<p. 468>**Water Resource Management in the Texas MegaCity:**
A Prima Facie Case for Comprehensive Resource Management

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Abstract

The Texas-MegaCity is shaped as a triangle formed by Dallas in the North, Houston in the Southeast and San Antonio in the Southwest. This area contains three metropolitan areas that are each larger than a million residents with more than 13.2 million residents in the entire region. The Texas-Triangle is greater than 25,000 square miles and contains three of the top five fastest growing metropolitan areas in the United States. The triangle impacts nine river basins and five aquifers. While rainfall is adequate to support the population most of the time, recent years of drought have resulted in shortages, and some areas are dealing with this on an ad hoc basis. In addition to problems of water *quantity*, the potential threats to water *quality* are located in the same general area as the key sources of water. As the population grows in the Texas Triangle there is a clear need to manage water resources in a comprehensive manner. Currently, water resources are managed by multiple jurisdictions associated with municipalities, county governments, watersheds and aquifers, and even the state agencies that often take opposing points of view. This has led to an hoc management of existing resources, characterized by some promising approaches to water management. This paper concludes that to meet the needs of a rapidly growing MegaCity like the Texas Triangle, comprehensive, regional management of water resources will be required.

Introduction

This paper examines the nature of water resources in the Urban Texas Triangle. The Urban Texas Triangle is an area comprised of the geographic region delineated by the metropolitan cities of Dallas/Fort Worth in the north, San Antonio/Austin in the southwest and Houston in the southeast. This area (Figure 1) contains approximately 25,000 square miles and 13.2 million residents. This paper examines the geographic distribution of existing population, water resources and potential threats to the quality of water. While the co-location of the vital water resources with the population is <p. 469>understandable and expected, the co-location of potential threats to the quality of water is sufficient cause for early alarm.

The Urban Triangle as MegaCity

Population in the Urban Triangle was 13.2 million in 1998, with 9.2 million residing in the four primary metropolitan areas of Dallas/Fort Worth, San Antonio, Austin and Houston. The concentration of population is also allocated along the transportation corridors provided by the Interstate highway system, specifically Interstates 10, 35 and 45, which provide the southern, western and eastern boundaries of the Triangle. Figure 2 shows that both the current population and rate of growth in the population and the rate of growth in the population are distributed in the Texas Urban Triangle.

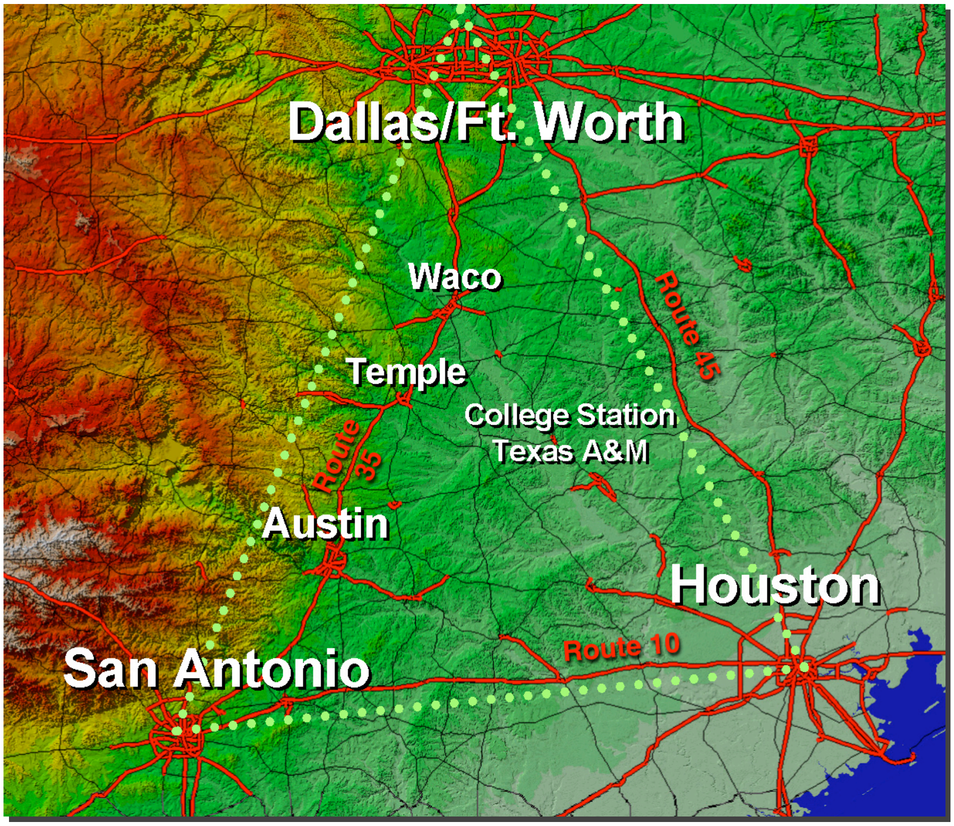

Figure 1. The Urban Texas Triangle

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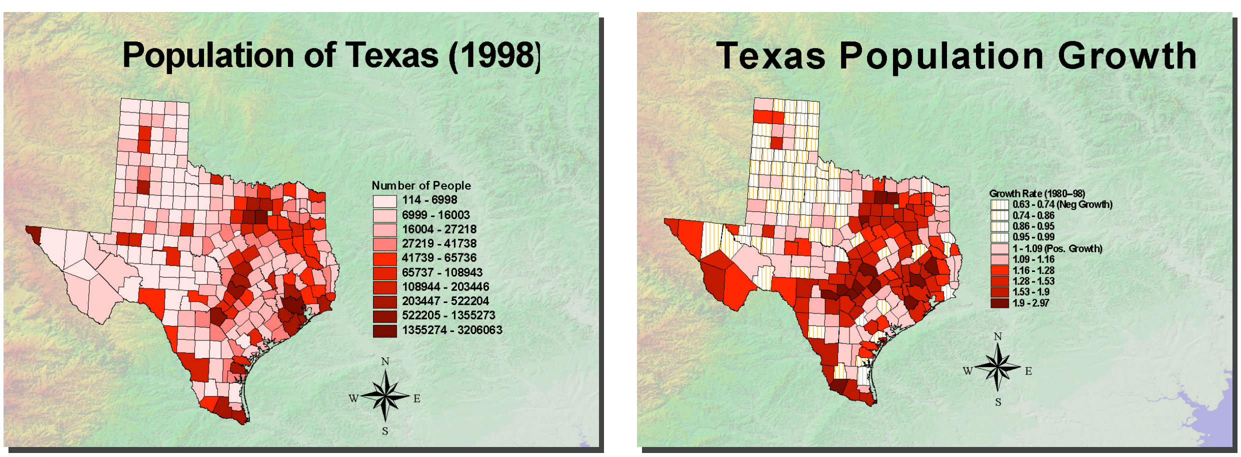

Figure 2. The Urban Texas Triangle is home to nearly half the population of Texas and is on of the fastest growing area in the United States (Texas State Data Center, 1998).

