3.0 FUTURE CONDITIONS AND PROSPECTIVE WATER NEEDS

3.1 STATEWIDE PERSPECTIVE

The quantity of water that is used for many purposes is dependent on the demographic, economic, climatological, water availability, and efficient water use through recognized conservation practices. These factors differ from city to city, county to county, and region to region across the state resulting in variations in the quantities of water used on an annual basis within each geographic location.

Interpretation of statewide aggregated statistics should be done with care since state totals may indicate trends that differ significantly from trends for specific regions and local geographical areas. However, statewide totals and statistics provide a general overall picture of the current and anticipated future conditions associated with the state's water resources.

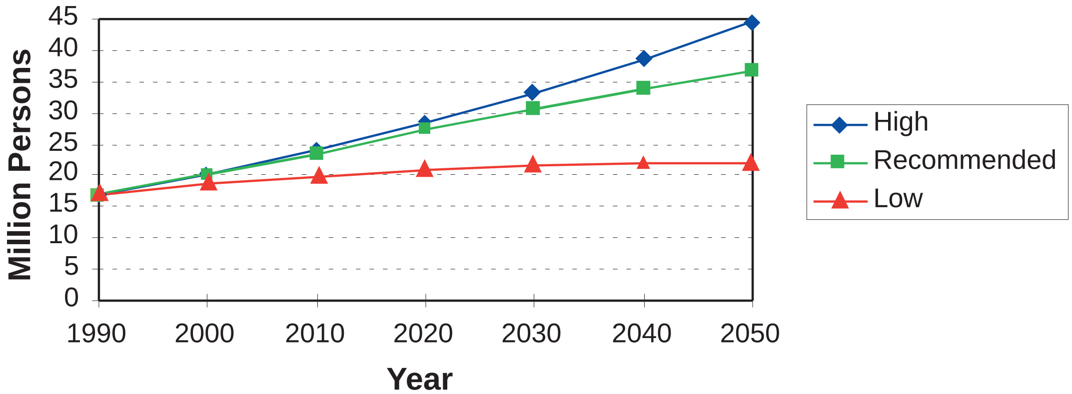
3.1.1 Population and Economic Growth

The population of Texas increased from 14.229 million people in 1980 to 16.987 million in 1990, an increase of almost 2.8 million people. Latest population estimates from the U.S. Bureau of the Census indicate that Texas is the second most populated state in the nation, having surpassed the State of New York and second only to California. Factors affecting population growth of the 1980s were significantly different from those of the 1970s. During the decade of the 1970s, migration of people into the state accounted for more than 58 percent of the state's population growth with the natural increase (births over deaths) accounting for the remaining 42 percent. This occurrence was reversed during the decade of the 1980s with migration accounting for about 34 percent of the population growth and the natural increase accounting for about 65 percent of the growth.

During the decade of the 1980s, the age composition of the state's population also changed significantly. Following national trends, the Texas population is becoming older although still relatively younger than the nation as a whole. The median age of the state's population increased from 28 years of age in 1980 to 30.8 years of age in 1990. This compares with the median age of the national population of 30 years of age in 1980 and 32.9 years of age in 1990.

Texas is also becoming more racially and ethnically diversified with minority populations growing faster than the Anglo population. During the decade of the 1980s, the state's Anglo population increased 10.1 percent, the Black population increased by 16.8 percent, the Hispanic population increased by 45.4 percent, and the other racial/ethnic populations (Asian and others) increased by 88.8 percent. Statewide, nearly half (49.3 percent) of the net increase in population between 1980 and 1990 was accounted for by Hispanics, and nearly two-thirds (65.9 percent) by all minority groups.

Based on the many factors associated with population growth that occurred during the decade of the 1980s, an array of alternative future populations for the state was developed for the



Year	1990	2000	2010	2020	2030	2040	2050
High	16.987	20.287	23.969	28.311	33.076	38.452	44.588
Recommended	16.987	20.231	23.492	27.281	30.674	33.840	36.671
Low	16.987	18.650	19.927	21.057	21.6a8	22.002	22.138

Figure 3-1
Projected Texas Population

1990-2050 planning horizon (see Volume III for details). The recommended-case population projections selected by the consensus planning staffs and a technical advisory committee indicates that the state's population is anticipated to increase to more than 36 million people by the year 2050 or an approximate doubling of the state's current population. Population projections based on various growth scenarios are presented in Figure 3-1.

The economic recession of the 1980s had serious implications with respect to economic growth in Texas over the latter part of the 1980s. This was a period of relatively slow growth with clear implications for income and employment for Texans. Real incomes of Texans generally failed to keep pace with inflation or with levels of growth for the nation as a whole. Median household income ($27,016), median family income ($31,553), and per capita income ($12,904) were lower in Texas than the nation as a whole ($30,056, $32,225 and $14,420 respectively).

Despite the relative declines in income, the supply of labor in Texas increased substantially compared to the nation. The size of the actual labor force (16 years of age and older) in Texas increased by 24.2 percent with the national labor force increasing by 18.0 percent during the decade of the 1980s. In Texas, the largest increases in employment occurred in such industries as entertainment and recreation (83.4 percent), health services (46.3 percent), business services

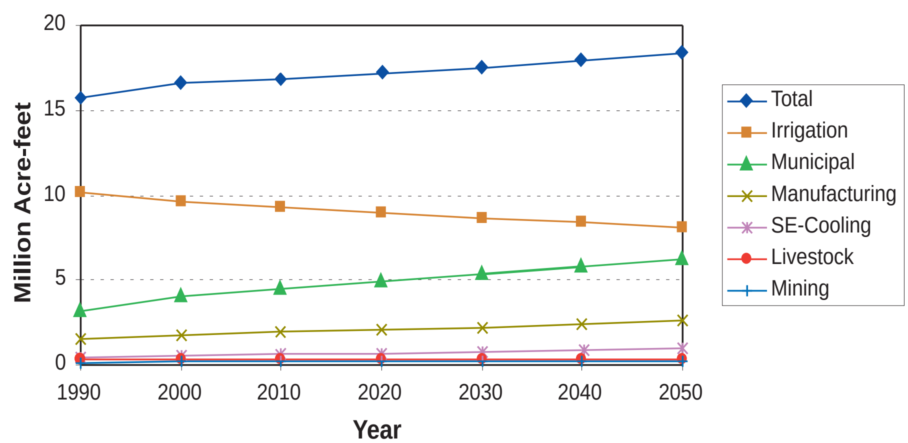
(43.8 percent), and finance, real estate, and insurance (38 percent). Conversely, significant declines in employment occurred in mining (-21.5 percent), construction (-5.7 percent), and durable manufacturing (-4.2 percent). Texas experienced similar patterns of employment change as the nation during the 1980s.

The patterns of demographic and economic change generally mirrored the dominant national trends during the decade of the 1980s — slower population growth than was experienced during the 1970s, an aging population base, increasing racial/ethnic diversity, and reduced average household size.

3.1.2 Water Uses

3.1.2.1 Total Statewide Use

Water is used for many purposes on a daily basis across the State of Texas. As indicated in Figure 3-2, the quantity of water used for municipal, industrial, and agricultural purposes in 1990 totaled 15.7 million acre-feet (ac-ft). One acre-foot of water is equivalent to 325,851 gallons of water. Changes in the state's water use pattern over the last decade have had a significant impact on



Year	1990	2000	2010	2020	2030	2040	2050
Total	15.729	16.586	16.867	17.135	17.489	17.900	18.354
Irrigation	10.123	9.641	9.284	8.952	8.650	8.363	8.089
Municipal	3.197	4.087	4.476	4.881	5.342	5.781	6.213
Manufacturing	1.560	1.793	1.974	2.090	2.194	2.391	2.596
SE-Cooling	0.426	0.530	0.616	0.700	0.782	0.842	0.938
Livestock	0.274	0.330	0.330	0.330	0.330	0.330	0.330
Mining	0.149	0.205	0.187	0.182	0.191	0.194	0.188

Figure 3-2
Projected Texas Water Use

the state's water requirements. For example, the state's total water use in 1980 was 17.8 million ac-ft or about 2.1 million ac-ft more than was used in 1990. This reduction in total water use is attributable to a 2.6 million ac-ft decline in water requirements for statewide irrigated agriculture. Over this same period, municipal and industrial water requirements increased by 463,000 ac-ft.

Based on the recommended-case projection scenarios for the various water use categories, future statewide water use is anticipated to increase from the 1990 annual use of 15.7 million ac-ft to 18.4 million ac-ft by the year 2050. This is an increase of about 2.7 million ac-ft above the 1990 annual use. Implicit in the consensus water use projections is the continued improvement in water use efficiencies in the major water use categories (irrigated agriculture, municipal, and industrial water use). Water use efficiencies included in the consensus projections account for potential annual water savings of 1.5 million ac-ft by the year 2020 and 2.6 million ac-ft by the year 2050.

Figure 3-3 indicates the anticipated changing composition of water use in Texas over time. Historically, agriculture water use has predominated state water use, currently accounting for over 67 percent of the State total. By the year 2050, its share of state water use is expected to

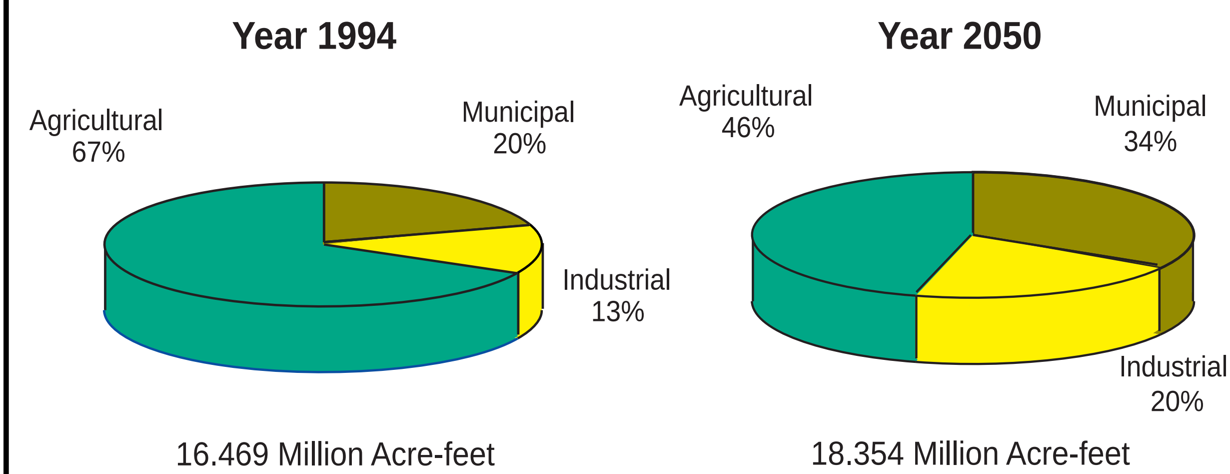


Figure 3-3
Composition of Current and Projected Texas Water Use

decline to around 46 percent. Municipal water use is anticipated to increase its share of State wide use from about 20 percent of the State total to about 34 percent.

As Texas' economy is changing from its historical base of oil and gas, manufacturing, and agriculture to more of a trades and service economy, so is the nature of its water use. It is anticipated by the decade of the 2040's that urban-related uses (municipal and industrial) will exceed that of agriculture (see Figure 3-4).

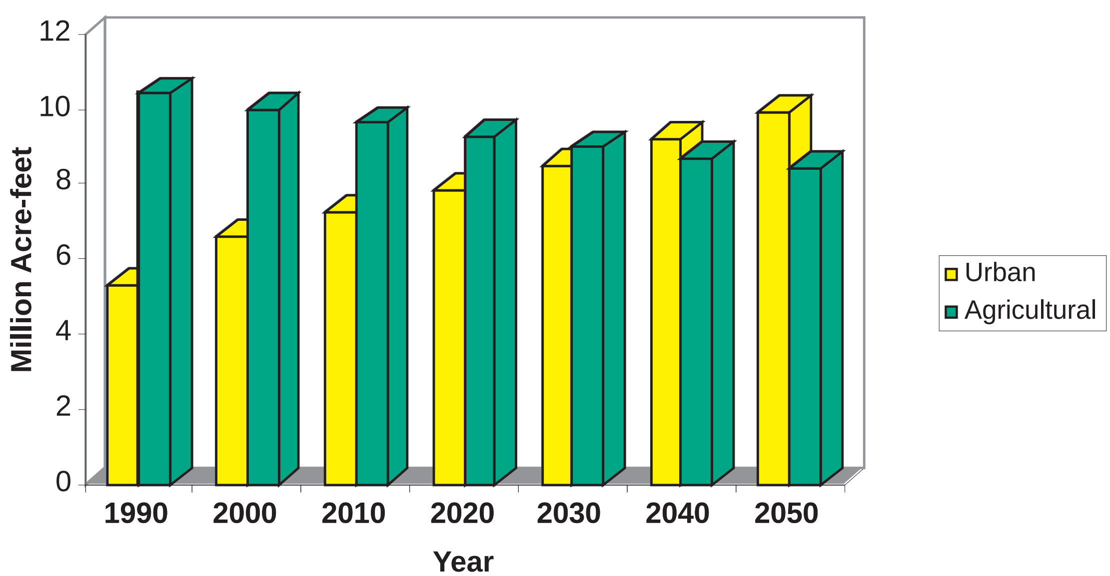
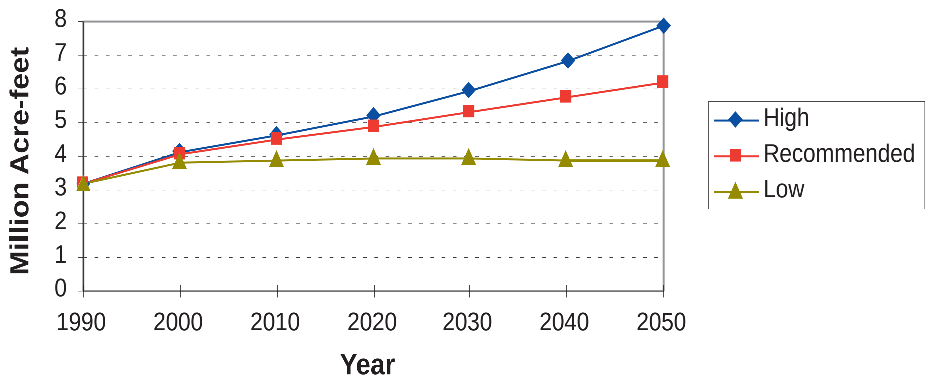


Figure 3-4
Projected Texas Urban and Agricultural Water Uses

Municipal Water Use

Statewide municipal water use in 1990 totaled 3.2 million ac-ft. Over the previous decade, statewide municipal water use increased by 384,000 ac-ft. Weather has a tremendous influence on water use in Texas. For instance had 1990 been as dry as the year 1980, the growth in population coupled with a dry-year increase in per capita use could have produced a ten-year increase of over 500,000 ac-ft.

