CONJUNCTIVE USE OF WATER ON THE TEXAS HIGH PLAINS

Otis W. Templer
Professor of Geography
Department of Economics and Geography
and
Lloyd V. Urban
Professor of Civil Engineering and
Director, Water Resources Center
Texas Tech University

INTRODUCTION

On the semiarid, water-short Texas High Plains conjunctive use is practiced with water from these sources: 1) groundwater in the dwindling Ogallala aquifer, 2) runoff water accumulating in the thousands of small playa lakes that dot the High Plains, and 3) the meager flow of the streams rising in or crossing the area. The Ogallala aquifer has long provided most of the water used for irrigation and it was the only source of municipal water supply for virtually all High Plains communities until the late 1960s. Most local runoff flows to shallow playa lake basins. Though playas are the chief source of recharge to the Ogallala aquifer, most of the water they store evaporates. Lake Meredith on the Canadian River is the largest of the few reservoirs on the High Plains.

Nineteen High Plains towns and cities, including Lubbock and Amarillo, receive most of their water supply from municipal water authorities or districts that distribute the waters of Lake Meredith and the much smaller Mackenzie and White River reservoirs to a population of almost 500,000. However, most member cities continue to use preexisting groundwater reserves to improve the quality of or to supplement their water supply, and the Canadian River Municipal Water Authority is acquiring extensive groundwater rights to augment and improve the quality of the water it distributes from Lake Meredith. Also, many High Plains farmers make conjunctive use of groundwater and water from the playa lakes. Many of the lake basins have been modified to improve recharge, concentrate water for irrigation pumping, or to aid in tailwater collection. Playa water is used mainly to supplement irrigation water drawn from the Ogallala. Experiments have been conducted for several decades on increasing recharge to the aquifer with playa water, and historically this was done on a limited scale.

Though conjunctive water use is widely practiced on the Texas High Plains, the interconnections between surface and groundwater and the relationship to watersheds are much less direct and obvious than for some other hydrologic situations in Texas, such as the unique Edwards aquifer of the San Antonio region. An integrated management plan like that which may be imposed on the Edwards aquifer would probably be both unwarranted and unrealistic under the hydrologic conditions on the High Plains. Instead, a major, bottom-up regional planning effort has been initiated. In this paper, the authors 1) briefly summarize Texas law pertaining to the High Plains water resources used conjunctively, 2) provide examples of conjunctive water use by High Plains communities and the agricultural sector, and 3) discuss the regional water conservation and management plan being developed for the High Plains, which they conclude will provide an appropriate institutional arrangement under regional hydrologic conditions.

TEXAS WATER LAW AND HIGH PLAINS WATER RESOURCES

As previously noted, conjunctive water use on the Texas High Plains involves percolating groundwater in the massive Ogallala aquifer which underlies most of the region and is the major water resource, diffused surface water, and the flow of the few streams on the High Plains. Texas law is clear concerning the use and ownership of percolating groundwater. The absolute ownership doctrine was established in the famous case of *Houston and T. C. Ry. Co. v. East* (1904). Under this doctrine, landowners can pump and use the groundwater beneath their property with little regulation. A few subsequent court decisions have established that landowners can sell their groundwater rights, that underground water can be used either on the land from which it is pumped or elsewhere and that liability can be imposed where negligent pumping causes land surface subsidence, but the rule has not been modified to any significant degree. The major control over landowner rights is exercised by local underground water conservation districts (UWCDs) established under a 1949 general law or by special legislation. At present, there are some 40 UWCDs operating in Texas, covering all or large portions of most major aquifers. Most UWCDs have rather broad statutory powers to make and enforce rules for conserving, preserving, protecting, recharging, and preventing waste of groundwater. The most significant regulatory powers the districts enforce pertain to well-spacing and the off-farm waste of groundwater or tailwater (Templer, 1985; 1992). Several of the eight UWCDs operating on the High Plains are among the oldest and largest in the state. Recently, a study compared New Mexico's prior appropriation system and Texas' local district approach to groundwater management. It concluded that New Mexico's centralized system was in no way superior, that differences in depletion of the Ogallala aquifer were insignificant, and that the local district approach was probably more conducive to sustaining the region's economic base (Emel and Roberts, 1995).

