Appendix 4D

Description of Major and Minor Aquifers Along Pipeline Route

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The Longhorn Pipeline System (System) crosses the outcrops (recharge zones) of several major and minor aquifers [as designated by the Texas Water Development Board (TWDB)] (Ashworth and Hopkins, 1995) along the 723-mile route from Galena Park, Texas to El Paso, Texas (including lateral routes). The potentially sensitive aquifers were identified from TWDB publications and databases and from registered concerns of the plaintiffs in the case of *Ethel Spiller and others vs. Robert M. Walker and others*. This listing of potentially sensitive aquifers is based on known hydrogeologic factors that may make these hydrogeologic units susceptible to contamination from a release of refined petroleum product from the System. These hydrogeologic factors may include (1) depth to water, (2) aquifer media, (3) soil development, (4) transmissivity, (5) whether confined or unconfined, and (6) net recharge. These aquifers are listed in Table 4-10 in order from east to west along the pipeline route.

These aquifers (Figure 4-7 and 4-8 in Chapter 4) are designated as major or minor by TWDB because they may serve as a primary or secondary potable drinking water source for public supply or domestic use. A major aquifer is generally defined as supplying large quantities of water in large areas of the state. Minor aquifers typically supply large quantities of water in small areas or relatively small quantities in large areas. These aquifers as presently defined, underlie approximately 81 percent of the state (Ashworth and Hopkins, 1995). Lesser quantities of water may be found in the remainder of the state.

The surface extent, or outcrop, of each aquifer is the area in which the host formations are exposed at the land surface. This area corresponds to the principal recharge zone for the aquifers. Ground water encountered within this area is normally under unconfined, water-table conditions and is most susceptible to contamination.

Some water-bearing formations dip below the surface and are covered by other formations. Aquifers with this characteristic are common. Aquifers covered by less permeable formations, such as clay, are confined under artesian pressure. Delineation of the downdip boundaries of such aquifers [i.e., Edwards (BFZ), Trinity, and Carrizo-Wilcox] is based on chemical-quality criteria. The downdip extent of aquifers that are confined by overlying low permeability strata are not considered sensitive because surficial contaminant sources would not have a direct hydraulic connection to the aquifer. Examples of such aquifers where the System crosses the confined portion of the aquifer but not the outcrop include the Capitan Reef Complex Aquifer and the Dockum Aquifer. Therefore, these aquifers are not considered sensitive.

Aquifer water quality is described in terms of dissolved-solids concentrations expressed in milligrams per liter (mg/L) and is classified as fresh (less than 1,000 mg/L), slightly saline (1,000 - 3,000 mg/L), moderately saline (3,000 - 10,000 mg/L), and very saline (10,000 - 35,000 mg/L). Aquifer downdip boundaries shown on the maps delineate extents of the aquifers that contain ground water with dissolved-solids concentrations that meet the needs of the aquifers' primary uses. The quality limit for most aquifers is 3,000 mg/L dissolved solids, which meets most agricultural and industrial needs. However, the limit for the Edwards (BFZ) is 1,000 mg/L for public water supply use. The limit for the Dockum and Rustler aquifers is 5,000 mg/L for specific irrigation and industrial uses. Some aquifers, such as the Hueco Bolson and Lipan, have depth limitations at which water of acceptable quality may be obtained.

The System traverses approximately 470 miles of aquifer outcrop along the existing route. All of that outcrop is potentially sensitive. However, much of the intervals of aquifer crossing may be designated as not sensitive depending on a number of screening criteria. These criteria are described above in the introduction to Section 4.2. In addition, in the aquifer descriptions below, many potentially sensitive intervals of sensitive aquifers will be described as not sensitive based on the screening criteria.

In addition, ground water also occurs in much smaller quantities and sometimes lower quality in sedimentary rocks and in unconsolidated stream terraces and alluvium that are apart from the major/minor aquifer systems along the pipeline route. Ground water development in these areas is typically limited to relatively few wells. These wells typically have low yield and are primarily used for domestic supplies and livestock watering.

The following descriptions provide general information pertaining to location, geology, quality, yield, common use, and specific problems of the aquifers that underlie the System. The aquifers are organized in the order of their occurrence along the pipeline route from east to west. A summary of the aquifer characteristics is listed in Table 4-10. In addition, each aquifer or aquifer system is described in detail below. In the section below, reference is made to a DOT classification of Unusually Sensitive Areas (USAs) (Pettyjohn, et., al., 1996). In this classification, Class I aquifers are highly vulnerable, Class II are moderately vulnerable, and Class II aquifers are not sensitive. Additional qualifiers on the class are “a”, unconsolidated formation; “b”, soluble or fractured formation; “c”, semi-consolidated formation; or “d”, covered formation.

Gulf Coast Aquifer System

The Gulf Coast Aquifer forms a wide belt along the Gulf of Mexico from Florida to Mexico. In Texas, the aquifer provides water to all or parts of 54 counties and extends from the Rio Grande northeastward to the Louisiana-Texas border. Municipal and irrigation uses account for 90 percent of the total pumpage from the aquifer. The Greater Houston metropolitan area is the largest municipal user, where well yields average about 1,600 gallons per minute (gpm).

