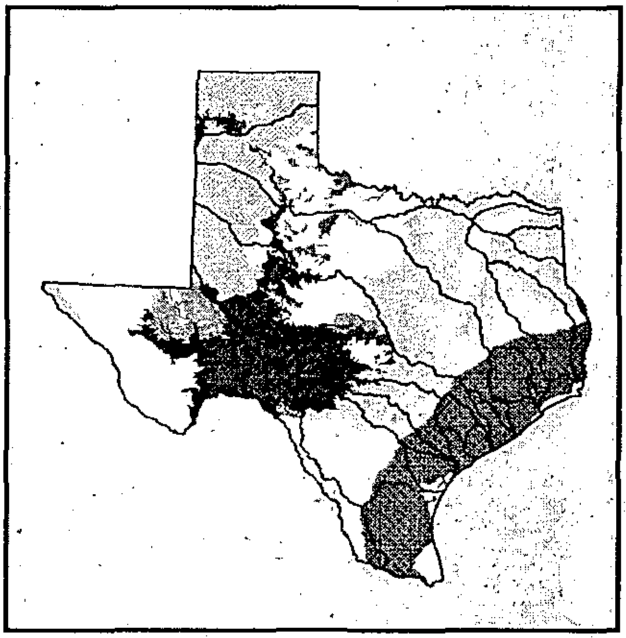
Surface Water/Groundwater Interaction Evaluation for 22 Texas River Basins



Prepared for

TNRCC

July 1999

Prepared by

PARSONS ENGINEERING SCIENCE, INC.

Austin, Texas

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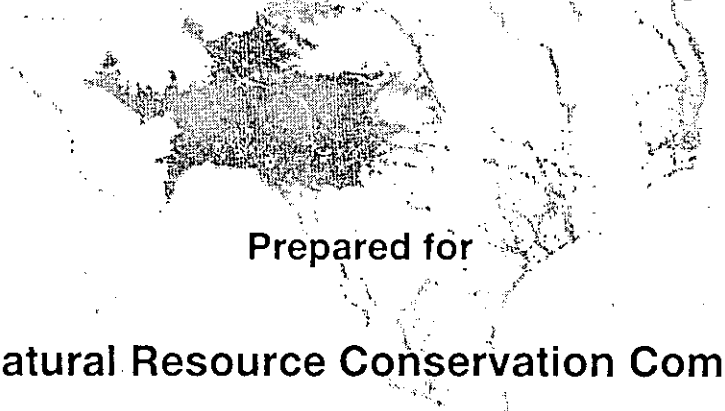

Prepared for

Texas Natural Resource Conservation Commission

Prepared by

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SECTION 1.0
INTRODUCTION

1.1 BACKGROUND AND PURPOSE

The statewide drought of 1996 exposed a number of issues in Texas' overall framework for water resources planning and management, prompting sharp focus by State leaders on water resources issues. In response to the drought, the Texas Legislature in 1997 enacted Senate Bill 1 (S.B.1) which, among its many provisions, directed the Texas Natural Resource Conservation Commission (TNRCC) to develop new surface water availability models for 22 of the 23 river basins in Texas.

In response to the requirements of S.B.1, the TNRCC initiated the Water Availability Modeling (WAM) Project. The goal of the WAM Project is to develop a new decision support system for the administration of the State's surface water rights permitting program. The central focus of the WAM project is the development of new water availability models for 22 of the river basins in Texas that will serve as the central tool in the new decision support system. Once developed, new models will replace outdated water availability models for eight of the State's 23 river basins and, for the first time, will provide water availability modeling capability for the other basins. These new models will provide an array of data analysis capabilities that are essential for sound water resources management, and for water resources planning.

Senate Bill 1 amended the Texas water code to include a number of requirements that the TNRCC evaluate and quantify interrelationships of surface water with groundwater when considering new appropriations for surface water. Section 4.02 of S.B. 1 specifically requires that, "In considering an application for a permit to store, take or divert surface water, the commission shall consider the effects, if any, on groundwater or groundwater recharge."

When surface and groundwater interconnections are recognized, another dimension added is the concept of "conjunctive management." It is a well-established fact that yields of a surface water system and yield of a groundwater system can be coordinated so that the total yield exceeds the sum of individually managed yields. Though this is not currently a part of the S.B.1 provisions, the TNRCC and the Texas Water Development Board (TWDB) may wish to use the new tools to analyze opportunities for joint efforts to maximize the availability of surface water for Texans.

Because the primary function of the commission under S.B.1 and the Texas water code is to identify available surface water and assess the effects of a proposed appropriation on groundwater, the only aquifers that really need to be considered are those which are connected to the surface streams. In addition, logic suggests that the only parts of the aquifers that really need to be modeled would be strips of land along both sides of streams or reservoirs. As one gets further from a stream, there is a point at which the groundwater may not be connected, and the most practical model would look only at these zones.

The problem with this logic is that groundwater model boundaries cannot be arbitrarily set. In order to model the physical processes at interior points, boundaries of the model must be established at locations such as the edge of the aquifer, at groundwater divides, at geologic barriers, or at or along water bodies. Experience has shown that, though desirable, models cannot be constructed to include only the areas affected by surface water. Thus, the entire aquifer is generally modeled even in instances where only the interconnection with streams is the objective. The focus of this study is, therefore to identify those sections of the major streams comprising 22 river basins that exhibit significant potential for interconnection with the underlying groundwater.

The TNRCC has authorized Parsons ES to identify the aquifers that will impact and be impacted by the streamflow of the 22 river basins. It is not the intention of this study to quantify the interaction but to identify potential interaction. Results of this task will be the input for the next stage of computer simulation. A more rigorous quantification is needed for simulation model input prior to the computer model construction.

1.2 SCOPE

In order to meet the purpose of the study, the following tasks for each of the 22 river basins have been undertaken:

- Literature and Data collection,
- Literature Review, and
- Report preparation.

There are 23 river basins in Texas. The Rio Grande is under the jurisdiction of the Internal Boundary Water Commission, jointly managed by the state of Texas, the USA and the Republic of Mexico. Therefore, the Rio Grande is not studied. The 22 river basins are:

1. Canadian River
2. Red River
3. Sulphur River
4. Cypress River
5. Sabine River
6. Neches River
7. Neches Trinity Coastal
8. Trinity River
9. Trinity-San Jacinto Coastal
10. San Jacinto River
11. San Jacinto-Brazos Coastal
12. Brazos
13. Brazos-Colorado Coastal
14. Colorado River
15. Colorado-Lavaca Coastal
16. Lavaca River
17. Lavaca-Guadalupe Coastal
18. Guadalupe River
19. San Antonio River
20. San Antonio-Nueces River
21. Nueces River
22. Nueces-Rio Grande Coastal

Literature Search. The TNRCC (formerly Texas Board of Water Engineers, Texas Department of Water Resources, Texas Water Commission) and the Texas Water Development Board have published groundwater resources for each counties and for major river basins. The US Geological Survey (USGS) also performed stream gaging and aquifer study for water supply. These three government agencies provide the majority of the water resources reports required for this work assignment. The University of Texas at Austin and the University of Texas at San Antonio also provided research results in groundwater; however, they were site- and problem-specific. Therefore, the primary source of literature search is TNRCC and USGS.

Literature Review. As a part of the WAM, Parsons ES has identified the major and minor aquifers along the 22 river basins from the existing documents. We have also identified the potential for interaction between the river and the aquifer. The following features were identified, if possible, along the river segments in view of the modeling requirements.

- Aquifer names
- Aquifer geometry and boundary conditions
- Aquifer transmissivity and storativity
- Aquifer recharge and discharge (rates and areas including, evapotranspiration, baseflow, wells, and springs)
- Aquifer regime (seasonal fluctuation and historical trend)
- Channel geometry and morphology
- Streambed thickness and vertical hydraulic conductivity
- Hydraulic gradients across the streambed (between river stage and the static groundwater elevation)
- And others.

The project emphasis was to perform a qualitative study identifying recharge (influent), transmission, and discharge (effluent) reaches of a major river. In most cases there was no quantification of the parameters listed above that were required for groundwater model input. Even the channel gain and loss investigation was not sufficient for model input, simply because the gain and loss investigation was performed during low flow, either in winter or in dry summer. The surface water and groundwater interaction is annual. Inference and deduction of the average amount of surface water gain and loss are necessary prior to model simulation.

Report Preparation

Once the list of stream reaches of potential impact by adjacent or underlying aquifers was identified, a report was prepared. This report presents the findings of the study, including a brief description of the methodology used and assumptions required. Since some areas of the state have significantly more data available to review than others, the interaction may not be clear or cannot be determined for some stream segments. This report provides remarks on those segments that do have adequate data and those that may need additional data. Maps will be prepared from the Global Imaging System that Parsons ES has prepared for the WAM project. The maps illustrate the stream and river segments evaluated in the study highlighting those reaches that are potentially interconnected to the adjacent or underlying aquifers.

Since it is not possible to assess within the limits of this study every stream in Texas for potential groundwater interaction, attention was focused upon TNRCC designated stream segments (primarily first and second order streams). However, since water rights are often located on smaller tributaries, the potential impacted tributaries were included in the mapping, even if they were not addressed in the body of the analysis report.

1.3 REPORT STRUCTURE

Section 1, the introduction, provides the purpose and scope of this study. Section 2 is a basic description of surface-water-and-groundwater interaction principles and input parameters for a numerical groundwater simulation model. Section 3 presents the bulk of this study, a presentation description of findings. Finally, conclusions and recommendations are stated in Section 4.

River modeling was performed basin by basin; therefore, reference literature pertinent to that river basin is presented immediately following each basin description, providing convenience for the modeler, hydrologist, and hydrogeologist to identify the references in the next phase of quantification. Consequently, there is no Section 5, list of references.

SECTION 2

SECTION 2.0 PRINCIPLES OF SURFACE WATER AND GROUNDWATER INTERACTION

2.1 HYDROLOGIC CYCLE

Hydrogeology is the study of the origins, occurrence, movement, and quality of groundwater, an important part of the hydrologic cycle (Figure 2.1). In order to understand the influences of the hydrologic cycle on groundwater, it is essential to have some basic knowledge of precipitation, infiltration, the relationship between groundwater and streams, and the impact of the geologic framework on water resources (EPA 1987).

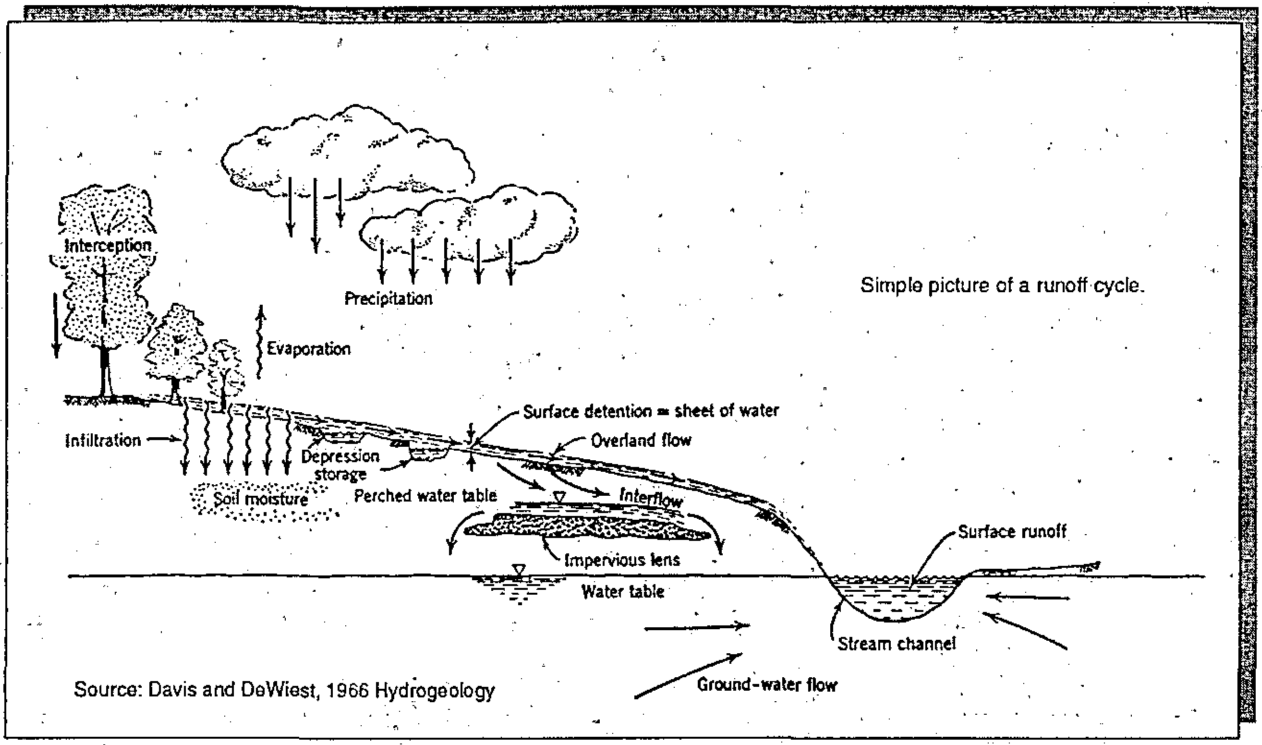
In general, water evaporates from the ocean, form clouds that move inland, then condenses to fall to the earth as precipitation. From land and through rivers and underground, water runs off to the ocean (Davis and DeWiest, 1966). This is the simplest form of the water cycle. However, some water molecules have local cycles and do not always return to the ocean. An example is evaporation of water from land that returns to land as a summer thunderstorm caused by local convection.

There are three types of precipitation: convectional, orographic, and cyclonic. Due to the location of the few mountains found in Texas, the effect of orographic precipitation is insignificant. Convectional precipitation is due to the uneven heating of the ground, which causes the air to rise and expand, vapor to condense, and precipitation to occur. This type of precipitation occurs in summer, producing high intensity and short duration rainfalls. Cyclonic precipitation is related to large low-pressure systems. It is also known as frontal precipitation, induced by the contact of a cold front from the north and a warm front from the Gulf or Pacific Ocean. A hurricane is a type of cyclonic precipitation. In Texas, this precipitation produces long durations of low intensity rain or snowfalls and has a major impact on the recharge of groundwater systems.

Prior to rainfall recharging the groundwater, a portion of the water is intercepted by trees and buildings, which evaporates back to the atmosphere. Retention occurs in low places and depressions with surface runoff moving over the land into streams. What rainwater remains infiltrates into the ground. The infiltrated water has to meet soil water deficits before it seeps down by gravity to the water table, completing the recharge to groundwater.

Groundwater occurs under water table and artesian conditions. Under water table condition, the water is unconfined and does not rise in wells above the level at which it is encountered. This level is known as the water table and is the upper surface of the zone of saturation. Water table conditions are usually found in the outcrop of permeable water-bearing rock beds. Under artesian conditions, the water is confined within rock strata by an overlying relatively impermeable bed. Due to the water being under pressure, water will rise in wells above the level at which it is encountered.

Figure 2-1
The Hydrologic Cycle



In most places, groundwater slowly moves under the influence of gravity from areas of recharge to areas of discharge. In the most permeable rocks, such as coarse sand and gravel and cavernous limestone, the water moves with comparative freedom, although the movement is relatively slow compared to the flow of a stream. The definition of an aquifer is a water-bearing unit that can yield enough water for at least a domestic water supply. In less permeable rock, such as fine sand, silt, shale, clay, or less fractured hard rocks, groundwater movement is even slower. Such a rock unit, even bearing water, will retard water movement. Hence, it is called an aquitard and forms the upper and lower confining beds, which produces a confined aquifer. A geologic unit that bears no water is called an aquiclude.

Groundwater is discharged from underground reservoirs through springs, seeps, wells, evaporation, and transpiration. On a yearly basis, the natural recharge is approximately equal to the average discharge. However, groundwater is like a surface water reservoir and will have negative or positive storage following wet and dry (drought) years. The difference between surface water and groundwater is that groundwater always lags behind surface water by several years in response to a climatic change, with the exception of the karstic Edwards and Glen Rose aquifers in Texas. These two aquifers respond to precipitation much quicker than any porous, sedimentary aquifer, as demonstrated by their return to pre-1956 draught condition in just one year in 1957.

2.2 INFLUENT, TRANSMISSION, AND EFFLUENT STREAMS

Streamflow, runoff, discharge, and yield of drainage basins are synonymous (EPA 1987). Runoff includes all of the water in a stream channel flowing past a cross section. This water may consist of precipitation that falls directly into the channel, surface runoff, and groundwater runoff. Surface runoff is the only source of water in ephemeral and intermittent streams. During dry weather, groundwater runoff may account for a stream's entire flow and is the major source of water to streams from late summer to winter. Other sources of streamflow include discharge of industrial and municipal wastewater and irrigation return flows.

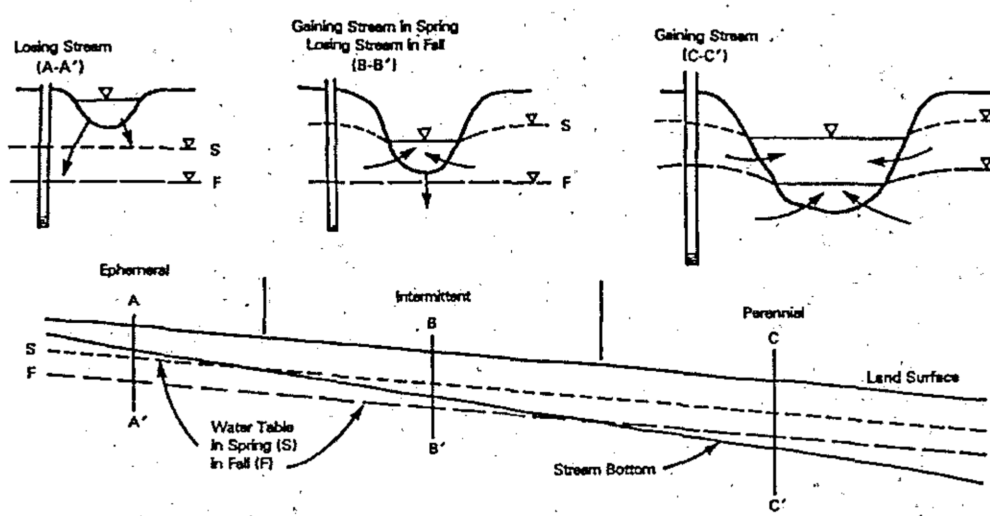
An ephemeral stream owes its entire flow to surface runoff. The water table consistently remains below the bottom of the channel (Figure 2.2). Water leaks from the channel into the ground, recharging the underlying strata. Ephemeral streams occur in headwaters of perennial streams or in arid zones. In general, an ephemeral stream is also called an influent stream.