Examined over the last two decades, population in the Triangle has grown from 8.95 million to over 13.2 inhabitants. Three of the metropolitan areas in the Triangle are among the five fastest growing metropolitan areas in the United States: Dallas, Austin and Houston. Moreover, while the growth in population is relatively linear, averaging approximately 300,000 per year (2.2% growth annually), the proportion of population in the state of Texas residing in the Triangle has grown in a non-linear manner from 42 % living inside the triangle in 1990 to 45.7% in 2000 (Figure 3). The 1990 annual median income per capita in the Texas Urban Triangle is $24,113, while the annual income per capita in the rest of Texas is only $20,952 (US Census Bureau, 1990). Figure 4 shows the median income distribution across Texas. <p. 471>

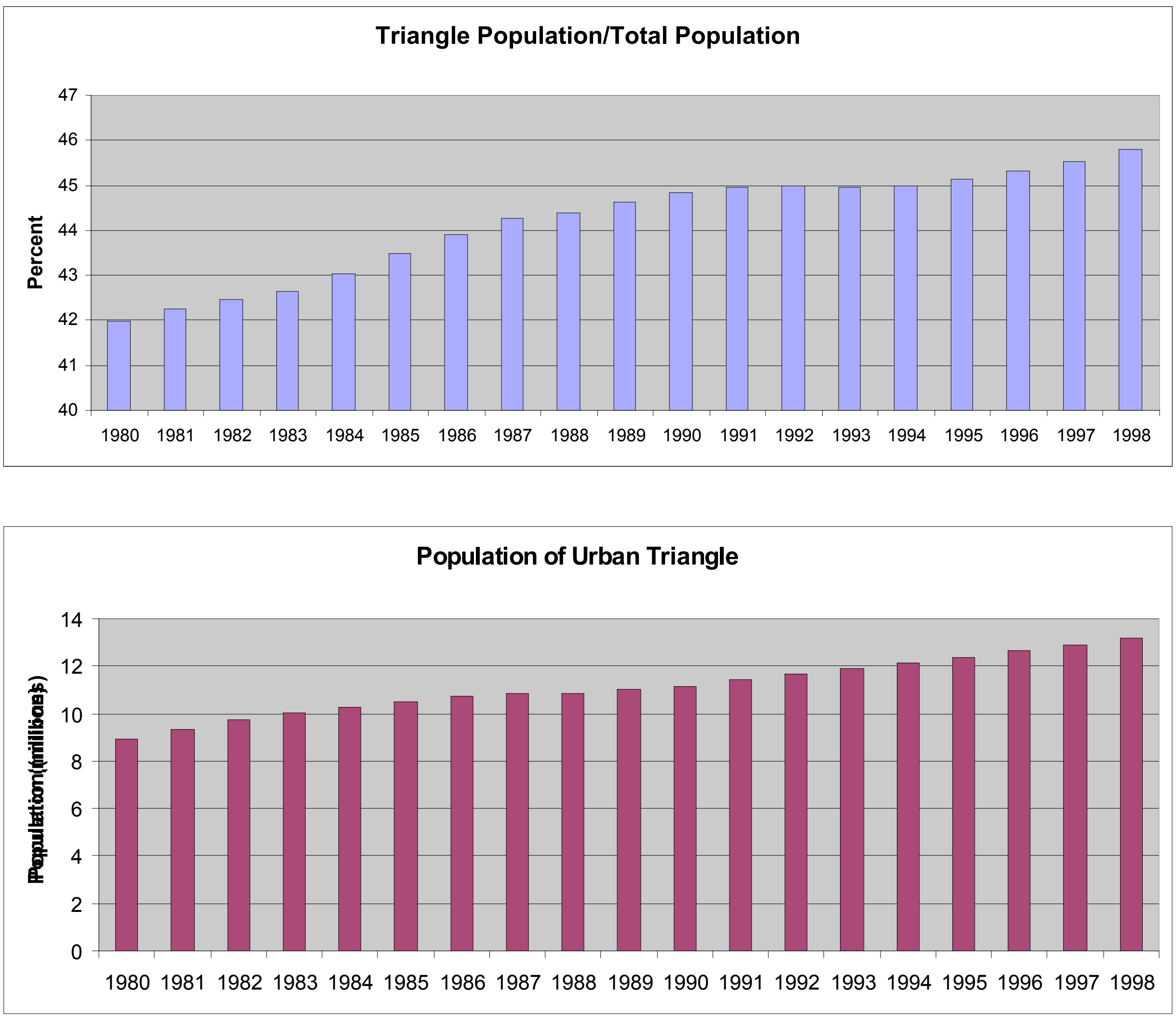

Figure 3. Comparison of population growth in the Texas Urban Triangle and the State of Texas (Texas State Data Center, 1998).

While the concentration of the population in the Urban Triangle is high in the metropolitan areas, much of the approximately 25,000 square miles in the Urban Triangle remains rural in nature. More importantly, the density in the metropolitan areas and along the transportation corridors has intensified with an average increase of 115 people/square mile over 18 years. The remainder of the state increased by an average of only 16 people/square mile over the same time period. Moreover, some of the most agriculturally productive lands in Texas Triangle are located along the transportation corridors and the urban/population development in the Triangle overlaps these areas. Figure 5 presents the spatial distribution of land uses in the Triangle. <p. 472>

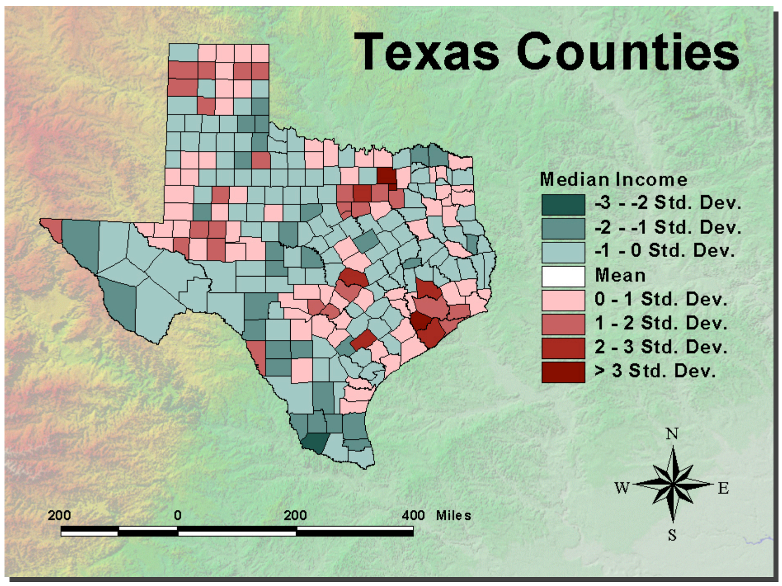

Figure 4. Distribution of median household income across Texas in 1990 (US Census Bureau).

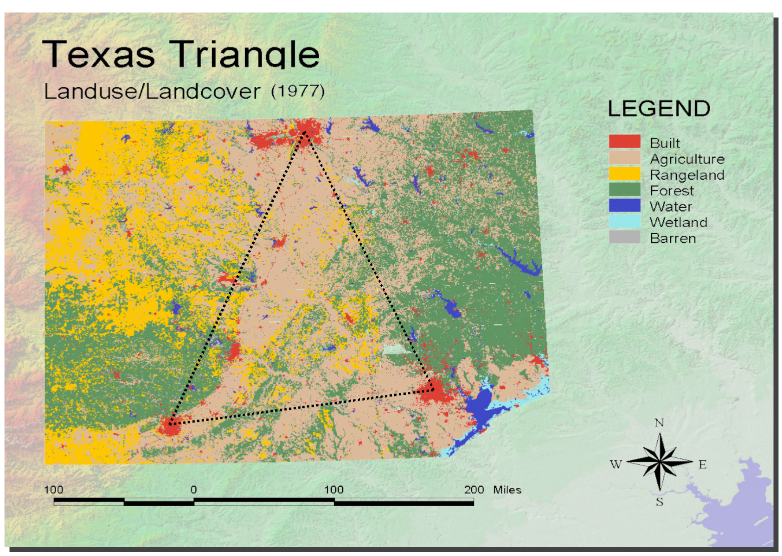

Figure 5. Land Use/Land Cover in the Urban Texas Triangle (US Geological Survey, 1977)

Methods, Measurement, Data, and Analysis

Data was acquired from numerous state and federal agencies such as the US Census Bureau, US Geological Survey, National Oceanic and Atmospheric Administration, and the Texas Natural Resources Information System. Socioeconomic data is aggregated at the county level while natural resource data was collected at scales appropriate for the phenomena being studied (generally 1:24,000 to 1:2,000,000). Whenever possible, the <p. 473>most recent releases of data are used in this analysis. However, some natural resources data are not collected on a regular basis and may be up to 25 years old or greater. Due to the diversity in methods of collecting the data used, they are not described in further detail here. Readers are urged to obtain available metadata records directly from the referenced agency.