The aquifer consists of complex interbedded clays, silts, sands, and gravels of Cenozoic age, which are hydrologically connected to form a large, leaky artesian aquifer system. This system comprises four major components consisting of the following generally recognized water-producing formations. The deepest is the Catahoula, which contains ground water near the outcrop in relatively restricted sand layers. Above the Catahoula is the Jasper Aquifer, primarily contained within the Oakville Sandstone. The Burkeville confining layer separates the Jasper from the overlying Evangeline Aquifer, which is contained within the Fleming and Goliad sands. The Chicot Aquifer, or upper component of the Gulf Coast Aquifer system, consists of the Lissie, Willis, Bentley, Montgomery, and Beaumont formations, and overlying alluvial deposits. Not all formations are present throughout the system, and nomenclature often differs from one end of the system to the other. Maximum total sand thickness ranges from 700 feet (ft) in the south to 1,300 ft in the northern extent.

Water quality is generally good in the shallower portion of the aquifer. Ground water containing less than 500 mg/L dissolved solids is usually encountered to a maximum depth of 3,200 ft in the aquifer from the San Antonio River Basin northeastward to Louisiana. From the San Antonio River Basin southwestward to Mexico, quality deterioration is evident in the form of increased chloride concentration and saltwater encroachment along the coast. Little of this ground water is suitable for prolonged irrigation due to either high salinity or alkalinity, or both. In several areas at or near the coast, including Galveston Island and the central and southern parts of Orange County, heavy municipal or industrial pumpage had previously caused an updip migration, or saltwater intrusion, of poor-quality water into the aquifer. Recent reductions in pumpage have resulted in a stabilization and, in some cases, even improvement of ground water quality.

Years of heavy pumpage for municipal and manufacturing use in portions of the aquifer have resulted in areas of significant water-level decline. Declines of 200 ft to 300 ft have been measured in some areas of eastern and southeastern Harris and northern Galveston counties. Other areas of significant water-level declines include the Kingsville area in Kleberg County and portions of Jefferson, Orange, and Wharton counties. Some of these declines have resulted in compaction of dewatered clays and significant land surface subsidence. Subsidence is generally less than 0.5 ft over most of the Texas coast, but has been as much as nine ft in portions of Harris and surrounding counties. As a result, structural damage and flooding have occurred in many low-lying areas along Galveston Bay in Baytown, Texas City, and Houston. Conversion to surface water use in many of the problem areas has reversed the decline trend.

The transmissivity of many aquifers in the system is in the range of 10^2 - 10^3 square ft per day with ground water movement measured in terms of only ft per year. Also, because of the generally deep and well-developed soils that overlie these aquifer outcrops, there are no sensitive or hypersensitive areas with regard to ground water along the Longhorn pipeline route over the Gulf Coast Aquifer System.

Brazos River Alluvium Aquifer

Water-bearing alluvial sediments occur in floodplain and terrace deposits of the Brazos River of southeast Texas. The Brazos River Alluvium Aquifer, up to seven miles wide, stretches for 350 miles along the sinuous course of the river between southern Hill and Bosque counties downstream to eastern Fort Bend County. Irrigation accounts for almost all of the pumpage from the aquifer. The System crosses this aquifer at the boundaries of Austin and Waller counties northeast of Bellville, Texas.

The Quaternary alluvial sediments consist of clay, silt, sand, and gravel, and generally are most coarse in the lower part of the accumulations. Saturated thickness of the alluvium is as much as 85 ft or more, with maximum thickness occurring in the central and southeastern parts of the aquifer. Some wells yield up to 1,000 gpm, but the majority yield 250 gpm to 500 gpm.

The chemical quality of the ground water greatly varies. In many areas, concentrations of dissolved solids exceed 1,000 mg/L. Most of the Brazos River Valley irrigated with this ground water contains soils sufficiently permeable to alleviate any soil salinity problems. In some places, the water from the aquifer is fresh enough to meet drinking water standards.

The Brazos River Alluvium Aquifer is highly transmissive and is readily susceptible to point and non-source pollution. This aquifer would be classified as a Class Ia aquifer under the proposed DOT classification of USAs. Also, the Brazos River Alluvium is rated with a DRASTIC index greater than 110, thereby qualifying it as sensitive.

Sparta Aquifer

The Sparta Aquifer extends in a narrow band from the Frio River in South Texas northeastward to the Louisiana border in Sabine County. The Sparta provides water for domestic and livestock supplies throughout its extent, and water for municipal, industrial, and irrigation purposes in much of the region. Yields of individual wells are generally less than 100 gpm, although most high-capacity wells average 400 gpm to 500 gpm. A few wells produce as much as 1,200 gpm.

The Sparta Formation, part of the Claiborne Group deposited during the Tertiary, consists of sand and interbedded clay with massive sand beds in the basal section. These beds dip gently to the south and southeast toward the Gulf Coast and reach a total thickness of up to 300 ft.