Diffused surface water is drainage over the surface of a tract of land before it is concentrated in a streamcourse. It remains as such until it reaches a stream, percolates underground, or evaporates. In Texas, the right of landowners to intercept and use diffused surface water on their property is superior to that of adjacent landowners and to any holder of surface water rights on streams into which the runoff might eventually flow. Texas landowners can impound diffused surface water in small farm ponds or stock tanks without a permit from the state, but are subject to certain storage capacity and use limitations. Though Texas courts have never directly addressed the issue of playa lake water, it has been declared by state water agencies and established by custom and administrative acquiesence to be the property of the landowner (Templer, 1978; 1990).

With regard to the flow of streams, Texas is a dual-doctrine state, recognizing both the riparian doctrine, a complex blend of Hispanic civil law and English common law principles, and the prior appropriation doctrine, which was adopted before the turn of the century, for allocating surface water rights. Needless to say, state water agencies and water users experienced great difficulty in coordinating the diverse private and public water rights emanating from the diametrically different doctrines, which existed side by side on the same stream. However, a massive, recently completed, state-wide surface water rights adjudication, begun in 1969 to merge all unrecorded surface water rights into the permit system, has largely resolved this complex management issue (Templer, 1992).

Thus, private or landowner rights generally pertain to percolating groundwater and diffused surface water, and the state has appropriated the flow of rivers and streams. These diverse private and public water rights for the different legal classes have made the conjunctive management of closely interconnected water resources more difficult (Templer, 1980).

The primary water resource of the Texas High Plains, one of the state's and nation's most productive agricultural regions, is the Ogallala aquifer. The extensive Ogallala Formation underlies most of the area and the region's irrigated agriculture and many of its towns are almost solely dependent on groundwater pumped from this nonrenewable source. A large part of Texas' groundwater reserves, about 385 million acre-feet, is stored in the Ogallala (Knowles, 1984). Recharge to the aquifer is derived solely from infiltration of local precipitation and from runoff accumulating in the playa lake basins. Studies have estimated that recharge from diffused percolation occurs at fractions of an inch per year, while playas may contribute up to a few inches per year (Peckham and Ashworth, 1993). Natural recharge is relatively small when compared to total pumpage. Between 1940 and the present, withdrawals have ranged between four and eight million acre-feet per year. It has been estimated that irrigated acreage will decrease to about one-third its present level unless another source of water can be found. The period from 1980 to 1990, however, saw a marked change in the trend of declining water levels. In about 40 percent of the area, water-level rises were observed, and declines were much less than had been predicted. Above-average precipitation during only two or three years during the period combined with potential benefits offered by conservation programs and improved irrigation management practices have resulted in a much more optimistic outlook toward the future for the region.

Most of the limited surface runoff on the High Plains accumulates in the playa lake basins. These small depressions of interior drainage are a major relief feature on the otherwise monotonously flat region and form about the only semblance of a surface drainage network. An average-sized playa is said to contain about 16 surface acres (Guthery and Bryant, 1982). It is estimated that 19,000 to 20,000 of these basins are of sufficient size to collect and briefly hold a significant amount of runoff. Various estimates of runoff collecting in the playas range from 1.8 to 5.7 million acre-feet per year. An acceptable conservative figure of about 2 million acre-feet per year equals from about one-fourth to one-third the amount of water pumped annually from the Ogallala aquifer for irrigation. The playas also serve as the major source of natural recharge to the underlying Ogallala aquifer. Over most of the High Plains only 10 to 15 percent of the water percolates underground because of the relative impermeability of the lake bottoms. Because of the playa lakes' shallow depth and large surface areas, most of the water that the basins collect is lost to evaporation, especially during the peak precipitation seasons in spring and summer, when evaporation rates are particularly high (Templer, 1978). A major difficulty in relying directly on the playas for water supply is that it is impossible to predict when the lakes will contain water. The timing of playa filling also presents problems. Because they fill after significant rainfall has occurred, their water is not needed immediately for irrigation, again resulting in rapid evaporation. To be of much value for irrigation the lakes must be integrated with a more dependable water source, usually groundwater from the Ogallala aquifer (Templer, 1990).