Future statewide municipal water use is projected to increase from the 1990 annual use of 3.2 million ac-ft to 6.2 million ac-ft by 2050 based on the recommended-case planning scenario (recommended population forecasts, assumed below-normal rainfall conditions, and expected water conservation savings). Under an assumed normal rainfall condition with expected conservation savings, municipal water use is anticipated to reach about 5.5 million ac-ft by the year 2050. Based on the recommended-case projection scenario, improvements in conservation practices and programs are expected to reduce annual statewide municipal water use by 913,000 ac-ft by the year 2020 and 1.5 million ac-ft by the year 2050. The consensus statewide municipal water use projections, based on various water conservation strategies, are presented in Figure 3-5.



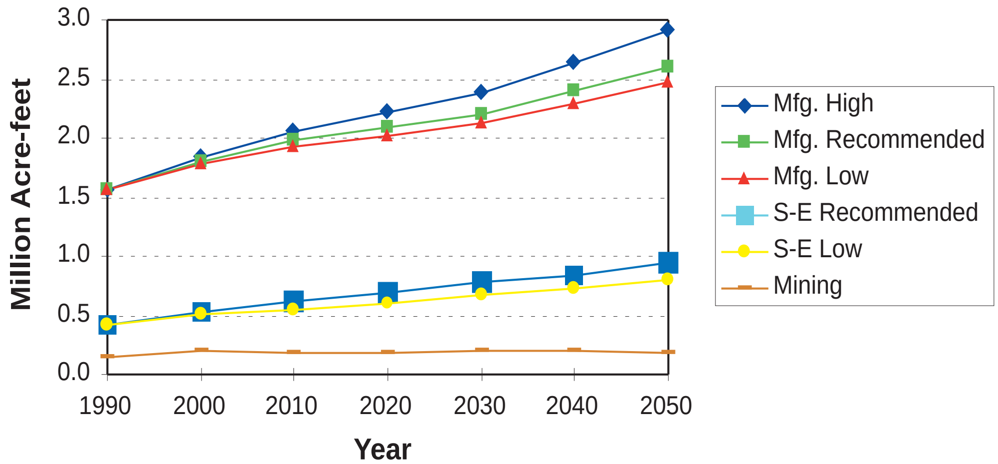
Year	1990	2000	2010	2020	2030	2040	2050
High	3.197	4.111	4.611	5.178	5.926	6.797	7.859
Recommended	3.197	4.087	4.476	4.881	5.342	5.781	6.213
Low	3.197	3.800	3.881	3.911	3.936	3.906	3.903

Figure 3-5
Projected Texas Municipal Water Use

Industrial Water Use

Manufacturing Water Use. Manufacturing establishments in Texas currently use 1.56 million ac-ft of water in the production of a range of products for domestic and foreign markets. Over the period 1980-1990, manufacturing firms increased their water use by about 40,000 ac-ft. The economic recession of the mid to late 1980s had a significant impact on many manufacturing firms' production levels and water use. For example, the Texas manufacturing sector used 1.51 million ac-ft of water in 1980 and by 1987 this level of water use had declined to 1.37 million ac-ft. As Texas began to recover from the recession, the state's manufacturing water use began to increase significantly. From 1987 to 1990, the Texas manufacturing sector increased its annual water use from 1.37 million ac-ft to 1.56 million ac-ft or an increase of about 191,000 ac-ft.

Based on the recommended-case projection scenario, the state's manufacturing water use is projected to increase from the 1990 level of 1.56 million ac-ft to 2.59 million ac-ft by the year 2050. Implicit in these consensus projections is the continuous improvements in water use efficiencies for the industries comprising the state's manufacturing sector. By the year 2020, annual manufacturing water use savings through more efficient water use technologies are anticipated to reach 223,000 ac-ft and approximately 410,000 ac-ft by the year 2050. The consensus manufacturing water use projections based on the various projection scenarios are presented in Figure 3-6.



Year	1990	2000	2010	2020	2030	2040	2050
Mfg. High	1.560	1.841	2.057	2.227	2.387	2.641	2.904
Mfg. Recommended	1.560	1.793	1.974	2.090	2.194	2.391	2.596
Mfg. Low	1.560	1.778	1.936	2.027	2.124	2.299	2.475
S-E Recommended	0.426	0.530	0.616	0.700	0.782	0.842	0.938
S-E Low	0.426	0.511	0.548	0.592	0.668	0.719	0.799
Mining	0.149	0.205	0.187	0.182	0.191	0.194	0.188

Figure 3-6
Projected Texas Industrial Water Use

Steam-Electric Power Generation. Water used for steam-electric power generation totaled about 426,000 ac-ft in 1990. This represents an increase in water use of nearly 122,000 ac-ft of water above the 1980 level of water use. Currently, water used for steam-electric power generation accounts for about 3 percent of the state's total water use.

Based on the recommended-case projection scenario, statewide water use for steam-electric power generation is projected to increase from 426,000 ac-ft in 1990 to about 938,000 ac-ft by the year 2050. The consensus projections for steam-electric water use are presented in Figure 3-6.

Mining Water Use. In 1990, mining operations in Texas used 148,839 ac-ft of water. While Texas' mining industry is a major producer of crude petroleum and natural gas, this industry also produces a wide variety of important nonfuel minerals used in the production of building materials. Currently, mining water use accounts for about one percent of the state's total water use. Mining water use is projected to increase from the 1990 use of 148,839 ac-ft to about 188,000 ac-ft by the year 2050. Projections of future mining water use are presented in Figure 3-6.

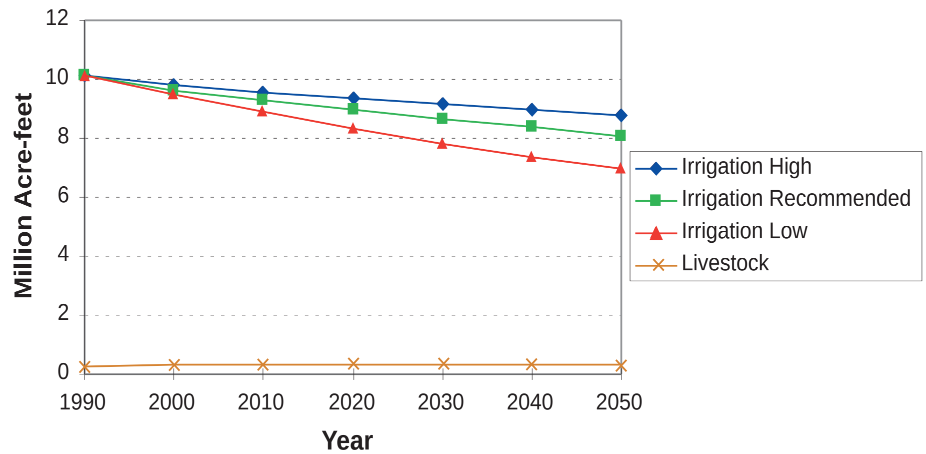
Agricultural Water Use

Irrigation. Irrigated agriculture is the largest water using category in Texas, accounting for more than 64 percent of the state's total water use. In 1990, water used for on-farm irrigation purposes totaled more than 9.5 million ac-ft. With the inclusion of surface water diversion losses, the 1990 water requirements for irrigated agriculture totaled 10.1 million ac-ft.

Water used for irrigation of Texas' crops peaked in 1974 with an annual use of 13.1 million ac-ft for on-farm irrigation and has declined steadily over the 1974-1990 period. There are many reasons for the decline in the amount of water required for irrigating the many crops grown in Texas. Probably the most significant reasons are: (1) improved irrigation management practices; (2) implementation of more water use efficient irrigation systems; (3) increased acreage being set-aside for compliance with federal farm programs; and (4) a decline in the number of farms.

The consensus projections of water use for irrigated agriculture reflects the historical trend of declining water requirements. Implicit in these projections is a continuing improvement in irrigation efficiencies related to irrigation systems as well as more efficient water canal systems used for transporting surface water from the diversion point to the farm. With continuing implementation of more water efficient irrigation systems, potential annual water savings are anticipated to reach 386,000 ac-ft by the year 2020, increasing further to 658,000 ac-ft by the year 2050. The consensus projections of statewide irrigation water use, including surface water diversion losses are presented in Figure 3-7.

Livestock Watering. Texas is a major producer of livestock for domestic and foreign markets. Types of livestock produced in Texas include cattle and calves, poultry, hogs, sheep, and goats. While livestock production in Texas generates about $8 billion for the Texas economy, water requirements for this industry are relatively minor in proportion to other water use categories. In 1990, water used for livestock watering is estimated at 274,000 ac-ft or about 1.7 percent of the state's total water use. Projections for this water use category are presented in Figure 3-7.



Year	1990	2000	2010	2020	2030	2040	2050
Irrigation High	10.123	9.828	9.575	9.338	9.133	8.936	8.747
Irrigation Recommended	10.123	9.641	9.284	8.952	8.650	8.363	8.089
Irrigation Low	10.123	9.492	8.928	8.322	7.818	7.386	6.982
Livestock	0.274	0.330	0.330	0.330	0.330	0.330	0.330

Figure 3-7
Projected Texas Agricultural Water Use

3.1.3 Water Supplies

3.1.3.1 Climatologic and Hydrologic Parameters

The climate across the vast expanse of Texas is marked by large geographic variations in precipitation, evaporation, temperature and runoff. The eastern third of the state experiences high relative humidity, copious rainfall, warm to hot summers and mild, wet winters. The central third of the state is characterized by moderate humidity, moderate rainfall amounts, hot summers and dry winters. The western third of Texas is characterized by little to no relative humidity, erratic rainfall, hot, dry summers and mild dry winters. Precipitation in this region mainly occurs in the summer and is concentrated in the mountain areas.

Precipitation

The Gulf of Mexico is the primary source of moisture for Texas. The rainfall distribution across the state ranges from more than 56 inches per year along the eastern Texas border, to less than 8 inches in West Texas. Figure 3-8 shows the rainfall pattern for Texas. The figure was a result of a water balance analysis for the climate years of 1961-1990 performed by the Center for

Research in Water Resources at the University of Texas. Note the strong east-west orientation of the rainfall amounts. This pattern is caused by the diminishing availability of moisture from the Gulf of Mexico from east to west. Nearly all of the precipitation in Texas falls as rain; however, snow does occur in the northern High Plains and in the Mountains of West Texas. The snow that falls is insignificant to the overall water supply of Texas.

Evaporation

Evaporation is primarily a function of atmospheric temperature, water surface area and wind speed. There are several different classifications of evaporation. For most water planning and management purposes, net lake evaporation is a useful measure of the overall loss of water from the lake due to evaporation, offset by the gain of precipitation onto the lake's surface. Evaporation's distribution across the state is much like the precipitation pattern, only reversed. In this case, mean annual net lake evaporation ranges from less than 16 inches in east Texas to more than 68 inches in west Texas (see Figure 3-9, TWDB, 1997).

Maximum evaporation rates occur during the summer months. During years with plentiful rainfall, evaporation rates are lower and result in less impacts on surface water supplies. However, during periods of drought, evaporation from lakes in conjunction with evaporation from vegetation transpiration work together to significantly increase water supply depletion rates. Since reservoirs act to store large amounts of water, which results in a large water surface area, evaporation is an important design criterion for any proposed, new or existing surface water supply project. Net lake evaporation is also a key factor in the feasibility of surface water reservoir projects in arid regions, where evaporation rates are high.

Runoff

Runoff is the end result of precipitation, interception, infiltration and evaporation processes. Runoff is highly dependent on terrain, evaporation rates, land use, vegetation cover and soil type. It is basically the water that is left over from rainfall after all losses are satisfied. It is a significant climate parameter because it is also the source of water for surface water supplies and is a source for the recharge to groundwater. The quality of runoff can have a significant and direct impact on the water quality of groundwater, especially with karst aquifers where very little filtration occurs before recharge. Reservoir success is dependent on a reliable source of runoff for capture and retention. Figure 3-10 from the report by Reed et al shows the average annual runoff distribution for Texas for 1961-1990. The chart shows the inches of runoff per unit area. The runoff ranges from more than 16 inches in east Texas to less than a half inch over much of the Panhandle and West Texas. The lack of significant runoff is the basis for the low viability of reservoir projects in arid regions. In those parts of Texas, dependence on groundwater supplies is high.