Intermittent streams flow only part of the year, generally from spring to summer, as well as during wet periods. During dry weather these streams flow because of the groundwater that discharge into them. The water table is above the base of the channel. Eventually, the water table is lowered below the base of the channel and the stream becomes dry.

Many streams, particularly those in humid and semiarid regions, flow throughout the year. These are called perennial streams. In this case, the water table is always above the stream bottom, groundwater is discharged, and streamflow increases downstream. This is called an effluent stream. A stream in which the discharge increases downstream is called a gaining stream. When the discharge of a stream decreases downstream due to leakage, it is called a losing stream or an influent stream. As stated before, most of the ephemeral streams are losing and most of the perennial, gaining. A unique feature of the Balcones fault zone (BFZ), extending 180 miles from Bell County to Kinney County, is that almost all streams that traverse this zone lose water to sinkholes and fault fractures. Sometimes the entire streamflow disappears from the streambed, as recorded for Cibolo Creek north of San Antonio. Below a major spring, such as Comal or San Marcos Springs, the stream becomes perennial again. Perennial conditions may be caused by man-made conditions, not necessarily by groundwater discharge. For example, wastewater disposal from a large city can create a perennial condition.

Figure 2-2
Water Table and Stream Type

Relation between water table and stream type.



Source: EPA, 1987 Handbook Groundwater

The water table may also be lowered below the stream channel due to the transpiration from phreatophytes. In the Red River basin of the Osage Plain, between Wichita Falls and Amarillo, after clearing of the phreatophytes, the water table rose more than 20 feet in some places near Vernon in Wilbarger County (Baker et al., 1963). Baker and Dale (1961) presented the same observation in the Lower Rio Grande Valley. An experiment performed by the Soil Conservation Services, the clearing of the mountain cedars west of San Antonio, also increased streamflow.

When a stream flows over an impermeable outcrop of bedrock, the stream will not gain or lose. This stretch can be considered as transmission reach. Examples are creek flow over the heavy clay of the Midway Group, which extends from Texarkana to San Antonio or the metamorphic rocks with few, small fractures in the Llano Uplift of central Texas. Streamflow losses through the transmission reach are evaporation from water surface, plant transpiration, and diversion.

2.3 INPUT PARAMETERS FOR GROUNDWATER MODELING

For a river basin, the numerical groundwater modeling must be capable of handling anisotropic and heterogeneous geologic conditions. One solution to this issue is to divide the simulation field into small areas so that the hydrogeologic conditions can be considered isotropic and homogeneous within this smaller area. There are two methods to divide the groundwater watershed. One is the finite difference method (FDM) and the other is the finite element method (FEM). FDM normally utilizes rectangular grids composed of links and nodes arranged to resemble fish net or mesh. Different mathematical algorithms operate the two methods, although both are built on Darcy's equation and the law of conservation. Although most of the aquifer simulations for the Edwards aquifer have been done using FDM, Kuniansky and Holligan (1994) employed the FEM for the simulations of flow in the Edwards-Trinity aquifer systems. The FEM is best suited for handling an anisotropic situation such as the BFZ mentioned before. An example of the FDM model is MODFLOW that is used for modeling groundwater basins with varying conditions and boundaries (McDonald and Harbaugh, 1988).

A conceptual hydrogeologic model should be constructed. Based on the conceptual model, the boundary and initial conditions can be established. Boundaries can be recharge, discharge, or no flow. Recharge can be set as a constant head boundary. Discharge can be simulated as sink node also with a constant head. For low permeability rocks, the grid and node is set as a no flow boundary. For a river basin whose groundwater watershed is different from its surface watershed, hydrogeologic properties of the neighboring watershed are needed for the simulation. Thus the geometry of the aquifer is important for simulation. Parameters assigned to each node are transmissivity (T), storativity (S), and head (H). Transmissivity indicates how fast the aquifer transmits water to a well or river and is the product of the aquifer's saturated thickness and its hydraulic conductivity. Due to anisotropy, in a three-dimensional Cartesian coordinate system, transmissivity values are different in x, y, and z directions. Storativity indicates how much water is stored in the aquifer and also indicates whether the aquifer is under the water table or an artesian condition.

A stream within the geographic boundaries is considered either a head dependent, source or sink node/grid. For an ephemeral stream, the node is set as a source. For a perennial steam, nodes along the stream are considered sinks. Therefore, it is necessary to delineate the gain or loss reaches and pertinent hydraulic properties associated with that reach. Input parameters could be the width of the stream, the thickness and vertical hydraulic conductivity of the streambed, the stage and water table elevations, and the horizontal transmissivity and storativity of each node of the underlying water-bearing unit (McDonald and Harbaugh, 1988). Otherwise, the node can be assigned as a constant head source or sink for losing and gaining reaches, respectively.

For groundwater and streamflow modeling, one needs to understand the relationship between surface water and groundwater. This section provides the basic hydrology and types of stream channels -- influent, transmission, and effluent reaches and also presents a minimum input parameters for computer modeling and, thus, the direction of data collection if the groundwater component is considered in the Water Availability Model. Section 3 provides a qualitative, basin-by-basin analysis of channel gain and loss based on the understanding of Section 2.

2.4 REFERENCES

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SECTION 3.0 SUMMARY OF SURFACE AND GROUNDWATER INTERACTION BY BASIN

This section presents the results of the literature review for each river basin, utilizing the hydrologic characteristics of each, with a focus on hydrogeology and streamflow. The significance of surface water and groundwater interaction is assessed. A table detailing the TNRCC designated stream segments corresponding to the river reaches being assessed, the existence of hydraulic interaction and reasons for that interaction, and the confidence level for the interaction follows. The confidence level is based on professional judgment and criteria stated in Section 2, unless the literature specifically states that the reaches (segment) of a river are gaining or losing. Finally, references are attached to each subsection, rather than at the end of this report, to facilitate potential further quantitative study and coupled streamflow-and-groundwater modeling.

3.1 THE CANADIAN RIVER BASIN

3.1.1 Hydrologic Characteristics

The Canadian River basin in Texas includes tributaries of the North Canadian River and the Canadian River, is bounded on the north by the North Canadian River basin and on the south by the Red River basin (Figure 3.1.1). The Canadian River heads in northeastern New Mexico, flows eastward across the Texas Panhandle, and merges with the Arkansas River in eastern Oklahoma. The North Canadian River originates in New Mexico and flows easterly through the Oklahoma Panhandle. It turns southeastward after passing the Panhandle and runs parallel with the Canadian River near Selling, Oklahoma. The North Canadian River debauches into Eufaula Reservoir west of Eufaula, Oklahoma. The Canadian River also discharges into Eufaula Reservoir.

Major tributaries of the Canadian River in Texas are Rita Blanca Creek that drains Dallam, Hartley, and Oldham Counties and Big Blue Creek near Borger. Tributaries to the North Canadian River are Wolf Creek that drains Ochiltree and Lipscomb Counties, Palo Duro Creek that drains Hansford, Hutchinson, Moore, and Sherman Counties, Coldwater Creek that drains Hansford, Sherman, and Dallam Counties, and the North Canadian River that drains a small portion of Sherman County. Total drainage area of this basin in Texas is about 12,700 square miles (TWDB, 1977; Manford, Dixon and Dent, 1960a,). Elevation of the basin ranges from 4,735 feet above mean sea level (msl) in the northwestern Dallam County to 2,167 feet msl where the Canadian River enters Oklahoma in Hemphill County.

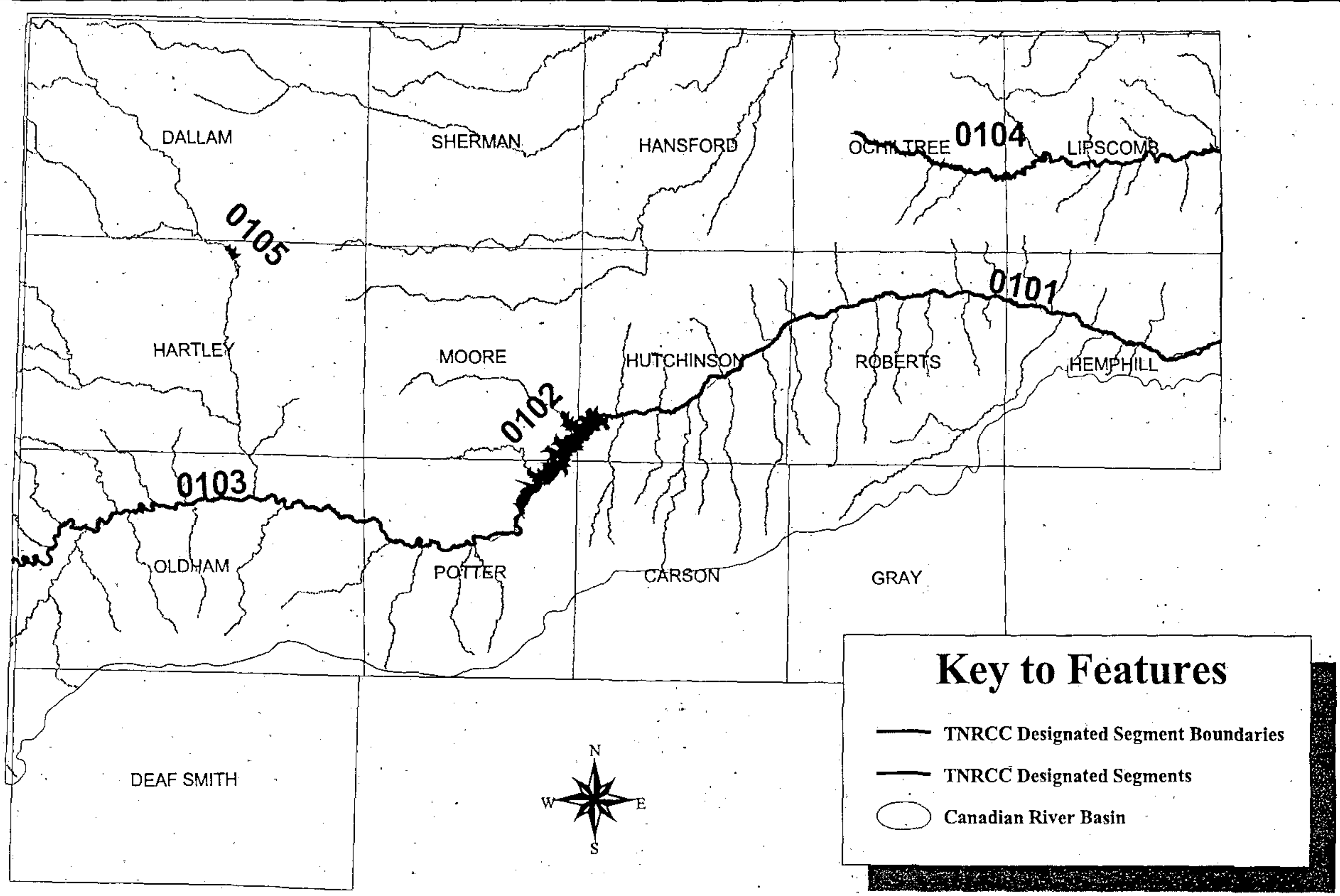

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FIGURE 3.1.1

CANADIAN RIVER BASIN
TNRCC Designated Stream Segments

Source: TNRIS/TNRCC Water Resource Management Division

The Canadian River basin is located in the High Plains Section of the Great Plains Province and the Llano Estacado Extension of the High Plains Extension. The High Plains is level to very gently rolling, except along the eastern and western margins of the High Plains where major streams are actively eroding headward in the Ogallala Formation (TWDB, 1977).

Climate of the Canadian River Basin is a dry, steppe type with mild winters. In an average, about 80% of the annual 23 inches rainfall occurs from May to October. Precipitation occurs most often in the form of thunderstorms that produce rapid runoff. Lake evaporation ranges from 50 to 55 inches per year.

Because the Canadian River cuts into the Permian rocks that contain salt, gypsum, and anhydrite in Oldham, Potter, and Hutchinson Counties, salt springs and seeps cause high total dissolved solids (TDS) in the surface water. At the Texas-New Mexico State line, the average TDS in the river ranges from 500 to 1,000 mg/L. Above Lake Meredith, the river contains about 1,000 mg/L. Below Lake Meredith, the river generally exceeds 1,000 mg/L TDS. In contrast, tributaries such as Palo Duro Creek, and Rita Blanca Creek have TDS below 500 mg/L (TWDB, 1977).

According to Manford, Dixon, and Dent (1960a) the Ogallala Formation occupies the entire river basin (Figure 3.1.2). Older rocks such as the Dockum Group of Triassic rocks and the Quartermaster Formation, Blaine Gypsum, and Glorietta Sandstone of the Permian rocks are exposed along the river canyon in Oldham, Potter, and Hutchinson Counties. The northeastern portion of Hemphill County is sand dune. The alluvium deposits appear along the Canadian River from Lake Meredith to the Texas-Oklahoma State line, and tributaries of the North Canadian River: Wolf Creek and Palo Duro Creek. The Dakota Sandstone of Cretaceous-age is found underneath the Ogallala Formation, about 150 square miles in northwest Dallam County. About half of the Dakota is in the North Canadian River basin and half in the Canadian River basin. Beneath the Dakota is the Dockum Group. Elsewhere of the basin, the Dockum Group directly underlies the Ogallala Formation.

Regions

The Canadian River basin in Texas is treated as two hydrologic units. Region I is the North Canadian River and Region II, the Canadian River (TWDB, 1977; Manford, Dixon, and Dent, 1960a).

Major Aquifers

In the High Plains, the major aquifer is the Ogallala that occupies the 15 counties of the Regions I and II (Figure 3.1.2). It reaches a thickness of 900 feet in the southeastern Ochiltree County. The Ogallala aquifer is mostly unconfined. Depth to water ranges

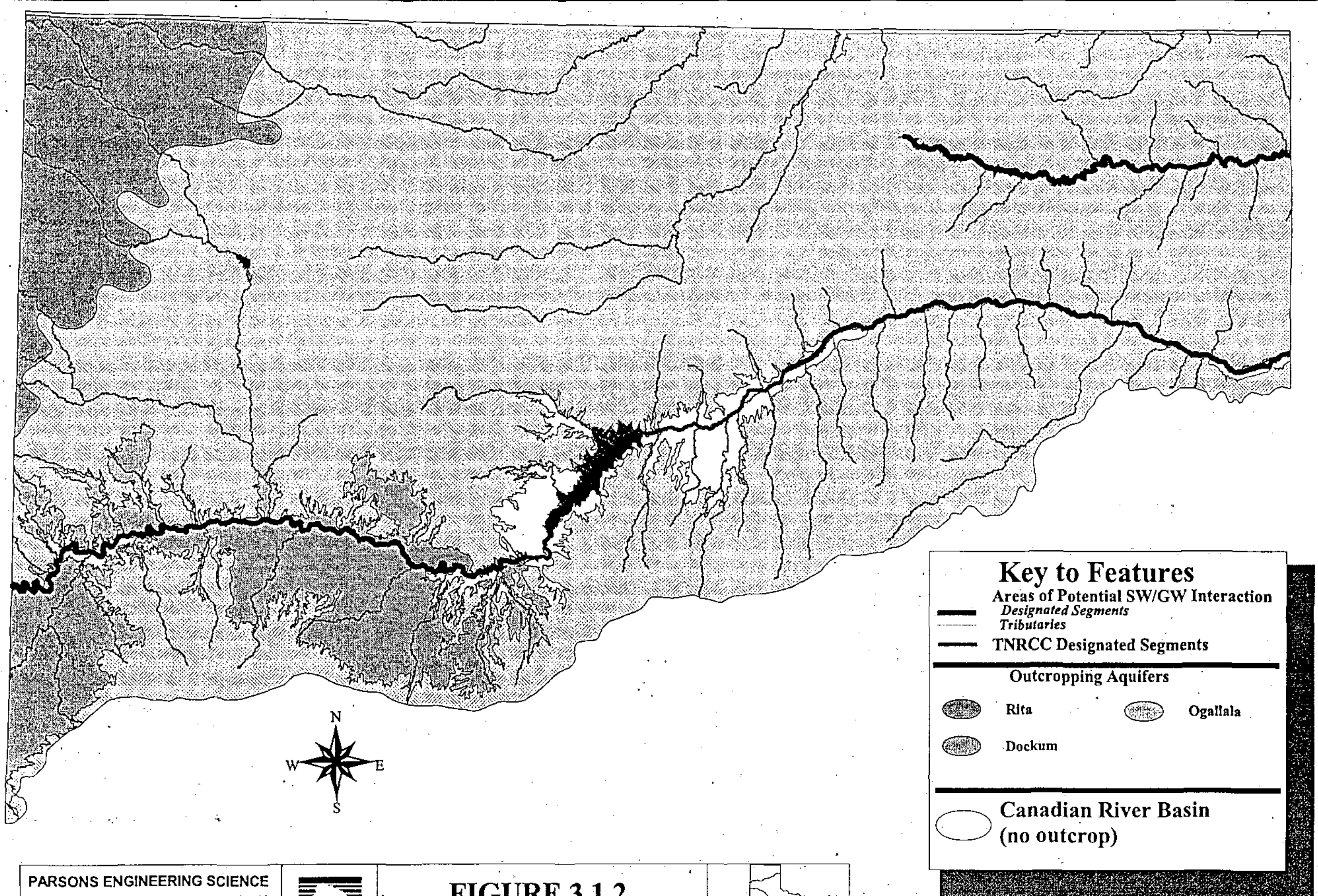

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FIGURE 3.1.2

CANADIAN RIVER BASIN
Potential Surface Water/
Groundwater Interaction

Source: TNRIS/TWDB GIS Planning Division

from 50 to 400 feet below land surface. Springs and seeps occur along the base of the escarpment and at locations where valleys have cut through the water table. Under natural hydraulic gradient, groundwater is moving toward east at a gradient of 10 feet per mile. Locally, it flows toward irrigation well fields such as found north of Dalhart in Dallam County and public water supply wells such as those north of the DOE Pantex Plant in Carson County for the city of Amarillo.