Surface drainage patterns on the High Plains are very poorly developed and stream dissection is slight, with only a few shallow canyons, or draws, cutting back beyond the Caprock Escarpment into the eastern edge of the tableland, the spectacular Palo Duro Canyon in the Red River watershed being a notable exception. These eastward-flowing, intermittent stream channels provide about the only semblance of an external drainage system. Though several major Texas streams, in particular the Red, Brazos and Colorado rivers, have their headwaters on the High Plains, their upper basins usually provide little surface flow to the area east of the Caprock Escarpment (Templer and Urban, 1995b). Thus, it is apparent that opportunities to develop these local intermittent streams are quite limited. Lubbock's long delayed and still uncompleted Lake Alan Henry on a Brazos River tributary provides an excellent example of the difficulties of trying to develop the region's meager surface water sources (Templer et al., 1993; Templer and Urban, 1995a).

The exception to the generalization of limited surface flow on the High Plains is the Canadian River which rises in the mountains of northeastern New Mexico. It has a greater sustained flow than the rivers rising on the High plains, and its waters were apportioned among New Mexico, Texas, and Oklahoma in the early 1950s. In its 180-mile eastward path across the Texas Panhandle, the river has cut a broad valley or gorge 400 to 500 feet deep through the alluvium of the Ogallala Formation. This valley, often referred to as the "Breaks of the Canadian River," has rugged, dissected terrain unsuited to irrigated agriculture. Thus, as the only stream on the High Plains capable of large scale development, it became the focus of the U. S. Bureau of Reclamation's unique Canadian River Project which resulted in the impoundment of Lake Meredith in the mid-1960s. The Canadian River Municipal Water Authority (CRMWA) was created by the Texas Legislature to distribute water from Lake Meredith to 11 member cities, including Lubbock and Amarillo, the largest urban centers on the High Plains. The CRMWA water distribution system consists of 322 miles of pipeline and 10 pumping stations. It transports Canadian River water into the Red, Brazos, and Colorado River watersheds and is one of the longest and oldest interbasin water transfers in Texas (Templer and Urban, 1995b; 1996). Eight other High Plains communities are supplied with surface water from two much smaller reservoirs. The Mackenzie Municipal Water Authority draws its water from a small reservoir on Tule Creek, a Red River tributary, and serves four towns on the High Plains. White River Reservoir on a Brazos River tributary provides water for four other towns through the White River Municipal Water District.

CONJUNCTIVE WATER USE ON THE HIGH PLAINS

Urban Water Use

Most High Plains cities that depend primarily on water drawn from Lake Meredith or Mackenzie and White River Reservoirs use this surface water in conjunction with groundwater pumped from the Ogallala aquifer. Until the late 1960s, almost all cities and towns on the Texas High Plains relied solely on the dwindling Ogallala aquifer for their municipal water supply. A number of communities, especially Lubbock and Amarillo, which could no longer expand their local well fields began purchasing large tracts of land, in some cases long distances away. The objective of these purchases was not to provide additional land, per se, but to obtain the right of capture to the underlying water. Lubbock has acquired over 80,000 acres in the Sandhills some 60-70 miles northwest of the city, and in the less intensively developed northern High Plains, Amarillo has acquired over 163,000 acres of groundwater rights in adjacent counties. Nevertheless, once water deliveries from Lake Meredith began in 1968, the Canadian River became the chief component of urban supply for the 11 member cities of the CRMWA (Templer and Urban, 1995b; 1996).

Conjunctive use of surface and groundwater was contemplated during development of the Canadian River Project. The Project's purpose was to impound relatively low quality river water in Lake Meredith to blend with higher quality Ogallala groundwater to attain a water supply appropriate for municipal use and human consumption (Texas Dept. of Water Res., 1977). Thus, most CRMWA member cities have continued to utilize their existing groundwater wells for blending and to augment the supply from Lake Meredith during seasonal periods of peak usage. Recently, however, due to the slowly degrading quality of groundwater in some areas of the High Plains and more stringent limits imposed by the Safe Drinking Water Act, some smaller member towns in the south have been forced to depend on the supply from Lake Meredith to meet all their water demands (Templer et al., 1993).

The Canadian River Project has encountered some problems that promote conjunctive use, among them: 1) reduced inflow and storage in Lake Meredith, and 2) increasing salinity of the lake's waters. The first problem has forced the CRMWA to reduce water delivery to member cities for the past decade or so to 80 percent of their original annual allocations. Excess salinity has also required blending more groundwater to improve water quality. Both problems have caused CRMWA cities to use and deplete their nonrenewable groundwater reserves more rapidly (Templer and Urban, 1996).