Water Resources

Rainfall in the Triangle (Figure 6) averages 39 inches per year, ranging from 7 inches in the western portion of the triangle to 49 inches in the eastern and coastal regions of the triangle. This means approximately 55 million acre-feet of rain falls on the Triangle per year. If 64% is used for irrigation (Water for Texas, 1997, p. 3-1), and another 9.9% is used for manufacturing, approximately 25% are available for direct support of the Triangle's population in other ways. Put differently almost 14 million acre-feet of water are available to support the population. This means that if available water were allocated to support population at a rate of 325,000 acres-feet per capita, rainfall in the area would support approximately 40 million people inhabiting the Texas Triangle. This assumes single use of water but of course water can be used, cleaned, and re-used many times.

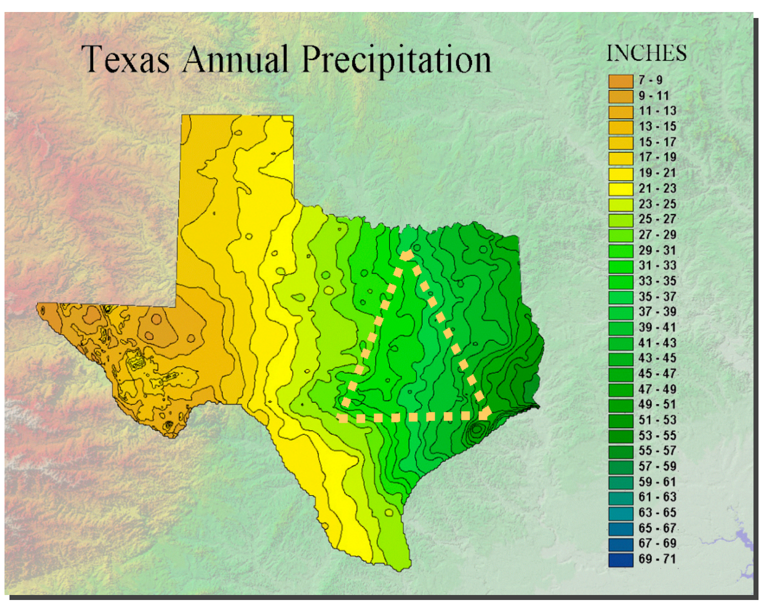

Figure 6. Texas annual precipitation inches (Source: NOAA).

The rainfall is collected in six river basins covering the Urban Triangle. The river basins are presented in Figure 7. Three major river basins in the Triangle include the Trinity River

Basin, running from Dallas/Fort Worth in the north to Houston in the southeast, the Brazos and Colorado River basin, running from New Mexico in the west to southwest of Houston. These three river basins account for 59% of the land area of the Texas Urban Triangle. <p. 474>

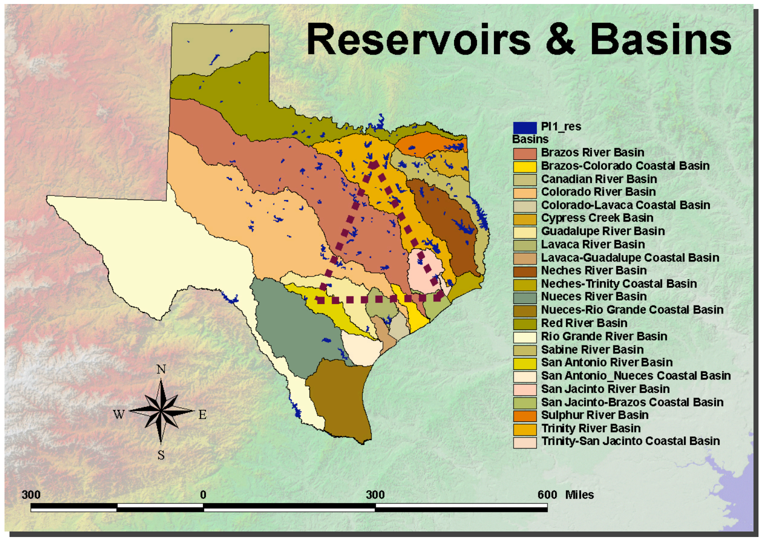

Figure 7. River basins and reservoirs in Texas (Source: Texas Natural Resources Information System)

There are four major aquifers in the Urban Triangle and a fifth aquifer of some significance (Figure 8). The northernmost aquifer is the Trinity Aquifer. The Trinity Aquifer runs from the Red River on the border with Oklahoma through Dallas southwestward to near San Antonio. The major use of the water contained in the Trinity Aquifer is for irrigation of agriculture. The Edwards Aquifer is the smallest, although not least important aquifer, in the Triangle. The Edwards Aquifer runs from the northeast of Austin, Texas to near the Rio Grande River (Mexican border). The water quality in the Edwards Aquifer is quite good, and is a major source of drinking water in Austin, Texas, in the northern part of the aquifer and used primarily for agriculture in the southernmost regions of the aquifer. The Carrizo Aquifer runs from the northeastern border with Arkansas to the southwest through San Antonio to the Mexican border at the Rio Grande River. Carrizo Aquifer water is used primarily for municipal water supplies (31%) and agricultural irrigation (81%) (Water for Texas 1997, p. 3.218). The Gulf Coast Aquifer is the southernmost aquifer in the area. It is geographically located from the border with Louisiana in the northeast through the Houston area to the Mexico border in the southwest. The Ogallala Aquifer is important, not because it is located in the Triangle but rather because, it is located at the uppermost portions of the major river basins that flow through the Texas Urban Triangle. To the extent it is used in the Texas Panhandle and allowed to flow into these basins, it is a potential issue impacting the Triangle. <p. 475>

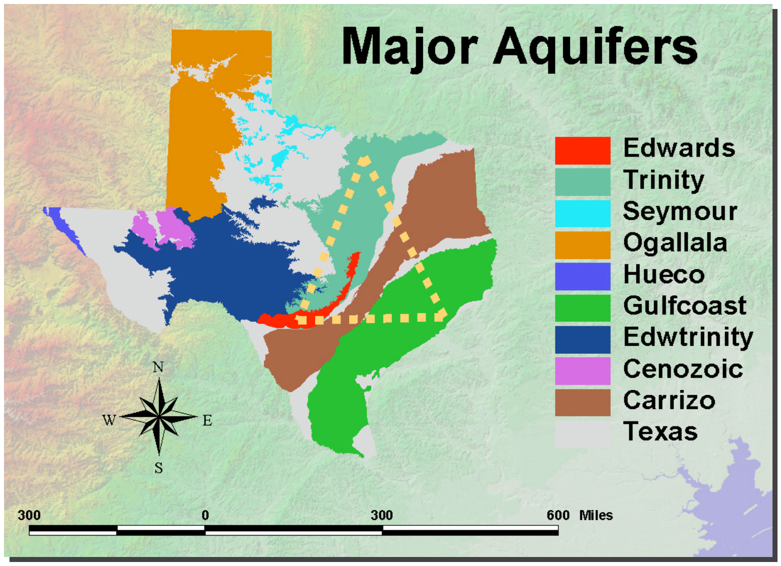

Figure 8. Major aquifers of Texas (Source: Texas Natural Resource Conservation Commission)