Along the Canadian River in the escarpment areas, some of the water being discharged as springs and seeps from the Permian rocks is water that has moved from the Ogallala into the Permian strata. Most of the fresh water found in the Permian rocks is believed to be water from the Ogallala (Manford, Dixon, and Dent, 1960a).

Minor Aquifers

The only minor aquifer considered by TWDB (1977) is the Purgatoire-Dakota aquifer. In addition to this aquifer Manford, Dixon, and Dent (1960a) also includes older water-bearing rocks such as the Dockum Group of Triassic age and the Permian rocks. As stated before, the Purgatoire-Dakota aquifer produces water in the sandstone zone in northwestern Dallam County and occupies 150 square miles. It's contribution to the baseflow of the North Canadian and the Canadian Rivers may not be significant. In Texas this formation only outcrops in a small area in the northwestern corner of Dallam County.

The Dockum Group underlies the Dakota Sandstone and is in direct contact with the Ogallala Formation where there is no Dakota. Due to erosion, the Dockum sandstone and shale crops out almost entirely in the Oldham County and the western portion of Potter County. Beneath the Dockum Group are the Permian Rocks including Quartermaster Formation, Blaine Gypsum, and Whitehorse Sandstone. Permian rocks occur along the Canadian River in western Oldham County and in Potter, Moore, and Hutchinson Counties, in the vicinity of Lake Meredith.

The recent alluvium deposits occur along the river below US Highway 385 bridge to the Texas-Oklahoma State Line, in Wolf Creek, and in Palo Duro Creek. Although the are not considered an important source of water in the Canadian River basin, the deposits are hydraulic connected with the Ogallala aquifer. Groundwater in the Ogallala aquifer can discharge into streams through the alluvium deposits (Manford, Dixon, and Dent, 1960a). Because the alluvium occupies almost half of the Wolf Creek watershed, one can surmise that the alluvium regulates the streamflow of this Region I tributary.

Reservoirs

Lake Meredith is constructed on the main stem west of Borger and north of Amarillo. Rita Blanca Lake is constructed on Rita Blanca Creek south of Dalhart in Hartley County. Further upstream above the Texas-New Mexico State line, the Conchas Lake of Ute Reservoir is constructed along the main stem of the Canadian River.

3.1.2 Significance of The Interaction

Region I

Except Wolf Creek that drains Lipscomb and Ochiltree Counties, all of the tributaries to the North Canadian River are ephemeral. Ephemeral streams indicate the recharge area while perennial streams, indicate groundwater discharge areas. Although the channel gain and loss investigation of Texas streams (Manford, Dixon, and Dent, 1960b) does not include Regions I and II of the Canadian River basin, one can postulate that the Ogallala aquifer contributes baseflow to Wolf Creek. In addition, the recent alluvium deposits occupy almost half of the Wolf Creek watershed, from which one can infer that the alluvium will regulate the streamflow of the Region II tributary. The USGS (1991) gaging record indicates that Wolf Creek near Lipscomb has an annual flow of 13.2 cubic feet per second (cfs) with a watershed area of 697 square miles. Small diversions upstream for irrigation and recreation are documented. TNRCC (1996) stated that wastewater effluent contributes to the creek flow. Besides surface runoff, irrigation return water is also a component of the streamflow.

Region II

In the Canadian River portion of the basin, streamflow records of the USGS indicate that discharge increases downstream. Factors governing downstream streamflow increases are a larger watershed area that produces more surface runoff, more groundwater discharge due to interception of water table, wastewater discharge from municipalities and industries, and irrigation return water. Evidently, water from the last two sources has to come from another river basin or groundwater; and not from the Canadian River basin. The stream could also lose water in the downstream direction due to diversion, lake evaporation, and evapotranspiration from phreatophytes. In the Canadian River basin, the invading species salt cedar consumes significant volumes of shallow groundwater along the stream banks.

Seventy miles west of the Texas-New Mexico State line at Logan, New Mexico, the Canadian River had an average discharge of 257 cfs prior to the construction of Ute Reservoir in 1962. About 134 river miles downstream at US Highway 287 north of Amarillo, the river discharges at 303 cfs. At Canadian in Hemphill County, 104 miles from the upstream gaging stream, the river flows at a rate of 549 cfs before the construction of Lake Meredith in 1964. (After 1964, discharge was regulated to 86.8 cfs near Canadian.) In a semi-arid environment such as the High Plains where evaporation is two to three times higher than precipitation, the increase of perennial streamflow downstream indicates groundwater contribution. It is documented that the Ogallala aquifer forms springs and seeps along the escarpment and "breaks" of eroded areas. Furthermore, the salinity problem of the Canadian River in New Mexico and Texas indicates salt seeps and springs from older Permian rocks that discharge into the river. Surface runoff from Rita Blanca and Palo Duro Creeks has TDS of less than 500 mg/L. During low flow, TDS levels of the Canadian River west of the Texas-New Mexico State line ranges from 1,000 to 2,000 mg/L. The water quality improved above Lake Meredith to 1,000 mg/L. Below Lake Meredith, TDS is above 1,000 mg/L.

Table 3.1.1
Surface Water and Groundwater Interaction, Canadian River Basin.

Reach	Water Quality Segment	SW/GW Interaction	Aquifer	Probability/ Comment
Canadian River below Lake Meredith and above the Texas-Oklahoma State line	0101	Yes, gaining.	Ogallala aquifer: outcrops contribute to stream flow in Hemphill County, sand dune deposits contribute to flow.	High: based on stream gage measurements.
Lake Meredith	0102	Yes, gaining or losing	Ogallala aquifer: seasonal variation—when lake stage is higher than the water table, losing; otherwise, gaining.	Medium: potential gains are without published document support.
Canadian River above Lake Meredith	0103	Yes, gaining	Ogallala aquifer: stream flow increases downstream over water bearing geologic units of the Ogallala, Dockum, and Permian rocks.	High: based on stream gage measurements
Wolf Creek	0104	Yes, gaining	Ogallala aquifer: baseflow to creek derived from the Ogallala aquifer.	Medium: potential judgement gains based on stream-flow record and geology; not on published documents

3.1.3 References

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3.2 THE RED RIVER BASIN

3.2.1 Hydrologic Characteristics

The Red River basin is bounded on the north by the Canadian River and on the south by the Brazos, Trinity and Sulphur River basins. Beginning in the High Plains of eastern New Mexico at an elevation of about 4,800 feet, the Red River flows eastward and forms the state line (100 degree meridian) with Oklahoma after leaving the Texas Panhandle. The river leaves Texas near Texarkana at an elevation of about 250 feet. Total drainage is 48,030 square miles, of which 24,463 square miles are in Texas. The North Fork of the Red River forms near Pampa and the Salt Fork, about 26 miles east of Amarillo. Both forks flow east and exit Texas into Oklahoma. Both forks then turn south and join the Red River individually about 17 miles north of Vernon, Texas. Palo Duro Creek turns into Prairie Dog Town Fork of the Red River east of Canyon after descending from the High Plains into the Palo Duro Canyon. The Prairie Dog Town Fork is named the Red River at the Texas-Oklahoma state line (Figure 3.2.1) (TWDB, 1977; Baker et al, 1963).

The Red River basin includes the Llano Estacado extension of the High Plains section of the Great Plains Province, the Osage Plains section of the Central Lowland Province, and the West Gulf Coast section of the Coastal Plain Province. The Llano Estacado is a nearly level, undissected, high tableland with slow to moderate surface drainage and many playas. The Osage Plains section is a broad, nearly level to rolling, grass and brush covered plain with moderate to rapid surface drainage and entrenched streams. Undulating prairies and nearly level valleys characterize the West Gulf Coast section. Average annual rainfall in the High Plains is about 19 inches. It varies from 14 inches at the Texas-New Mexico state line to about 20 inches near the escarpment to the east. Annual rainfall in the Osage Plains is about 25 inches. It varies from 20 inches to the west to about 28 inches near the Montague and Cooke county line. Average rainfall in the West Gulf Coast is 42 inches. It varies from 28 inches to the west to about 48 inches near Texarkana. In this watershed, the annual net lake evaporation is 55 inches in the High Plains and 5 inches near Texarkana (TDWR, 1984; TWDB,1977).

According to USGS (1991) water resources data, a majority of the watershed in the High Plains will not contribute runoff to the stream channel. For example, the Prairie Dog Town Fork of the Red River covers 4,211 square miles but 3,281 square miles, i.e., 78%, are not contributing. Moreover, the City of Amarillo contributes a significant amount of permitted wastewater discharge to the streamflow. Because of the low rainfall and high evaporation, low flow conditions dominate in the High Plains. Moreover, salt seeps and oil field brines of the High Plains and the Osage Plains accentuate the water quality problem.

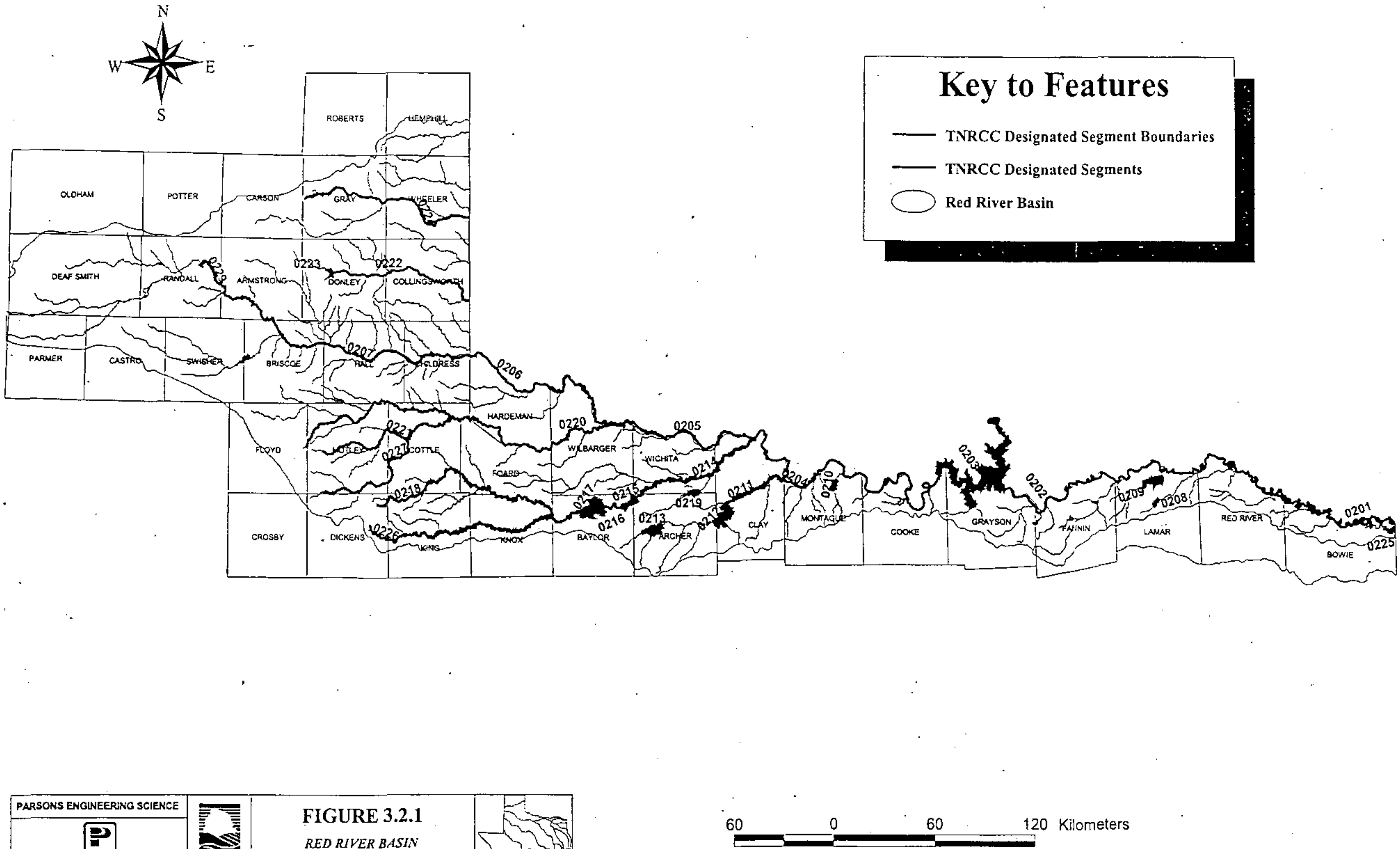

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FIGURE 3.2.1

RED RIVER BASIN
TNRCC Designated Stream Segments

Source: TNRIS/TWDB GIS Planning Division

TWDB (1977) stated that the Prairie Dog Town Fork, Red River, Pease River, and Wichita River are highly saline, frequently exceeding 25,000 mg/L TDS during low flows. Pease River joins the Red River near Vernon, Wilbarger County and the Wichita River joins the Red River in Clay County northeast of Wichita Falls, Wichita County. It is obvious that the lakes in the High and Osage Plains would have TDS above 2,000 mg/L. The Red River near Gainsville where I-35 crosses has a discharge-weighted TDS of 1,100 mg/L. Downstream from I-35 on the main trunk of the Red River, Lake Texoma receives inflows from the Washita River in Oklahoma. The resulting TDS is 800 mg/L. Below Lake Texoma, water of all tributaries is low in TDS. The Red River near De Kalb, Bowie County, has about 500 mg/L TDS.

Regions

The Red River basin covers three hydrologic regions: the High Plains, the Osage Plains, and the West Gulf Coastal Plain.

Major Aquifers

Major aquifers in the Red River basin are the Ogallala (Region I), the Alluvium (Region II), and the Trinity (Region III) (Figure 3.2.2). The Ogallala aquifer underlies the High Plains in the western part of the basin. The aquifer consists of interbedded sand, clay, silt, gravel, and caliche. Total thickness reaches 900 feet with a saturated thickness of 225 feet. The Ogallala is a high yield aquifer with average well capacity of 500 gpm, up to 1,100 gpm. The movement of groundwater is to the southeast towards the natural discharge. Locally the direction of movement is diverted toward streams or discharging wells. Natural discharge also occurs along the escarpment as springs (TWDB, 1977; Baker et al, 1963; TDWR, 1984).

In the central part of the Red River basin, the Osage Plains, the Alluvium aquifer consisted of interbedded sand, gravel, silt, and clay. The aquifer is composed of remnants of the Seymour Formation and recent alluvial deposits along the major streams. Generally, the thickness is 100 feet or less but locally it may reach 360 feet. Saturated thickness ranges from 50 to 150 feet. Average well capacity is 300 gpm, up to 1,300 gpm. In some localities, the groundwater is saline.

The Trinity aquifer is composed of the Paluxy Sand, Glen Rose Limestone, and Travis Peak Formation, in descending order. The Glen Rose Limestone is not known to yield water to wells in the Red River basin. Total thickness of the Travis Peak and Paluxy varies from 400 feet to 1,000 feet. Well yields average 325 gpm to 700 gpm. This aquifer outcrops in Montague and Cooke Counties, west of I-35 and dips east and southeast toward the Gulf (Figure 3.2.2). Unless it is through upward leakage, the subsurface Trinity aquifer east of the outcrop provides little baseflow to the Red River. Water contains less than 1,000 mg/L TDS, but TDS increases downdip and toward the east.(Baker et al, 1963; Bayha, 1967; Nordstrom, 1982).

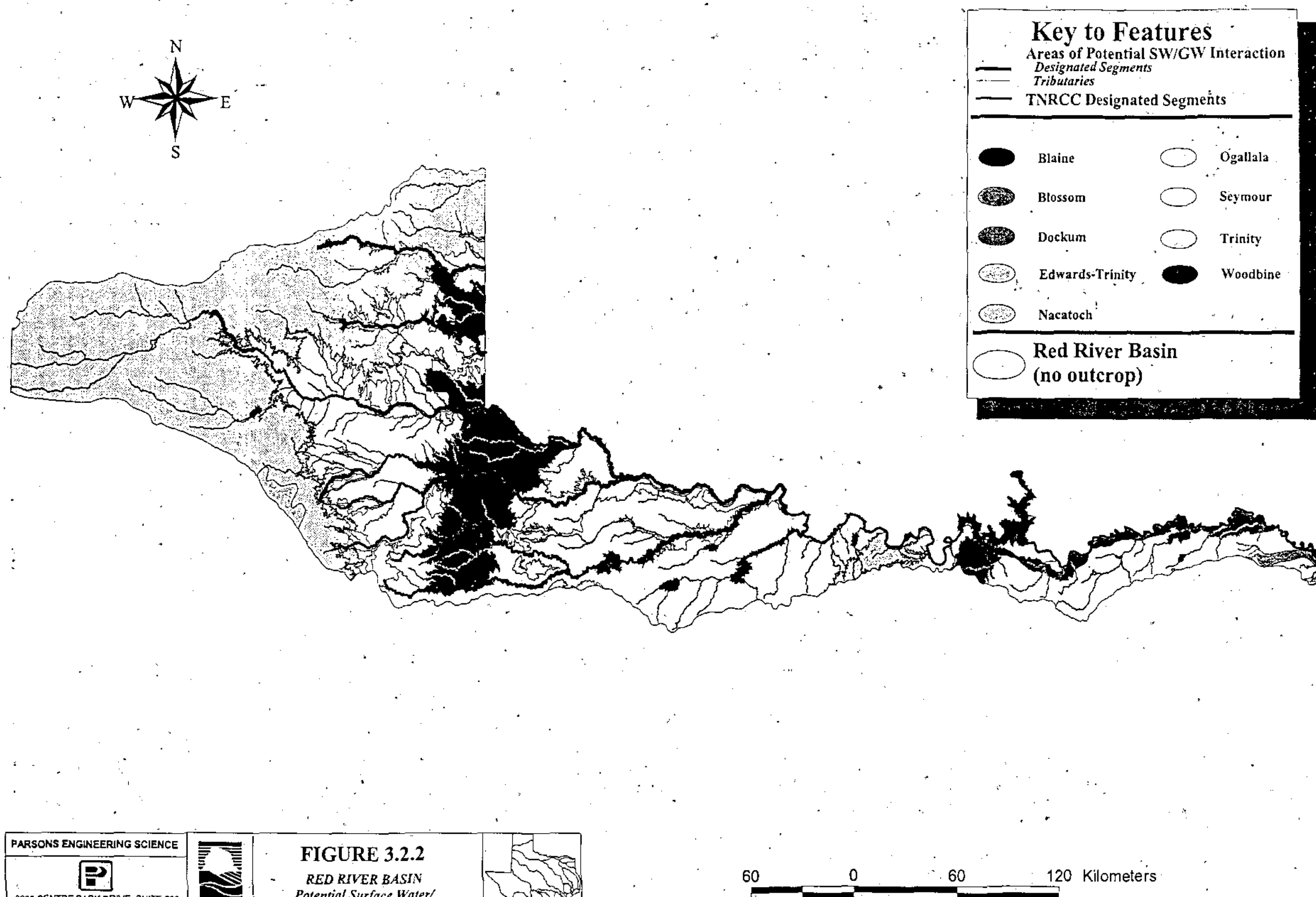

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FIGURE 3.2.2

RED RIVER BASIN
Potential Surface Water/
Groundwater Interaction

Source: TNRIS/TWDB GIS Planning Division

Minor Aquifers

Minor aquifers include from west to east the Dockum Group, the Blaine Gypsum aquifer, the Cisco and Wichita aquifer, the Whitehorse Group, the Woodbine Sand aquifer, the Blossom Sand aquifer, and the Nacatoch Sand aquifer.