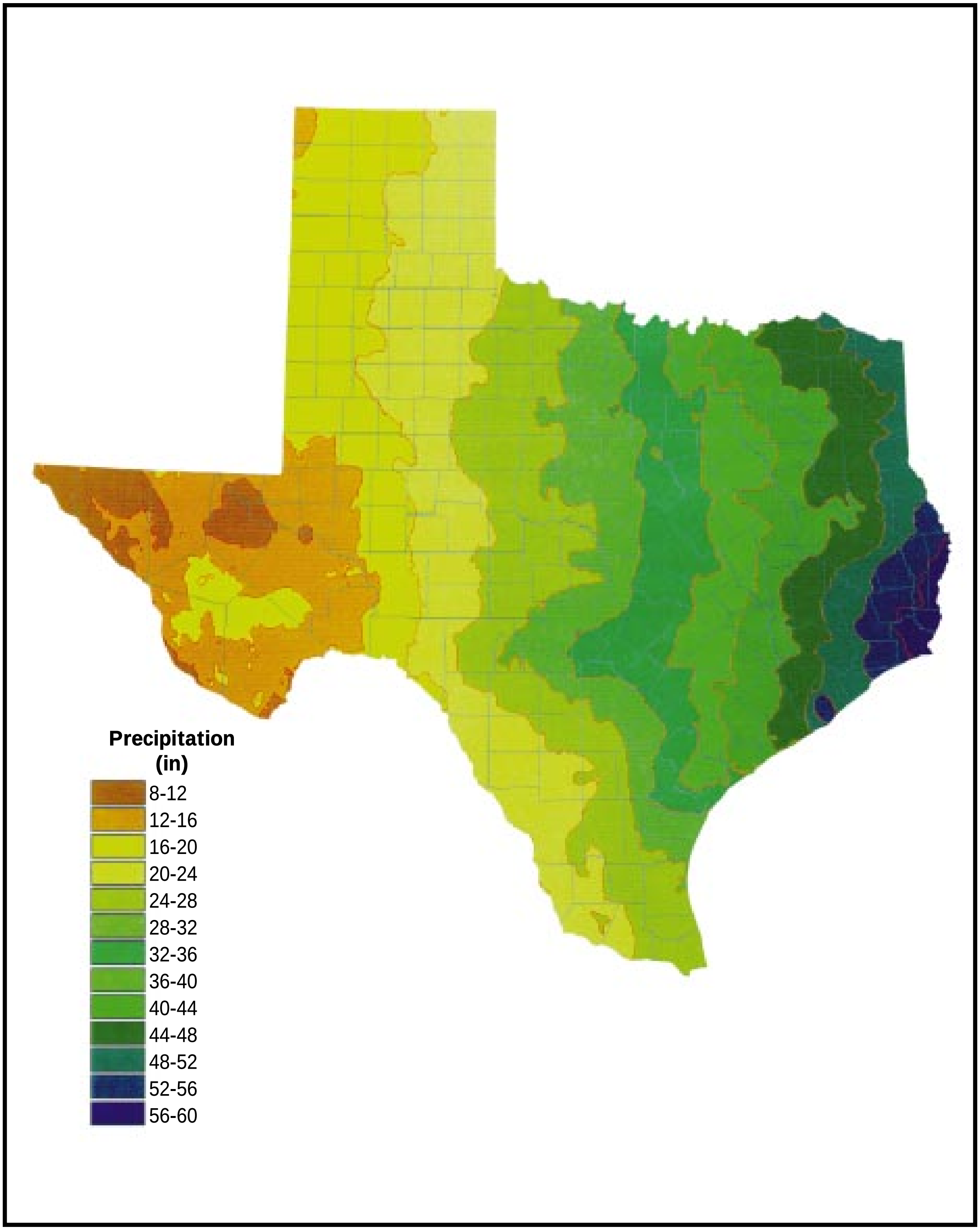


Figure 3-8
Average Annual Precipitation in Texas, 1961-1990

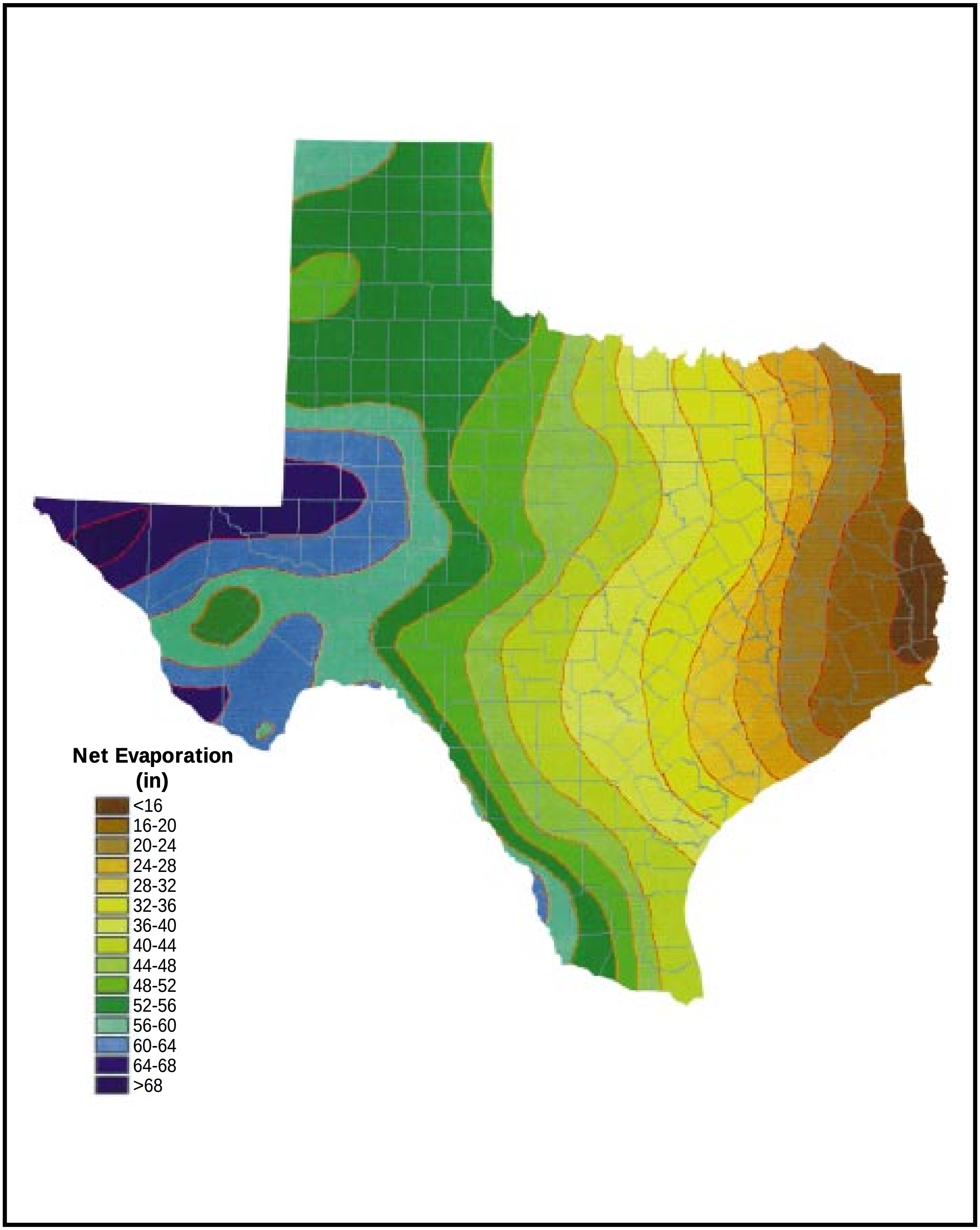


Figure 3-9
Average Annual Net Lake Evaporation in Texas, 1961-1990

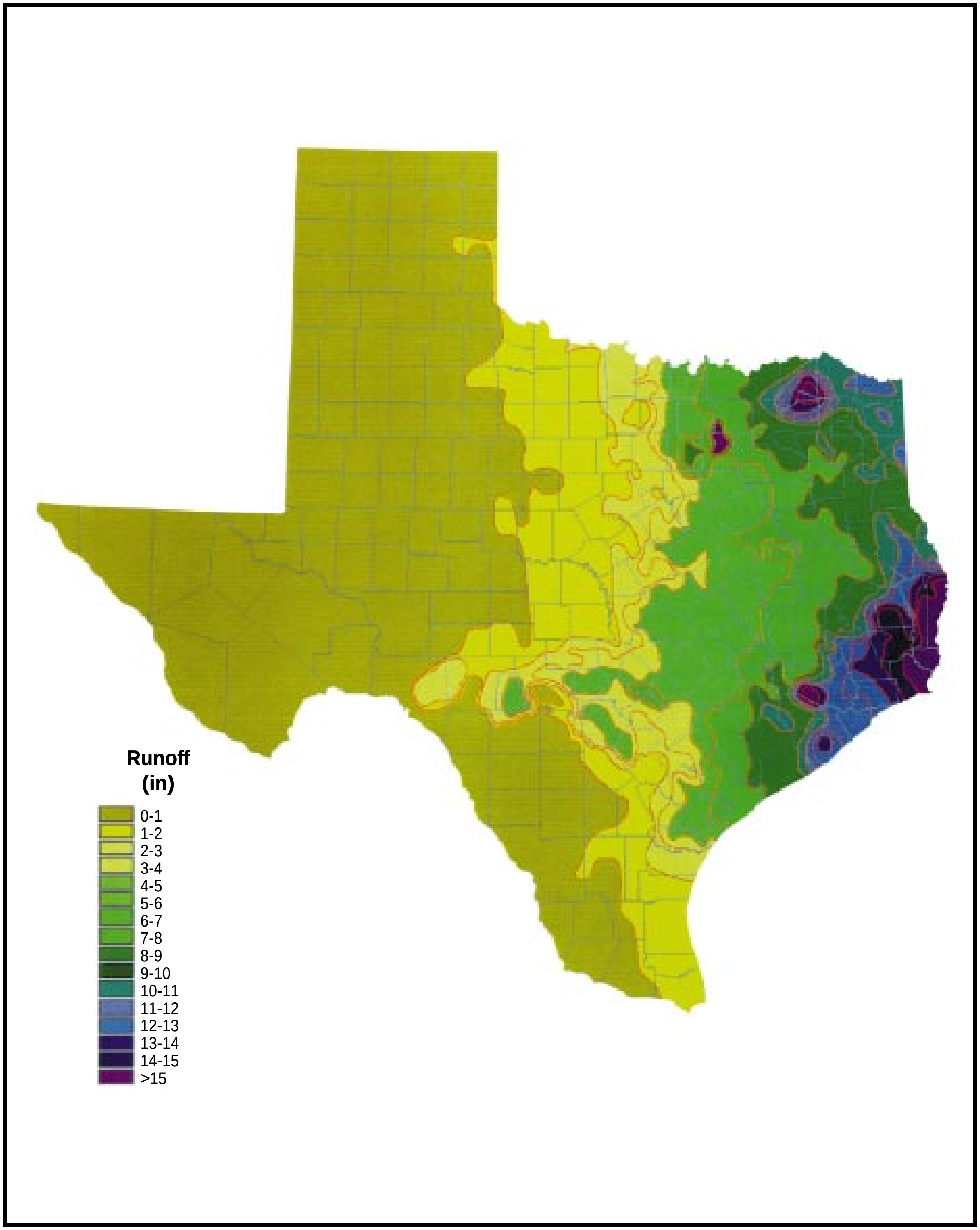


Figure 3-10
Average Annual Runoff in Texas, 1961-1990

One problem with runoff in Texas is when it causes flooding. When too much rain falls, the soils become saturated and almost all forms of water loss are canceled. The result is deadly flooding that chronically affects many parts of central and east Texas. In some cases flood waters are diverted to resupply aquifer sources or are held in overflow reservoirs designed for that purpose. The retention of flood waters could result in significant additions to the state water supply.

3.1.3.2 Total Statewide Water Supplies

Currently, groundwater and surface water resources each supply roughly equal shares in meeting the State's water needs. With lessening availability of ground-water supplies through depletion over time, it is projected that by the year 2050 surface water use will meet about 69 percent of the State's water needs with the ground-water share of total statewide water supplies declining to about 31 percent by that time (see Figure 3-11).

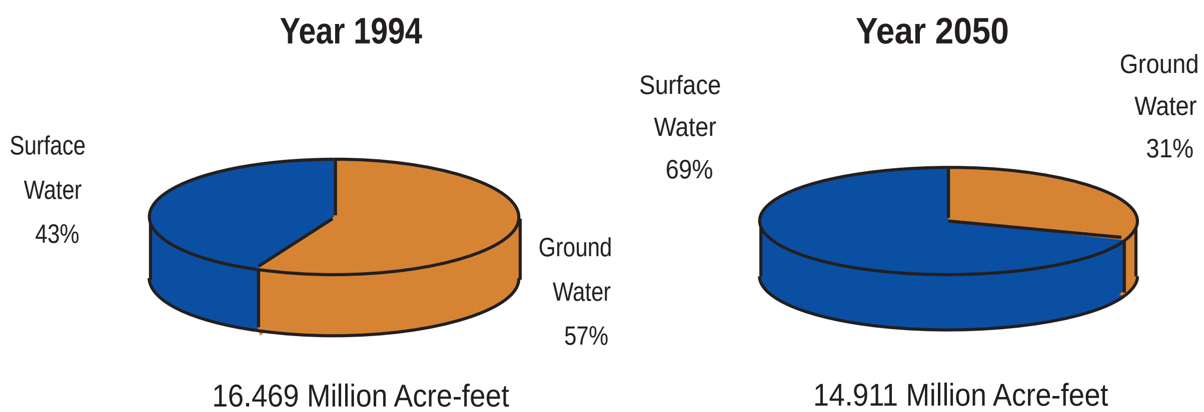


Figure 3-11
Composition of Water Supplies to Meet Water Uses, 1994 and 2050

Surface Water

Surface water is a major water resource in Texas, supplying approximately 7.1 million ac-ft or 43 percent of the 16.5 million ac-ft in total water use statewide in 1994. As seen in Figure 3-12, almost one-half of the 7.1 million ac-ft of surface water used in Texas in 1994 was for agricultural purposes, followed with 26 percent used for municipal purposes. Over time as ground-water resources become more depleted, increased reliance will be placed on surface water resources. As indicated in Figure 3-12, surface water use in Texas is expected to increase to around 10.3 million ac-ft by the year 2050 with the municipal share increasing to about 47 percent of total State surface water use by that time. Together, the urban-oriented water uses for municipal and industrial purposes are anticipated to comprise over 78 percent of statewide surface water use by 2050.