Threats to Water Quality

The potential threats to water quality considered are presented in Figure 9. There is no attempt to show how these potential threats are directly related to degradation of water quality in the paper. These data only show that some of the potential threats to water quality are located in the Urban Triangle. Moreover, we do show that the threats are concentrated in the areas characterized by the highest population and the fastest growing population areas of the Triangle. As would be expected the number of sanitation land fills is directly related to population concentrations, with there being about one landfill site per seven square miles in the Triangle and about one landfill site per 1100 square miles in the other areas of the state. (Figure 9a)

The concentrations of public water systems in the Triangle that exceed fecal coliform standards are generally located in those areas of the Triangle that have the highest concentrations of populations. (Figure 9b) This data on fecal coliform provide the most direct indication of some already existing contamination of water supplies in the Texas Urban Triangle.

Figure 9c presents some preliminary evidence that toxic releases have occurred in the Urban Triangle. Moreover, these releases are co-located with the production of hazardous materials and the population concentration of hazardous materials and the population concentrations of the Triangle. Figure 9d offers some preliminary evidence that emissions into the air are also concentrated in the Texas Triangle. The Dallas metropolitan has now (in 2000) met federal standards for emissions for automobiles. The Houston area has yet to meet these standards and has recently surpassed Los Angeles <p. 476>as the smoggiest city in the United States. These releases have been concentrated in the Urban Triangle in the same fundamental areas that produce hazardous chemicals, releases toxins to surface water and sewer systems, and where the population is located. Adjusting the size of releases and emissions by land area does not significantly alter the pattern reflected in the geographic distribution of the data.

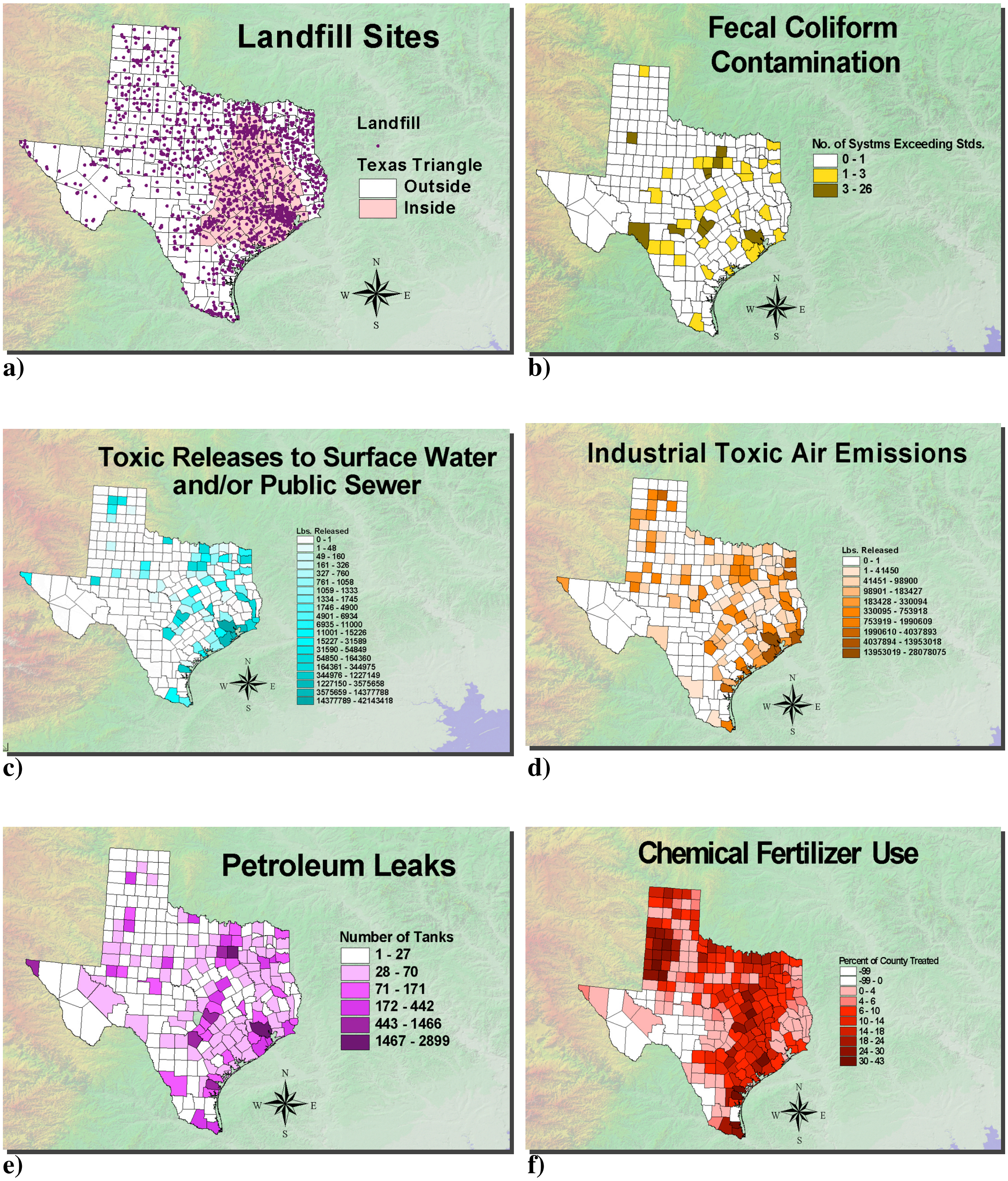

Figure 9. Threats to water quality (Texas Center for Policy Studies, 2000) <p. 477>

Figure 9e shows the geographic distribution of the number of leaks in petroleum tanks. All counties have reported leaks occurring within their boundaries. The familiar pattern of the

Texas Triangle once again emerges. As would be expected the number of leaks is spatially distributed with the residential population.

The geographic distribution of chemical fertilizer use is presented in Figure 9f. This data indicates that the application of chemical fertilizer is not only concentrated in the Texas Urban Triangle, but also in the areas upstream to the Triangle in both the Brazos and Colorado River basins.

Projections for the Future

This section of paper presents projections of population in the Texas Urban Triangle and uses those to project the usage of water on the basis of population. Figure 10 shows the projected population numbers, collected at the county scale from the Texas State Data Center and amalgamated to represent population in the Texas Triangle up to the year 2050. These projections indicate that the population will grow from 13.2 million in 1998 to 27 million in 2050 in the Texas Triangle. The pattern of water use seems to depend on population (Figure 11). Here, county level water use data was normalized by population and displayed to show the per capita water use spatial distribution.