In the High Plains (Region I), the Dockum outcrops occur along the rim of the escarpment. The Dockum Group dips west underneath the Ogallala aquifer. The strata consist of shale, sandstone, and conglomerate of continental origin. Depth to the top of Dockum varies from zero at the outcrop to 500 feet in Parmer, Castor, and Floyd Counties to the southwest. In general, Dockum Group can produce moderate quantities of fresh water in a few places. However, it has low to moderate yield formation with salinity concerns, not suitable for irrigation and public supply.

The Blaine Gypsum aquifer occurs along the 100 degree meridian in Wheeler, Collings-Worth, Childress, Cottle, Hardeman, Foard King, and Knox Counties in Region II. The aquifer consists of gypsum interbedded with anhydrite, shale, and dolomite. Porosity is primarily the result of solution cavities developed in the gypsum bed. Its thickness reaches to 250 feet. The average well yield is 400 gpm but locally can attain 1,500 gpm. This aquifer yields high TDS groundwater ranging from 2,000 to more than 5,000 mg/L, not suitable for drinking. The Blaine Gypsum is the middle stratum of the Peace River Group. The upper stratum is the Dog Creek Shale and the lower formation is the Flowerpot Shale and San Angelo Sandstone. The Dog Creek and Flowerpot are not considered aquifers in the Red River basin; however, several standby wells in Wheeler County tap into the Dog Creek. The quality of these wells is too poor for regular use (Baker et al, 1963).

The Cisco-Wichita Groups crop out in Wilbarger, Baylor, Wichita, Archer, Clay and Montague Counties in the eastern portion of Region II. The rocks dip gently toward the west or northwest below Permian rocks or Quaternary alluvial deposits. The groups consist of alternating beds of shale, sandstone, limestone, and conglomerate. The rocks yield mineralized and small quantities of water to wells near Wichita Falls. In Region II, the Whitehorse Group crops out west of the Blaine aquifer outcrop and east of the Caprock Escarpment of the High Plains, amidst the outcrops of the Seymour and recent alluvial deposits. The Whitehorse consists of fine sand, gypsum, anhydrite, shale, and dolomite.

In Region III, the Woodbine aquifer outcrops in a north-south orientation along the Cooke and Grayson County line and also extends eastward as a promontory along the Red River in Grayson County into the western part of Fannin County. The Woodbine then outcrops locally in the northern tips of Lamar and Red River Counties along the River (Figure 3.2.2.) The aquifer consists of medium- to coarse-grained sand interbedded with clay and lignite. Most of the sand is in the lower part of the aquifer. Total thickness ranges from 400 to 600 feet. Well capacity ranges from 175 gpm to 700 gpm.

The Blossom Sand aquifer occurs in a narrow band across the southern edge of the basin in Region III (Figure 3.2.2). Because the outcrop occurs at the watershed divide, the Blossom Sand may not contribute groundwater to the Red River streamflow directly in Region III. It occupies Grayson, Fannin, Lamar, and Red River Counties. Another secondary aquifer, the Nacatoch Sand, may have interaction with the Red River because it crops out along the line connecting De Kalb, Bowie County and Cooper, Delta County as a southwest-northeast trending band across Bowie County. The Nacatoch Sand juxtaposes with the Alluvium deposits of the Red River, and it is possible that it has hydraulic communication between the Nacatoch and the River.

Baker et al (1963) considers the Quaternary alluvium as a potential aquifer in the West Coastal Plain of the Red River basin. The alluvial deposits along the Red River are in the form of terraces formed at different stages of the river. Its thickness ranges from zero at its contact on the surface with older rocks to over 100 feet in Bowie County. In general, the alluvial deposits thicken eastward with a corresponding increase in flow of the Red River. The movement of groundwater in the alluvial aquifer is toward the Red River.

Reservoirs

Reservoirs in Region I are Buffalo Lake midway between Hereford and Canyon along Terra Blanca Creek. This creek joins Palo Duro Creek northeast of Canyon. On Palo Duro Creek is Bivins Lake, northwest of Canyon. On the Salt Fork of the Red River, there is the Greenbelt Lake below the escarpment.

Reservoirs in Region II are on the major tributaries. They are Lake Kemp and Lake Dundee on the main trunk of the Wichita River. North Fork Buffalo Creek Reservoir and Lake Wichita are off the main trunk on tributaries of the Wichita River. South of the Wichita River is the Little Wichita River. West of Archer City is Lake Kikapoo and east of Archer City is Lake Arrowhead.

Reservoirs in Region III are Lake Texoma, Pat Mayse Reservoir and Lake Crook. Lake Texoma is the largest man-made lake in the Red River basin. North of Paris, Lake Crook dams Pine Creek runoff and Pat Mayse Reservoir dams Sanders Creek.

3.2.2 Significance of The Interaction

Factors govern the streamflow are the baseflow contributed by groundwater discharge, the rainfall and snow-melt runoff exceeding infiltration rate, evapotranspiration produced by phreatophytes, and bank storage. Man-made factors are irrigation diversion from a stream or irrigation tail (return) water, dams, and wastewater disposal from cities. The source of irrigation return water could originate from another river basin or groundwater. It is possible that the irrigation return water from the High Plains contributes streamflow of the Osage Plains. As with wetlands, a perennial stream could be created solely by the wastewater discharge from a large municipality.

Region I, The High Plains

As formerly stated, 78% of the watershed in Region I, the High Plains, contributes no runoff to the channels. If there is streamflow after a storm event, it is most likely that the water will recharge the Ogallala aquifer. There is no continuous USGS gaging station in Region I indicating a losing stream condition.

Region II, the Osage Plains.

(1) The North Fork Red River is intermittent after descending down the escarpment. Streamflow data collected near Shamrock at US Highway 83 indicated that the North Fork could have no-flow days in June through October (USGS, 1991). Therefore, in this segment between the escarpment and the Texas-Oklahoma state-line, the North Fork could be gaining or losing depending on seasons. It is likely that the North Fork is a perennial stream after it merges with Sweetwater Creek east of the state-line in Oklahoma. The Alluvium aquifer may contribute baseflow to the North Fork.

(2) Streamflow of the Salt Fork Red River is probably regulated by the Greenbelt Reservoir north of Claredon and by the Seymour and Alluvium aquifers. Salt Fork is perennial near Wellington at the US Highway 83, before entering into Oklahoma.

(3) The Pease River becomes perennial below the confluence of the North and Middle Pease Rivers east of US Highway 83. There are flood control structures upstream from the confluence, and it is probable that the upstream reaches are ephemeral and intermittent in nature. The Pease River joins the Red River east of Vernon.

(4) The streamflow of the Wichita River is regulated by Lake Kemp, Diversion Lake, Lake Wichita and North Fork Buffalo Reservoir. On the South Wichita River at the US Highway 83 near Guthrie, the USGS gaging station registered a perennial condition. Near Guthrie, salinity is above 35,000 mg/L. Further downstream, the North and South Wichita Rivers (upstream from the State Highway 6 near Benjamin) have salinity issues. Salinity is generally above 10,000 mg/L. Streamflow from both forks are pumped into a man-make lake, Truscott Brine Lake, west of State Highway 6 between the South and the North Rivers for treatment by evaporation. From this, one can postulate that salt seeps and oil field brine disposal contribute to the perennial flow of the Wichita River. The City of Wichita Falls augments the streamflow by discharge treated wastewater into the Wichita River. The lakes will recharge the shallow groundwater locally but, in general away from the reservoirs, the Wichita River is a gaining river.

(5) Before the Red River flows into Region III, from Permian rocks into Cretaceous rocks and from Osage Plains into the West Gulf Coast Plains, the Little Wichita River joins the Red River near Terral, Oklahoma. Above Archer City, the Little Wichita River is a losing stream. Below State Highway 79, the river is potentially perennial. The Little Wichita River is perennial below Lake Kemp. Of course the streamflow is regulated by the lake.

(6) The Prairie Dog Town Fork Red River is recorded perennial at the USGS gaging station near Wayside, Armstrong County. The City of Amarillo on the High Plains discharges treatment wastewater into this stream. Salinity is above 3,000 mg/L at 9 cfs and above 15,000 mg/L at 0.7 cfs. There are small diversion dams between Wayside and Childress, but the USGS gaging station near Childress at US Highway 83 registered perennial flow. The annual streamflow increases from 27 cfs near Wayside to 113 cfs near Childress. One can assume that baseflow accounts for a portion of the streamflow near Childress. Between US Highway 83 and the Montage and Clay County-line, the Red River is a gaining reach. At the boundary of Regions II and III, the Red River has an annual discharge of 2,387 cfs.

Region III, the Western Gulf Coast.

After the Red River exits into Arkansas, the gaged flow is 12,520 cfs near the state line. Thus, the Red River gains about 10,000 cfs while it travels about 386 river miles of Region III. In Cooke County, the Red River is effluent. It was a similar situation in Grayson County before the creation of Lake Texoma in 1943. It is recorded that Lake Texoma recharges the sands of Trinity Group and has saturated about 80 ft of previously dry material (Baker et al, 1963). The well field of Sherman, about ten miles south of the lake, induces Lake Texoma water southward. The water level map constructed by Nordstrom (1982) indicates that the Red River loses water to the Woodbine aquifer. Downstream from Lake Texoma, it is believed that groundwater from the Blossom Sand and Nacatoch Sand may contribute baseflow to the Red River.

Table 3.2.1
Surface Water and Groundwater Interaction, Red River Basin.

Reach	Water Quality Segment	SW/GW Interaction	Aquifer	Probability / Comment
North Fork Red River	0224	Yes, gaining or losing.	Ogallala and Alluvium aquifers: Ogallala aquifer discharges along the base of the escarpment. The Alluvium aquifer also discharges along its outcrop. May be losing depending on seasons.	Medium: based on one stream gage station.
Salt Fork Red River	0222	Yes, gaining	Ogallala and Alluvium aquifers: Ogallala aquifer discharges along the base of the escarpment. The Alluvium aquifer also discharges along its outcrop. May be losing depending on seasons.	Medium: the river is perennial near Wellington

Table 3.2.1 (Continued)
Surface Water and Groundwater Interaction, Red River Basin.

Reach	Water Quality Segment	SW/GW Interaction	Aquifer	Probability / Comment
Prairie Dog Town Red River	0229, 0207	Yes, gaining	Ogallala and Alluvium aquifers: Ogallala aquifer discharges along the base of the escarpment. The Alluvium aquifer also discharges along its outcrop. May be losing depending on seasons.	Medium: City of Amarillo (and probably City of Canyon) disposes wastewater to 0229 segment, and streamflow gage measurements show downstream increases.
Red River	0206 & 0205	Yes, gaining	Alluvium aquifer: river gains over outcrops of Seymour/alluvial deposits and Permian water-bearing rocks.	High
Pease River	0220	Yes, losing before the confluence with the Middle Pease River, and gaining downstream.	Alluvium aquifer: river gains over outcrops of Seymour/alluvial deposits and Permian water-bearing rocks.	Medium
North Wichita River above Lake Kemp	0218	Yes, gaining	Alluvium aquifer: river gains over outcrops of Seymour/alluvial deposits and Permian water-bearing rocks. Salt seeps are also found.	High
South Wichita River above confluence with the North	0226	Yes, gaining	Alluvium aquifer: river gains over outcrops of Seymour/alluvial deposits and Permian water-bearing rocks. Salt seeps are also found.	High: based on stream gage measurements.
Little Wichita River above Lake Arrowhead	0213	Yes, losing	Alluvium aquifer: river gains over outcrops of Seymour/alluvial deposits and Permian water-bearing rocks. Salt seeps are also found. However, water table may be higher than the streambeds.	Medium: Lakes Kikapoo and Arrowhead build up head that induces recharge to groundwater. There is the possibility the recharge from Lake Kikapoo first becomes underflow and then surfaces in the streambed east of state highway 79.

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3.3 THE SULPHUR RIVER BASIN

3.3.1 Hydrologic Characteristics

The Sulphur River basin is bounded on the north by the Red River basin, on the west by the Trinity River basin, on the south by the Sabine and Cypress Creek basins, and on the east by the Texas-Arkansas state line. Fifteen-river miles southeast of the state-line, the Sulphur River joins the Red River east of Doddridge, Arkansas. Originating in the southeastern Fannin County, the North Sulphur River flows eastward, joining the South Sulphur River at the Red River and Lamar County-line. The South Sulphur River also originates in Fannin County, flows southeast past Commerce, Hunt County, then eastward to the confluence with the North Sulphur Creek. The Sulphur River exits the state line in Bowie County (Figure 3.3.1). The North Sulphur River flows 50 river miles;

the South Sulphur River, 60 miles; and the Sulphur River, 75 miles. White Oak Bayou is the major tributary. Total drainage area of the Sulphur River in Texas is 3,558 square miles (TWDB, 1977; Baker et al, 1963).

The Sulphur River basin is in the West Gulf Coast section of the Coastal Plains province. The Blackland Prairies in the western part of the basin is a level to rolling, well dissected prairie with moderate to rapid surface drainage. The East Texas Timberlands consist of nearly level to gently undulating, well dissected woodlands. Mean annual rainfall is 45 inches, ranging from 42 inches in the west to 49 inches in the east. Annual lake evaporation is 25 inches in the western part and 10 inches east near the state line. Because of the abundance of rainfall, irrigated land is limited in acreage (TWDB, 1968).

Regions

The Sulphur River basin is treated as on hydrologic unit. No regions are divided.

Major Aquifers

Two major aquifers supply large quantities of water in this basin. They are the Trinity Group in the western part of the basin and the Carrizo-Wilcox aquifer in the south and eastern parts of the basin (Figure 3.3.2). Four minor aquifers providing water to local areas are Woodbine, Blossom Sand, Nacatoch Sand, and Queen City aquifers (TDWB, 1977). The strata dip southward toward the Gulf. Along the channels, the alluvial and terrace deposits also yield water to shallow wells.

The Trinity aquifer is composed of the Paluxy Sand, Glen Rose Limestone, and Travis Peak Formation, in descending order. This aquifer outcrops west of the Sulphur River basin (Figure 3.3.2). Unless through upward leakage, the subsurface Trinity aquifer would provide little baseflow to the Sulphur River. The Woodbine Formation is younger than the Trinity and does not crop out in the Sulphur River basin. As with the Trinity aquifer, Woodbine aquifer contribution to the river is limited. Both Trinity and Woodbine aquifers are under confined conditions. However, the Luling-Mexia-Talco Fault, an arch that generally follows the South Sulphur and the Sulphur Rivers, may cause groundwater discharge into the rivers.

The Carrizo Sand and Wilcox Formation crop out in the south and eastern portion of the watershed. The sand layer in the Wilcox reaches 100 feet thick. The Carrizo and Wilcox are treated as one hydrologic unit. The maximum thickness of Carrizo-Wilcox aquifer is about 900 feet. Baker et al (1972) stated that at the outcrop area, the presence of numerous springs seeps and marshes suggests that recharge is being rejected. The Sulphur River, which flows diagonally across the outcrop into Lake Texarkana (Lake Wright Patman) is effluent. Because of this reason, Lake Texarkana will recharge the Carrizo-Wilcox aquifer where the reservoir stage is higher than the water table elevation.