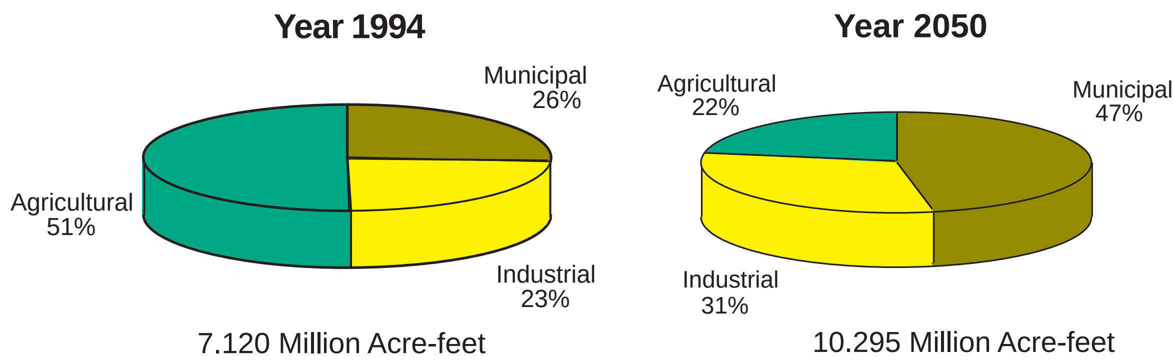


Figure 3-12
Composition of Current and Projected Surface Water Use, 1994 and 2050

Groundwater

Groundwater is a major water resource in Texas, supplying approximately 9.4 million ac-ft or 57 percent of the 16.5 million ac-ft in total water use statewide in 1994. As seen in Figure 3-13, more than 80 percent of the 9.4 million ac-ft of groundwater used in Texas in 1994 was for agricultural water use, followed with about 15 percent used for municipal purposes. Total groundwater use in Texas is expected to decline to around 4.6 million ac-ft by the year 2050 with agriculture's share declining to about 59 percent of total State ground-water use. With irrigation ground-water use falling and municipal ground-water use expected to remain about the same statewide, municipal's percentage share of total ground-water use should more than double.

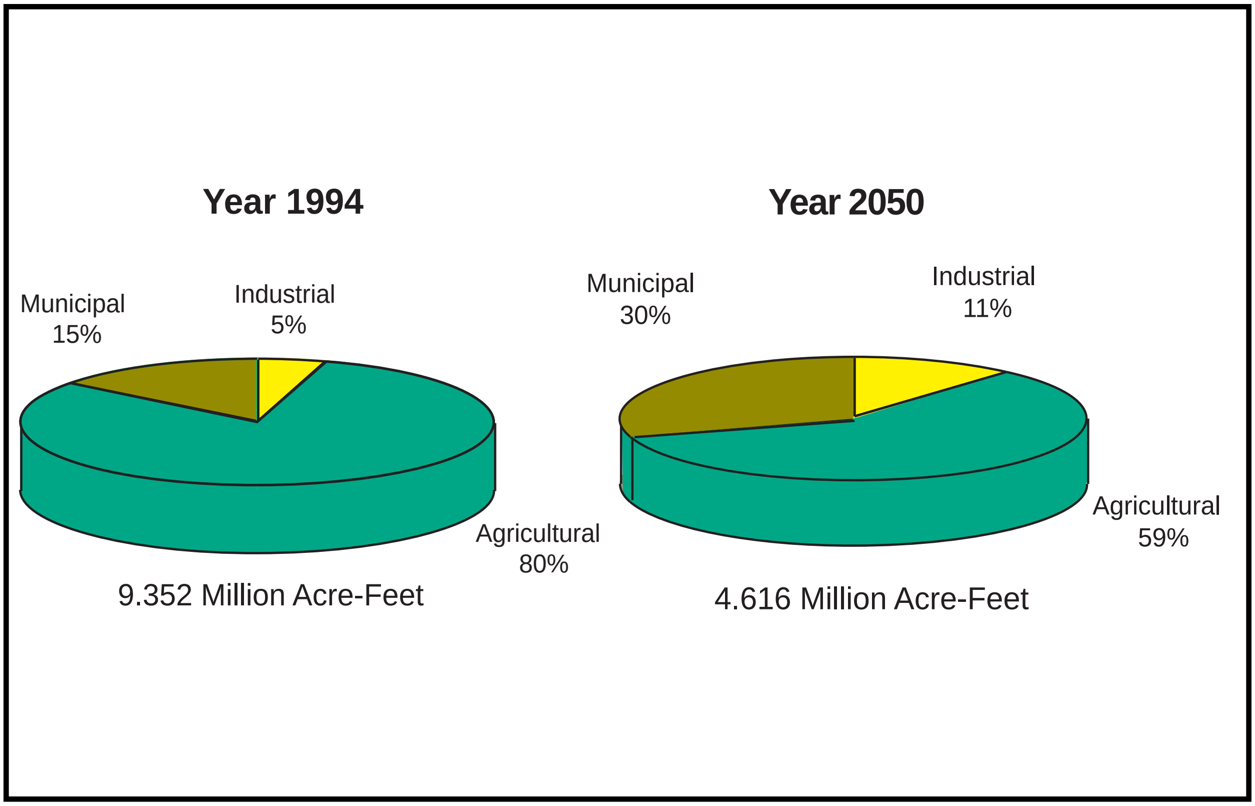


Figure 3-13
Composition of Current and Projected Ground-water Use, 1994 and 2050

3.1.4 Environmental Resources

3.1.4.1 Bay and Estuarine Ecology

There are many environmental concerns of importance in Texas, but none involve more public lands, waters and wildlife than the vital need for freshwater inflow to the State's bays and estuaries. Texas has seven major and three minor estuarine (tidal) systems located along 367 linear miles of Gulf coastline (Figure 2-1). These estuaries are generally characterized as formed from drowned river mouths when sea levels rose at the end of the last Ice Age. They are complemented by elongated barrier islands that enclose about 1.5 million acres of open water bays, at least 1.1 million acres of upland and adjacent wetlands (including 570,000 acres of emergent intertidal marshes and mudflats), and 250,000 acres of submerged aquatic vegetation (seagrass beds). The typically high levels of biological production in the estuarine ecosystems results primarily from their shallow, warm coastal waters being enriched by freshwater inflows and associated sediments and nutrients. This mechanism is enhanced by the barrier islands, which partially isolate the bays from the Gulf of Mexico, keeping the nutrient-laden waters inside and preventing them from being diluted or washed out to sea as quickly.

Seventeen of the State's 23 river and coastal basins drain into the coastal environments. During the 47-year period from 1941 to 1987, gaged river flows to all estuarine (tidal) systems except the Laguna Madre have averaged approximately 23.3 million ac-ft per year, while the ungaged contributions from the coastal drainage basins have averaged about 6.8 million ac-ft per year or 22.6% of the total. The functional role of these inflows in the ecology of the bays and estuaries is highly complex but includes the transport of sediments, nutrients, and food materials, as well as the dilution of Gulf marine waters to form a salinity gradient of brackish waters in the bays that allows the inhabiting organisms to survive, grow, and reproduce. In addition, the periodic flushing of the estuaries by high (flood) flows stimulates the cycling of essential nutrients, dilutes or removes pollutants, and eliminates or at least limits many of the marine parasites, predators, bacteria and viruses that are harmful to estuarine-dependent organisms.

Nevertheless, this does not mean that estuarine needs for freshwater inflow are in some way constant or uniform. In fact, dynamic inflow fluctuations within the productive range, both seasonally and annually, are realistic and desirable for Texas bays and estuaries. However, extended or semi-permanent inflow conditions which consistently fall below the maintenance level of the ecosystem can lead to degraded estuarine environments, loss of vital nursery areas for the young of economically important fish and shellfish (seafood) resources, and a reduction in the tremendous potential for natural assimilation of organic and nutritive wastes produced by man's activities (e.g., municipal, industrial and agricultural wastes).

Texas bays and estuaries provide natural and man-made resources that contribute to the State's economy in many ways including (1) a navigation network of national importance; (2) an environmental source of natural waste treatment for nutritive materials and other by-products of our modern society; and (3) a vast resource base for minerals, seafoods, and recreational opportunities. For example, sport and commercial fishermen in Texas harvest approximately 100 million pounds of coastal fish and shellfish annually from the bays, estuaries, and near shore Gulf waters. Gulf of Mexico fishermen take an additional 100 million pounds of seafood (primarily menhaden and shrimp) to other states each year for processing. The total annual impact on the State's economy from commercial fishing, sport fishing, and other recreational activities associated with the bays and estuaries has been estimated to exceed $3.5 billion (1994 dollars).

More than 90 percent (by weight) of the marine species harvested are considered to be estuarine-dependent during at least some portion of their life cycle, particularly the larval or juvenile life stages. The estuaries, in turn, are dependent upon freshwater inflows from Texas rivers and streams for sediments, nutrients, and a viable salinity gradient that allows the inhabiting organisms to survive, grow, and reproduce. The 5.3 million people who will live on or near the Texas Gulf Coast in the year 2000 will also be dependent upon the availability of the same limited freshwater supplies. Since the health, welfare, and quality of life for all these people are ultimately tied to the ecological health of their environment, it is crucial that we learn to beneficially use the limited freshwater supplies efficiently and to share them with the bays and estuaries as necessary to create and maintain a sustainable economy.

3.1.4.2 Instream Ecology

The 191,000 miles of rivers and streams (named and unnamed) in Texas provide habitat for 247 species of freshwater and coastal fishes (Hubbs et al. 1991), and a very diverse complement of aquatic fauna and flora, which are all adapted to the natural hydrology of their respective watersheds. Indeed, with over 150 species of native freshwater fishes, Texas streams and rivers are among the most biological diverse in the nation. Only Missouri, Alabama, Georgia, Tennessee, Kentucky, and Arkansas have more native freshwater fishes, a result of their biogeographic association with the immense drainage system of the Mississippi River, the largest and most diverse river system in North America. Moreover, Texas ranks second nationally in terms of angler days of sport fishing, both inland and coastal, with an economic impact estimated at $1.475 billion annually (TPWD, 1995-96).

Anderson et al. (1995) assessed temporal trends in Texas freshwater fish communities by comparing collections made by Hubbs et. al. (University of Texas at Austin, 1986) with those made in 1953 from 129 sites across the state. The study indicated relative stability in statewide fish communities, though species such as catfishes, darters, minnows, and suckers adapted to flowing-water habitats were shown to have reduced relative abundances while opportunistic species have increased. Regional analyses demonstrated some significant changes in east Texas river basins. For example, significant decreases in species diversity and changes in fish community assemblages were revealed. Hubbs et. al. (1991) indicated that at least five native Texas fishes are now extinct and three more have been extirpated throughout the Texas portion of their species range. About 20% of all Texas fishes are potentially threatened with extinction or extirpation from the Texas portion of their species range.

Natural flow regimes are a key element in maintaining these diverse aquatic ecosystems, and they exhibit tremendous variability across Texas including occasional flash floods, stable base flows, seasonal periods of low flow, and extended periods of drought. These large variations in the flow regime generally can be attributed to the geographical variation and size of Texas which experiences disparate regional precipitation patterns (56 inches per year in east Texas to 8 inches in far west Texas) and in the seasonal patterns of rainfall. Many aquatic species have specific habitat and life history requirements related to natural flow regimes and associated seasonal trends.
For example, fishes in prairie stream communities are adapted to harsh environmental conditions, such as low flow events, but also have spawning activities keyed to high flow events. The health and maintenance of various riparian areas, hardwood bottomlands and associated wetland ecosystems are also intimately linked to natural flow regimes. Additionally, rivers, streams and riparian areas cumulatively assimilate large volumes of nutrients and organic materials from both natural and anthropogenic sources, such as wastewater and non-point source runoff. It is critical that Texas streams and rivers have sufficient quantity and quality of instream flows in order to maintain these assimilative capacities that are vital for the preservation of human health and enjoyment of the natural bounty of Texas.

The intrinsic value of free-flowing rivers and streams enhances the quality of life for present and future generations of Texans. Although Texas has 3,700 named streams and rivers, very few can be considered free-flowing. Every major river basin in Texas has been impounded and nearly 6,000 small dams for stock ponds have been constructed statewide. In addition, more than 200 major dams have been constructed on Texas rivers and streams for flood control and municipal supply reservoirs, usually with some alteration of downstream flow regimes and water quality. Impoundments block many aquatic organisms' innate requirement for upstream and downstream migration; act as heat, sediment and nutrient sinks; alter downstream water quality and structural characteristics of stream channels; and fragment aquatic habitats, isolating aquatic populations and making them more susceptible to ecological disaster.