Water of excellent quality is commonly found within the outcrop and for a few miles downdip, but it deteriorates with depth in the downdip direction. Locally, water within the aquifer may contain iron concentrations in excess of drinking water standards.

The outcrop of the Sparta Aquifer occurs along the System. The Sparta Aquifer is a semi-consolidated, high-yield aquifer classified as a Class Ic USA under the DOT classification system. The Sparta Aquifer is therefore considered sensitive with regards to ground water contamination.

Queen City Aquifer

The Queen City Aquifer extends across Texas from the Frio River in South Texas northeastward into Louisiana. The aquifer provides water for domestic and livestock purposes throughout most of its extent, significant amounts of water for municipal and industrial supplies in Northeast Texas, and water for irrigation in Wilson County. Yields of individual wells are commonly low, but a few exceed 400 gpm.

Sand, loosely cemented sandstone, and interbedded clay units of the Queen City Formation of the Tertiary Claiborne Group make up the aquifer. These beds fill the east Texas structural basin adjacent to the Sabine Uplift and then dip gently to the south and southeast toward the Gulf Coast. Although total aquifer thickness is usually less than 500 ft, it can approach 700 ft in some areas of northeast Texas.

Water of excellent quality is generally found within the outcrop and for a few miles downdip, but water quality deteriorates with depth in the downdip direction. In some areas, water of acceptable quality may occur at depths of approximately 2,000 ft. The water may be acidic in much of northeast Texas and relatively high in iron concentrations in some locations.

The Queen City Aquifer is a semi-consolidated, high-yield aquifer classified as a Class Ic USA under the DOT classification system. The Queen City Aquifer is therefore considered sensitive with regard to ground water contamination.

Carrizo-Wilcox Aquifer System

The Wilcox Group and the overlying Carrizo Formation of the Claiborne Group form a hydrologically connected system known as the Carrizo-Wilcox Aquifer. This aquifer extends from the Rio Grande in South Texas northeastward into Arkansas and Louisiana, providing water to all or parts of 60 counties. The Carrizo Sand and Wilcox Group crop out along a narrow band that parallels the Gulf Coast and dips beneath the land surface toward the coast, except in the East Texas structural basin adjacent to the Sabine Uplift, where the formations form a trough.

Municipal and irrigation pumpage account for about 35 percent and 51 percent, respectively, of total pumpage. The largest metropolitan areas dependent on ground water from the Carrizo-Wilcox Aquifer are Bryan-College Station, Lufkin-Nacogdoches, and Tyler. Irrigation is the predominant use in the Winter Garden region of South Texas.

The Carrizo-Wilcox Aquifer is comprised of the Carrizo Formation of the Claiborne Group and the underlying Calvert Bluff, Simsboro, and Hooper Formations of the Wilcox Group. The Carrizo and Simsboro are the main aquifer units. The Carrizo-Wilcox Aquifer is predominantly composed of sand locally interbedded with gravel, silt, clay, and lignite deposited during the Tertiary Period. The Simsboro Formation is not present as a distinct unit south of the Colorado River or north of the Trinity River. Aquifer thickness in the downdip artesian portion ranges from less than 200 ft to more than 3,000 ft.

Well yields are commonly 500 gpm, and some may reach 3,000 gpm downdip where the aquifer is under artesian conditions. Some of the greatest yields (more than 1,000 gpm) are produced from the Carrizo Sand in the southern, or Winter Garden, area of the aquifer. Yields of greater than 500 gpm are also obtained from the Carrizo and Simsboro formations in the central region.

Regionally, water from the Carrizo-Wilcox Aquifer is fresh to slightly saline. In the outcrop, the water is hard, yet usually low in dissolved solids. Downdip, the water is softer, has a higher temperature, and contains more dissolved solids. Hydrogen sulfide and methane may occur locally. Excessively corrosive water with a high iron content is common throughout much of the northeastern part of the aquifer. Localized contamination of the aquifer in the Winter Garden area is attributed to direct infiltration of oil field brines on the surface and to downward leakage of saline water to the overlying Bigford Formation.

Significant water-level declines have developed in the semi-arid Winter Garden portion of the Carrizo Aquifer, as the region is heavily dependent on ground water for irrigation. Since 1920, water levels have declined as much as 100 ft in much of the area and more than 250 ft in the Crystal City area of Zavala County. Significant water-level declines resulting from extensive municipal and industrial pumpage also have occurred in northeast Texas. Tyler and the Lufkin-

Nacogdoches area have experienced declines in excess of 400 ft, and in a few wells, as much as 500 ft since the 1940s. In this area, conversion to surface water use is slowing the rate of water-level decline. The northeast outcrop area has been dewatered in the vicinity of lignite surface-mining operations, and the Simsboro Sand Formation of the Wilcox Group has been affected by water-level declines in parts of Robertson and Milam counties.

The Carrizo-Wilcox Aquifer is a semi-consolidated, high-yield aquifer classified as a Class Ic USA under the DOT classification system. The Carrizo-Wilcox Aquifer is therefore considered sensitive with regard to ground water contamination.