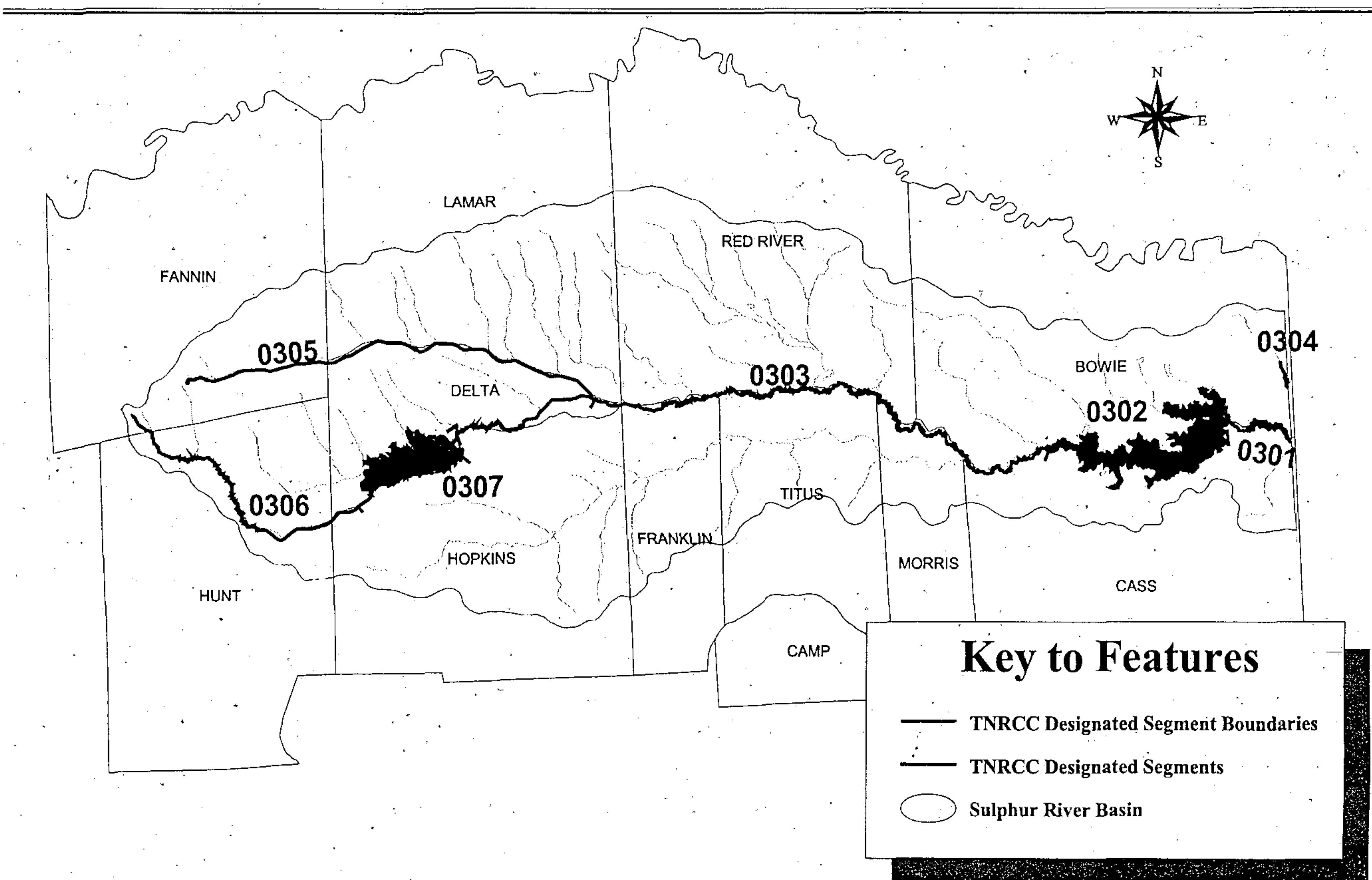

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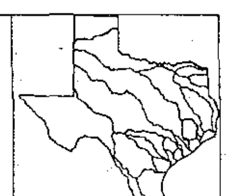
FIGURE 3.3.1

SULPHUR RIVER BASIN
TNRCC Designated Stream Segments



Minor Aquifers

The Blossom Sand aquifer occurs in a narrow band across the northern edge of the basin. Because the outcrop occurs at the watershed divide, the Blossom Sand may not contribute groundwater to the Sulphur River streamflow. Another secondary aquifer, the Nacatoch Sand, may have interaction with the Sulphur River because it crops out along the South Sulphur River as a southwest-northeast trending band across the basin. This sand is younger than the Blossom Sand but older than the Carrizo-Wilcox aquifer. Its thickness varies from 500 feet in Bowie County to the east and 350 feet in Delta and Hunt Counties to the west. The relationship between the Nacatoch Sand and the North and South Sulphur Rivers, which flow for several miles on the outcrop, is not known completely. However, based on a few water levels in the outcrop of the Nacatoch Sand, the streams are probably effluent (Baker et al, 1963).

The Queen City Sand crops out in a narrow band over the watershed divide south of Lake Wright Patman (Figure 3.3.2). It also dips southeastward away from the Sulphur River. The Queen City aquifer probably will not contribute baseflow to the Sulphur River. This geologic unit is younger than Carrizo Sand.

Although Baker et al (1963) and TWDB (1977) did not consider the Quaternary alluvium as a potential aquifer within the Sulphur River basin, the BEG (1979) atlas indicates that bands of alluvial and terrace deposits occur along the North, South, and the main Sulphur Rivers and White Oak Bayou. At some reaches, this band can reach a width of 5 miles. Baker et al (1963) stated that groundwater in the Quaternary alluvium is moving toward the Red River, immediately north of the Sulphur River basin; therefore, one can postulate that the alluvium groundwater of the Sulphur River basin would also flow toward the Sulphur River.

Reservoirs

Reservoir lakes along the trunk of the Sulphur River include Cooper Lake on the South Sulphur River with a storage capacity of 273,000-acre feet. Lake Wright Patman (capacity, 2,654,300 acre feet) is constructed on the Sulphur River southeast of Texarkana, Texas. A small, off channel reservoir, River Crest Lake, is on the north bank of the Sulphur River along Highway 271, which connects Paris and Mount Pleasant. Near Sulphur Springs, there is the Lake Sulphur Springs impound surface runoff in the main trunk of White Oak Bayou (BEG, 1979).

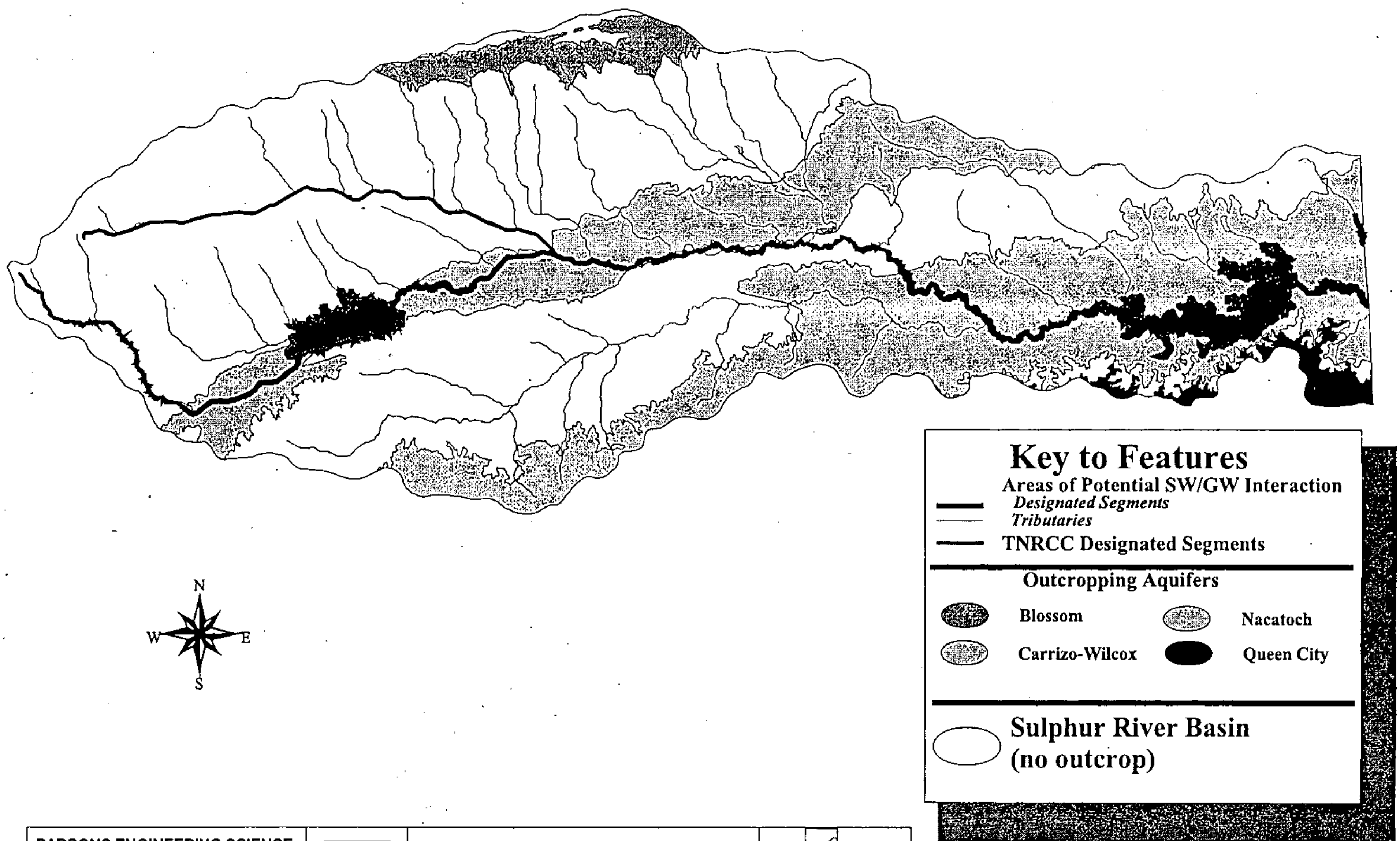


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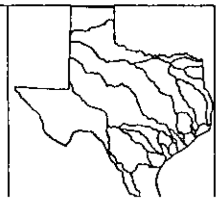
FIGURE 3.3.2

SULPHUR RIVER BASIN
Potential Surface Water/
Groundwater Interaction



3.3.2 Significance of The Interaction

According to the TNRCC (1996), the North Sulphur River receives drainage and wastewater discharge from cities of Paris and Honey Grove. Also the North Sulphur River flows over non-water bearing geologic formations; thus, the possibility for surface water and groundwater interaction is minimal. The only possible reach of interaction is immediately above the confluence with the South Sulphur River where the Nacatoch Sand aquifer outcrops. The alluvium deposits along the North Sulphur River may hold groundwater as bank storage and release back to river after a flood event. However, the magnitude of this bank storage to the streamflow of the North Sulphur River can not be ascertained due to data limitation.

The Nacatoch Sand crops along the South Sulphur River in Hunt County where the river turns from southeastern to northeastern. The channel reservoir, Cooper Lake, sits between Commerce and Cooper and also over the Nacatoch Sand; alluvium deposits may contribute perennial flow to the South Sulphur River below the dam.

Although a portion of the reach between the confluence of the South and North Sulphur Rivers and Lake Wright Patman is over a non-water-bearing geologic unit, the Navarro and Midway Clays, the upstream Nacatoch Sand should contribute baseflow to the Sulphur River.

As indicated by the Geologic Atlas of Texas, Texarkana Sheet, White Oak Bayou is a perennial stream below Lake Sulphur Springs. The USGS record (Water Resources Data, 1991) indicated that this bayou has a 41-year average discharge of 465 cfs near Talco in Titus County. This is equivalent to 12.78 inches of runoff annually for a watershed area of 494 square miles up-gradient from Talco. One would postulate that the perennial flow indicates groundwater contribution to the baseflow of White Oak Bayou. However, possible sources for the perennial condition would be 1) the seepage from Lake Sulphur Springs, 2) wastewater discharge from the city of Sulphur Springs, 3) evenly distributed rainfall throughout the year and low evaporation rate, and 4) the groundwater in the alluvium/terrace deposits and in the Carrizo-Wilcox aquifer. The Carrizo-Wilcox unit outcrops below Talco along the White Oak Bayou. The main trunk of the bayou flows over the Midway Clay and the Carrizo-Wilcox Sand. The Midway Clay is not an aquifer and therefore would not constitute surface water-groundwater interaction.

Table 3.3.1
Surface Water and Groundwater Interaction, Sulphur River Basin.

Reach	Water Quality Segment	SW/GW Interaction	Aquifer	Probability/ Comment
North Sulphur River	0305	No, but possible if minor water bearing units outcrop.	Trinity and Woodbine aquifers: River loses over non-water bearing geologic units.	Medium: Major aquifer formations do not outcrop and contributions, if any, are minimal. Possibility for interaction where Nacatoch Sand aquifer or Alluvial deposits outcrop.
South Sulphur River	0306	No	Trinity and Woodbine aquifers: River loses over non-water bearing geologic units.	Medium: Major aquifer formations do not outcrop and contributions, if any, are minimal. Possibility for interaction where Nacatoch Sand aquifer or Alluvial deposits outcrop.
Sulphur River	0303	Yes, gaining	Carrizo-Wilcox aquifer: outcrop area provides discharge to river. The upstream Nacatoch Sand may also contribute.	High where Midway Clay changes to Carrizo-Wilcox Sands near US Highway 82.
Lake Wright Patman	0302	Yes, losing	Carrizo-Wilcox aquifer: the lake is over the non-water bearing Navarro and Midway Clays.	High
Sulphur River	0301	Yes, gaining	Carrizo-Wilcox aquifer: Carrizo-Wilcox Sand outcrops, providing groundwater discharge to the river.	High: but streamflow may be significantly augmented by the seepage from Lake Sulphur Springs' dam.
White Oak Bayou above Talco	N/A	No, but possible of alluvial or terrace outcrops exist.	Carrizo-Wilcos aquifer: Bayou is over non-water bearing geologic unit Midway Clay.	Medium: possible interaction with alluvium and terrace deposits
White Oak Bayou below Talco	N/A	Yes, gaining	Carrizo-Wilcox aquifer: outcrop provides groundwater discharge to surface water.	High

3.3.3 References

Baker, E. T., A. T. Long, Jr., R. D. Reeves, and L. A, Wood, 1963. Reconnaissance Investigation of the Ground-Water Resources of the Red River, Sulphur River, and Cypress Creek Basins, Texas, Texas Water Development Board, July 1963.

BEG, 1979. Geologic Atlas of Texas, Texarkana Sheet, Bureau of Economic Geology, University of Texas at Austin.

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3.4 THE CYPRESS CREEK BASIN

3.4.1 Hydrologic Characteristics

The Cypress Creek basin is bounded on the north by the Sulphur River basin, on the west and south by the Sabine River basin, and on the east by the Texas state line (Figure 3.4.1). The headwaters of Big Cypress Creek form in the southeastern Hopkins County at a streambed elevation of 445 feet. Big Cypress Creek is joined from the north by Boggy Creek near Lone Star and becomes Big Cypress Bayou in Marion County. Lilly Creek and Caney Creek join to form Little Cypress Creek near Gilmer. About 20 river miles downstream from the confluence of Lilly and Caney Creeks, at the Harrison County line, Little Cypress Creek becomes Little Cypress Bayou. Little Cypress Bayou joins Big Cypress Bayou at elevation of about 170 feet and about 10 river miles above Caddo Lake and 12 miles from the state line. Big Cypress Bayou empties into the Red River near Shreveport, Louisiana. Total drainage area is 2,812 square miles in Texas (TWDB, 1977; Baker et al, 1963).

North of Caddo Lake (Figure 3.4.1) is Frazier Creek (WQ Segment 0407). Frazier Creek merges with Jims Bayou just west of the state line and discharges into James Bayou, an arm of Caddo Lake. Further north is Black Bayou (WQ Segment 0406). Black Bayou crosses the state line near the tri-state corner into Louisiana. The USGS converted annual runoff measured in the stream channels into inches per year (in/yr). This conversion can be used to gauge the portion of rainfall becoming runoff. For the gaging station that has a man-made reservoir, USGS did not convert discharge into in/yr. The average runoff for Frazier Creek near Linden is 12.7 in/yr; for Little Cypress Creek near Jefferson, 10.56 in/yr; for Black Cypress Bayou at Jefferson, 12.91 in/yr; and for Big Cypress Creek near Winnsboro, 12.91 in/yr (USGS, 1991).

The Cypress Creek basin is in the West Gulf Coast section of the Coastal Plains province. Most of the basin is a well dissected, undulating woodland. Mean annual rainfall is 45 inches, ranging from 42 inches in the west to 49 inches in the east. In general rainfall is plentiful and evenly distributed throughout the year. Annual net lake evaporation is 15 inches in the western part and 5 inches east near the state line. Because of the abundance of rainfall, irrigated land is limited in acreage (TWDB, 1968).

Regions

The Sulphur River basin is treated as a hydrologic unit. No regions are divided.

Aquifers

TDWB (1977) classified one major aquifer and one minor: the Carrizo-Wilcox aquifer and the Queen City aquifer, respectively (Figure 3.4.2). The Carrizo Sand crops out along the arch from Lake Wright Patman to the east to Lake Bob Sandlin in the west in Titus and Franklin Counties. Southeast of the Carrizo-Wilcox band is the outcrop of Reklaw Formation, Queen City Sand, Weches Formation, and Spartan Sand. Near Caddo Lake, the Wilcox geologic unit crops out (BEG, 1975, Broom, 1971); however, the TDWB 1971 report combined the Wilcox, Carrizo, Reklaw, and Queen City into the Cypress aquifer.

The Wilcox is about 300 feet thick in the areas of outcrop, and is normally about 450 feet thick elsewhere. Typically, the Wilcox is composed of interbedded sand, silt, clay, and lignite. Medium to fine quartz sand constitutes one-third to one-half of the unit. It yields 200 gpm in outcrop areas. (Broom, 1971). The Carrizo Sand overlies the Wilcox Formation unconformably. It consists of a fine to medium sand and a sequence of fine sand, silt, and clay near the top of the formation. The thickness of Carrizo Sand varies from 0 to 150 feet, and would yield 300 gpm to a well (Broom, 1971 and Baker et al., 1963).

The Reklaw Formation conformably overlies the Carrizo Sand. It crops out south and east of the Carrizo outcrop band near Lake Bob Sandlin. It also crops out in the southeastern portion of the basin. In fact, north of Marshall, Texas, both Little Cypress Creek and Big Cypress Bayou cut into the Reklaw Formation (BEG 1979 and 1975). The Reklaw is a clay unit but may contain sand and lignite locally. The Reklaw yields small quantity of water to domestic wells in Cass and Marion Counties (Broom, 1971).

The Queen City Sand has the most extensive outcrop area that occupies the middle of and about one-half of the watershed. It attains a maximum thickness of 400 feet. Up to 80 percent of the thickness is quartz sand. This sand is tapped mostly by domestic water well, but would also yield 200 gpm to a well. Overlying the Queen City Sand is the Weches Formation, mostly as scattered outliers on the high hills and ridges. The Weches reaches a maximum thickness of 60 feet and contains iron ore. It is not considered an aquifer. The Spartan Sand overlies the Weches Formation as erosional remnants on the higher ridges and hills. The Spartan Sand rarely reaches 50 feet thickness but locally contributes groundwater to domestic wells.

