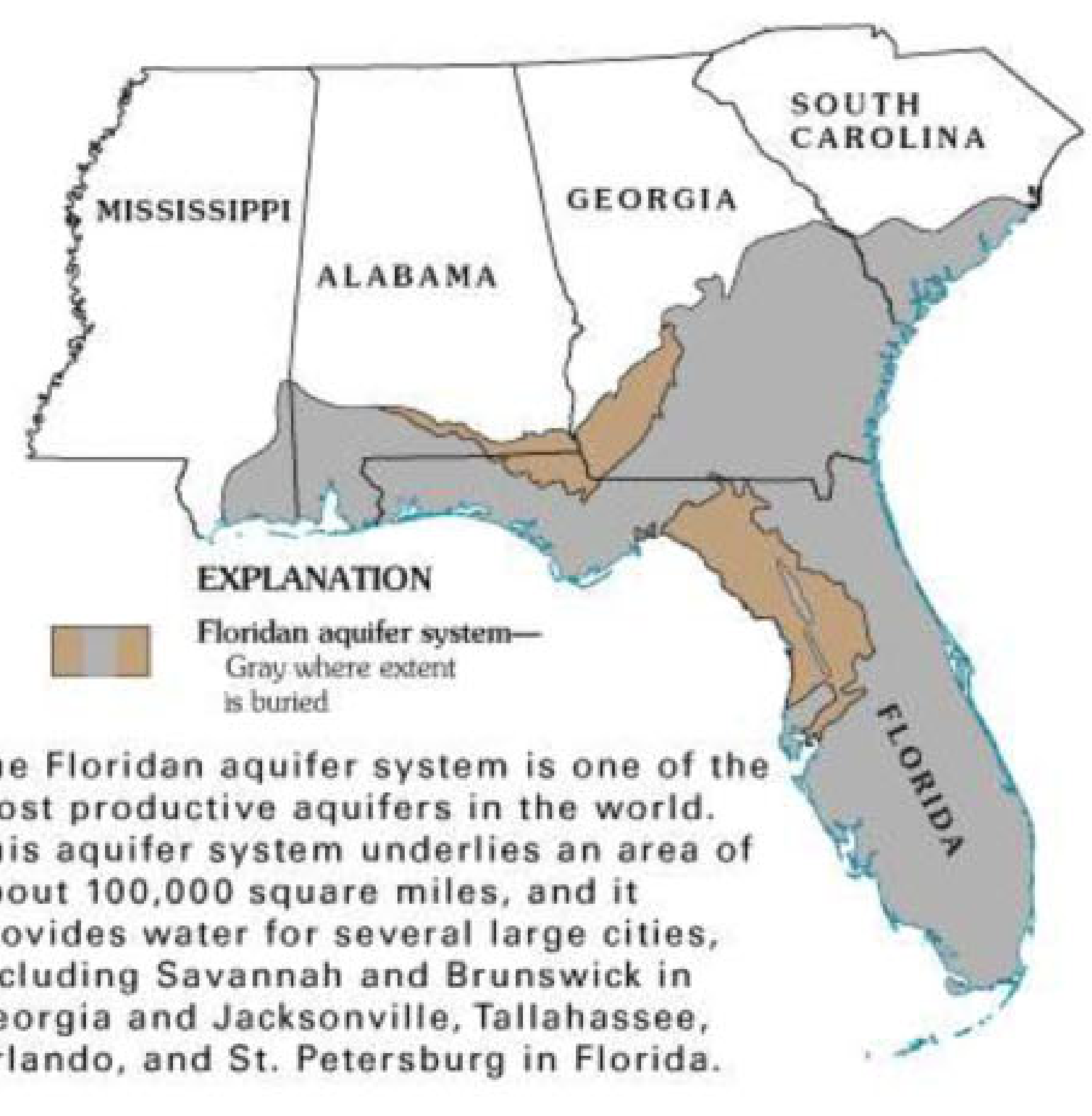

Figure 1: The Floridian Aquifer
Source: USGS

As a consequence of the extensive and severe problems of water sufficiency and quality, Florida has the distinction of having the largest concentration of desalination plants in the U.S. Ninety-three percent of Florida's 16 million residents rely on groundwater as their drinking water supply (Sutherland 2002). Faced with long-term water problems, studies and public opinion polls show strong public support (up to 70 per cent) for pumping water from outside the Tampa region as a substitute to continued reliance on local groundwater (ibid). Such a move could lead to serious competition for contested water supplies among different communities in Florida when cities can not afford to produce all their water needs through local wells and desalination.