Colorado River Alluvium Aquifer

Water-bearing alluvial sediments occur in floodplain and terrace deposits of the Colorado River of south-central Texas. The Colorado River Alluvium, up to four miles wide, stretches for approximately 200 miles from Austin to Wharton, Texas. The aquifer is used for municipal, domestic, industrial, irrigation, and stock supplies.

The Quaternary alluvial sediments consist of clay, silt, sand, and gravel with the accumulations generally arranged in a fining-upward sequence. The Colorado Alluvial Aquifer is a laterally continuous, hydraulically-interconnected series of alluvial and terrace deposits. Thickness of the alluvium is typically 20-40 ft with the saturated thickness dependent upon the stage of the river. Base flow of the Colorado River is controlled by the Lower Colorado River Authority (LCRA) and varies from approximately 150 cubic ft/second (ft^3/s) (Nov. – Mar.) to 2200 ft^3/s (Apr. – Oct.).

The chemical quality of the ground water is generally similar to that of the Colorado River as the alluvium is in direct hydraulic connection with the river. The quality of the ground water of the Colorado River Alluvium is considered exceptional and is regularly used as public supply for municipalities that include the cities of Bastrop, Austin, Manor, Garfield, and Manville (Saunders, 1996).

The Colorado River Alluvium Aquifer is highly transmissive and is readily susceptible to point and non-source pollution. This aquifer is classified as a Class Ia aquifer under the DOT classification of USAs. Also, the Colorado River Alluvium is rated with a DRASTIC index greater than 110, thereby qualifying it as sensitive.

Edwards Aquifer (Balcones Fault Zone)

The Edwards Aquifer (Balcones Fault Zone, or BFZ) covers approximately 4,350 square miles in parts of 11 counties. The aquifer forms a narrow belt extending from a ground water divide in Kinney County through the San Antonio area northeastward to the Leon River in Bell County. A poorly defined ground water divide near Kyle in Hays County hydrologically separates the aquifer into the San Antonio and Austin regions. The name Edwards (BFZ) distinguishes this aquifer from the Edwards-Trinity (Plateau) and the Edwards-Trinity (High Plains) aquifers.

Water from the aquifer is primarily used for municipal, irrigation, and recreational purposes. Approximately 54 percent is used for municipal supply. San Antonio, which obtains its entire municipal water supply from the Edwards Aquifer, is one of the largest cities in the world to rely solely on a single ground water source. The aquifer feeds several well-known recreational springs and underlies some of the most environmentally sensitive areas in the state.

The aquifer, composed predominantly of limestone formed during the early-Cretaceous, exists under water-table conditions in the outcrop and under artesian conditions where it is confined below the overlying Del Rio Clay. The Edwards Aquifer consists of the Georgetown Limestone, formations of the Edwards Group (the primary water-bearing unit) and their equivalents. Thickness ranges from 200 to 850 ft.

Recharge to the aquifer occurs primarily by the downward percolation of surface water from streams draining off the Edwards Plateau to the north and west and by direct infiltration of precipitation on the outcrop. Recharge reaches the aquifer through crevices, faults, and sinkholes in the unsaturated zone. Unknown amounts of ground water enter the aquifer as lateral underflow from the Glen Rose Formation. Water in the aquifer generally moves from the recharge zone toward natural discharge points such as the San Antonio, Comal, San Marcos, Barton, and Salado springs. Water is also discharged artificially from hundreds of pumping wells, particularly municipal supply wells in the San Antonio region and irrigation wells in the western extent.

In the updip portion, ground water moving through the aquifer system has dissolved large amounts of rock to create highly permeable solution zones and channels that facilitate rapid flow and relatively high storage capacity within the aquifer. Highly fractured strata in fault zones have also been preferentially dissolved to form conduits capable of transmitting large amounts of water. Due to its extensive honeycombed and cavernous character, the aquifer yields moderate to large quantities of water. Some wells yield in excess of 16,000 gpm, and one well drilled in Bexar County flowed 24,000 gpm from a 30-inch diameter well. The aquifer is significantly less permeable farther downdip where the concentration of dissolved solids in the water exceeds 1,000 mg/L.

The chemical quality of water in the aquifer is typically fresh, although hard, with dissolved-solids concentrations averaging less than 350 mg/L. The downdip interface between fresh and slightly saline water represents the extent of water containing less than 1,000 mg/L. Within a short distance downgradient of this “bad water line,” the ground water becomes increasingly mineralized.

Due to its highly permeable nature in the fresh-water zone, the Edwards Aquifer responds quickly to changes and extremes of stress placed on the system. This is indicated by rapid water-level fluctuations during relatively short periods of time. During times of adequate rainfall and recharge, the Edwards Aquifer is able to supply sufficient amounts of water for all demands as well as sustain spring flows at many locations throughout its extent. However, under conditions of below-average rainfall or drought when discharge exceeds recharge, springflows may be reduced to environmentally detrimental levels, and mandatory rationing may be established.

The Edwards Aquifer (BFZ) is classified as a Class Ib aquifer under the DOT classification system primarily due to well developed karst topography in the outcrop areas. The outcrop of the Edwards Aquifer (BFZ) is considered sensitive with several intervals regarded as hypersensitive. These hypersensitive intervals include the outcrops of the Leached and Collapsed Members (undivided) of the Person Formation; and the Kirshberg Evaporite Member of the Kainer Formation (Rose, 1972).