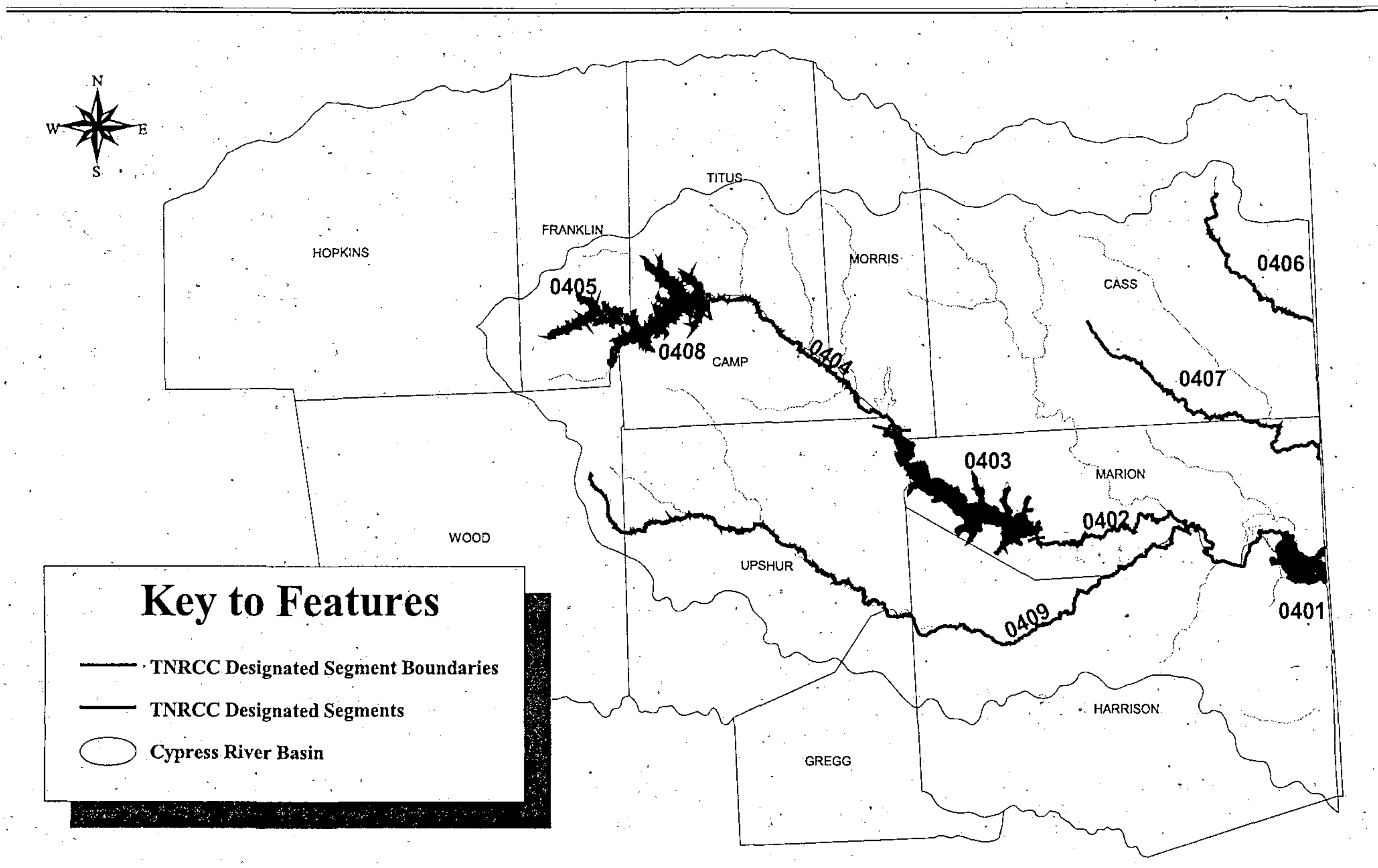

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FIGURE 3.4.1

CYPRESS RIVER BASIN
TNRCC Designated Stream segments

10 0 10 Kilometers

Source: TNRIS/TNRCC Water Resource Management Division

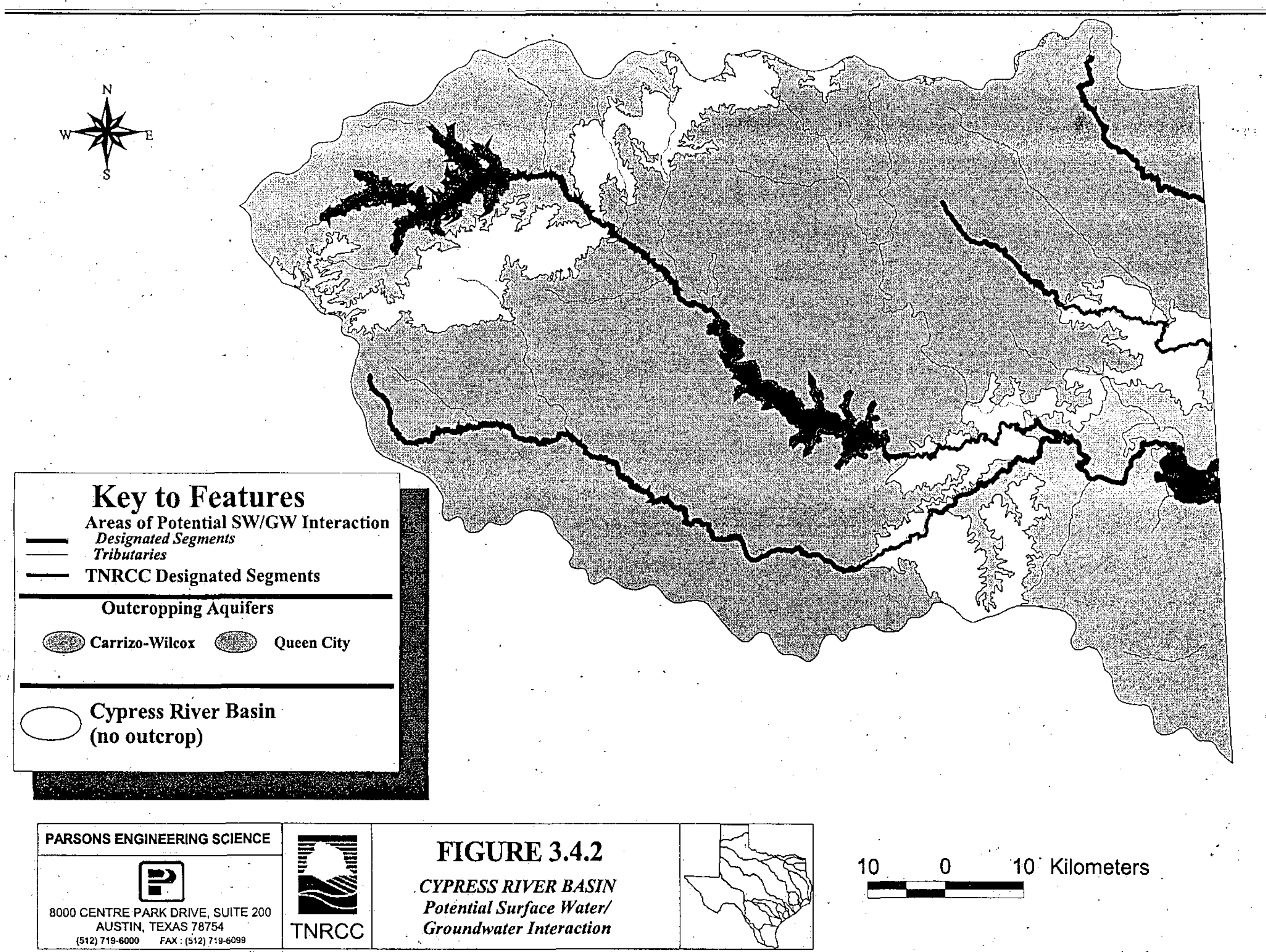

FIGURE 3.4.2

CYPRESS RIVER BASIN
Potential Surface Water/
Groundwater Interaction

The alluvium and terrace deposits occur along the channels of Big and Little Cypress Creeks (BEG 1975). As stated in Section 3.3, alluvium and terrace deposits may contribute baseflow to a stream. Broom (1971) stated that the alluvium deposits reach 25 feet thickness along Big Cypress Bayou and would yield small quantities of water to wells.

Reservoirs

There are five major reservoirs constructed along the trunk of Big Cypress Creek/Bayou. Lake Cypress Springs, Lake Monticello, and Lake Bob Sandlin (capacity, 251,000 acre feet) are in the headwaters. In the middle of the watershed is the Lake O' the Pines (capacity, 842,100 acre-feet). To the east, at the state line, is Caddo Lake, which is formed by the Caddo Dam in Louisiana.

3.4.2 Significance of The Interaction

Because the trunks of the Big and Little Cypress Bayou, Frazier Creek and Black Bayou cut into the outcrops of water-bearing units, there is the certainty of surface water and groundwater interaction. Broom (1971) estimated that the quantity of water being discharged to the streams as rejected recharge is significant in Cass and Marion Counties, probably equal to or greater than 8.5 million gallons per day (mgd) or about 13 cfs.

Heavy groundwater withdrawal in Cass County created cones of depression in Atlanta-Queen City and in the Rodessa Oil Field. This might prevent or reduce groundwater contribution to Black Bayou and Frazier Creek. However, it is not likely that this localized phenomenon would impact groundwater discharge to Big and Little Cypress Creeks.

Table 3.4.1
Surface Water and Groundwater Interaction, Cypress Creek Basin.

Reach	Water Quality Segment	SW/GW Interaction	Aquifer	Probability/ Comment
Big Cypress Creek above Lake Bob Sandlin dam	0405, 0408	Yes, gaining or losing	Carrizo-Wilcox and Cypress aquifers: The creek gains over the aquifer outcrops. Away from the lake, the stream may gain from groundwater; at the lake, the groundwater would gain from the lake.	High
Big Cypress Creek below Lake Bob Sandlin and above Caddo Lake	0404, 0403, & 0402	Yes, gaining or losing	Cypress aquifer: outcrop area of aquifer allows stream to gain from groundwater; but at Lake O' the Pines and Caddo Lake, surface water may recharge groundwater.	High
Little Cypress Creek	0409	Yes, gaining	Cypress aquifer: almost completely flows over aquifer outcrop.	High: based on USGS stream flow record.
Frazier Creek	0407	Yes, gaining or losing	Cypress aquifer: Creek flows over outcrops	High: based on USGS stream flow record in the Rodessa oil field in Cass County where County Highway 49 crosses the creek, the creek may lose water due to pumping from the oil field (Figure 4, Broom 1971).
Black Bayou	0406	Yes, losing	Cypress aquifer: Bayou is over outcrop area. However, municipal pumping may reduce groundwater contribution.	Medium: due to the pumping by cities of Atlanta and Queen City (Figure 4, Broom 1971)

3.4.3 References

Baker, E. T., A. T. Long, Jr., R. D. Reeves, and L. A, Wood, 1963. Reconnaissance Investigation of the Ground-Water Resources of the Red River, Sulphur River, and Cypress Creek Basins, Texas, Texas Water Development Board, July 1963.

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USGS, 1991. Water Resources Data, Texas, Water Year 1991, USGS Water-Data Report TX-91-1

3.5 THE SABINE RIVER BASIN

3.5.1 Hydrologic Characteristics

The Sabine River basin is bounded on the north by the Sulphur River and Cypress Creek basins, on the west and south by the Trinity and Neches River basins, and on the east by the Texas state line (Figure 3.5.1). The headwaters of the Sabine River are located in the vicinity of Greenville in Hunt County, Texas. The Sabine River flows to the south-southeast and forms the lower state boundary between Texas and Louisiana. The Sabine River eventually discharges into Sabine Lake, which then empties into the Gulf of Mexico. Larger tributaries, which drain portions of the basin, include Lake Fork Creek and Big Sandy Creek. Total drainage area is 2,812 square miles in Texas (TWDB, 1977).

The Sabine River basin is in the West Gulf Coast section of the Coastal Plains province. The upper portion of the basin is a well dissected, undulating woodland. Closer to the coast the basin transitions into coastal plain. Mean annual rainfall ranges from 44 inches in the upper headwaters of the basin to 54 inches where the Sabine River eventually discharges into Sabine Lake (TWC, 1963).

Aquifers

TDWB (1991) classified two major aquifers and three minor aquifers that crop out within the Sabine River Basin (Figure 3.5.2). The major aquifers are the Carrizo-Wilcox and the Gulf Coast; the minor aquifers include the Nacatoch Sand, Queen City, and Sparta.

The Carrizo-Wilcox aquifer crops out in a band orthogonal to the Sabine River immediately below Lake Tawakoni south about 20 miles to just below and including Lake Fork Reservoir WQ segment 0515. The Carrizo-Wilcox aquifer crops out again within the Sabine River basin near Lake Cherokee south of Longview, Texas. The outcrop extends south and east to the Texas-Louisiana border and Toledo Bend Reservoir.

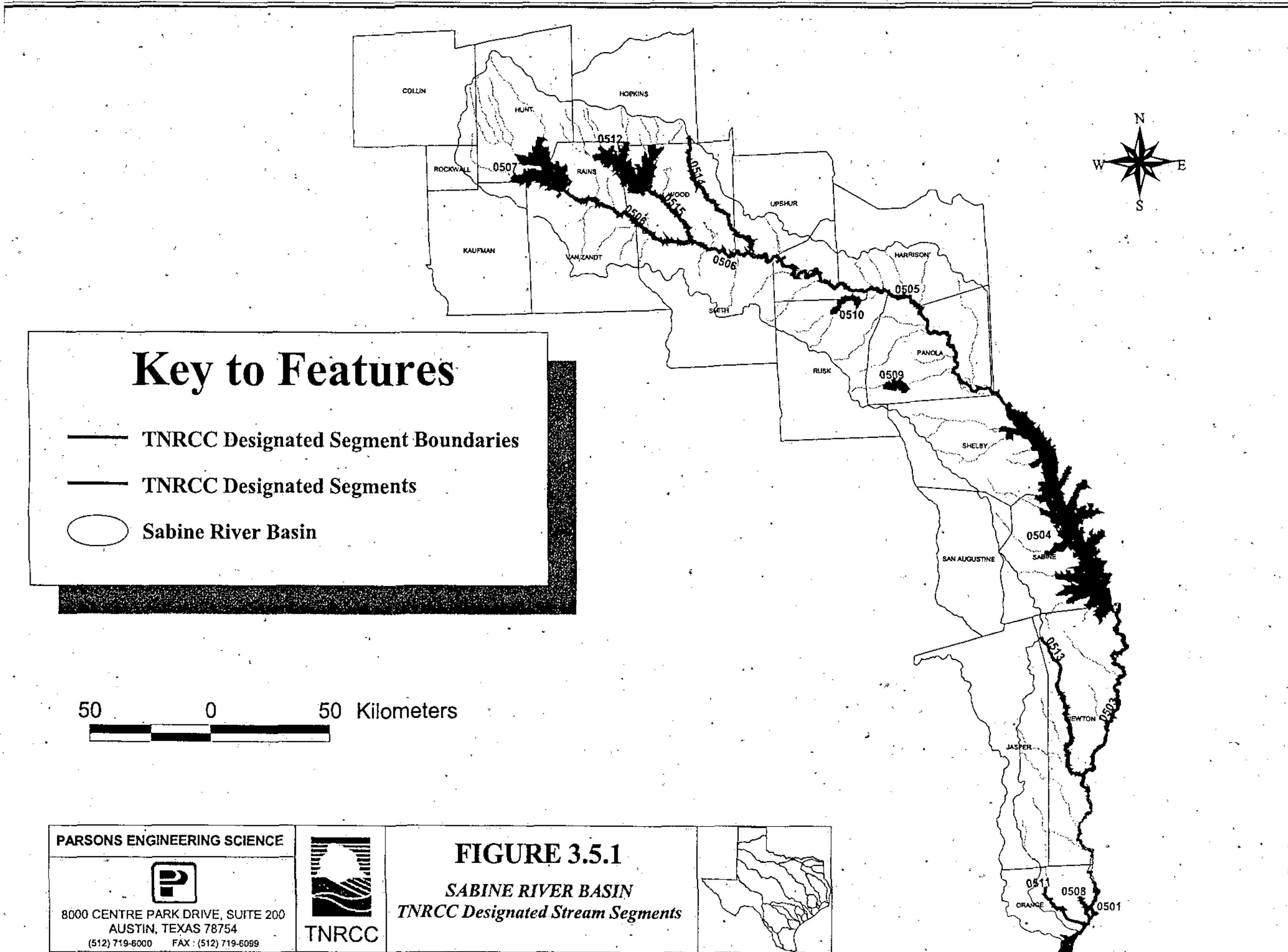

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FIGURE 3.5.1

SABINE RIVER BASIN
TNRCC Designated Stream Segments

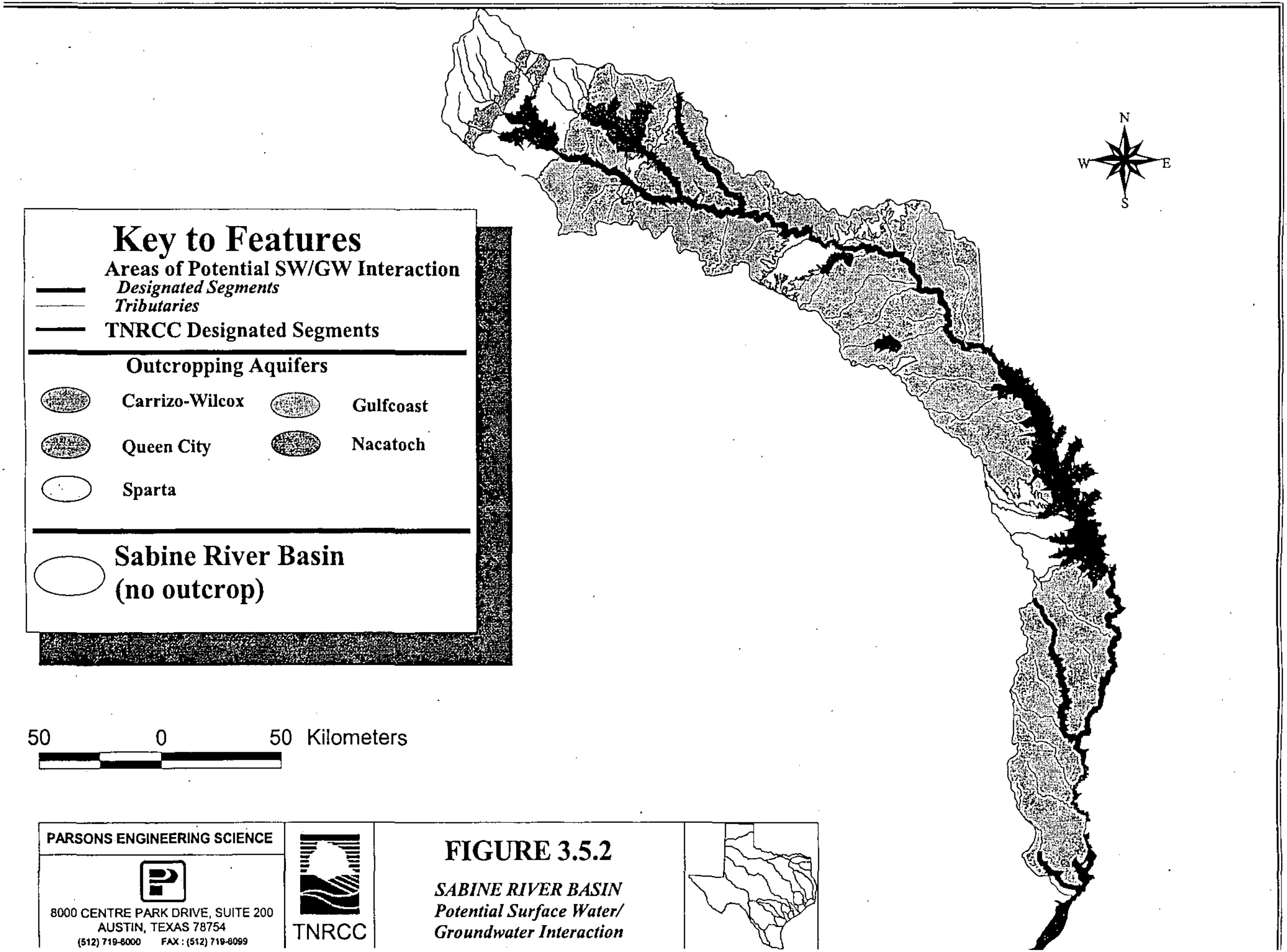

FIGURE 3.5.2

SABINE RIVER BASIN
Potential Surface Water/
Groundwater Interaction

The Wilcox Group consists of interbedded gravel, sand, clay, and shale, with lignite deposits in some areas. These rocks were deposited in river, delta, and shallow marine environments, with the more massive sands occurring in the river alluvium and delta parts of the system. In east Texas, the total thickness of the Wilcox varies from 0 to about 1,100 feet near the outcrop, but may thicken to well over 2,000 feet in the downdip portion. Since the deposition of the sand portion of the Wilcox Group was in river and delta environments, individual sand units are linear in nature following stream courses. The Wilcox is characterized by linear, northwest-southeast trending areas with not only higher percentages of sand, but with thicker individual sand bodies. The high producing wells completed in the Wilcox within the Sabine River basin are located in areas of thick sands (TWDB, 1991).