In 1994, the CRMWA proposed an Alternate Water Supply Project to acquire groundwater rights to a large acreage in southwestern Roberts County, located in the Texas Panhandle east of Lake Meredith. This will allow the Authority to significantly augment and increase the amount of water supplied to member cities. All CRMWA member cities have agreed to pay their share of the estimated $81 million cost of this project. Ogallala groundwater will be pumped from the almost 43,000-acre Roberts County well field through a 40-mile-long pipeline to connect with the CRMWA's existing pipeline aqueduct. This project, which should be in operation in 1999, is expected to yield an additional 30,000 to 65,000 acre-feet of water per year. Roberts County was chosen over other potential groundwater sources because the supply there is expected to last from 35 to 50 years. An additional benefit of this conjunctive use will be that high-quality Roberts County groundwater will be blended with lake water in a 30-70 ratio, thus reducing salinity in addition to augmenting water supply (Kelley, 1995).

Lubbock provides yet another example of conjunctive water use. Some of the city's sewage effluent is used for irrigation on a nearby farm. The water table of the Ogallala aquifer under this farm is quite high due to percolation and reliance on wastewater rather than the Ogallala for irrigation. Lubbock pumps groundwater from the farm back to the city's northern edge to provide water for the Canyon Lakes, a chain of small recreational lakes in Yellowhouse Canyon (Headstream et al., 1976). In addition, some of the water is used to irrigate other public use areas.

<u>Agricultural Water Use</u>

The primary conjunctive water use by High Plains farmers involves pumping from the Ogallala aquifer supplemented by diffused surface water accumulating in the playa lake basins. At present, direct pumping for irrigation is the most efficient and feasible method of using playa water. In years past, much research focused on reducing evaporation losses and increasing groundwater recharge by modifying lake bottoms to confine accumulated water in smaller, deeper impoundments with less surface area (Dvoracek, 1981). Thousands of High Plains playas have been modified to improve water storage, and the number continues to increase. Also, tailwater, surplus Ogallala groundwater that collects at the end of irrigation furrows, is often collected along with runoff in the modified basins. It is less expensive to pump water back to the fields from playa level than from the Ogallala aquifer where the water table may be 200-300 feet beneath the surface (Templer, 1990).

For several decades experimentation continued over using playa water to artifically recharge the underlying Ogallala aquifer. It was thought that artificial recharge could stabilize and replenish groundwater supplies, eliminate the great loss of water to evaporation, and help reclaim low-lying playa basins from intermittent flooding. Jones and Schneider (1972) estimated that demand on the Ogallala could be reduced by almost 30 percent by direct pumping from the playas in combination with recycling irrigation tailwater and artifically recharging the aquifer with playa water. Most of this research was directed toward the use of injection wells; however, the problem of preventing or remedying clogging of the aquifer by sediment in the playa water remained (Valliant, 1975). An experimental method of recharge employing geotextile materials buried in the lake bottoms which filtered out sediment appeared to have good results (Urban and Claborn, 1984).

Though these recharge methods appeared to show promise for more effectively using playa water, artificial recharge experiments have been shelved due to water quality concerns. Recent studies showed that detectable levels of triazine herbicides or aldicarb insecticides may be present in playa waters (Mollhagen et al., 1993). While contaminant levels did not appear to be sufficiently high or in locations to present a significant risk to human or environmental health, the future of using playa water for artificial recharge remains uncertain because of legal constraints prohibiting water quality degradation in existing aquifers (Tex. Nat. Res. Cons. Com., 1995).

Recently, there has been considerable interest and research on the significance of playas as habitat for resident wildlife and migratory waterfowl, as well as on their recreational potential for hunting. A debate continues as to whether the kinds of direct use of playa water discussed above or the lakes' significance for wildlife habitat and recreation is of greater importance (Templer, 1990).

HIGH PLAINS OGALLALA AREA WATER MANAGEMENT PLAN

Water professionals in the region have recognized the need for long-range planning and have initiated a planning effort to augment and extend the Texas Water Development Board's biannual water plan. Officially titled the "High Plains Ogallala Area Water Management Plan," the study will cover 47 counties with a combined area of over 34,000 square miles. The mission of the study is to "develop, promote and implement water conservation and management strategies to provide adequate water supplies for the Ogallala Region of the High Plains of Texas and to stabilize or improve the economic and social viability and longevity of the region through these activities."

The plan will take both near- and long-term perspectives, address the entirety of the region, and specify various policy and implementation initiatives needed to support an improved water management future. Encompassing a 60-year study period (1990-2050), the plan will evaluate available resources and recommend water management strategies by county, individual municipal and rural county areas for seven standard classes of consumptive water use, including municipal, manufacturing, steam-electric cooling, mining, irrigation, recreation/wildlife, and livestock needs.