Trinity Aquifer

The Trinity Aquifer consists of early-Cretaceous age formations of the Trinity Group where they occur in a band extending through the central part of the state in all or parts of 55 counties, from the Red River in North Texas to the Hill Country of south-central Texas. Trinity Group deposits also occur in the Panhandle and Edwards Plateau regions where they are included as part of the Edwards-Trinity (High Plains and Plateau) aquifers.

The litho-stratigraphic units comprising the Trinity Group vary extensively between the geologic provinces within the Trinity Aquifer region. Within the BFZ, these formations and their individual members generally are (from oldest to youngest) the Houston Formation; Sligo Formation; Pearsall Formation (includes Pine Island Shale, Cow Creek Limestone, and Bexar Shale Members); and the Glen Rose Limestone (lower and upper members).

Within the Hill Country and southeastern Edwards Plateau, the Trinity Group is comprised of the Sycamore Sand, Hammett Shale, Cow Creek Limestone, Hensel Sand, and Glen Rose Limestone. Updip (northwest), where the Glen Rose thins or is missing, the Trinity Group rocks grade or transition into the basal Cretaceous sand known as the Antlers Formation. The Antlers Formation is comprised of up to 900 ft of sand and gravel, with clay beds in the middle section. Water from the Antlers Formation is mainly used for irrigation in the outcrop area of north and central Texas.

In north-central Texas, the uppermost unit of the Trinity Group, the Paluxy Sand overlies the Glen Rose Limestone. The Paluxy Sand consists of up to 400 ft of predominantly fine-to coarse-grained sand interbedded with clay and shale. The formation pinches out downdip and does not occur south of the Colorado River.

Extensive development of the Trinity Aquifer has occurred in the Fort Worth-Dallas region where water levels have historically dropped as much as 550 ft. Since the mid-1970s, many public supply wells have been abandoned in favor of a surface water supply, and water levels have responded with slight rises. Water level declines of as much as 100 ft are still occurring in Denton and Johnson counties. In the Waco area, the Trinity Aquifer is most extensively developed from the Hosston and Hensel formations where the water level has declined by as much as 400 ft.

The Trinity Aquifer areas traversed by the Longhorn pipeline are classified under the DOT system as Class IIa (moderately susceptible). Generally, the Trinity Aquifer system is rated with a DRASTIC index less than 110. Karst areas of the Trinity Aquifer are relatively uncommon except in the vicinity of the BFZ. Therefore, the Trinity Aquifer area that is traversed by the Longhorn pipeline is not classified as sensitive or hypersensitive for the purposes of this study.

Hickory Aquifer

The Hickory Aquifer occurs in parts of 19 counties in the Llano Uplift region of Central Texas. Discontinuous outcrops of the Hickory Sandstone overlie and flank exposed Precambrian rocks that form the central core of the uplift. The downdip artesian portion of the aquifer encircles the uplift and extends to maximum depths approaching 4,500 ft. Most of the water pumped from the aquifer is used for irrigation. The largest capacity wells, however, have been completed for municipal water supply purposes at Brady, Mason, and Fredericksburg.

The Hickory Sandstone Member of the Cambrian Riley Formation is composed of some of the oldest sedimentary rocks found in Texas. In most of the northern and western portions of the aquifer, the Hickory can be differentiated into lower, middle, and upper units, which reach a maximum thickness of 480 ft in southwestern McCulloch County. In the southern and eastern extents of the aquifer, the Hickory consists of only two units. Block faulting has compartmentalized the Hickory Aquifer, thus restricting flow.

Ground water from the aquifer is generally fresh. However, locally, the aquifer produces water with excessive alpha particles and total radium concentrations in excess of drinking water standards. The water can also contain radon gas. The upper unit of the Hickory produces ground water containing concentrations of iron in excess of drinking water standards.

The Hickory Aquifer outcrops at intermittent intervals of the existing Longhorn route along the southern margin of the Llano Uplift in Blanco, Gillespie, and Mason counties. The Hickory Aquifer is classified as a Class IIa aquifer under the DOT system. The Hickory outcrops are generally associated with the Cap Mountain Limestone Member of the Riley Formation. The Cap Mountain Limestone Member is identified as exhibiting characteristics of karst topography, therefore, qualifying it and the associated hydraulically connected Hickory outcrops as sensitive for the purposes of this investigation. In addition, the Texas DRASTIC map identifies these outcrops with an index greater than 110 that also classify the Hickory as sensitive.

The Aquifer Avoidance/Minimization Route Alternative traverses a relatively small interval of confined Hickory Aquifer in the subsurface of northern Concho County. The aquifer is at a depth of approximately 4,200 ft and is not considered at risk or sensitive in this area.

Ellenburger-San Saba Aquifer

The Ellenburger-San Saba Aquifer occurs in parts of 15 counties in the Llano Uplift area of Central Texas. Discontinuous outcrops of the aquifer encircle older rocks in the core of the uplift, and the remaining downdip portion extends to depths of approximately 3,000 ft below land surface. Regional block faulting has significantly compartmentalized the aquifer.