The Queen City is made up of sand interbedded with shale and sandy shale. The sands are generally fine grained. The total thickness of the Queen City ranges from 0 to about 600 feet. The net sand thickness varies from 25 to 85 percent and dips to the south and southeast toward the Gulf of Mexico at 60 to 70 feet per mile (TWDB, 1991).

The Sparta Formation consists of massive, poorly cemented sand in the lower portion, with thinner sands interbedded with clays and shale in the upper part. The thickness of the Sparta ranges from 0 to about 260 feet at the outcrop, but may increase to nearly 350 feet in some down-dip areas (TWDB, 1991).

The ultimate source of the groundwater within the Carrizo-Wilcox, Queen City, and Sparta aquifers in the Sabine River basin is rainfall on the outcrop, with significant portions coming from the areas where the runoff from this rainfall is concentrated, such as rivers and lakes. Recharge to these aquifers occurs mostly on outcrops, especially outcroping sandy portions of the formations. The outcrop areas in Panola, Shelby, Nacogdoches, and Rusk Counties provide much of the recharge. While some of the discharge continues through seeps and springs, especially on the outcrop, pumpage is by far the largest contributor to drainage of the aquifer (TWDB, 1991).

Recharge to the Sparta and Queen City aquifers occurs on the outcrop over their entire areal extent. Because of their large amount of outcrop and the gently rolling flat topography over most of it, and the relatively large amounts of rainfall, which occurs in the area, these two aquifers probably receive a maximum amount of recharge. While pumpage is significant in some parts of the basin, natural discharge through seeps and springs and downward into the underlying aquifers is probably a more important outlet for water from these aquifers (TWDB, 1991).

The Gulf Coast Aquifer System (GCAS) is the primary aquifer in the lower portion of the basin below Toledo Bend Reservoir. Since the Sabine River forms the boundary between Texas and Louisiana at the bottom half of the watershed, the areal extent of the GCAS recharge area in Texas is limited to the western side of the basin.

The principal formations of the GCAS in the northern third of the basin are the Catahoula, Oakville, and Lagarto. These formations yield moderate to large quantities of water to wells in the northern portion of the Sabine River basin.

The Goliad Sand, Willis Sand, and Lissie Formation are the local formations of the GCAS that outcrop in the central third of the Sabine River Basin. The Goliad Sand is comprised of bentonitic clay interbedded with reddish colored sand and gravel, which are cemented with lime. The Goliad ranges in thickness from 0 to 500 feet. The Willis Sand is dominantly a fine to coarse sand containing gravel, silt, and clay well mixed with the sand, or as lenses interbedded with the sand. The Willis Sand ranges in thickness from 0 to 400 feet. The Lissie Formation is composed mainly of beds and lenses of coarse to fine light-colored sand, grading into and interbedded with sandy clay, clay, and gravel. The Lissie Formation, along with the Goliad Sand and Willis Sand constitute the greatest source of groundwater throughout the region. The aquifer is recharged at the surface and the water moves downdip through the sand beds of the Lissie Formation for great distances from the outcrop. This is considered the only usable groundwater of sufficient quantity for municipal and industrial use in the region (TWC, 1963).

The Beaumont Clay is the principal formation of the GCAS in the southern third of the basin. The Beaumont Clay is principally a poorly bedded calcareous clay of various colors, containing thin stringers and beds of silt and fine sand. Wells tapping sand beds in the Beaumont Clay yield small to moderate amounts of water throughout the basin. Permeability of the Beaumont Clay is considered to be low. The upper part of the Beaumont Clay, which outcrops in the Sabine River Basin, fronts many lagoons and bays along the coast and extends inland adjacent to the major river valleys as alluvial plains. The formation here is composed of interbedded, unconsolidated, light-colored sands and clays and ranges in thickness from 0 to 200 feet (TWC, 1963).

The alluvium and terrace deposits occur along the channels of the Sabine Rivers (BEG, 1992). As stated in Section 3.3, alluvium and terrace deposits may contribute baseflow to a stream.

Regions

The Sabine River basin is treated as on hydrologic unit. No regions are divided.

Reservoirs

There are three major reservoirs constructed along the Sabine River. Lake Tawakoni (capacity, 936,000 acre-feet) and Lake Fork Reservoir (capacity, 675,800 acre-feet) are in the headwaters. Toledo Bend Reservoir is located in the middle of the watershed (capacity, 4,661,000 acre-feet).

3.5.2 Significance of the Interaction

Since the Carrizo Formation and the Wilcox Group outcrop over a large portion of the basin, there are several reaches along the Sabine River where interaction between the river and underlying aquifer could occur. The high permeability and sandy nature of these formations indicate that a high probability of interaction exists along these reaches. The Queen City Formation outcrop located between the two outcrops of the Carrizo-Wilcox also has a high probability of interaction between the river and the underlying aquifer.

The Nacatoch and Sparta outcrop areas are of very limited extent where the Sabine River bisects the outcrop. Even if the permeability were moderate to high at the outcrop, the percent lost or gained by the Sabine River as a results of interaction would be very small.

Table 3.5.1
Surface Water and Groundwater Interaction, Sabine River Basin.

Reach	Water Quality Segment	SW/GW Interaction	Aquifer	Probability/ Comment
Sabine River above confluence with Lake Fork Creek including Lake Tawakoni and Lake Fork Reservoir	0506 upper half, 0507, 0512, & 0515	Yes, losing or gaining	Nacatoch Sand and Carrizo-Wilcox aquifer: River is over aquifer outcrops.	High: upstream of Nocatoch Sand outcrop, Streams are losing. Nocatoch sans may contribute baseflow sand of Greenville. Lake Tawakoni is over Midway Clay. which is not an aquifer.
Sabine River below confluence with Lake Fork Creek and above Longveiw, Texas including Lake Fork Creek and Big Sandy Creek	0506 lower half & upper half of 0505	Yes, gaining	Queen City aquifer: River is over outcrop areas.	High: dam seepage from Lake Tawakoni may also contribute to baseflow.
Sabine River below Longview, Texas and above Toledo Bend Reservoir including the upper half of the reservoir	0510, 0509, & 0504	Yes, gaining	Carrizo-Wilcox aquifer: River is over aquifer outcrops.	High: stream is gaining but near the dam where the reservoir stage is higher than the water table, the reservoir may lose to groundwater.
Sabine River below Toledo Bend Reservoir to Sabine Lake	0513, 0503, 0501, 0508, & 0511	Yes, losing or gaining	Gulf Coast aquifer: system formations outcrop	Low to Medium: upstream ,the river may recharge the Gulf Coast aquifer; downstream the river may gain from the Gulf Coast aquifer

3.5.3 References

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TWC, 1963. Reconnaissance Investigation of the Ground-Water Resources of the Gulf Coast Region, Texas, Texas Water Commission, Bulletin 6305, June 1963.

TWDB, 1977. Continuing Water Resources Planning and Development for Texas.

TWDB, 1991. Evaluation of Ground-Water Resources in the Vicinity of the Cities of Henderson, Jacksonville, Kilgore, Lufkin, Nacogdoches, Rusk, and Tyler in East Texas, Texas Water Development Board, February,1991.

3.6 THE NECHES RIVER BASIN

3.6.1 Hydrologic Characteristics

The Neches River Basin is bounded on the east and north by the Sabine River Basin, on the west by the Trinity River Basin and on the south by the Neches-Trinity River Basin in east Texas (Figure 3.6.1). Three main tributaries of the Neches River are the Angelina River, Pine Island Bayou, and the Attoyac Bayou. The total drainage area of the basin is approximately 10,011 square miles and includes all or part of 21 counties (TWC, 1963). The basin altitudes range from sea level, at the river's mouth to about 600 feet above sea level in the upper reaches. Due to the basin's large areal extent, the Neches River Basin is divided into two regions.

Region I

Region I constitutes the upper watershed of the Neches River Basin. The total drainage area for the region is 7,006 square miles. The topography consists of rolling hills with heavily wooded forests. A flat flood plain occurs along the Neches River and its larger tributaries. The region exhibits a warm, humid climate with mean annual precipitation ranging from slightly less than 44 inches in the westernmost part of the region to about 52 inches in the southeastern part of the region (TWC, 1963).

Region II

Region II constitutes the lower drainage area of the Neches River Basin. The total drainage area for the region is 3,005 square miles. The topography consists of mostly hilly and heavily forests becoming relatively flat near the coast. The region exhibits a warm, humid climate with mean annual precipitation ranging from 52 to 56 inches (TWC,1963).

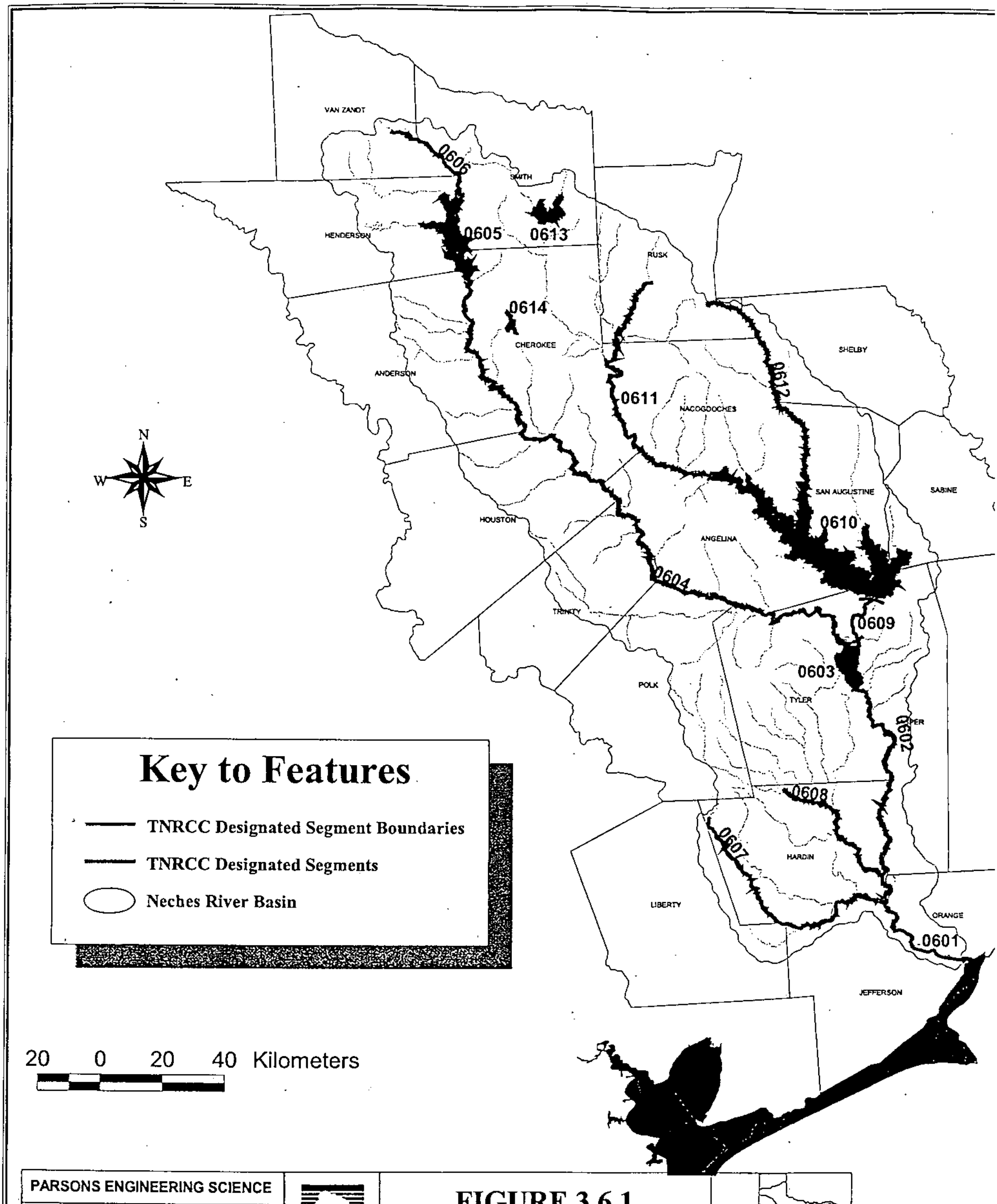

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FIGURE 3.6.1

NECHES RIVER BASIN
TNRCC Designated Stream Segments

Source: TNRIS/TNRCC Water Resource Management Divisic

The geology of the Neches River Basin consist of rocks and sediments from the Tertiary and Quaternary Periods (Figure 3.6.2). Throughout the basin the geologic formation dips generally south and southeast towards the Gulf Coast. The history of the Tertiary and Quaternary periods is a repetitive series of marine transgressions and regressions that deposited an alternating sequence of marine and continental sediments. The marine sediments are characterized by clay, shale, marl, and minor amounts of sand which account for poor groundwater bearing properties. The continental deposits consist mainly of sand with small amounts of shale, clay, and lignite which account for the major groundwater bearing units of the basin (TWC, 1963).

Major Aquifers

Four of the state's major aquifers, the Carrizo-Wilcox sands, the Catahoula-Oakville-Lagarto sands, the Goliad-Willis-Lissie sands, and the Beaumont sands, occur in the Neches River Basin. By definition the four major aquifers are subdivided into primary and secondary aquifers.

Primary Aquifers

The stratigraphic units which make up the primary aquifers consist of the Carrizo Formation and Wilcox Group (Carrizo-Wilcox aquifer) and the Catahoula Sandstone, Oakville Sandstone, Lagarto Clay, Goliad Sand, Willis Sand, Lissie Formation, and Beaumont Clay (Gulf Coast aquifer).

The Carrizo-Wilcox aquifer is the primary source of groundwater in Region I of the Neches River Basin (Figure 3.6.2). The aquifer is comprised of two geologic units: the Carrizo Formation and the Wilcox Group. Both units are predominantly comprised of sand, although the Wilcox Group does contain interbedded layers of shale, clay and minor amounts of lignite. The natural gradient of the aquifer is generally downdip. The Carrizo-Wilcox aquifer outcrops in the northern and northeastern portions of Region I. Recharge of the aquifer occurs in the outcrop areas. Groundwater is discharged naturally from the aquifer by springs and seeps (TWC, 1963).

The Gulf Coast aquifer is located within Region II of the Neches River Basin. Based on differing physical properties, the aquifer is made up of seven geological formations. The Gulf Coast aquifer is a complex network of sand, silts , and clays. The regional dip of the aquifer as well as the water quality may abruptly change in local areas due to the occurrence of salt domes. The aquifer generally outcrops over all of Region II. Recharge of the aquifer is generally very good due to large amounts of rainfall within the outcropped area (TWC, 1963).

Secondary Aquifers

The stratigraphic units, which make up the secondary aquifers, are the Queen City Formation (Queen City aquifer) and the Sparta Formation (Sparta aquifer).