To some degree aquatic ecosystems can respond to these alterations but generally at some cost to biological integrity and diversity. Opportunistic species may dominate aquatic communities at the expense of specialists and species adapted to flowing water habitats, such as certain kinds of darters, minnows, suckers, molluscs and other invertebrates, which are not locally common below lakes and reservoirs. These shifts in community structure can be ecologically significant downstream of reservoirs. Negative impacts on upstream fish communities have also been documented (Winston et. al. 1991).

Moderation and attenuation of high flows by flood control projects and water supply reservoirs influence long-standing relationships between rivers and streams and their associated riparian ecosystems. This attenuation disrupts exchanges of nutrients and organic materials, sediments, and water between stream resources and floodplains, causing ecological impacts to riparian ecosystems. The maintenance of these riparian areas is dependent on the timing, duration, and intensity of streamflows that cause overbanking into primary and secondary terraces, sloughs, adjacent bayous, and other types of riparian wetlands. Lack of overbanking flows shifts the community from bottomland hardwoods toward upland vegetation communities. Bank-full or flushing flows are also important for channel maintenance. If necessary flows (with appropriate magnitude, frequency and duration) are not available for self-maintenance of stream channels, streams tend to accumulate and clump sediments, increase bank erosion rates, and allow vegetative encroachment. These and other processes can result in reduced capacity to efficiently handle flood flows and accumulation of fine sediments.

Diminished base flows, largely due to direct diversions, inadequate reservoir releases, and ground-water withdrawals that intercept artesian (spring) discharges, cause reductions in habitat diversity and availability, alterations to trophic and community structure, and consequently a resultant loss of stream productivity. Reduced base flows can cause biologically important changes in water quality characteristics, such as reduced assimilative capacity, reaeration, and thermal buffering capacity, as well as alterations to nutrient dynamics and assimilation of organic matter.

Although low flow events are natural components of flow regimes, human-induced increased durations and frequencies of low flow events can have serious impacts on fish and wildlife resources. The riverine aquatic communities in Texas have evolved to withstand severe droughts with prolonged periods of reduced streamflow. Desiccated (partially dry) streams obviously provide little aquatic habitat and extended periods of low flow generally result in pool habitats separated by dry reaches of streambed. If pools become severely reduced, temperatures can rise to lethal levels and the concentration of dissolved oxygen may not be sufficient for the survival of many desirable species. Consequently, populations of aquatic organisms needed for recruitment may not exist once streamflows return. The threat of significant impact on river and stream communities is especially serious in those river basins where water rights have been over-appropriated. In addition, the integrity of spring-fed ecosystems is at stake when ground-water pumping rates exceed the rate of aquifer recharge. Of the 281 springs identified by Brune (1981) as historically significant, more than one quarter (80) no longer flow, and those that remain have significantly diminished discharges at times.

Instream flow and the instream uses and resources dependent on these flows would be best served by recognizing the value of approaching water resource development on a watershed basis. Watersheds are the only logical planning unit upon which to base both short term and long term development activities related to water. Any smaller geographic approach fails to deal with interconnectedness and dynamic nature of the watersheds in Texas. Often, a river basin or subbasin will be the appropriate unit for planning water development that minimizes the impact on fish and wildlife resources.

It is obvious in any water planning effort, that human uses of water will have changing priorities through time. It is also obvious that the best knowledge of the flow regimes adequate for conserving aquatic ecosystems still is in the future. Therefore, it makes perfect sense to view planning and permitting efforts for instream flows as yet another human effort that should retain as much flexibility as possible. As demands for water resources decrease or increase in some areas, as priorities change through time, as better technologies become available to provide water, watershed water resources need to regularly be revisited to satisfy the human uses of water, including instream uses and flows for fish and wildlife resources.

The Lower Colorado River Authority's Water Management Plan (1992) is an example of comprehensive watershed planning that also incorporates periodic review and revisions. Demand centers change within the basin, revisions can be made to provide for more equitable solutions to supplying demands, more knowledge about instream flows and inflows to bays and estuaries becomes available, new technologies and conservation techniques become factors, and priorities can be revisited to ensure that the best solutions and knowledge continues to be incorporated into the plan. Water planning and management that is comprehensive and sufficiently dynamic to respond to changes throughout time has the best opportunity for conserving aquatic ecosystems while still providing for other human water supply needs.

To maintain the high quality of life for humans in Texas, flowing rivers and streams must be conserved, maintained or restored to ensure that the invaluable natural heritage of Texas persists for present and future generations. Rivers and streams that must be altered for human purposes should be maintained to provide for native aquatic communities in a manner that as closely as possible emulates natural conditions. Water planning for instream flows should abandon the minimum streamflow concept, work towards watershed based planning efforts, and recognize the importance of maintaining flexibility so that new knowledge can be incorporated into developing water supply for future generations.

3.1.4.3 Wetland and Terrestrial Ecologies

Water development activities that involve impoundment and diversion of Texas rivers and streams can also affect local riparian (river bank and floodplain) environments, including the 6,068,000 acres of bottomland hardwoods and other forested wetlands that remain in Texas and are of particular concern. Indeed, construction of lakes and reservoirs in Texas so far this century have replaced over 600,000 acres of forested wetlands with deep-water aquatic systems, and another 52,667 acres may be lost if all eight of the Water Plan's recommended reservoirs are built in the next 50 years. This represents the difficult decisions that must be made and the trade-offs required in order to secure a reliable future water supply for the people and the economy of Texas.

However, no loss of wetlands should be taken lightly because Texas wetlands provide abundant ecological and cultural values that are important to the people and the economy of the State. It is State and Federal policy that there be no net loss of wetlands, which can be accomplished by restoring and rehabilitating native wetlands. While many goods and services associated with Texas wetlands can be valued monetarily (e.g., sport and commercial fishing, waterfowl hunting, and eco-tourism), many others can not. These would include environmental quality functions such as maintenance of water quality and biodiversity, and the hydrological functions of aquifer recharge and buffering of impacts from storms, floods, and erosion. As a result, the true value of Texas wetlands would only be comprehended if all of the goods and services provided by wetlands had to be replaced by our human society.

Although statutory requirements for mitigation of environmental losses can take several forms, such as changes in the location or operation of a water project, terrestrial mitigation often takes the form of "in-kind" compensatory land acquisition (replacement of each acre lost with a similar acre purchased elsewhere). For federally sponsored water projects, the mitigation lands are usually dedicated as preserves or refuges and administered by the U.S. Fish and Wildlife Service, which also conducts its own ambitious Bottomland Hardwoods Acquisition Program with a reported goal of acquiring over 250,000 acres in Texas. For state or locally sponsored water projects, the mitigation lands are usually dedicated as state parks or wildlife management areas, which are administered by the Texas Parks and Wildlife Department. In general, the establishment of state parks in association with new lakes and reservoirs provides greater public access and appreciation of our natural resources than do other types of compensatory land acquisition. However, parks are not necessarily managed to compensate for fish and wildlife losses as are specific mitigation areas that become wildlife management areas.

A viable alternative to the establishment of small, isolated parcels of mitigation lands, which are known to have little ecological value, is the development of regional mitigation banks that contain large, consolidated tracts of land with fully functional ecosystems that can be managed more efficiently and effectively to return long-term environmental benefits. Currently, a lot of mitigation funds and efforts are wasted on acquisitions that are too small to provide ecosystem- level benefits.

3.1.5 Water-based Recreation

3.1.5.1 Recreational Water Resources

Water resources in Texas are major outdoor recreation attractions. Water acts as a focal point for parks and linear greenways. Participation in outdoor recreation in Texas peaks during the summer months when millions of recreationists flock to water resources.

Water-related outdoor recreation activities, such as fishing, boating, water skiing, swimming, waterfowl hunting, and nature study, occur directly on or in the water. Other activities, such as camping, picnicking, and trails activities, occur adjacent to or along water resources. Another variant of water-based recreation is the growing number and attraction of commercial water recreational parks.

Numerous recreational activities are enhanced if the opportunity is provided in the proximity of a water resource. Thus, water resources attract recreationists to recreational areas and add to the experience upon arrival. Recreational water resources in Texas consist of wetlands, rivers and streams, freshwater lakes and reservoirs, saltwater bays and estuaries, and the State territorial waters of the Gulf of Mexico.

Exhibit 3-1
Recreational Water Resources in Texas

Freshwater Lakes and Reservoirs

Texas has 6,687 square miles of inland water, ranking it seventh among the 48 contiguous states, and first among those states in amount of public fresh waters. There are about 5,700 reservoirs in Texas with surface areas of 10 acres or larger. Three-fourths of the state's freshwater lake acres are located in the eastern half of Texas. The Texas Parks and Wildlife Department's 1990 Texas Outdoor Recreation Plan (TORP) estimates a total of 1.2 million surface acres of fresh water in Texas are suitable for boating, fishing, and water-skiing.

Rivers and Streams

The USGS identifies 11,247 named streams in Texas, with a combined length of about 80,000 miles. Over 13,000 miles of these waterways are classified as rivers.

Saltwater Resources

Saltwater resources within the bays and estuaries, and out to nine nautical miles into the Gulf of Mexico, total 4 million acres. Approximately 3.9 million square yards of saltwater are designated for swimming (TPWD, 1990).

Wetlands

Estimates of the various types of wetlands found in Texas vary considerably. Wetlands provide a natural environment that is often used for recreation and nature appreciation. Wetlands are increasingly desired destinations for recreation, including wildlife observation, general aesthetics, hunting and fishing, hiking and boating (TPWD, 1995).

3.1.5.2 Water-Related Recreation Participation

When residents were asked which three of nine types of outdoor areas they would most like to visit in Texas, water-based recreation activities ranked very high: placing second, third, fourth, and eighth among the nine types of outdoor areas surveyed (see Table 3-1). Besides water's many other vital uses, these responses also illustrate the importance that citizens place on water resources as an amenity when recreating and traveling in Texas. Such quality of life considerations are also importance in attracting economic development to the State.

Participation in all but six of the 26 activities presented in the 1990 TORP may occur on, in, or adjacent to water resources. Seven of the 26 outdoor recreation activities analyzed in the 1990 TORP occur in or on some type of water body. These seven activities account for 19 percent of the total participation occurring in 1995. Participation in other activities, such as hunting and nature study, occurs on both land and water resources. Trail activities account for 47 percent of the participation occurring in 1995. Many trails are constructed along rivers and streams, or around lakes, reservoirs, and saltwater bodies. Greenbelts along streams have become central attractions in many cities such as Austin, Dallas, Houston, Fort Worth, and San Antonio. Recreation areas such as golf courses are improved with water bodies.

Table 3-1
Outdoor Recreation/Tourism Preferences in Texas

	Preference	Rank
Mountains	62%	#1
Rivers or streams	61%	#2
Lakes or reservoirs	58%	#3
Gulf Coast	48%	#4
Forests	42%	#5
Open ranch land	9%	#6
Desert	7%	#7
Swamps or marshes	2%	#8
Other	1%	#9

Source: TPWD, 1987.

3.1.5.3 Economic Impact of Water Resources Used for Recreation

The total economic value, or benefit, of a resource or site to society is not a concept easily understood, and few studies attempt to measure the total economic benefit of resources or sites. Water resources used for recreation are no exception. Drs. Loomis and Peterson describe the components of total economic value of a public recreation resource to include recreational, commercial, option, existence, and bequest values. Both the Contingent Value Method and the Travel Cost Method are approved by the federal Office of Management and Budget for use when estimating the value of a resource site for inclusion in a benefit-cost analysis (TPWD, 1990). The real economic value of resources for recreation purposes will be more apparent as these methods are applied.

Boat registrations and hunting and fishing license sales indicate the value recreationists in Texas place on water resources. Current boat registrations in Texas maintained by the Texas Parks and Wildlife Department total 618,512. The significance of recreation is evident with 610,713, or 99 percent, of these registered as pleasure boats. Resident fishing license sales in Texas topped one million in FY 95, generating over $13 million in revenue. Saltwater sportfishing stamps totaled 624,000 for $4.1 million in revenue. Non-resident and temporary fishing license sales totaled 219,671 exceeding $3 million. Resident combination hunting and fishing license sales of 514,758 generated another $12.4 million. These license sales combined resulted in $32.5 million in revenue for the state (TPWD, 1995).

Sporting goods expenditure data in 1987 showed that Texans spent over $1.5 billion dollars annually (in 1994 dollars) on recreation equipment and clothing. Boating expenditures ranked first with nearly $548 million, or 35 percent of the total. Spending on fishing equipment totaled $46 million. Water skiing accounted for over $12 million in spending. Other traditional outdoor activities like camping at $68 million rank high in spending. Indeed, many state park visitors are willing to pay more for a campsite adjacent to a water resource. These expenditure estimates by TPWD (1990) illustrate the importance of water resources to recreationists statewide. Also, according to a 1991 national survey of fishing, hunting, and wildlife-associated recreation, the total economic impact of waterfowl hunting in Texas was $96 million, while the nonconsumptive appreciation of the State's waterfowl had an even greater value of $240 million.

Texas tourism and the associated travel revenues, valued at $21.4 billion in 1992, are the state's third largest industry behind gas and oil and agriculture (Texas Department of Commerce). A large portion of this economic impact is by Texans engaged in recreational travel. Water resources are a major reason Texans engage in recreational travel. In 1983, a study by the Texas Parks and Wildlife Department showed that Texans spent $13.7 billion (converted to 1994 dollars) on recreational travel in Texas for 20 outdoor recreation activities. Texans spent $3.3 billion, or 24 percent of the total expenditures, on travel to fish, swim, boat, and water-ski. Other recreational travel which may be related to water resources showed that sightseeing and driving for pleasure generated another $3 billion in travel expenditures, trails activities $3.9 billion, hunting $862 million, camping $516 million, and picnicking $374 million. Recreational travel is important to the Texas economy, and water and wildlife resources are an integral part of that economic activity (TPWD, 1984).