Why Do Aquifers Matter?

Aquifers are important because they hold the bulk of freshwater available for terrestrial use on the planet. Conditions that impair or deplete the freshwater in aquifers present a serious risk to communities that will depend on aquifers in the future.

The time frames in which surface water systems and groundwater systems operate are substantially different. Surface water systems such as streams, lakes and rivers, typically move water through the hydrologic cycle in days, months or a few years. Major aquifers, by comparison, hold and move water through their systems in a time frame usually measured in decades, centuries or millennia. Where a groundwater and a surface water system meet, such as the bed of a stream, the stream can be a "gaining" or "losing" water body. A gaining stream receives additional water from a connected aquifer, thus increasing its flow volume. A losing stream loses water through the stream bed into an aquifer, diminishing the volumetric flow of the stream. This water can recharge the aquifer below.

When droughts strike, surface water bodies are impacted first. The response to low or no recharge will take longer to be reflected in a groundwater system. Once the drought ends, it takes an aquifer's water table longer to rebound to its pre-drought levels than it does a surface water system to recover. Depending on the degree of depletion, the groundwater system may not fully return to its earlier level. This is especially true where there is a large distance between recharge areas and the point of water withdrawals. Also, where aquifers are already stressed due to consumptive use from human activity, recharge is rarely able to replace all the lost water and return the aquifer back to its pre-drought condition.

The issue of time is reflected in another way in an aquifer system. Recharge, the process of adding water to an aquifer, is usually not a continuous process. Recharge occurs in intervals or slugs of water, usually after a substantial precipitation event. But, even after a rain storm, recharge may substantially stop or decrease during the spring/summer growing season when plants are actively taking up water. Plants tend to capture much of the water, depriving the aquifer of recharge from the typical summer rain storm.

As climate change progresses, precipitation patterns and storm intensity are likely to change. When rain becomes concentrated in strong storms where runoff is increased, the total amount of recharge available to aquifers may not be significantly enhanced because the water moves off the land too quickly. The soils become saturated making it harder for additional water to be accepted into the soil and percolate into the aquifer.

A drought deprives an aquifer of replenishing recharge. Major land areas have experienced drought in the past decade. China, Australia, Spain, Turkey, the U.S. west, southwest and southeast are just a few examples where low rainfall has been documented since the beginning of the 21st century.

Perhaps the most important reason why aquifers matter is because as surface water sources dry up, more communities will turn to aquifers for water. Aquifers will become the water supplies of last resort. This is already occurring in Australia. Thus, aquifers will need to be protected and managed for those users presently relying upon them as well as the water supply for communities that traditionally have used other sources. This competition for aquifer water is already playing out in areas like Jordan, Israel and the Golan Heights (Rogers 2008).

Aquifer Management and Protection in the U.S.

In the U.S., an early effort highlighting the need to protect aquifer systems came with the enactment of the Federal *Safe Drinking Water Act* of 1974 (Sec. 1424(e) of the Safe Drinking Water Act of 1974). This national legislation was mainly intended to ensure that public drinking water systems in the U.S. all met the same minimum standards for quality. It was a public health measure. For groundwater dependent communities, if an aquifer provided over 50 per cent of a municipality's water supply, the Safe Drinking Water Act allowed these aquifers to be given the special designation of "**sole source aquifers**." Since the first four Sole Source Aquifers were designated in 1978, 75 aquifers had received the designation by 2008.

The original purpose of the Sole Source Aquifer designation was to require that extra level of environmental review be given when federal projects were proposed over sole source aquifers so that the projects would not have the unintended consequence of damaging the aquifer. The US Environmental Protection Agency (US EPA), often in collaboration with a local agency, can conduct Sole Source Aquifer reviews.