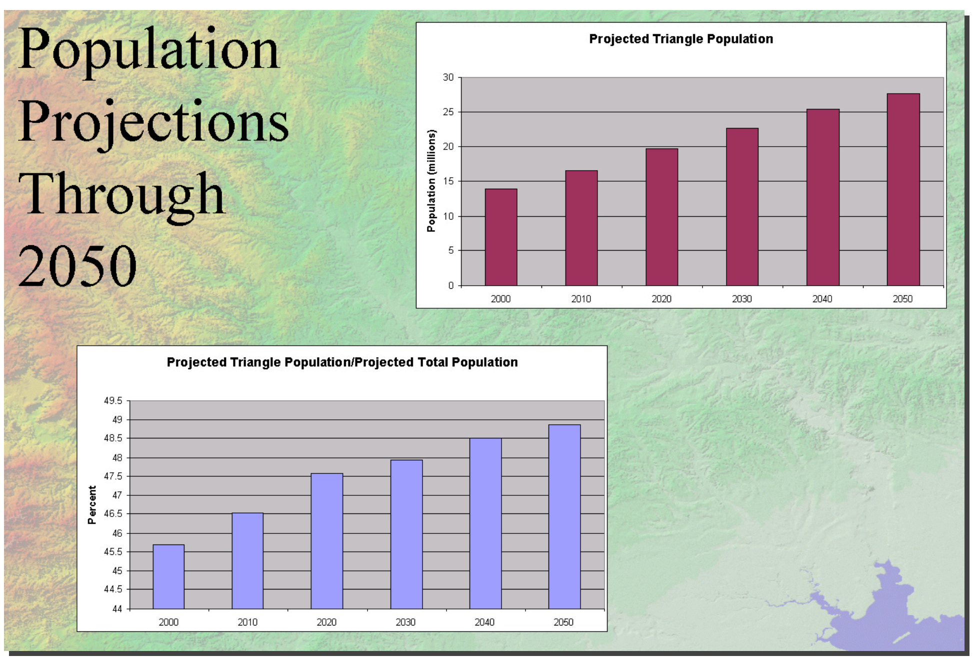

Figure 10. Texas Population Projections through 2050 (Source: Texas State Data Center)

Water use projections based on expected population means that water use will expand from 5 million acre-feet to 10 million acre-feet by the middle of the next century. <p. 478>The proportion of water use in the Urban Triangle is projected to expand from 21% to over a quarter or 26% of the State of Texas' use of water. This indicates that anticipated water use might be met without the need for recycling water. It becomes clear that without the consideration of recycled water resources the quantity of water is adequate for projected urban growth. Hence, water quantity and projected use alone does not seem to create a meaningful limit to development in the Texas Urban Triangle.

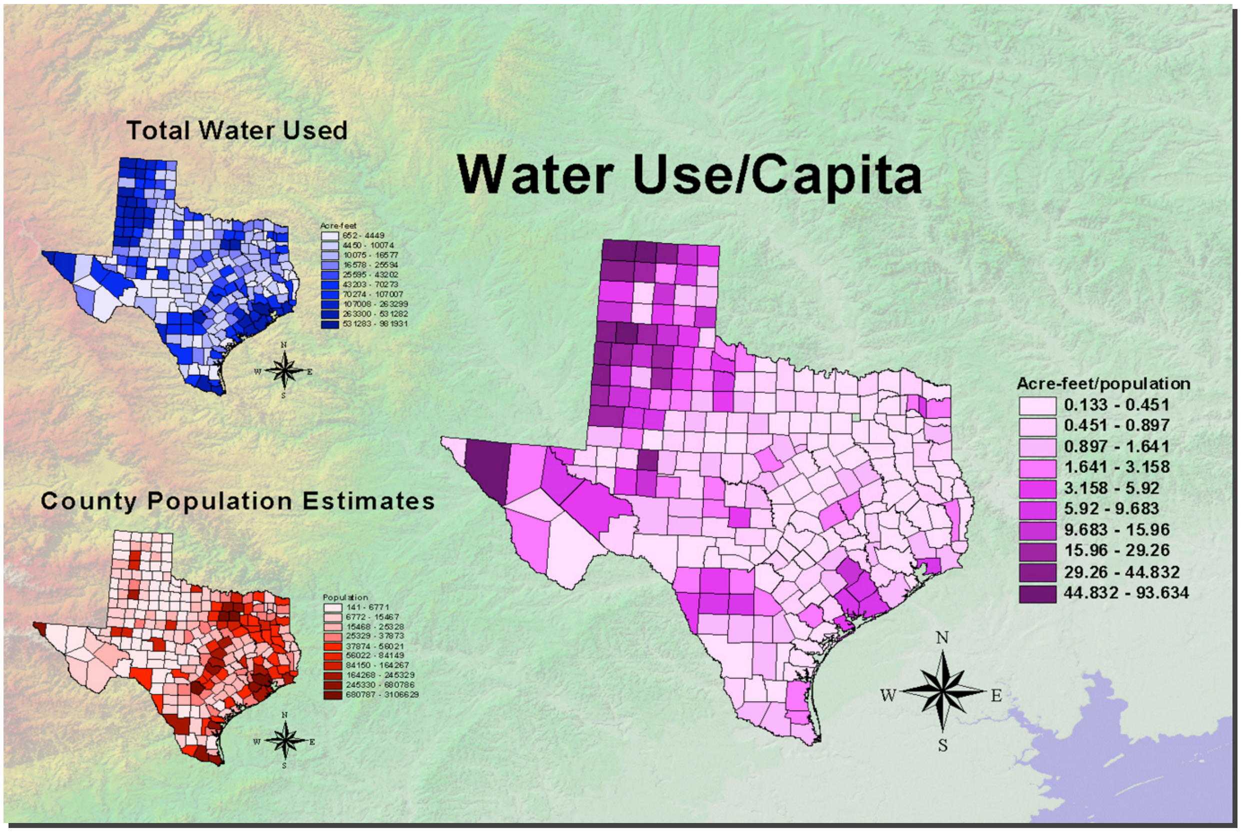

Figure 11. Texas water use per capita (Source: Texas Environmental Almanac, 2000)

Prospects for Water Resource Management

This section presents a series of "anecdotes' that provide examples of activities in the Urban Triangle that have had impacts on, or are related to, water issues. It begins with two examples of situations where water resource consideration have (and are) directly guiding land-use and development in the Woodlands and Austin, Texas. Next the section will present some preliminary discussion of an economic model of water resource allocation being discussed by some serious entrepreneurs. Next two communities, San Antonio and Cuero, where flooding has been a repeated problem, will be discussed. And finally, a summary of one environmental clean-up effort in the Colorado River Basin will be summarized. These examples provide a caricature of the prospects for water resource management in the Triangle. These anecdotes are intended to be a comprehensive or <p. 479>systemic analysis of the prospects for water resource management, but rather highlight the kinds of activities (related to water) underway in the area.

The Woodlands development was one of New Town communities with roots in the Johnson Administration's vision of better cities in the United States which gave rise to the New Community Act of 1970. The design of Woodlands was influenced by Ian McHarg's vision of limiting impact on water resources, and the environment. The intensity of the development was matched to the soil-type to enable a "zero-impact" design principle. Areas with soils that prevent water penetration (eg. clays) were reserved for the most intense development of shopping areas, multiple-family dwelling units and other concrete/asphalt dominated uses. Adjacent to these areas water retention ponds collect excess water from heavy rains. These retention ponds provide a visual amenity for the area and prevent increases in down stream flooding associated with increased runoff. Areas with porous-soils (eg. sands) were reserved for parks and wildlife refuges. In areas where residential development was permitted, residents are required to preserve ground cover. Strictly enforced deed restrictions provide use guidelines to allow both water conservation and preservation. The proportion of each residential property covered in lawn is restricted to conserve water use and the allowable concrete and asphalt coverage is restricted to assure penetration of available water. These design features, together with the social/cultural emphasis on mixed use of land and heterogeneous community, have helped make the Woodlands one of the most successful communities developed under the New Town Act of 1970.