3.1.5.4 Recreational Water Needs

The sensitivity of water-based recreation to availability of water was highlighted during the 1996 drought. Revenue at Texas State parks was dramatically down, indicating water availability for recreation is a deciding factor for many in selecting recreational destinations. News articles across the State not only described the shortfall endured by the State park system, but also the devastating effects seen by private, county and city facilities dependent on water for recreation-based revenue generation.

Improved access to water bodies is also needed to meet recreational demand in Texas. Streams, saltwater bays, wetlands, and beaches are resources unlike reservoirs because they are impractical to create. Their recreational use is sometimes limited by inadequate public access. River access is generally confined to public parks, boat ramps, bridges, or road crossings. Saltwater access is limited to areas of the coast served by public roads or public recreation areas. The key to meeting the recreational needs for streams and salt water is ensuring adequate public access.

Although some rivers have recreationally benefitted from reliable and extended flows supplied by reservoir storage, studies such as those conducted by the National Park Service have shown that free-flowing rivers are also among the nation's leading recreational resources.

3.1.6 Water Quality

3.1.6.1 Surface Water Quality

The Water Plan uses information and graphics from the TNRCC's Clean Rivers Program to visually present water quality information by basin. Water quality graphics presented here are taken from Texas Water Quality, A Summary of River Basin Assessments (TNRCC, December 1996). Questions concerning water quality data presented in the graphics should be directed to the TNRCC or individual Clean Rivers Program contractors.

Using historical surface water quality data, the Texas Natural Resource Conservation Commission (TNRCC) biennially prepares their Water Quality Inventory report which describes the water quality status of the State's waters. The State of Texas Water Quality Inventory is prepared and submitted to the United States Environmental Protection Agency (EPA) in accordance with Section 305(b) of the federal Clean Water Act. The 1996 Water Quality Inventory report analyzed the water quality data of the classified segments for four years covering the period of September 1990-August 1994. Toxic substance data in sediment and fish tissue were evaluated over a 10-year period of September 1984-August 1994. The TNRCC analyzed the water quality data for compliance with their Surface Water Quality Standards (Title 30 TAC, §§307.1-307.10) along with other screening criteria.

Exhibit 3-2
Water Use Designations
for Water Quality Considerations

Many waterbodies (streams, rivers, reservoirs, bays and estuaries) have been designated for a specific use(s) by the TNRCC. The uses are based on the goals of the Federal Clean Water Act. Some examples are:

- Contact Recreation such as swimming
- Noncontact Recreation such as boating
- Public Water Supply (drinking water)
- Aquatic Life, where the waters are protected for the propagation of e.g., fish; endangered species
- Fish for consumption
- Agricultural Water Supply (irrigation, livestock)
- Industrial Water Supply
- Oyster Waters, where the waters are protected for edible species of clams, oysters, or mussels

Classified waterbody segments are designated by the TNRCC. According to the TNRCC, "classified segment" refers to the surface waters of an approved planning area exhibiting common biological, chemical, hydrological, natural, and physical characteristics and processes.

The Texas Surface Water Quality Standards specify the appropriate water uses (see Exhibit 3-2) for a waterbody and the physical, chemical, and biological criteria that are necessary to support those uses. The water uses are based on the goals of the Federal Clean Water Act, which are to restore and maintain the chemical, physical, and biological integrity of the nation's waters.

Specific water uses such as aquatic life, contact or noncontact recreation, oyster waters, public water supply, aquifer protection, industrial water supply, agricultural water supply and navigation are assigned to each classified stream, river, reservoir, bay and estuary segment in Texas by the TNRCC.

Classified Streams and Rivers

According to the TNRCC's 1996 The State of Texas Water Quality Inventory, approximately 69 percent (9,743.5 miles) of assessed stream and river miles fully supported their overall uses, 9 percent (1,313 miles) partially supported their uses, and 22 percent (3,119.5 miles) did not support their uses. Overall use support of 69 percent in streams and rivers represents about a 3 percent improvement since 1994. Major causes for use nonsupport were identified as elevated levels of fecal coliform, metals in water, and depressed levels of dissolved oxygen. Major sources contributing to use impairments were domestic wastewater discharges to water, unknown sources, agricultural runoff, and urban runoff.

The percentage of stream and river miles supporting aquatic life uses decreased from 93 percent in 1994 to 91 percent in 1996. The number and percentage of stream and river miles that supported the contact recreation use remained essentially the same between 1994 and 1996 at 72 percent. The number of stream and river miles supporting the fish consumption use declined slightly from 1994 to 1996 since a fish consumption advisory for Big Cypress Creek (Cypress River Basin) was issued by the Texas Department of Health. Fifty of the 222 (22 percent) stream and river segments had sediments with elevated toxic substances.

Classified Reservoirs

Overall use support in classified reservoirs declined substantially statewide from 1994 (98 percent) to 1996 (78 percent) primarily due to issuance of consumption advisories by the Texas Department of Health for four reservoirs in East Texas with elevated mercury levels in edible aquatic life. Aquatic life support in classified reservoirs also declined from 1994 (98 percent) to 1996 (91 percent) primarily due to depressed dissolved oxygen levels (66 percent) and toxic substances in the water (34 percent). Reservoirs that supported the contact recreation use also declined slightly from 1994 (99 percent) to 1996 (97 percent). Thirty-one of the 99 reservoir segments (31 percent) had sediments with elevated toxic substances. Five reservoirs (Lake Meredith, Lake Whitney, Lake Granbury, Possum Kingdom, and E.V. Spence) have naturally elevated levels of chloride, sulfate, and total dissolved solids. All classified reservoirs designated for public water supply use were in attainment, as no closures of supplies for water quality concerns occurred during the past four years. Major sources that contributed to use nonsupport included unknown sources, atmospheric deposition, natural conditions, and domestic wastewater discharges to water.

Classified Bays and Estuaries

All 44 classified bay segments were assessed in 1996, with overall use support in 65 percent of the bays; 30 percent partially supported overall uses; and 6 percent did not support their uses. Elevated fecal coliform densities were the major cause of use nonsupport. Agricultural runoff, urban runoff, onsite sewage facilities, and natural conditions have been identified as major sources contributing to impairment of overall uses. Attainment of overall use support improved in classified bays from 1994 (60 percent) to 1996 (65 percent). Attainment of aquatic life use decreased slightly from 98 percent in 1994 to 94 percent in 1996. Contact recreation use and support of oyster waters remained about the same for 1994 and 1996. Major sources that contributed to use nonsupport included agriculture, urban runoff, on-site sewage facilities, and natural conditions.

3.1.6.2 Ground-water Quality

Ground-water quality and chemical composition changes along its flow path from point of entry as recharge to exit at a point of discharge or removal. Natural ground-water quality is dependent upon many factors including reactions which take place between the water and the aquifer matrix, mixing of water from various sources, flow velocity, distance along the flow path, and residence time in the aquifer. The environment in which the aquifer was deposited will influence the chemical character of the water. Ground-water chemical quality between individual aquifers will vary, due to differences in both geologic and hydraulic conditions (TWC, 1989).

Natural contamination probably affects the quality of groundwater in the State more than all other sources of contamination combined. Leaching of contaminants from overlying soils and rock units, and migration from deeper, more saline aquifers, can affect its quality. Natural contamination can take many forms, including mineralization and addition of toxic substances and nuisance materials (TWC, 1989). Natural contaminants, such as nitrates, sulfates, chloride, iron, and radium, are found in various aquifers of the State.

Man-made causes of ground-water quality impairment can range from: degradation of ambient ground-water quality through excessive withdrawals; contamination from septic tanks, agricultural practices, waste disposal, and non-point runoff; and induced contamination from natural sources due to improperly completed and/or abandoned wells.

Comparison of ground-water quality analyses to State drinking-water standards indicate that water from 32 percent of the wells sampled around the State contain one or more of the following constituents in excess of State drinking-water standards (indicated in parentheses): dissolved solids (1,000 mg/L), chloride (300mg/L), nitrate (10 mg/L as nitrogen), and fluoride (2.0 mg/L). It is also estimated that about 1 to 2 percent of the State population had, at some time, used drinking water from ground-water sources that had one or more of these constituents in excess of Texas drinking-water standards (USGS, 1986).

3.1.7 Prospective Water Needs and Recommended Management Measures

3.1.7.1 Integrated Management Approach

In order to assess the new water management needs of Texas, the TWDB prepares a "no action" scenario that portrays statewide demographic/economic growth occurring as anticipated with only currently available water supply infrastructure and no further improvement in water demand management. TWDB forecasts indicate that water shortage problems could blanket the entire State with every Texas county in deficit at some point in the 50-year planning period. So, what can be done about this prospective situation?

In the past when resources were plentiful, the traditional response was to build a near-by lake or drill some wells, and decisions were less complex and more straightforward. However, the State is in an era of increasing resource scarcity, more pronounced competition for those limited resources, and heightened environmental awareness. The older traditional methods of just building a new water supply are not only less politically and regulatively feasible, but increasingly more costly, and sometimes still insufficient to meet the full extent of anticipated water needs.

Today and even more in the future, a whole "toolkit" of both traditional and more innovative management measures will be needed to not only meet the physical or volumetric aspects of these needs, but also the growing political and regulatory expectations that water is being managed and used wisely before new major devel-

Table 3-2
Water Management Strategies
Used to Meet State Water Needs in the Year 2050

Management Strategy	Need Met* (mill. ac-ft)	% of Total
Current Water Infrastructure	11.58	55.3%
Expanded Infrastructure to Local Supplies	0.55	2.6%
Reuse/Return Flows	0.68	3.2%
Reallocation of Reservoir Storage	0.16	0.8%
Water Marketing	0.24	1.1%
New Ground-water Development	0.31	1.5%
New Interbasin Transfer of Existing Supplies	0.97	4.6%
New Reservoir Development	0.42	2.0%
sub-total water used to meet demands	*14.91*	*71.2%*
Unmet Irrigation Demand	3.44	16.4%
sub-total of composite set of demands	*18.35*	*87.6%*
Water Conservation compared with "no action" scenario	2.60	12.4%
Total of "no action" set of demands	**20.95**	**100.0%**

opment occurs. As previously discussed, the planning approach used in this State Water Plan was to first identify and recommend less-impacting, economic water management measures first and then subsequently recommending more impacting and costly measures to meet remaining water needs.

The various water management measures, referenced in Table 3-2 and described below, should not be naively followed in a prescribed order. Some management options may prove more economic or less-impacting than others earlier in the list, and some entities are facing very significant, near-term water supply problems that require proceeding on many fronts at once. And in other situations, the planning, design, and regulatory activities of major project action may be pursued at the same time less impacting or less costly measures are being implemented to address more near-term problems.

In other words, a good integrated plan needs to initially consider all meaningful options together with broad public involvement to determine both a strategic course of action and create public acceptance for viable solutions at the same time.

Current Water Infrastructure

A large portion of the State's capability to meet the water needs of the year 2050 can be provided through current infrastructure capability, assuming adequate rehabilitation and replacement of current facilities. All totaled, about 11.6 million ac-ft or about 55% of the State's year 2050 water needs can be supplied through current local infrastructure capacity and existing volumes of interbasin transfers.

Water Conservation

Because of water-efficient plumbing legislation passed by the Texas Legislature in 1991 and simply good public interest and economic sense, water conservation savings were incorporated in the recommended water demand forecasts for municipal, industrial, and irrigation uses. A various array of water conservation practices were assessed for their likelihood to be implemented both locally and statewide as a result of either regulatory compliance or just sound business decisions. It is not anticipated that these measures would noticeably affect the "quality of life," and in fact, may help preserve it into the future. These practical water conservation measures, which essentially represent a level of effort similar to what have been termed the "best management practices" of other states, should contribute the equivalent of 2.6 million ac-ft/yr or about 12% of statewide water needs by the year 2050.

Expanded Infrastructure to Existing Local Supplies

The next water management measure applied was to expand infrastructure to access additional water supplies from existing local or regional sources. An example of this is a new pipeline to serve the Round Rock-Georgetown area from the existing Stillhouse Hollow Reservoir. The expanded use of existing local supplies is expected to contribute approximately 0.6 million ac-ft/yr or about 3% of statewide water needs in the next 50 years.

Reuse/Return Flows

The next measure employed was various supply management measures related to water reuse and expanded use of return flows. It is anticipated that most direct reuse will be consistent with existing permit provisions and not require any amendment of water rights permits. Where return flows were utilized as a new supply, the availability of this resource was modeled as a new appropriation, subject to consideration for impacts to downstream water rights and environmental water needs. These direct and indirect reuse options are expected to contribute about 0.7 million ac-ft/yr or about 3% towards meeting statewide water needs by 2050.

Reallocation of Reservoir Storage

In many areas of the State, existing reservoirs were built to address a variety of different types of water purposes identified in their original feasibility studies, manifested in their ownership shares, and reflected in their permitted storage and uses. These "multi-uses" typically could include water supply, flood control, hydroelectric power generation, water quality, recreation, and so forth. However in some cases, the anticipated need for some of these uses have not been fully realized or may be of less public value than some other types of possible water use. There were some opportunities identified in the State Water Plan for re-allocating reservoir storage to water supply purposes. These prospective storage reallocations could provide an additional 0.2 million ac-ft or about 1% towards meeting State water needs by the year 2050. Reallocation of storage in a Federal reservoir project does have constraints, including time, cost, and, in some cases, Congressional concurrence is required.