Sole Source Aquifer Designation and Review as established by the Safe Drinking Water Act.

"If the Administrator [of the US EPA] determines, on his own initiative or upon petition, that an area has an aquifer which is the sole or principal drinking water source for the area and which, if contaminated, would create a significant hazard to public health, he shall publish notice of that determination in the Federal Register. After the publication of any such notice, no commitment for federal financial assistance (through a grant, contract, loan guarantee, or otherwise) may be entered into for any project which the Administrator determines may contaminate such aquifer through a recharge zone so as to create a significant hazard to public health, but a commitment for federal assistance may, if authorized under another provision of law, be entered into to plan or design the project to assure that it will not so contaminate the aquifer" (Public Law 93-523).

Beyond the Sole Source Aquifer designation, important aquifer areas can be managed or protected by special management and control districts, similar to the function of River Basin Commissions. In riverine systems running through multiple jurisdictions, such as rivers that run through several states, or across international boundaries, a River Basin Commission will ensure that the entire river system is protected and managed for all the users along its course. Each state in the river basin is represented on the Commission's governing board but day-to-day operations are handled by a staff of professionals. The Commissions often conduct studies to better understand and protect the rivers, undertake planning and management activities, and can set allowances with built-in safety factors for water withdrawals among the users. The goal is to provide an equitable division of the water for all stakeholders. In this context, stakeholders include the fish, wildlife and the ecosystem of the river as well as humans interested in the water.

In parts of the U.S., a similar entity may be given jurisdiction over an aquifer system, whether or not the system crosses state boundaries. Like River Basin Commissions, the aquifer districts are intended to provide professional expertise for management of the aquifer by carrying out studies, determining safe levels of withdrawal and allocating water drawn from the aquifer.

Edwards Aquifer Authority

To demonstrate that this approach is respected and effective, a few examples from the U.S. are presented. In Texas, for example, where government regulation is not taken lightly, there is an aquifer management district for the important Edwards Aquifer that supplies water for areas between Austin and San Antonio. The **Edwards Aquifer Authority** "began operation in 1996 as a 'conservation and reclamation district' to manage the southern portion of the Edwards Aquifer..." (Edwards Aquifer Authority 2003). Its mission statement reads, "[T]he Edwards Aquifer Authority is committed to manage and protect the Edwards Aquifer system to ensure the entire region of a sustainable, adequate, high quality and cost effective supply of water, now and in the future" (ibid. 1).

The specific duties of the Authority as established in the enabling legislation are to:

$ protect the water quality of the aquifer;
$ protect the water quality of the surface streams to which the aquifer provides streamflow;
$ achieve water conservation;
$ maximize the beneficial use of water available for withdrawal from the aquifer;
$ protect aquatic and wildlife habitat;
$ protect species that are designated as threatened or endangered under state or Federal law;
$ provide for instream uses, bays and estuaries;
$ protect domestic and municipal water supplies;
$ protect the economic development of the State;
$ prevent the waste of water from the aquifer; and
$ increase recharge of water to the aquifer (ibid 1-2).

To meet these objectives, the Authority established an annual withdrawal cap from the aquifer of 450,000 acre-feet through the year 2007. The permitted withdrawal was then reduced to 400,000 acre-feet per year.