The planning effort will include the assessment of regional water demands and the availability of surface and groundwater resources to meet demands in the seven consumptive classes. After identifying deficiencies, the plan will identify water conservation measures to offset demands and propose management measures including improved systems operation, conjunctive use, secondary and groundwater recovery, reuse, and development of new projects to augment water supplies. Another important outcome of the plan will be the identification of state and federal institutional or noninstitutional policy initiatives that may be needed to better manage High Plains water resources.

Financial support for the planning effort has been attained through a contract with the Texas Water Development Board. The contract is administered through the High Plains Underground Water Conservation District No. 1 with additional management coordination accomplished through the Water Resources Center at Texas Tech University. The overall study is being accomplished through a 3-tiered structure consisting of 1) an overall Planning Group (approximately 120 members), 2) a Management Team (25 members), and 3) an Executive Committee (10 members). Membership in the various groups includes representatives of surface and groundwater districts and authorities, municipalities, agricultural producer groups, industry, research, education, and others. Study completion target date is December 1998.

CONCLUSIONS

In this paper, the authors have identified underground water, diffused surface water, and surface water in streams as the sources used conjunctively on the Texas High Plains. Also, they have summarized state water law pertaining to each legal class. Underground water and diffused surface water can be intercepted and used by private landowners and well-recognized private property rights pertain to them. Conversely, surface water in streams has been appropriated by the state and thus can be managed by the state in the public interest. These diverse private and public rights in closely interconnected water resources make coordinated management of the total resource difficult or impossible but may not preclude conjunctive use.

Unlike the closely interconnected surface and groundwater in the Edwards aquifer region, the hydrologic connections between the different water resources used conjunctively on the High Plains are not readily apparent. An example is the use of Canadian River water and Ogallala groundwater by CRMWA member cities such as Lubbock. Lake Meredith lies about 160 miles north of Lubbock and the city's groundwater reserves in the Sandhills are 60 to 70 miles northwest of the city. When groundwater from distant Roberts County becomes integrated into the CRMWA system this will expand the distance still farther. In addition, these water sources are located many miles apart from each other. The Canadian River does not provide recharge to the Ogallala well fields, nor does the aquifer contribute significant baseflow to the Canadian River or other High Plains streams or affect the water supply impounded in Lake Meredith. Thus, any hydrologic connections are quite tenuous. Though the playa lake water and Ogallala groundwater used conjunctively by High Plains irrigators is in close proximity, again the interconnections are not easily established. Pumpage from the Ogallala aquifer does not affect accumulation of surface runoff in the playas, and because such a high percentage of their water evaporates, direct pumping from the playas will not significantly affect recharge to the Ogallala aquifer.

It is apparent that these diverse and widely scattered water sources on the Texas High Plains do not need to be brought under a centralized management system imposed from the top down. To do so would surely infringe on established and well-recognized private property rights. Where it is legally, technologically, or economically feasible to make conjunctive use of the region's sparse water resources, local communities and the agricultural sector often do so, and such practices are actively encouraged by UWCDs and other local districts and authorities. Instead, a bottom-up strategy, such as that envisioned in the High Plains Ogallala Area Water Management Plan, involving input and management by a wide range of existing local entities seems destined to achieve the most flexible and appropriate institutional arrangement for the hydrologic conditions on the Texas High Plains.

REFERENCES

Dvoracek, M. J., 1981. Modification of the Playa Lakes in the Texas Panhandle. In: *Playa Lakes Symposium Proceedings.* U. S. Fish and Wildlife Service, Washington, DC, pp. 64-82.

Emel, J. and R. Roberts, 1995. Institutional Form and Its Effect on Environmental Change: The Case of Groundwater in the Southern High Plains. *Annals of the Association of American Geographers* 85(4):664-683.

Guthery, F. S. and F. C. Bryant, 1982. Status of Playas in the Southern Great Plains. *Wildlife Society Bulletin* 10:309-317.

Headstream, M. et al., 1976. *Recreational Reuse of Municipal Wastewater--Phase II.* Water Resources Center, Texas Tech University, Lubbock, Texas, WRC-76-2, 84 p.

Houston & T. C. Ry. Co. v. East, 1904. 98 Tex 146, 81 SW 279, Tex. Sup. Ct.