Three-fourths of the water pumped from the aquifer is used for municipal water supplies at Fredericksburg, Johnson City, Bertram, and Richland Springs. Also, a large portion of water flowing from San Saba Springs, which is the water supply for the city of San Saba, is believed to be from the Ellenburger-San Saba and Marble Falls aquifers.

The aquifer occurs in limestone and dolomite facies in the San Saba Member of the Wilberns Formation of late-Cambrian age, and in the Honeycut, Gorman, and Tanyard formations of the Ellenburger Group of early Ordovician age. Water in the aquifer primarily occurs in solution cavities formed along faults and related fractures. The Ellenburger-San Saba Aquifer in some areas may be hydrologically connected to the Marble Falls Aquifer. Water produced from the aquifer is inherently hard and usually has less than 1,000 mg/L dissolved solids.

The Ellenburger-San Saba Aquifer is classified as under the DOT system as a Class Ib aquifer that makes it highly susceptible to contamination. This aquifer system is also representative of karst and solution features that qualify outcrops as sensitive. The Texas DRASTIC map also rates these outcrops with an index greater than 110.

Marble Falls Aquifer

The Marble Falls Aquifer occurs in several separated outcrops, primarily along the northern and eastern flanks of the Llano Uplift. It provides water to parts of Blanco, Burnet, Lampasas, McCulloch, and San Saba counties, and to smaller parts of Kimble, Llano, and Mason counties in central Texas. San Saba and Rochelle are the two largest communities that withdraw water from the aquifer for public supply use. Wells have been reported to yield as much as 2,000 gpm; however, most wells produce substantially less.

Ground water occurs in fractures, solution cavities, and channels in the limestone of the Marble Falls Formation of the Pennsylvanian Bend Group. Maximum thickness of the formation is 600 ft. Where underlying beds are thin or absent, the Marble Falls and Ellenburger-San Saba aquifers may be hydrologically connected. Numerous large springs issue from the aquifer and provide a significant part of the baseflow to the San Saba River in McCulloch and San Saba counties and to the Colorado River in San Saba and Lampasas counties.

The quality of water produced from the aquifer is suitable for most purposes. The downdip artesian portion in most areas is not extensive and becomes significantly mineralized within relatively short distances from the outcrop recharge area.

The Marble Falls Aquifer is classified as a Class Ib aquifer under the DOT system that describes it as highly susceptible to contamination. The outcrops of the Marble Falls Limestone along the existing Longhorn pipeline route are confined to the bottom of the Pedernales River crossing and the bottom of the Llano River crossing. These two areas are therefore classified as sensitive for the purposes of this investigation. The Marble Falls Aquifer is completely avoided by the Aquifer Avoidance/Minimization Route Alternative.

Edwards-Trinity (Plateau) Aquifer

The Edwards-Trinity (Plateau) Aquifer underlies the Edwards Plateau east of the Pecos River and the Stockton Plateau west of the Pecos River, providing water to all or parts of 38 counties. The aquifer extends from the Hill Country of central Texas to the Trans-Pecos region of west Texas. Irrigation accounts for 70 percent of the total pumpage, whereas municipal use accounts for 15 percent.

The aquifer consists of saturated sediments of lower-Cretaceous age Trinity Group formations and the overlying limestones and dolomites of Fredericksburg and Washita Groups. The Glen Rose Limestone is the primary unit of the Trinity Group in the southern part of the plateau and is replaced by the Antlers Sand north of the Glen Rose pinchout. The Maxon Sand is present in the western Stockton Plateau region. Maximum saturated thickness of the aquifer is greater than 800 ft.

The aquifer generally exists under water-table conditions; however, where the Trinity is fully saturated and a zone of low permeability occurs near the base of the overlying Edwards Aquifer, artesian conditions may exist in the Trinity. Reported well yields commonly range from less than 50 gpm, where saturated thickness is thin, to more than 1,000 gpm, and large-capacity wells are completed in jointed and cavernous limestone.

Chemical quality of Edwards-Trinity (Plateau) water ranges from fresh to slightly saline. The water is typically hard and may vary widely in concentrations of dissolved solids made up mostly of calcium and bicarbonate. The salinity of the ground water tends to increase toward the west. Certain areas have unacceptable levels of fluoride.

There is little pumpage from the aquifer over most of its extent, and water levels have remained constant or have fluctuated only with seasonal precipitation. In some instances, water levels have declined as a result of increased pumpage. Although historical declines have occurred in the northwestern part of the aquifer in Reagan, Upton, Midland, and Glasscock counties as a result of irrigation, none of the areas has experienced declines greater than 20 ft since 1980.

The Edwards-Trinity Aquifer System is classified as a Class Ib aquifer that is highly susceptible to contamination. The portions of this aquifer system that are comprised of outcrops of the Washita Group Limestones are considered karst areas. The Edwards-Trinity Aquifer System is the largest single sensitive area identified in this investigation. The Texas DRASTIC map does not classify this area as sensitive because of the inadequacy of DRASTIC when applied to karst terrains. The large interval of Longhorn pipeline route that is classified as sensitive may be reduced when subsequent filter criteria of the DOT method are applied.