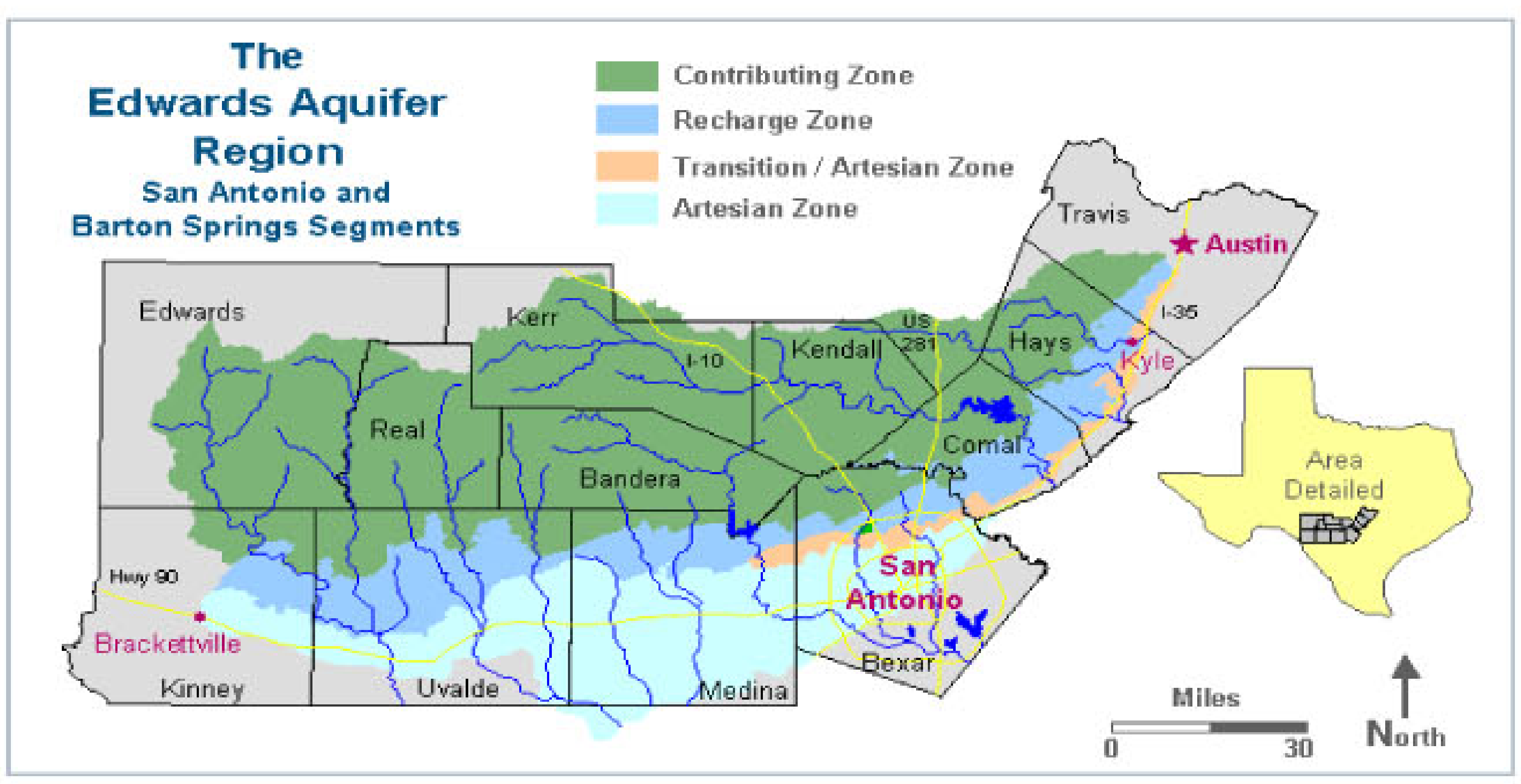

Figure 2: The Edwards Aquifer Region of Central Texas
Source: www.edwardsaquifer.net

Ogallala Aquifer Conservation Districts

Another well-known example of the district management approach is the assorted districts that oversee water taken from the Ogallala Aquifer. As the largest aquifer in the U.S., it is crosses beneath eight states in the middle of the U.S.: South Dakota, Wyoming, Nebraska, Colorado, Kansas, New Mexico, Oklahoma, and Texas. This area, often referred to as the High Plains, contains one-fifty of all cropland in the nation (Guru 2000). Four states in particular (Texas, Colorado, Kansas and Nebraska) have been very active in exerting management controls over their part of the resource. In Texas, the **High Plains Underground Conservation District #1** controls aquifer withdrawals within 15 counties.

Figure 3: The Ogallala Aquifer Area Occurs Beneath 8 States. The Ogallala Aquifer (shaded area) is in a state of overdraft owing to the current rate of water use. If withdrawals continue unabated, the aquifer could be depleted in only a few decades.
Source: www.waterencyclopedia.com/Oc-Pc/ogallala-Aquifer.html

The management efforts for the Ogallala Aquifer include strategies to reduce pumpage, to change agricultural practices and to increase recharge.