Jones, O. R. and A. D. Schneider, 1972. Groundwater Management on the Texas High Plains. *Water Resources Bulletin* 8:516-522.

Kelley, J., Canadian River Municipal Water Authority, 1995. Personal communication, February 27, 1995.

Knowles, T. R., 1984. Assessment of the Ground-Water Resources of the Texas High Plains. In: *Proceedings of the Ogallala Aquifer Symposium II,* G. A. Whetstone (ed.). Water Resources Center, Texas Tech University, Lubbock, Texas, pp. 217-237.

Mollhagen, T.R. et al., 1993. *Assessment of Non-Point Source Contamination of Playa Basins in the High Plains of Texas (Brazos Basin Watershed, Phase 1).* Water Resources Center, Texas Tech University, Lubbock, Texas, 23 p.

Peckham, D. S. and J. B. Ashworth, 1993. *The High Plains Aquifer System of Texas, 1980 to 1990, Overview and Projections.* Texas Water Development Board, Report 341, Austin, Texas, 34 p.

Templer, O. W., 1978. An Analysis of Playa Lake Water Utilization on the Texas High Plains. *Water Resources Bulletin* 14(2):454-465.

Templer, O. W., 1980. Conjunctive Management of Water Resources in the Context of Texas Water Law. *Water Resources Bulletin* 16(2):305-311.

Templer, O. W., 1985. Water Conservation in a Semiarid Agricultural Region: The Texas High Plains. *Forum of the Association for Arid Lands Studies* 1:31-38.

Templer, O. W., 1990. Diffused Surface Water Use on the Texas High Plains: A Study in Applied Legal Geography. *Papers and Proceedings of the Applied Geography Conferences* 13:44-52.

Templer, O. W., 1992. Hydrology and Texas Water Law: . . . A Logician's Nightmare. *Great Plains Research* 2(1):27-50.

Templer, O. W. and L. V. Urban, 1995a. Lake Alan Henry: Lubbock's Twenty-first Century Water Supply? *Forum of the Association for Arid Lands Studies* 10:57-64.

Templer, O. W. and L. V. Urban, 1995b. The Canadian River Project: A Quarter Century of Interbasin Transfer. In: *Proceedings of the Symposium on Water Management in Urban Areas*, Mark L. Loethen (ed.). American Water Resources Association, Herndon, Virginia, pp. 93-102.

Templer, O. W. and L. V. Urban, 1996. The Canadian River Municipal Water Authority: Urban Water Supplier for the Texas High Plains. *Forum of the Association for Arid Lands Studies* 11:50-58.

Templer, O. W., L. V. Urban and D. A. Hawkins, 1993. Municipal Water Supply Development for Lubbock, Texas: An Ongoing Quest. *Papers and Proceedings of the Applied Geography Conferences* 16:103-110.

Texas Department of Water Resources, 1977. *Continuing Water Resources Planning and Development of Texas.* Texas Department of Water Resources, Austin, Texas, v. p.

Texas Natural Resources Conservation Commission, 1995. *TNRCC Rules (Chapter 331, Underground Injection Control).* Texas Natural Resources Conservation Commission, Austin, Texas, v. p.

Urban, L. V. and B. J. Claborn, 1984. Recharge with Playa Lake Water and Filter Underdrains. In: *Proceedings of the Ogallala Aquifer Symposium II,* G. A. Whetstone (ed.). Water Resources Center, Texas Tech University, Lubbock, Texas, pp. 217-237.

Valliant, J., 1975. Opportunities for Artificial Recharge. *Texas Water Resources* 1:1-4.

Otis W. Templer received a J.D. degree from the University of Texas School of Law and his Ph.D. in Geography from the University of California - Los Angeles. He has taught at Texas Tech University since 1968. For the past three decades, he has investigated the legal, political, and geographic problems confronting water resource development, use, and management in Texas and the American Southwest. He has authored or edited over 80 publications dealing primarily with these topics.

Lloyd V. Urban received his Ph.D. in Civil Engineering from The University of Texas at Austin. His professional expertise lies in the areas of water resources, environmental engineering, and environmental impact analysis. His research activities include artificial ground water recharge, water conservation, and stormwater utilization in arid/semiarid areas, regional water resources management, and geologic and hydrologic site characterization. Currently, he is serving as Co-Chairman of the multiyear *High Plains Ogallala Area Regional Water Management Plan* project.