Water Marketing

In some instances, there were situations identified where the marketing (sale, lease, or transfer) of water supplies made the most economic and environmental sense. These perceived marketing or transfer opportunities assumed a willing buyer and seller and typically involved a change of use from a lowered-valued application to a higher-valued water use. However, these water marketing transactions or transfers could occur in a variety of ways. In some cases, this transfer of water would simply result from a conversion of farming land uses to urban land uses. In other cases, unused water rights or land rights to undeveloped water could be bought or leased with little or no effect upon agricultural water needs. In some instances, marketing or transfer of agricultural water supplies could affect the level of agricultural production. While still in other cases, "win-win" marketing opportunities are possible in joint-partnerships to improve agricultural conveyance efficiencies with little or no affect upon agricultural supplies. It is anticipated that approximately 0.2 million ac-ft (1%) of statewide needs will be met in this manner by 2050.

New Ground-water Development

In some instances, entities will access new supplies of groundwater that they had not previously utilized, totaling about 0.3 million ac-ft/yr (1.5%) of new supply towards the State's 2050 water needs.

New Interbasin Transfers of Existing Supplies

With respect to another needed management measure, it is not well known that currently about 20-25 percent of our State's total surface water use with a noticeable percentage of our existing major metropolitan populations is supplied from interbasin transfers. It is anticipated that additional interbasin transfers of existing water supplies would contribute one million ac-ft/yr (4.6%) to addressing state water needs by the year 2050, having a pronounced effect on resolving the prospective deficit situation for many of the State's major metropolitan growth areas (Houston, D/FW, and San Antonio metropolitan areas, Corpus Christi, Abilene, Brownsville, and Longview).

New Reservoir Development

And finally, State and local decision-makers must not be misled that the magnitude of prospective growth in Texas can be addressed only through expanded use of existing supplies, minor local supply development, improved management measures, or interbasin transfers. Even after all of this, there still remains a need for additional water supply development. Eight new reservoirs, contributing 0.4 million ac-ft (2%) towards meeting State water needs, have been recommended to meet remaining "economic" water needs of the State by 2050. Of these eight recommended reservoir projects, one-half have been proposed for generally less-impacting off-channel locations away from the main river tributary.

3.1.7.2 Major Project Needs

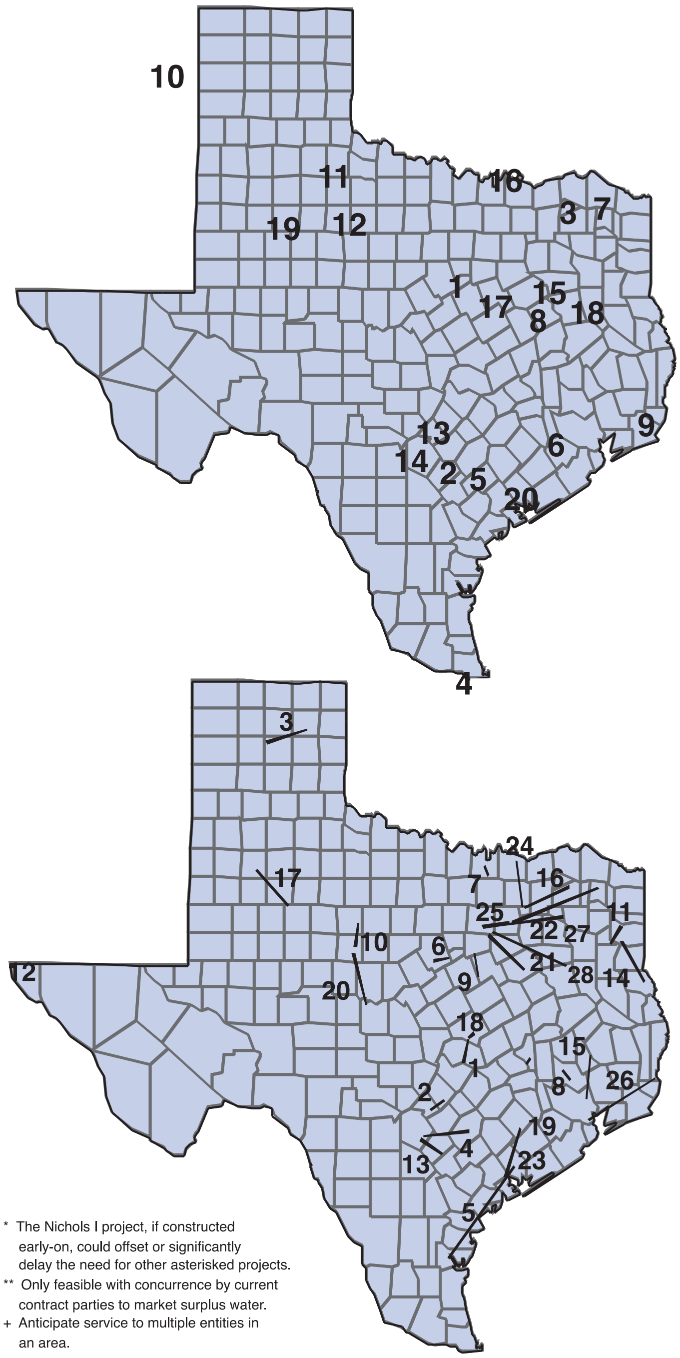
Figure 3-14 illustrates the conceptual location of recommended major water supply and conveyance projects anticipated as needed within the 50-year planning period. In the upper portion of the figure are eight new reservoirs, four major chloride (salinity) control projects, three projects reflecting reallocation or subordination of currently-permitted storage, and two projects which would involve substantial use of return flows diverted into off-channel reservoir storage. Three reservoirs currently have a state water right permit, but are not identified as needed during the planning period. In the bottom portion of the figure, major pipeline or canal conveyances are recommended to access both existing water supplies, as well as that provided from new supply development. Of these 28 major conveyance projects, 12 projects (about one-half) would involve a prospective interbasin transfer of water supplies.

A more specific mapping of existing, recommended, and state-permitted (but as yet unbuilt) major water supply projects can be found on the larger-size foldout map, "Existing major water supply reservoirs and recommended projects", contained in the map pocket at the end of the report.

More specific information concerning each of these recommended projects can be found in the following planning region and river basin discussions. The State Water Plan identifies a list of recommended projects in order to provide the public with an organized schedule of needed activities that best balance competing needs, economic considerations, supply availability, and acceptable environmental impact. Hopefully, such a specified "plan of action" will guide the decision-makers towards reasonable water supply development choices and minimize any conflicts in competition for the resource.

However, this process is not infallible. It is difficult to accurately assess all of the factors that affect project feasibility in a statewide plan, and some would say any 50-year forecasts are inherently wrong to some degree. The TWDB acknowledges these issues. Various things can happen that could modify or nullify some of the Plan's recommendations, such as different actions by local decision-makers; changes in the rate or pattern of growth; discovery of unknown, significant environmental effects; changing regulations; new technical knowledge about the resource; and so on. The State Water Plan should be looked at as a benchmark of today's knowledge about a reasonable plan of action.

Because of these uncertainties, it is prudent planning to also indicate what alternatives might exist to the recommended list of water supply development projects. Figure 3-15 provides a listing of various water supply development sites that could serve as alternatives to the recommended sites in the future.



Water Supply (Date Needed)

1 - Paluxy Reservoir (2010)
2 - Cibolo Reservoir (2010)
3 - Parkhouse II Reservoir * (2015-20)
4 - Rio Grande Wier (2005-2010)
5 - Sandies Creek Reservoir (2025-30)
6 - Allens Creek Reservoir (2025-30)
7 - Nichols I Reservoir *(2015-40)
8 - Tehuacana Reservoir (2050)

Chloride Control

9 - Neches River (2000)
10 - Canadian River (2000)
11 - Red River (2005)
12 - Brazos River (2015)

Reallocation/Modification

13 - Canyon Lake subordination (2000-05)
14 - San Antonio return flow diversion (2010)
15 - Trinity River return flow diversion * (2025-30)
16 - Lake Texoma reallocation (2045-50)
17 - Lake Whitney reallocation (2045-50)

State Permitted Projects

18 - Eastex
19 - Post
20 - Palmetto Bend II

Conveyance

1 - Stillhouse to Williamson Co.+ (2000-05)
2 - Canyon to Hays Co. + (2000-05)
3 - Roberts Co. to CRMWA + (2000-05)
4 - Guadalupe to Bexar Co. + (2005-10)
5 - Texana to Nueces Co. + (2005-10)
6 - Paluxy to Stephenville (2005-10)
7 - Moss to Gainesville (2005-10)
8 - Conroe to Conroe (2005-10)
9 - Whitney to Cleburne (2005-10)
10 - Abilene to Stamford (2005-2010)
11 - Lake O' the Pines to Gregg Co. + (2005-10)
12 - Rio Grande to El Paso Co. + (2005-15)
13 - Cibolo to Bexar Co. + (2010-15)
14 - Toledo Bend to Harrison Co. + (2010-15)
15 - Luce Bayou to Harris Co. + (2015-20)
16 - Parkhouse II to NTMWD *+ (2015-20)
17 - Alan Henry to Lubbock (2025-30)
18 - Belton to Williamson Co. **+ (2025-30)
19 - Allens Creek to Ft. Bend & Brazoria Cos . + (2025-30)
20 - Ivie to WCTMWD + (2025-30)
21 - Richland Chambers to TRWD *+ (2025-30)
22 - Nichols I to DFW *+ (2015-40)
23 - Garwood to Nueces Co. + (2035-40)
24 - Texoma to NTMWD + (2045-50)
25 - Nichols I to DFW *+ (2025-40)
26 - Sabine to Harris Co. + (2045-50)
27 - Lake Fork to Dallas + (2005)
28 - Lake Palestine to Dallas + (2015)

* The Nichols I project, if constructed early-on, could offset or significantly delay the need for other asterisked projects.
** Only feasible with concurrence by current contract parties to market surplus water.
\+ Anticipate service to multiple entities in an area.

Figure 3-14
Recommended Major Water Supply and Conveyance Projects, 1996-2050

1. Sweetwater Creek
2. Lower McClellan Creek
3. Elm Creek
4. Lelia Lake Creek
5. Dozier
6. Dry Salt Creek Brine
7. Buck Creek
8. Little Red River Brine
9. Caddo Enlargement
10. Dilworth
11. Ringgold
12. Bonham
13. Big Pine
14. Pecan Bayou
15. Liberty Hill
16. Barkman
17. Black Cypress
18. Marshall
19. Carl Estes
20. Belzoria Landing
21. Waters Bluff
22. Kilgore II
23. Prairie Creek
24. Kilgore
25. Rabbit
26. Cherokee II
27. Eightmile
28. Carthage
29. Socagee
30. Tenaha
31. Stateline
32. Little Cow Creek
33. Big Cow Creek
34. Newton
35. Bon Weir
36. Sabine Diversion
37. Sabine River Salt Water Barrier
38. Fastrill
39. Weches
40. Cochino
41. Rockdale
42. Dam A
43. Ponta
44. Attoyac
45. Roanoke
46. Tennessee Colony
47. Upper Keechi
48. Bedias
49. Hurricane Bayou
50. Lower Keechie
51. Harmons
52. Gail
53. Mustang
54. Caney
55. Long King
56. Liberty
57. Nelsons
58. Catfish Creek
59. Cleveland
60. Humble
61. Lake Creek
62. Upper Lake Creek
63. Seymour
64. Padgett
65. Elm Creek
66. South Bend
67. Breckenridge
68. Turkey Creek
69. Inspiration Point
70. Turkey Peak
71. Kickapoo Peak
72. Sanchez
73. Hightower
74. Bee Mountain
75. Stephenville
76. Parkhouse I
77. South Fork
78. Brushy Creek
79. San Gabiel
80. Little River
81. Davidson
82. Caldwell
83. Oak Knoll
84. Navasota
85. Millican/Panther Creek
86. South San Gabriel
87. Nugent
88. Post
89. Duck Creek
90. Pecan Bayou
91. Fox Crossing
92. San Saba
93. Mason
94. Llano
95. Pedernales
96. Clearview
97. La Grange
98. Baylor Creek
99. Shaw's Bend
100. Cummins Creek
101. Matagorda
102. Winchell
103. Rattler
104. Pametto Bend II
105. Garcitas
106. Ingram
107. Uppper Guadalupe
108. Cloptin
109. Lockhart
110. Confluence
111. Wimberley
112. Smith
113. Dam 7
114. Belmont
115. Bear North
116. Peach Creek
117. Ecleto
118. Goliad (EHA)
119. Karnes City
120. Falls City
121. Blanco
122. Beeville
123. Woodsboro
124. Bayside
125. Montel Site 'B'
126. Concan
127. Sabinal
128. Zavala
129. Caimanche
130. Cotulla
131. Fowlerton
132. Bluntzer
133. R&M
134. Whitsett
135. Tom Null Hill
136. Kingsville
137. Alpine Lake
138. Site B Channel Dam
139. Applewhite
140. Cuero
141. Bosque County
142. Eastex
143. Big Sandy
144. Little Cypress
145. Nichols II
146. Millican/Peach Creek

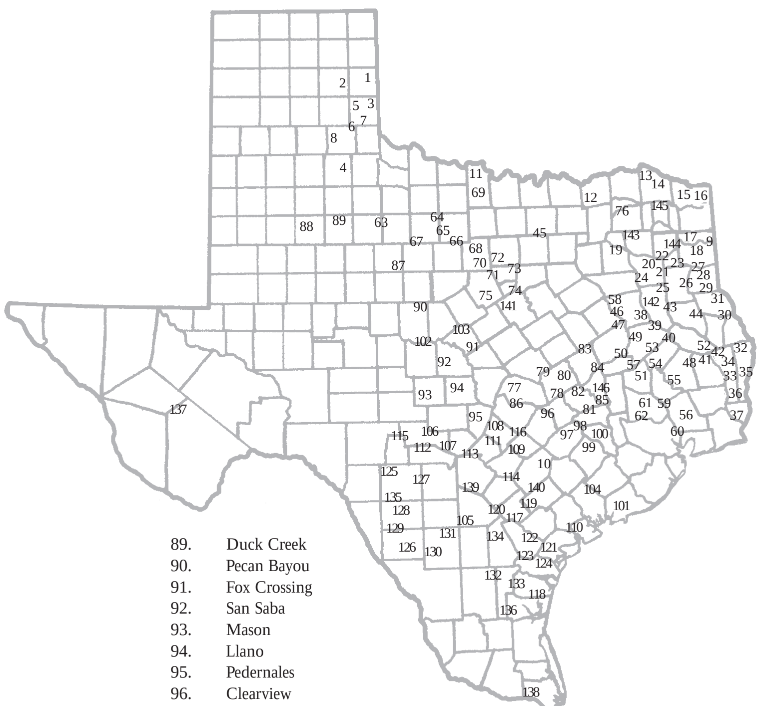


Figure 3-15
Alternative Water Supply Development Sites

3.1.7.3 Uneconomic Needs

One aspect of the State Water Plan's forecast for Texas that should be highlighted is the amount of current irrigation water use that is anticipated to be "economically" supported in the future, given declining water supply availability (primarily ground-water) that the Board has estimated for this purpose and the relatively high cost of replacement supplies. Affordable water supplies (without significant government water-cost subsidy) could not be identified for approximately 3.4 million ac-ft of projected irrigation water demand by the year 2050. In economic terms, this is not a true "shortage or deficit" in that supplies could be made available, but can not be afforded by this use. These irrigation water use estimates are reflected in the plan as adjustments to irrigation demands, resulting in decreasing amounts of irrigated agricultural water use over time.