Florida Groundwater Management

There are five water management districts in Florida. One example is the **Southwest Florida Water Management District** which serves the Tampa area along the Gulf coast of Florida. The recent drought has made the Districts' role especially important since the aquifers provide nearly 90% of the drinking water for Florida.

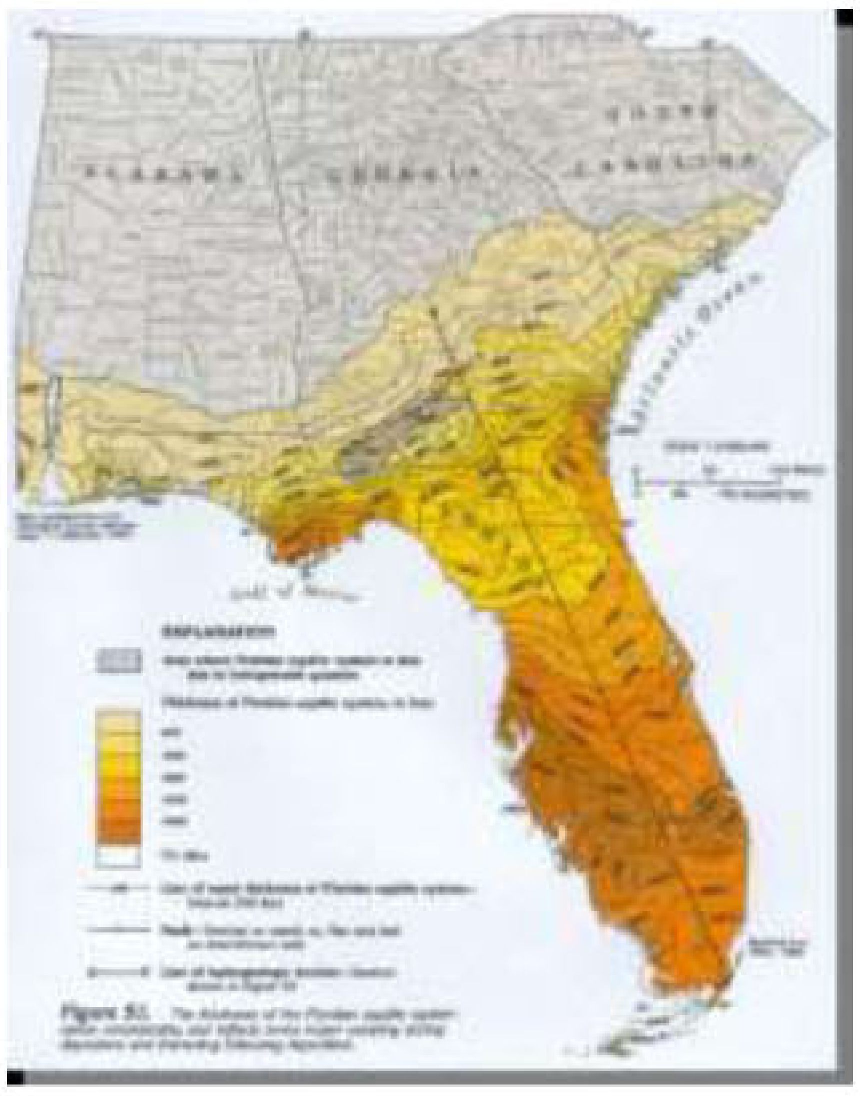

Figure 4: The Floridian Aquifer
The formation lies beneath four states: South Carolina, Georgia, Arkansas and Florida.
Source: USGS

Cape Cod, Massachusetts
Groundwater management takes a slightly different form in Cape Cod, Massachusetts. There, the 15 towns in Barnstable County, Cape Cod, use the services of the **Cape Cod Commission**. This land use and planning agency oversees many aspects of landuse, development, planning and resource management and protection. Specialized responsibility areas are organized into individual offices. The Office of Water Resources, with a staff of 4 specialists, has a mission set forth in the Regional Policy Plan:

$ to maintain the overall quality and quantity of Cape Cod's groundwater to ensure a sustainable supply of high quality untreated drinking water and to preserve and improve the ecological integrity of marine and fresh surface waters;
$ to protect the public interest in the coast and rights for fishing, fowling and navigation, as well as to preserve and, where appropriate, expand public access to the shoreline; and
$ to limit development in high-hazard areas in order to minimize loss of life and structures and the environmental damage resulting from storms, natural disasters and sea-level rise (Cape Cod Commission).