The City of Austin obtains the majority of its drinking water from the Edwards Aquifer. The Edwards Aquifer is also recharged in the Austin area via several creeks in the area (e.g. Barton, Onion) which collect surface water in the area and provide it to the aquifer through the karst topographic features in the aquifer recharge zone. The benefit of the water is clear, but the potential to collect environment pollutants along with the water in developed areas of the recharge zone is real. The City of Austin recognizes this problem and has developed a comprehensive plan (Figure 12) that encourages development in areas that are outside the recharge zones. For example, a well known computer company recently was encouraged to locate their facility outside the recharge zone by giving tax incentives only if they would locate outside the recharge zone. The Barton Creek/Edwards Aquifer Authority was created in 1993 by the Texas Legislature to "to manage, preserve and protect the Edwards Aquifer". The authority is working toward that goal by a) encouraging growth management, b) the use of xeriscaping that promotes water conservation via low maintenance, c) protecting the recharge from pollution, and d) assuring recharge by protecting and restoring the flow of clean water into the aquifer.

Recent droughts in Texas have highlighted potential problems with water quantity. Figure 13a shows the geographic distribution of the water deficits compared to historical average rainfall. Figure 13b shows the impact these shortages have had on selected reservoirs. This situation has given rise to recent discussion among entrepreneurs to develop private enterprise water projects that would purchase water rights in the Texas Panhandle and build a water delivery system, presumably, a pipeline or canal, to transport that water to the San Antonio area, a distance of approximately 300 <p. 480>miles. The economic losses in agriculture alone, due to the drought, total a staggering $600 million. This situation recently led to a national disaster declaration. Hence, the current drought has created a potential for entrepreneurial activity associated with water resources. While the effectiveness of business organizations at meeting public needs is not questioned here, the potential vulnerability created by water resources being owned and managed by private enterprise is of concern. Without effective regulatory authority, complete privatization of water resources would create the opportunity for "public blackmail" associated with both the quantity and quality of this vital resource.

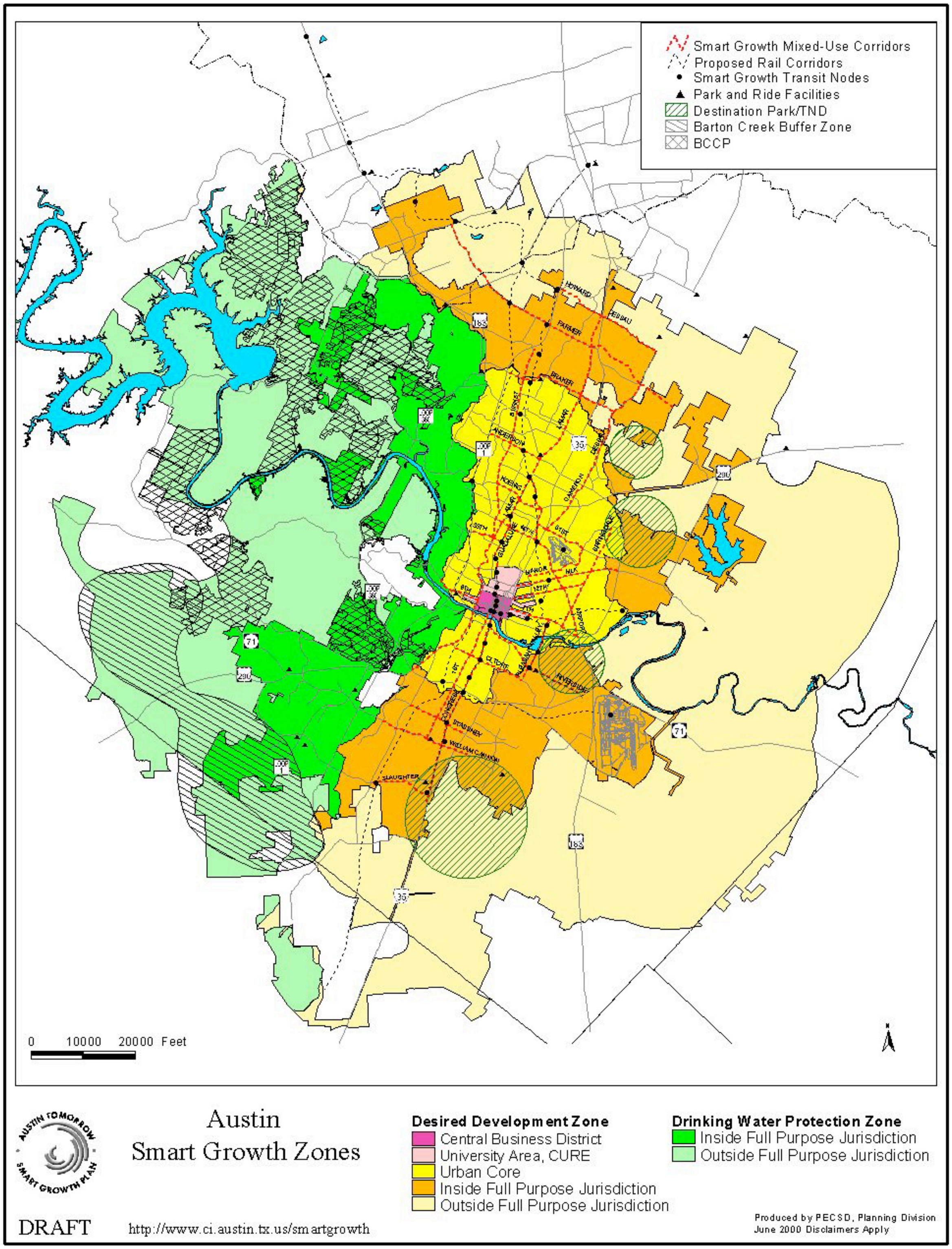

Figure 12. City of Austin Smart Growth Zones (Source: City of Austin). <p. 481>

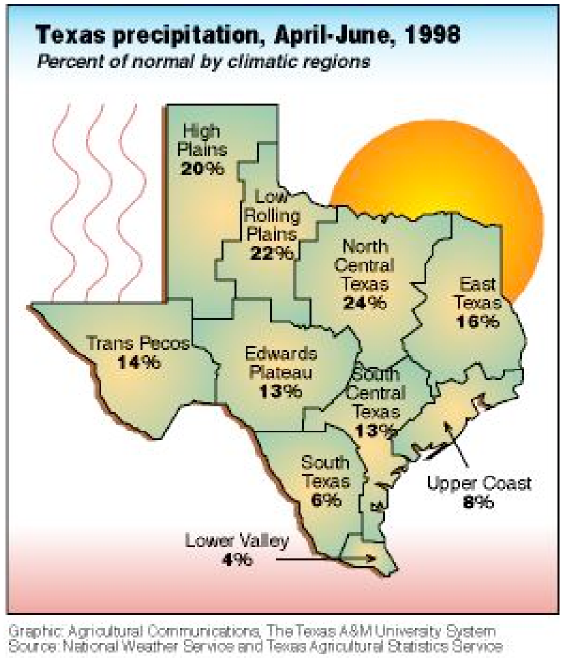

Figure 13a. Drought conditions are depleting water supplies and affecting water quality (Source: National Weather Service and Texas Agricultural Statistics Service)