The Aquifer Avoidance/Minimization Route Alternative bypasses a large portion of this previously described sensitive area except for the areas in Reagan, Irion, and Tom Green counties.

Cenozoic Pecos Alluvium Aquifer

The Cenozoic Pecos Alluvium Aquifer, located in the upper part of the Pecos River Valley of west Texas, provides water to parts of Andrews, Crane, Ector, Loving, Pecos, Reeves, Upton, Ward, and Winkler counties. The aquifer is the principal source of water for irrigation in Reeves and northwestern Pecos counties, and for industrial, power generation, and public supply uses elsewhere. A significant amount of water is exported to cities east of the area. Approximately 81 percent of the water pumped from the aquifer is used for irrigation.

The Cenozoic Pecos Alluvium of Quaternary age consists of up to 1,500 ft of alluvial fill and occupies two hydrologically separate basins: the Pecos Trough in the west and the

Monument Draw Trough in the east. The aquifer is hydrologically connected to underlying water-bearing strata, including the Edwards-Trinity in Pecos and Reeves counties and the Triassic Dockum in Ward and Winkler counties.

Ground water in the Cenozoic Pecos Alluvium aquifer occurs under semi-confined or unconfined (water-table) conditions, although confining clay beds may create localized artesian conditions. Moderate to large yields can generally be expected from wells completed in this aquifer.

The chemical quality of water in the aquifer is highly variable, differing naturally with location and depth, and is generally better in the Monument Draw Trough. Water from the aquifer is typically hard and contains dissolved-solids concentrations ranging from less than 300 mg/L to more than 5,000 mg/L. Sulfate and chloride are the two predominant constituents. A natural deterioration of quality occurs with increasing depth of the water-bearing strata. Some quality deterioration has resulted from past petroleum industry activities in Loving, Ward, and Winkler counties, and from irrigation in Pecos, Reeves, and Ward counties.

Water-level declines in excess of 200 ft historically have occurred in south-central Reeves and northwest Pecos counties, but have moderated since the mid-1970s with the decrease in irrigation pumpage. Ground water that once rose to the surface and flowed into the Pecos River, now flows in the subsurface toward areas of heavy pumpage. As a consequence, baseflow to the Pecos River has declined. Elsewhere, only moderate water-level declines have occurred as a result of less intense pumpage for industrial and public supply uses in Ward and Winkler counties.

The Cenozoic Pecos Alluvium Aquifer is classified as a Class Ia aquifer in the DOT system because of the highly transmissive nature of the unconsolidated sediments of the region. All stream drainages and their associated watersheds are considered primary recharge areas. The surficial alluvial deposits of the Pecos River Valley itself are considered hypersensitive because the DRASTIC index for this area is in excess of 110.

Dockum Aquifer

The Dockum Group of Triassic age underlies much of the Ogallala Formation of the High Plains area of Texas and New Mexico, the northern part of the Edwards Plateau, and the eastern part of the Cenozoic Pecos Alluvium. Where exposed east of the High Plains caprock and in the Canadian River Basin, the land surface takes on a reddish color. In the subsurface, the Dockum is commonly referred to as the “red bed.” The primary water-bearing zone in the formation, the Santa Rosa, consists of up to 700 ft of sand and conglomerate interbedded with layers of silt and shale.

Ground water from the Dockum Aquifer is used for irrigation in the eastern outcrop area of Scurry and Mitchell counties and for municipal water supply in the central part of the High Plains where marginally acceptable quality conditions prevail. Elsewhere, the aquifer is used extensively for oil field water-flooding operations, particularly in the southern part of the High Plains.

Concentrations of dissolved solids in the ground water range from less than 1,000 mg/L near the eastern outcrop to more than 20,000 mg/L in the deeper parts of the aquifer to the west. Relatively high sodium concentrations pose a salinity hazard for soils, thereby limiting regional long-term use of the water for irrigation. The extent of the aquifer that is delineated includes the area in which the Dockum ground water contains less than 5,000 mg/L dissolved solids.

The Dockum Aquifer is not considered sensitive for the purposes of this investigation because it does not outcrop along the Longhorn route and is generally not considered a public water supply.

Capitan Reef Complex Aquifer

The Capitan Reef formed along the margins of the Delaware Basin, an embayment covered by a shallow Permian sea. In Texas, two arcuate strips of the reef, 10 to 14 miles wide, are exposed in the Guadalupe, Apache, and Glass mountains; elsewhere, the reef is in the subsurface. The reef extends northward into New Mexico where it provides abundant fresh water to the City of Carlsbad.

Most of the ground water pumped from the aquifer in Texas is used for oil reservoir water-flooding operations in Ward and Winkler counties. A small amount is used for irrigation of salt-tolerant crops in Pecos and Culberson counties.