The Critical Role of Groundwater Management Districts
The real value of Groundwater Management Districts is that they represent an established management agency authorized for the sole purpose of being the professional overseer of a critical resource. A district can carry out four important management functions and provide consistent, impartial management oversight and protection. Once the goal is articulated for a district, it can carry out its four main functions which are to:

1. develop the necessary scientific and technical understanding needed to establish management policies and to make changes over time as research and science supports; studies can include evaluations of climate change impacts;
2. develop the necessary regulatory procedures to implement and enforce the management program, including the equitable allocation of water among the recognized stakeholders;

also, set a safe reserve for the ecosystem needs;

3. establish the long-term requirements necessary to protect the resource, while allowing it to be managed sustainablly; and

4. provide regular reports, summarizes, updates, and public education meetings and materials to ensure that the public and the elected officials in the area know and understand the short-term and long-term conditions of the aquifer, the risks to it, and the need to remain vigilant.

Long Island: A Case Study

While many aquifers in the U.S. may be protected or regulated by a management district, some important ones are not. A notable aquifer missing comprehensive protection is one of the best studied groundwater systems in the country, the Long Island, New York aquifer system. This water resource consists of a sequence of three geological formations which together provide all water to the 3 million residents of Nassau and Suffolk Counties and a portion of Queens County. No water is moved from the New York City water system to Long Island or vice versa.

Figure 5: Long Island, New York

Source: NOAA

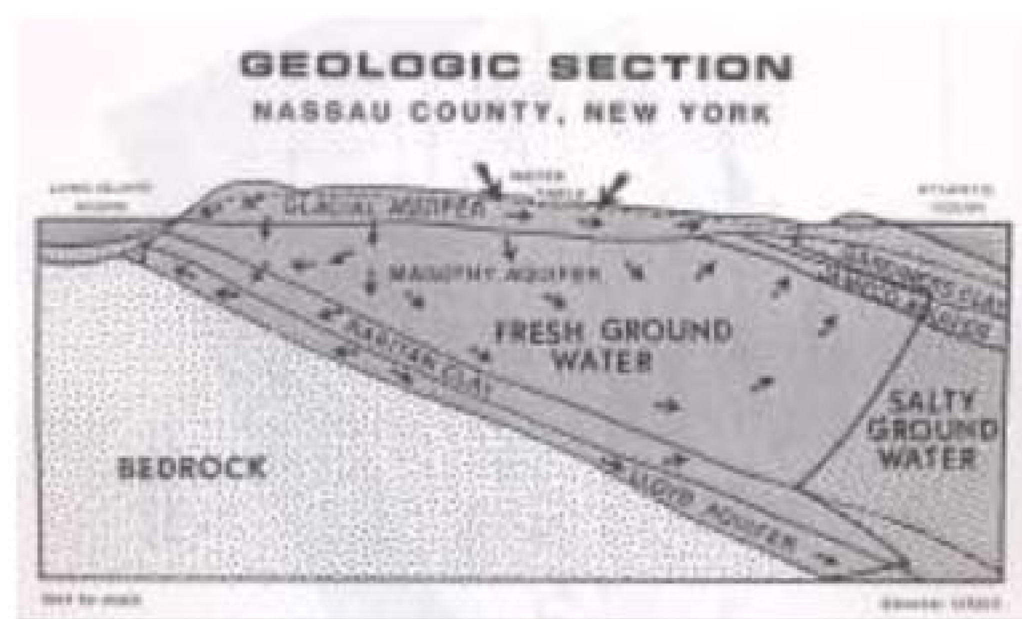

Figure 6: The Aquifer System of Long Island
Source: USGS

Long Island, New York is the largest island in the continental US. The Long Island Aquifer System was one of the first four designated Sole Sources Aquifer in 1978. Forty years later, the aquifer system is still without comprehensive oversight. Various state laws have provided partial protection to portions of the aquifer but taken as a whole, there is no day-to-day oversight or management of the resource. Beyond the granting of well permits by the New York State Department of Environmental Conservation, and the periodic inspection of certain pollution sources by health agencies, the aquifer system is left to its own fate. Although a number of plans, studies, and controversies have marked the troubled history of the groundwater system, the aquifer today is more vulnerable than ever. Portions of the aquifer are quantity-stressed although no regulatory action is presently underway.