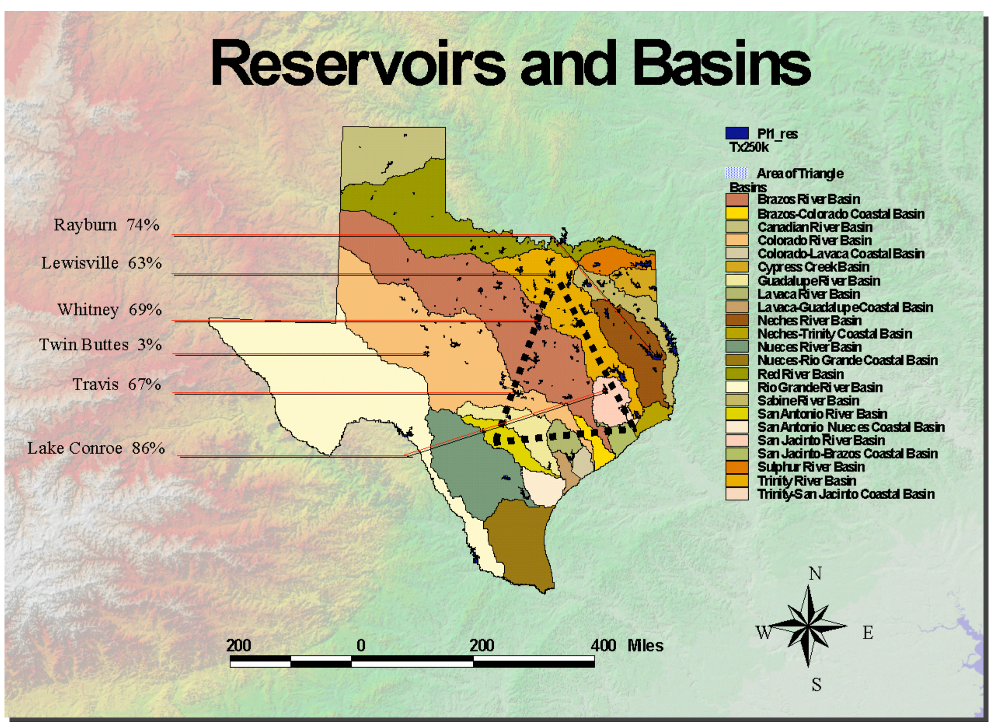

Figure 13b. Drought causes significant shortages in drinking water supplies (Houston Chronicle, 2000) <p. 482>

In the City of San Antonio (and other places) an innovative approach to flood control involves intercepting flood waters upstream from the city and channeling the water into a siphon, where it passes beneath the city and exits below threatened areas (Figure 14). This "flood-tube" has been used not only to capture flood waters and channel them effectively through the city, but also as a storage device for use during long dry periods that may impact river use and its esthetic value. The San Antonio flood tube was designed by the United States Army Corp of Engineers. Construction began in 1987 and was completed in 1997. Since its completion, it has been used to flush the river running through the city by pumping water out of the tube and into the river upstream and replacing it by pumping it out of the river and back into the tube downstream. Water in aquifers is no longer used for this purpose in San Antonio. The water stored in San Antonio's flood tube is also used in a limited way for a irrigation source for public parks and other public areas.

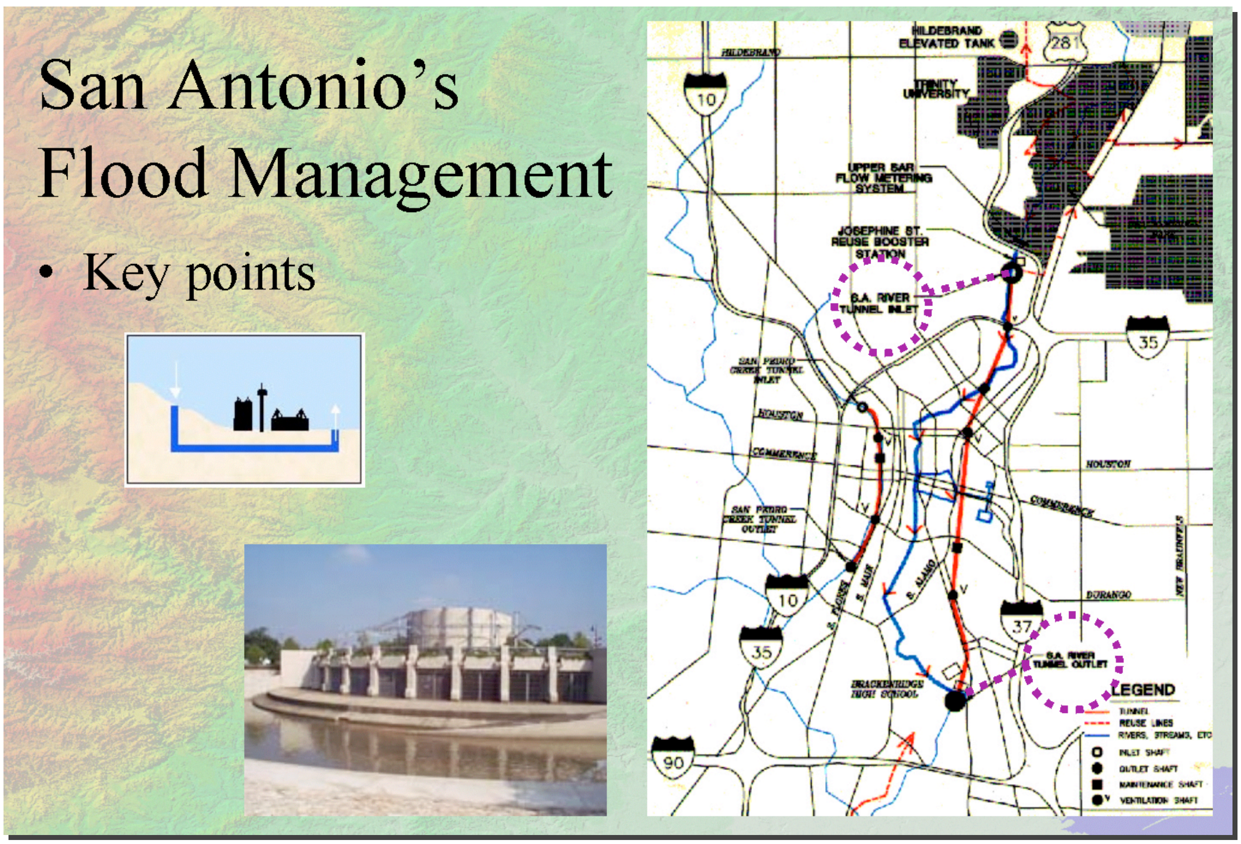

Figure 14. San Antonio's Flood Tunnel is also used to maintain water quality.

Cuero, Texas is a small town of about 7000 residents located near the southern edge of the Texas Triangle in DeWitt County. The per capita annual income in Cuero is approximately $9500 compared to the per capita annual income of $21,800 for the State of Texas as a whole. Cuero first recorded a flood in 1913, then again in 1936, 1952, 1972, 1987, 1991 and 1993. It is interesting to note that the average time between floods from the first five events is a flood about

18.5 years, while the time between the last four events averages about 3.7 years. These data may reflect an increasing propensity to <p. 483>flooding associated with growing urbanism in the southeast corner of the Texas Urban Triangle. The most recent flooding event occurred in the third week of October 1998. The flood was a result of both an extreme rainfall event and a runoff event from downstream areas. The flood crested at about 50 feet above flood-stage, which was approximately 30 feet greater than National Weather Bureau predictions. This was an unusual event to be sure, but it illustrates the kind of extreme events that can occur in the Texas Urban Triangle. The kind of events to which the growth in the Triangle may be contributing.