In Texas, the aquifer is composed of up to 2,360 ft of dolomite and limestone deposited as reef, fore-reef, and back-reef facies. Water-bearing formations include the Capitan Limestone, Goat Seep Limestone, and most of the Carlsbad facies of the Artesia Group—including the Grayburg, Queen, Seven Rivers, Yates, and Tansill formations.

The aquifer generally contains water of poor quality and yields small to large quantities of moderately saline to brine water. Water of the freshest quality is located on and near areas of recharge where the reef is exposed at the surface in the three mountain ranges.

The Capitan Reef Complex Aquifer is not considered sensitive for the purposes of this investigation because it does not outcrop along the Longhorn route and is generally not considered a public water supply.

Rustler Aquifer

The Rustler Formation of Permian age crops out in eastern Culberson County in the Trans-Pecos region of Texas and extends eastward into the subsurface of the Delaware Basin. The aquifer is principally located in Loving, Pecos, Reeves, and Ward counties where it yields water for irrigation, livestock, and water-flooding operations in oil-producing areas. High dissolved-solids concentrations render the water unsuitable for human consumption.

Water occurs in highly permeable solution zones that have developed in dolomite, limestone, and gypsum beds of the Rustler Formation. The dissolved-solids concentrations of the water increase downgradient, eastward into the basin, with a shift from sulfate to chloride as the predominant anion.

The Rustler Aquifer is not considered sensitive for the purposes of this investigation because it is generally not considered suitable for either domestic or public water supply.

Hueco-Mesilla Bolson

The Hueco and Mesilla Bolson aquifers are located in El Paso and Hudspeth counties in the far western tip of Texas. The aquifers are composed of Tertiary and Quaternary basin-fill (Bolson) deposits that extend northward into New Mexico and westward into Mexico. The Hueco Bolson, east of the Franklin Mountains, is the principal aquifer in the El Paso area; to the west is the Mesilla Bolson. Eighty-seven percent of the water pumped from the aquifers is used for municipal supply, primarily for the City of El Paso. Across the international border, water for Ciudad Juarez is supplied from the Hueco Bolson.

The Hueco Bolson, approximately 9,000 ft in total thickness, consists of silt, sand, and gravel in the upper part, and clay and silt in the lower part. Only the upper several hundred ft of the bolson contain fresh to slightly saline water. The majority of the Hueco water in Texas occurs in the El Paso metropolitan area; very little occurs in Hudspeth County.

The Mesilla Bolson consists of approximately 2,000 ft of clay, silt, sand, and gravel. Three water-bearing zones in the Mesilla (shallow, intermediate, and deep) have been identified based on water levels and quality. The shallow water-bearing zone includes the overlying Rio Grande Alluvium.

The chemical quality of the ground water in the Hueco Bolson differs according to its location and depth. Dissolved-solids concentrations in the upper, fresher part of the aquifer range from less than 500 mg/L to more than 1,500 mg/L and average about 640 mg/L. Quality of Hueco Bolson water in Mexico is slightly poorer.

Chemical quality of ground water in the Mesilla Bolson ranges from fresh to saline, with salinity generally increasing to the south along the valley. The water is commonly freshest in the deep zone of the aquifer and contains progressively higher concentrations of dissolved solids in the shallower zones. Increasing deterioration of quality of these aquifers is the result of large-scale ground water withdrawals, which are depleting the aquifers of the freshest water.

Historical large-scale ground water withdrawals, especially from municipal well fields in the downtown areas of El Paso and Ciudad Juarez, have caused major water-level declines. These declines, in turn, have significantly changed the direction of flow, rate of flow, and chemical quality of ground water in the aquifers. Declining water levels have also resulted in a minor amount of land-surface subsidence.

The Hueco Bolson is the only portion of this aquifer system that underlies the Longhorn route. Although it is generally under water table or semi-confined conditions, it is not considered sensitive because of the extremely slow infiltration rate from the surface downward.

Lipan Aquifer

The Lipan Aquifer is located in the Lipan Flats area of eastern Tom Green, western Concho, and southern Runnels counties. The water is principally used for irrigation, with limited amounts used for rural domestic and livestock purposes.

The aquifer comprises up to 125 ft of saturated alluvial deposits of the Leona Formation of Quaternary age. Also included in the aquifer are the updip portions of the underlying Choza Formation and Bullwagon Dolomite of Permian age. The updip portions are hydrologically continuous with the Leona and contain fresh to slightly saline water.

Ground water in the Lipan Aquifer discharges naturally by seepage to the Concho River and by evapo-transpiration in areas where the water table is at or near land surface. Well yields commonly range from 100 gpm to more than 1,000 gpm.

Ground water in the Leona Formation ranges from fresh to slightly saline and is very hard. Water in the underlying updip portions of the Choza and Bullwagon tends to be slightly saline. The chemical quality of ground water in the Lipan Aquifer often does not meet drinking water standards; however, it is generally suitable for irrigation.

The Lipan Aquifer is classified as a Class Ia aquifer under the DOT system because it is highly permeable. However, because the quality of the water is generally not suitable for public supply, it is not considered sensitive for the purposes of this investigation. The Aquifer Avoidance/Minimization (Northern Alternative) Route traverses the southern margin of the Lipan Aquifer in Concho County.