The list of problems experienced by the Long Island groundwater supply is long and growing. Documented problems with the water supply and the Island's hydrologic system include the following:

$ over-pumping and a drop in the water table over time in major portions of the aquifer;

$ saltwater intrusion beneath highly populated sections of the coastline;

$ the loss of stream flow where water tables have dropped below stream beds, turning the streams from gaining to losing streams;
$ a large number of toxic waste (superfund) sites that have never been fully remediated; and
$ the detection of numerous pollutants in a growing number of the 1,350 public supply wells across the Island; and
$ the potential risk to Long Island's groundwater from sea level rise is presently unexplored and unaddressed.

Some of the pollutants detected in the raw groundwater or in drinking water wells include:

a. nitrates
b. pesticides (herbicides, insecticides, and their degradation products) such as Aldicarb, Chlordane, Atrazine, metolachlor, cyanazine, and metalaxyl (Suffolk County Department of Health Services 2000)
c. toxic chemicals (trichloroethane, carbon tetrachloride, and similar solvents)
d. Trihalomethanes such as chloroform
e. radiological contaminants such as tritium, strontium, etc.
f. BTX, and MTBE (methyl teriary butyl ether) which are pollutants from gasoline spills
h. perchlorate
i. pharmaceutical and person care products such as drugs, caffeine, pain killers, DEET insect repellant, flame retardant chemicals (some only in groundwater and not yet in wells)
j. chlorides from saltwater intrusion (New York State Department of Health 2003).

The long list of pollutants detected in the groundwater and the changes occurring to the hydrologic system due to over-pumping should be causing alarm among Long Island resident. However, without the benefit of a multi-jurisdictional, groundwater management agency to regulate users and educate the public, most Long Islanders believe that the water supply will be sufficient far into the future, hundreds of years from now. This is partly because they know little about the actual details of what is happening such as how much water is annually pumped from the aquifer, how much more pumpage the aquifers can safely support, the trends of water table decline, the changes in saltwater intrusion, or other essential benchmarks of aquifer health. The U.S. Geological Survey stated in a 2005 study that, "no method is currently available that can assess data from Long Island's groundwater monitoring [well] network to provide Federal, State and local agencies with timely warnings of severe water-level declines"(USGS 2005).

Although Long Island residents can read stories in the *New York Times* or from the Internet about water problems in China, Australia, or Israel, there are rarely reports about their own water supply that go beyond a local controversy. One major water utility has fostered public complacency by repeatedly claiming, incorrectly, that the aquifer could be pumped for hundreds of years, even if recharge stopped completely. The presence of a regional Groundwater Management Agency could help dispel must misinformation. For now, the public and their representatives continue to be unaware and unmotivated to protect or manage their sole source aquifer.

Conclusion

Worldwide, there is a growing acceptance that freshwater supplies are and will continue to be under increasing stress. Population growth, increased water demand, pollution and changing climate conditions all will play a role in creating stress. Great concern is being expressed for regions of the world where water is already scarce or water resources are being rapidly depleted. Nations and international organizations are stepping up efforts to grapple with what is widely described as a global water crisis. One way to help respond to this awareness is to create management agencies that have the primary responsibility of controlling and managing high priority water sources, including aquifer systems.

Unlike surface water that can be directly observed and easily monitored, aquifers are a hidden resource. Their waters are harder to track and their processes harder to understand and regulate. But because aquifers store the bulk of the earth's liquid freshwater and form an important part of many regional water systems, aquifers must be better defined, managed and protected. They are important today and they may be one of our last options for reliable water supplies in the future. Assorted groundwater management models exist and are working today. Their use should be expanded to protect all significant aquifer systems.

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