The Lower Colorado River Authority (LCRA) was formed by the Texas Legislature in 1934 as a conservation and reclamation district. Its mission is to improve the quality of life in the Central Texas served by the Lower Colorado River. In 1988, a group of citizens became concerned about the water quality in the basin, and formed the Clear Clean Colorado Foundation. Initially the Todd foundation provided support for students in Austin to monitor the quality of water along Walnut Creek at three locations. Five new monitoring teams were added in 1989, and over the next two years support was added by a local school district, and a clothing company. In 1991, the effort received a four-year grant from the National Science Foundation to help support the program. During this period the LCRA took over operations of the River Watch Foundation. In 1993 the U.S. Environmental Protection Agency supported an effort to develop quality control/quality assurance procedures for chemical parameters. River Watch currently supports monitoring groups at about 70 locations involving about 20 local school districts in the LCRA drainage area. The program involves students from local schools monitoring the quality of water in tributary streams. The program has enjoyed tremendous success in involving local citizens in the process of monitoring and improving water quality in the basin.

Regulatory Resources

There are two distinct genre of socio-political organizations that control and impact both the quality and quantity of water resources in the Texas Triangle. These resources may be thought of as primary and secondary. Primary water resource management organizations have as their primary function the protection and delivery of the water supply; they are in most instances charged in the most direct way, with assuring adequate supply of quality water resources. Secondary organizational structures are responsible for water supply and quality, but only as one of many other responsibilities. The primary organizations are Water Districts, Basin Authorities and Aquifer Authorities. Secondary structures generally fit into the categories of Municipal Governments, County Governments, Regional councils of government and their planning organizations, and state and federal agencies.

There are numerous Water Districts and Special Utility Districts involved in the Texas Triangle. These authorities are primarily involved in end-user supply of water. Most are run by a board of users elected by users in their districts. There are numerous river basin authorities associated with the Texas Triangle. The six river basins plus <p. 484>the Colorado, Brazos, Trinity and San Jacinto are split into upper and lower basin authorities. In addition, the Lavaca, Guadalupe, and San Antonio basins combine in the southern part of the Triangle to form another basin and attendant authority. These basin authorities are authorized by the State of Texas and managed by authorities appointed by the governor. There are four aquifer authorities acting in the Texas Triangle. These authorities operate under the auspice of the state legislature with boards appointed by the governor. These aquifer authorities often take direct action in their load areas (e.g. Edwards Aquifer Authority) to protect water quality and assure water supplies. This often involves coordinating with local municipal and county government organizations and the public at large.

There are 64 county governments and multiple municipal governments in each county of the Texas Urban Triangle. Municipal governments are of an elected mayor and council structure and many have an administration hired by the elected structure to handle municipal business. Municipal governments most frequently operate municipal wastewater treatment plants for the vast majority of residents in the area. County governments are typically structured as a county judge and several county commissioners that are elected by the residents. The county government is usually responsible for governmental services outside the municipalities. The county governments are also most likely to be the regulatory authority in charge of residential wastewater treatment outside municipal areas via county public health organizations. Many of the municipal and county governments operate utility companies that distribute water, electricity and natural gas and other public services.

There are various state and federal agencies that have at least some jurisdiction over water resources. State agencies involved include the Texas Water Development Board, the Texas Natural Resource Conservation Commission and the Texas Wildlife and Fisheries Department. Conflicts can arise between the agencies with conflicting purposes. The Texas Water Development Board is primarily charged with developing water resources while the Texas Natural Resource Conservation Commission is charged with environmental compliance. Federal agencies can include the Environmental Protection Agency (EPA), the Army Corp of Engineers, the Bureau of Land Management (BLM) and the Federal Emergency Management Agency (FEMA). The EPA and the Corp and BLM often come into conflict over the development of new reservoirs while FEMA is often called upon to administer flood insurance mitigation and protection programs.

Conclusions

To be clear, this paper has not attempted to conduct a comprehensive analysis aimed at assessing the quantity and quality of water resources in the Texas Urban Triangle. This paper has attempted to examine, in the broadest of terms, the nature of the geographic distribution of population, water resources and potential threats to the integrity of those resources in the Texas Urban Triangle. This paper also presents some limited anecdotes of water activities in the area. These examples are intended to exemplify the range of <p. 485>activities in these areas to protect and assure the quantity and quality of water in the area and the range of issues in the area. This paper also examines the regulatory structures involved in management of water resources in the Texas Urban Triangle. This paper is not intended to present definitive analysis of water resources and their management in the Triangle. Rather, it examines the existing evidence to the extent required to address the question of does water limit development what are the critical issues relating to water in the urban development in the Triangle?

The primary conclusion of this limited qualitative analysis is that quantity of water resources alone is not sufficient to limit growth of urban development in the Texas Triangle. That is to say that water scarcity has not stopped or slowed urban development in any appreciable way and the anticipated available water anymore than we currently us water on a per capita basis. And this conclusion assumes a conservative "single use" water strategy, which is already being to violated. This being the case what is likely to inhibit urban development in the future? And why has water been such an important topic of discussion in recent months in the Texas Urban Triangle?

Before attempting to address these questions directly, the discussion of evidence regarding potential threats to water quality is in order. The co-location of potential threats to water quality with both population and the concentrations of urban population alone gives rise to sufficient alarm to require both a more detailed analysis than possible here and the development or refinement of management structures to address the quantity and quality of water in the Triangle in a comprehensive examination is warranted. Secondly, the concentration of population and potential threats to water contamination materialize. Third, potential threats to water resource quality located upstream of the Triangle indicates both impact of external areas on the Triangle and the Triangle on the external areas need to be considered. Finally, the implications of the water as a carrier for human and industrial waste for the use-and-re-use of water needs to be considered in a more comprehensive manner throughout the Triangle.

This paper presented a small selection of anecdotes to highlight some of the activities regarding water resources in the Texas Urban Triangle. The long-term development strategies of zero-impact on water runoff in the Woodlands provides one small example of successful development without significant impact on water resources. The comprehensive planning in Austin with respect for the intricacies of the Edwards Aquifer recharge area provides both short-term and long-range benefits to the local area. The clean up of the Colorado River provides an example of public participation and extensive participation of stakeholders in developing the program to help clean up the basin for all users. The flood tube in San Antonio provides an example of an innovative technological solution to a flooding problem that provides solutions to additional problems related to water in the local area.

The multiple jurisdictions involved in the regulation of water in the Urban Triangle create a fractured if not disjoint management structure for the water resources in the region. The multiplicity of regulatory organizations, can be found to be overlapping and confused, and are easily seen to lead to a potential for jurisdictional disputes. For example, some are charged with the distribution of water for use, while the <p. 486>aim of others is clearly conservation. Missions can be found to conflict making it difficult to effectively manage the available water resources, especially when missions, objectives and strategies are not coordinated between agencies and levels of regulatory authority. Achieving a comprehensive management strategy that encompasses the full-cycle use-and-re-use of fundamental resources is critical to assuring availability of key resources necessary to support life in the emerging megacity.

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