3.1.8 Costs and Finance

As previously discussed in Section 2.2.3, the costs of recommended water-related infrastructure needs were developed from a variety of sources, ranging from specially-commissioned engineering reports to surveys of utilities to inventories of available utility capital improvements programs to projections made by Board staff. Even so, Board staff feels that these water-related infrastructure cost estimates are conservative, particularly in the area of flood protection measures where the identification of needs is typically a very detailed and costly study.

Table 3-3
Projected Capital Cost of Water-related Infrastructure Needs, 1996-2050

Water-related Infrastructure	Projected Cost for Time Period (million 1996$)*			
	1996-2000	2001-2020	2021-2050	1996-2050
Water Utilities	$1,927.7	$11,153.2	$19,373.6	$32,454.5
Water Supplies				
Reservoirs	$0.0	$467.0	$864.1	$1,331.1
Chloride Control	$0.0	$495.6	$0.0	$495.6
Reallocation/Modifications	$0.0	$0.5	$142.5	$143.0
Conveyance	$32.6	$1,213.0	$1,481.6	$2,727.2
Supplies Total	$32.6	$2,176.1	$2,488.2	$4,696.9
Wastewater Utilities	$1,546.9	$8,949.8	$15,546.0	$26,042.7
Flood Protection	n.a.	n.a.	n.a.	$2,200.0
Total Infrastructure Costs	$3,507.2	$22,279.1	$37,407.8	$65,394.1

* includes mitigation costs of an average of 14% of total costs

Table 3-3 indicates a 50-year forecast for various different types of water-related facilities, totaling more than $65 billion during the next 50 years. Water utilities and wastewater utilities data shown in the table refer to the typical utility infrastructure present in most municipalities; water and wastewater treatment plants, water storage, water and wastewater pumping, water transmission and distribution, and wastewater collection and major conveyance systems.

As highlighted in Figure 3-16, this "everyday" infrastructure need for water and wastewater utility facilities accounts for almost 90 percent of the projected 50-year infrastructure needs for Texas, dwarfing the seven percent cost share shown for new water supply and conveyance and known flood protection costs. Besides providing for projected growth, some of the large cost share for water utilities (almost 50 percent) is the projected costly compliance associated with the new Federal Safe Drinking Water Act.

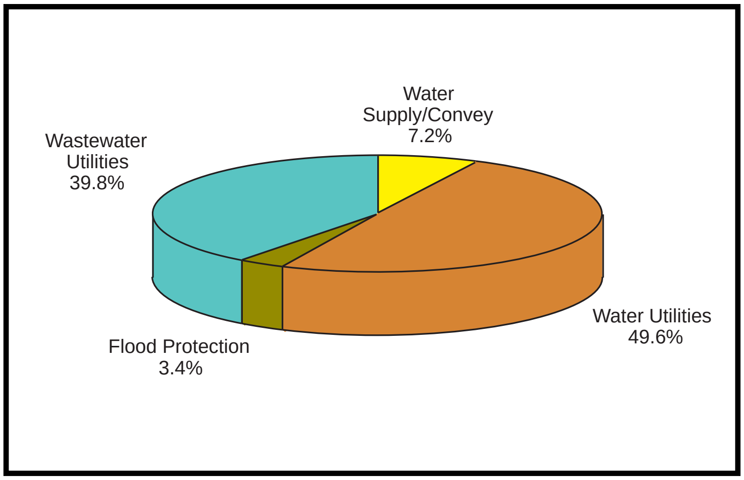


Figure 3-16
Composition of Projected Water-related Infrastructure Costs, 1996-2050

Within the $65 billion of total water-related infrastructure needs of the State over the next 50 years, the cost of recommended major water supply and conveyance systems is projected to total "only" about $4.7 billion dollars. Details and cost shares of these estimates are shown in Table 3-4 and Figure 3-17.

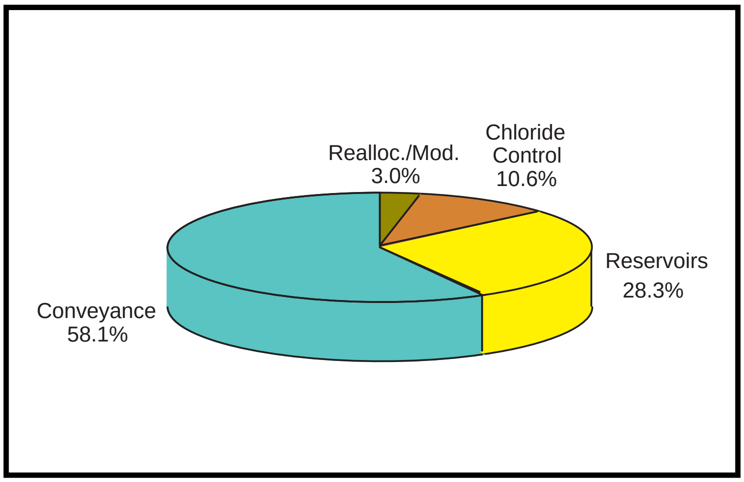


Figure 3-17
Composition of Projected Water Supply and Conveyance Costs, 1996-2050

Pipeline and canal conveyance from existing supplies and new reservoirs are expected to account for almost 60 percent of the cost of developing or accessing new water supplies in the next 50 years with actual water supply reservoir development only accounting for about 1/4 of these costs.

Infrastructure costs for various individual water planning regions are presented in the following Section 3.2

Table 3-4

Projected Capital Costs of Recommended Major Water Supply and Conveyance Projects

Projects	Date Needed	Supply (000 ac-ft)	Projected Cost by Time Period (mill. 1996$) 1996-2000	2000-2020	2020-2050	1996-2050
Reservoirs						
Paluxy	2010	12.0	$0.0	$74.6	$0.0	$74.6
Cibolo	2010	122.0	$0.0	$236.8	$0.0	$236.8
Parkhouse II	2020	134.0	$0.0	$120.5	$0.0	$120.5
Rio Grande Weir	2010	40.0	$0.0	$35.0	$0.0	$35.0
Sandies Creek	2025	97.6	$0.0	$0.0	$267.2	$267.2
Allens Creek	2025	74.0	$0.0	$0.0	$169.0	$169.0
Nichols I*	2035	470.4	$0.0	$0.0	$318.0	$318.0
Tehuacana	2050	65.5	$0.0	$0.0	$135.7	$135.7
Subtotal			$0.0	$467.0	$864.1	$1,331.1
Reallocation/Modification						
Canyon Lake	2005	35.0	$0.0	$0.5	$0.0	$0.5
Trinity Reuse**	2025	73.5	$0.0	$0.0	$18.7	$18.7
Lake Texoma	2050	72.0	$0.0	$0.0	$1.0	$1.0
Lake Whitney	2050	124.7	$0.0	$0.0	$122.8	$122.8
Subtotal			$0.0	$0.5	$142.5	$143.0
Chloride Control						
Canadian	2005		$0.0	$9.0	$0.0	$9.0
Red	2005		$0.0	$225.0	$0.0	$225.0
Brazos	2015		$0.0	$183.6	$0.0	$183.6
Neches	2015		$0.0	$78.0	$0.0	$78.0
Subtotal			$0.0	$495.6	$0.0	$495.6
Conveyance						
Stillhouse to Wm. Co.	2000		$32.6	$0.0	$0.0	$32.6
Canyon to Hays Co.	2005		$0.0	$9.0	$0.0	$9.0
Guadalupe to Bexar Co.	2005		$0.0	$116.4	$0.0	$116.4
Texana to Nueces	2005		$0.0	$135.0	$0.0	$135.0
Lake Fork to Dallas	2005		$0.0	$194.6	$0.0	$194.6
Paluxy to Stephenville	2010		$0.0	$15.7	$0.0	$15.7
Roberts Co. to CRMWA	2005		$0.0	$80.4	$0.0	$80.4
Moss to Gainesville	2005		$0.0	$3.8	$0.0	$3.8
Conroe to Conroe	2005		$0.0	$4.0	$0.0	$4.0
Whitney to Cleburne	2005		$0.0	$11.4	$0.0	$11.4
Hamlin to Stamford to Anson	2005		$0.0	$5.0	$0.0	$5.0
Lake O' the Pines to Longview	2005		$0.0	$25.0	$0.0	$25.0
Cibolo to Bexar Co.	2010		$0.0	$52.0	$0.0	$52.0
Luce Bayou to Harris Co.	2015		$0.0	$39.0	$0.0	$39.0
Parkhouse II to NTMWD	2020		$0.0	$192.8	$0.0	$192.8
Rio Grande to El Paso	2015		$0.0	$134.0	$0.0	$134.0
Palestine to Dallas	2015		$0.0	$195.0	$0.0	$195.0
Alan Henry to Lubbock	2025		$0.0	$0.0	$57.9	$57.9
Belton to Williamson County***	2025		$0.0	$0.0	$45.6	$45.6
Brazos to Brazos Co.	2025		$0.0	$0.0	$33.2	$33.2
Ivie to WCTMWD	2025		$0.0	$0.0	$44.9	$44.9
Nichols I to DFW*	2035		$0.0	$0.0	$543.9	$543.9
Garwood to Nueces Co.	2035		$0.0	$0.0	$21.7	$21.7
Richland-Chambers to TRWD**	2040		$0.0	$0.0	$231.8	$231.8
Texoma to NTMWD	2045		$0.0	$0.0	$148.0	$148.0
Lavon to TRWD (Nichols)*	2045		$0.0	$0.0	$178.0	$178.0
Sabine to Harris Co.	2045		$0.0	$0.0	$176.6	$176.6
Subtotal			$32.6	$1,213.0	$1,481.6	$2,727.2
Total - All Projects			**$32.6**	**$2,176.1**	**$2,488.3**	**$4,696.9**

* Full lake size and full capacity pipeline to Lavon. Possible later stub to TRWD if reuse not pursued. Otherwise, sale and conveyance to other area entities. Yield estimate for Nichols assumes Parkhouse II is built first.

** Within the 50 year planning period, this reflects the full-size pipeline costs from Ennis to TRWD, but only the Richland-Chambers reuse and pipeline to Ennis initially, then outside the planning horizon, the later Cedar Creek reuse and pipeline to Ennis.

*** Only feasible with concurrence by current contract parties to market surplus water.

3.2 REGIONAL PERSPECTIVE

While Chapter 16.051 of the Texas Water Code requires evaluation and planning along river basin boundaries, most of the State's river basins cover vast geographic expanses, extending from one end of the State to the other. The Brazos River Basin, for instance, includes portions of 74 counties stretching from the Texas Panhandle to the Gulf Coast, and encompasses a wide range of socio-economic, climatological, hydrologic, and physiographic characteristics.

There is no optimal method of drawing regional water planning boundaries. Our river (and watershed) basin boundaries mostly run diagonally across the State, while major and minor aquifers, in many instances, run perpendicular to the surface water basins. Socioeconomic and utility development patterns are not constrained by water resource boundaries and often overlap them. The regional planning boundaries (shown in 2-2, page 2-10) have been developed by Board staff after many years of professional debate and public comment. These boundaries reasonably "package" common water problem areas into regional study units.

Most water-related problems as well as opportunities for action take place at the local or regional level rather than at the river basin level. In order to be responsive to water problems and needs of diverse regions, the State Water Plan developed analyses for 16 planning regions. It is a goal of the State Water Plan to provide analyses along regional boundaries to help promote unified, efficient, and coordinated planning of the state's water resources.

The following regional analyses include historical and projected economic, demographic, and water use information, as well as a discussion of regional and local water-related problems, needs and recommended solutions. To highlight important trends in water use characteristics, regional population and water use statistics are presented in comparison to the state as a whole, and in comparison with population and water use changes over time.