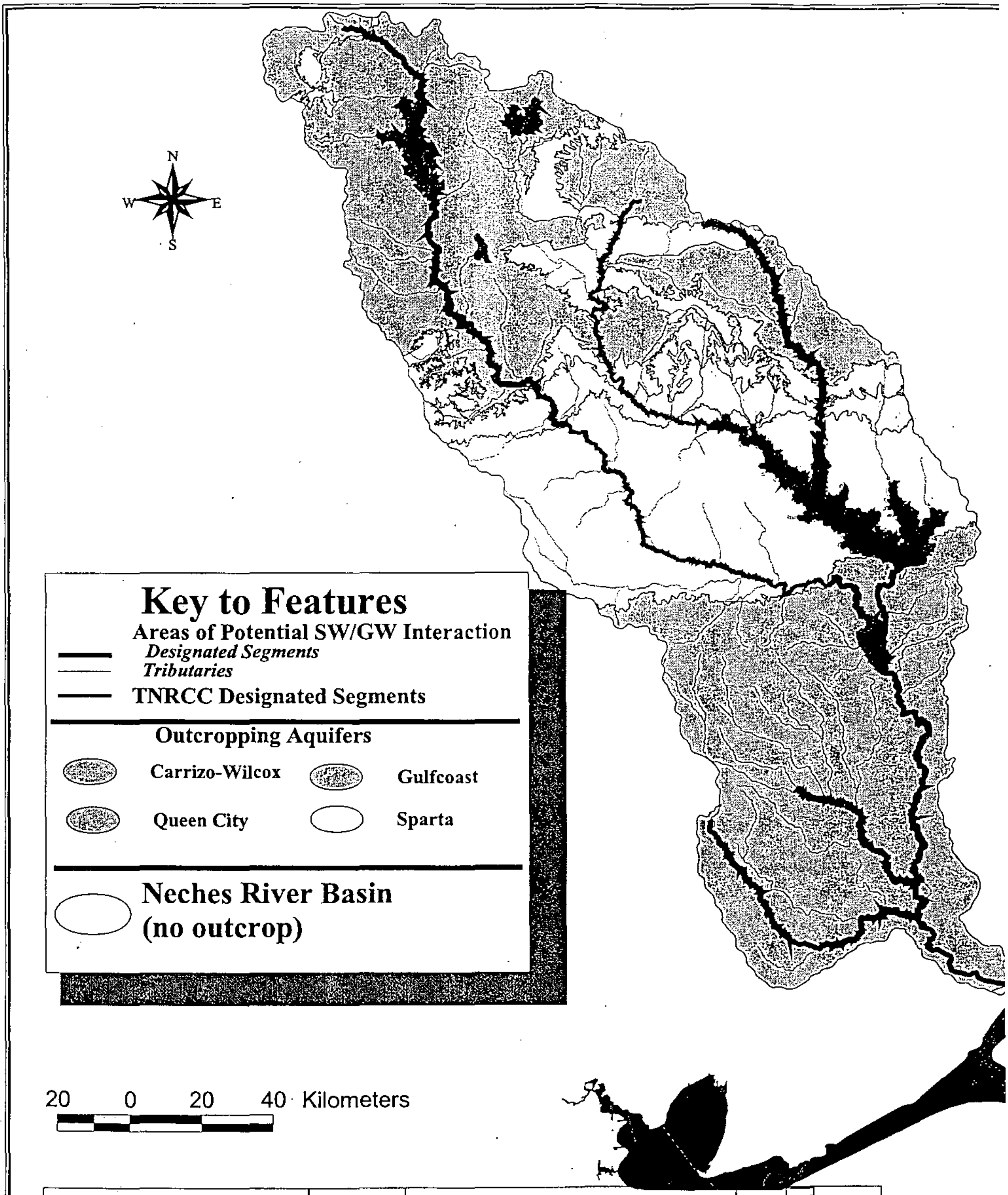

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FIGURE 3.6.2

NECHES RIVER BASIN
Potential Surface Water/
Groundwater Interaction

Source: TNRIS/TWDB GIS Planning Divisi

The Queens City aquifer is located within Region I of the Neches River Basin (Figure 3.6.2). The geology of the aquifer consists of sand with interbedded shale and sandy shale. Generally, the movement of groundwater within the Queens City aquifer is controlled by the elevation of the land surface and therefore moves from the basin boundaries toward the Neches River and its tributaries. The aquifer outcrops along the northern portion of Region I. Recharge of the aquifer is generally very good due to the amount of rainfall within the outcrop area (TWC, 1963).

The Sparta aquifer is located within Region I of the Neches River Basin. The geology of the aquifer consists of sand with interbedded layers of clay and shale. Groundwater within the Sparta aquifer moves south and southeast down dip of the formation. The aquifer outcrops across the middle part of Region I with an outlying outcrop along the northern portion of the region. Recharge of the aquifer occurs along the outcrop areas (TWC, 1963).

Minor Aquifers

In addition to the four major aquifers, two minor aquifers (Yegua Formation and the Jackson Group) exist within the Neches River Basin. The Yegua Formation exists only in Region I while the Jackson Group exists in both Region I and II. The Yegua Formation is located in the south central portion of Region I just north of the Jackson Group. Both minor aquifers produce minimal water and are used mainly for small industrial and municipal needs.

Reservoirs

There are nine (9) lakes within the Neches River Basin. Four of the lakes (Lake Athens, Lake Palestine, Lake Jacksonville, and BA Steinhagen) are located along the Neches River while five lakes (Lake Tyler, Lake Tyler East, Striker Creek Reservoir, Lake Nacogdoches, and Sam Rayburn Reservoir) are located along the Neches Rivers main tributaries (the Angelina River and Attoyac Bayou). Sam Rayburn Reservoir is the largest in size. The lakes within the Neches River Basin are used for flood control, recreation, and drinking water.

3.6.2 Significance of The Interaction

The Neches River Basin is comprised of the Neches River and its three main tributaries: the Angelina River, Pine Island Bayou, and Attoyac Bayou. Several reaches of the Neches River and its tributaries flow through or headwater within outcrop areas of both the major and minor aquifers in the basin. These reaches have a low to high potential to act as recharge zones for the aquifers. At the downstream parts of the aquifer outcrops, groundwater may contribute to streamflow where the stream fed cuts below the water table. The following table summarizes the surface water and groundwater interaction within the Neches River Basin.

Table 3.6.1
Surface Water and Groundwater Interaction, Neches River Basin.

Reach	Water Quality Segment	SW/GW Interaction	Aquifer	Probability/ Comment
Neches River, Lake Palestine and above	0605 & 0606	Yes, gaining	Carrizo-Wilcox and Queen City aquifers: units outcrop along these segments.	High: very sandy surface lithology within the Carrizo-Wilcox; large surface area with large surface water impoundment within the Queen City.
Neches River, BA Steinhagen to Lake Palestine	0604	Yes, gaining	Queen City, Sparta, Yegua, Jackson, and Gulf Coast aquifers: the formations outcrop along this reach.	Low to Medium: large outcrop area for Queen City, industrial and municipal pumping from Sparta, Yegua, and Jackson, sandy, flat outcrop for Gulf Coast.
Neches River, BA Steinhagen to Coast	0603, 0602, 0608, 0607, & 0601	Yes, gaining	Gulf Coast aquifer: outcrop in area of river.	High: large, sandy, flat surface area.
Angelina River	0611	No, but potential interaction near alluvial/terrace deposits along the river.	Pecan City and Carrizo-Wilcox aquifer outcrop North of Nacadoches.	Low: potential SW/GW interaction with alluvium and terrace deposits. Upper portion of the watershed, i.e., north of State Highway 21, is Queen City and Carrizo-Wilcox aquifer outcrops.
Attoyac Bayou	0612	Yes, gaining	Carrizo-Wilcox aquifer: outcrop.	High: large, sandy surface outcrop for Carrizo-Wilcox.
Sam Rayburn Reservoir to BA Steinhagen	0610 &0609	Yes, gaining	Yegua, Jackson, and Gulf Coast aquifers: units outcrop	High: large body of water that crosses several aquifer outcrop areas provides high potential for interaction.

Although there are interactions between the surface water and groundwater, physical properties such as evaporation, evapotranspiration, and rainfall will make it difficult to determine what the true interaction is between the surface water and groundwater.

3.6.3 References

TWC,1963: Reconnaissance Investigation of the Ground-Water Resources of the Neches River Basin, Texas, Texas Water Commission, Bulletin 6308, August 1963.

3.7 THE NECHES-TRINITY COASTAL BASIN

3.7.1 Hydrologic Characteristics

The Neches-Trinity Coastal Basin is bounded on the east and northeast by the Neches River Basin and on the west by the Trinity River Basin (Figure 3.7.1). The southern extent of the basin is bordered on the southwest by East Galveston Bay, on the south by the Gulf of Mexico, and on the southeast by Sabine Lake. Total drainage area of the basin is 769 square miles (TWDB, 1997). The basin is located in the West Gulf Coast section of the Coastal Plains province, which is predominantly a smooth, featureless, depositional plain rising from sea level to an altitude of about 200 feet. The basin exhibits a moist subhumid climate with a mean annual rainfall of about 52 inches (TWC, 1963).

The sediments that are exposed on the land surface and in the surface water channels throughout the Neches-Trinity Coastal Basin consist of beds, lenses, and stringers of gravel and coarse to fine sand interbedded with silt and clay beds and lenses. These sediments form a series of gently dipping truncated wedges, which thicken toward the coast, causing each wedge to have a slightly steeper dip than the overlying wedge. At depth, the lithology of these sediments become more dominantly silt and clay (TWC, 1963).

Due to the shallow depths to groundwater and the surficial exposure of sediments in the outcrop of the Gulf Coast Aquifer System (GCAS), it is expected that groundwater would generally discharge into drainage-ways and coastal embayment throughout the basin.

Regions

The Neches-Trinity Coastal Basin is treated as one hydrologic unit.

Major Aquifers

The Neches-Trinity Coastal Basin is underlain by the Gulf Coast Aquifer System (GCAS) as shown in Figure 3.7.2. The GCAS is a complex network of interbedded sediments which have been segregated into four generally recognized water producing formations. Aggregately, these formations form a large leaky artesian aquifer system, the GCAS, and that provides groundwater for agricultural, industrial, and municipal uses. The Lissie Formation and the Beaumont Clay are the two local formations that make up the uppermost portion of the GCAS that outcrop in the Neches-Trinity Coastal Basin. The Lissie Formation is composed mainly of beds and lenses of coarse to fine light-colored sand, grading into and interbedded with sandy clay, clay, and gravel. This formation, along with the Goliad Sand and Willis Sand constitute the greatest source of groundwater throughout the region. The aquifer is recharged at the surface and the water moves downdip through the sand beds of the Lissie Formation for great distances from the outcrop and constitutes the only usable groundwater of sufficient quantity for municipal and industrial use in the region (TWC, 1963).

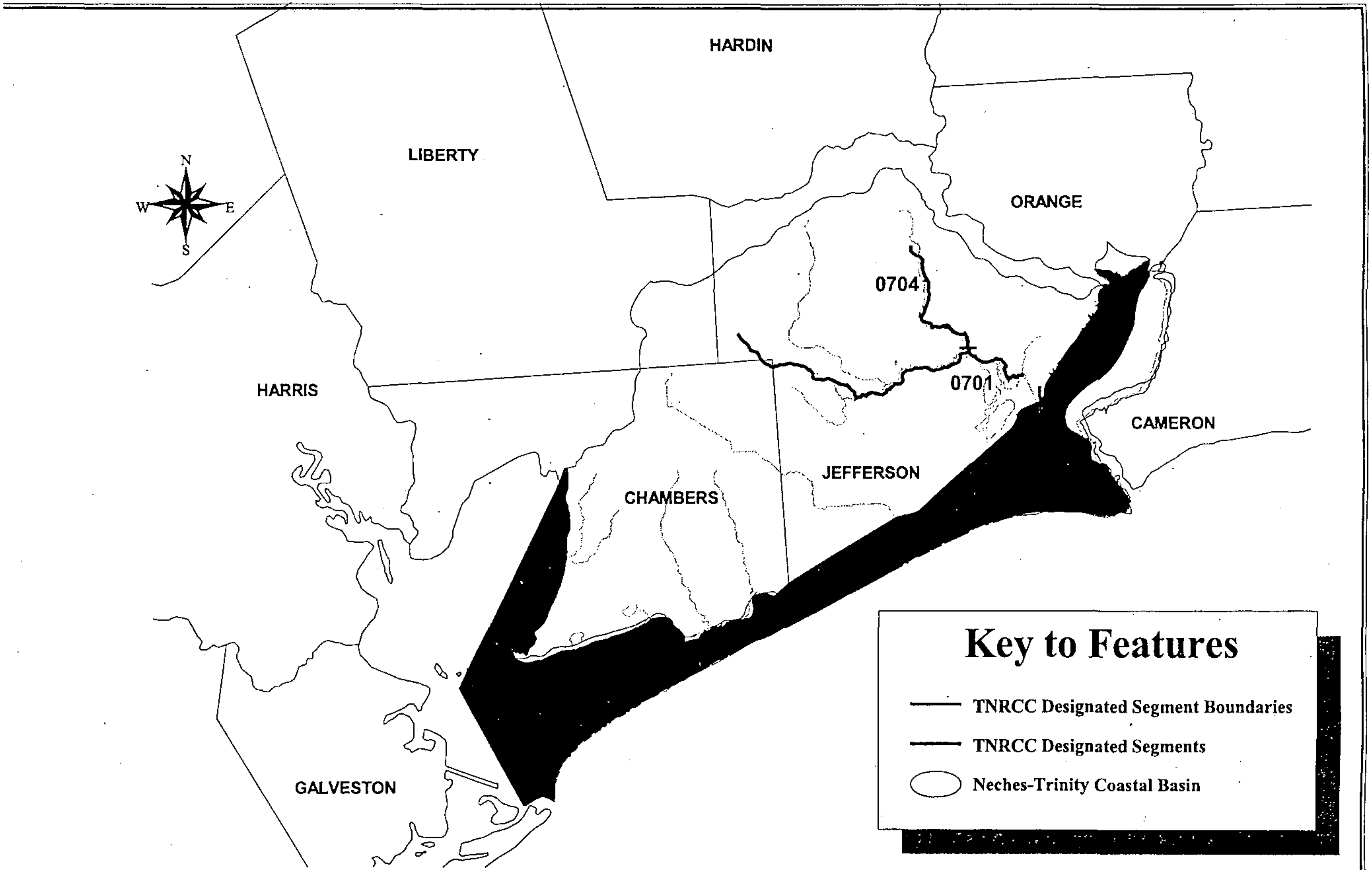

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FIGURE 3.7.1

NECHES-TRINITY COASTAL BASIN
TNRCC Designated Stream Segments

10 0 10 Kilometers

Source: TNRIS/TNRCC Water Resource Management Division

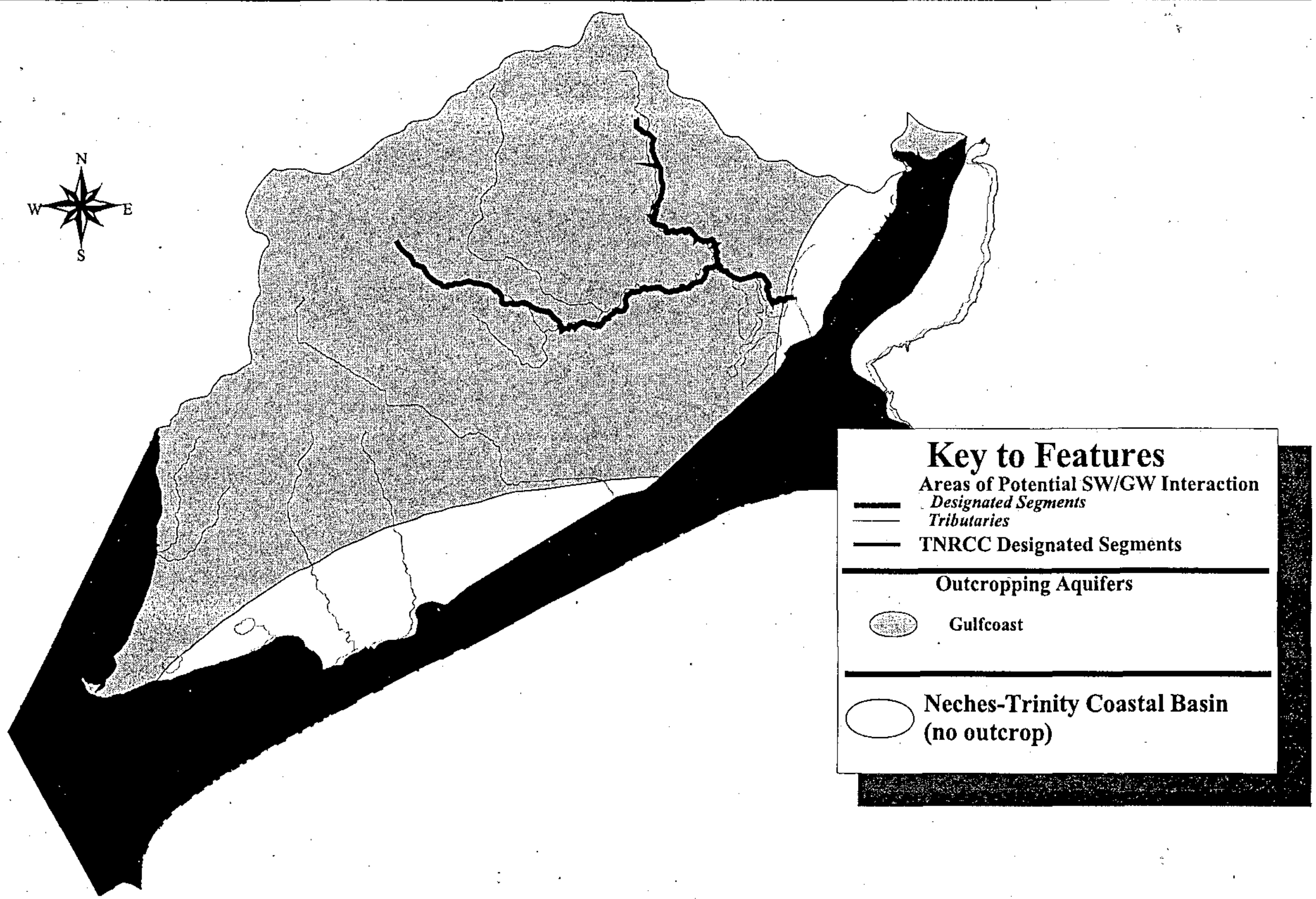

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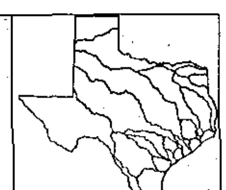
FIGURE 3.7.2

NECHES-TRINITY COASTAL BASIN
Potential Surface Water/ Groundwater Interaction



10 0 10 Kilometers

The Beaumont Clay is an aquifer in a large part of the region between the Nueces and Sabine Rivers. The Beaumont Clay is principally a poorly bedded calcareous clay of various colors, containing thin stringers and beds of silt and fine sand. Wells tapping sand beds in the Beaumont Clay yield small to moderate amounts of water throughout the basin. The upper part of the Beaumont Clay, which outcrops in the Neches-Trinity Coastal Basin, fronts many lagoons and bays along the coast and extends inland adjacent to the major river valleys as alluvial plains. The formation here is composed of interbedded, unconsolidated, light-colored sands and clays and ranges in thickness from 0 to 200 feet. (TWC, 1963)

Minor Aquifers

There are no minor aquifer systems in the Neches-Trinity Coastal Basin.

Reservoirs

There are no storage reservoirs in the Neches-Trinity Coastal Basin.

3.7.2 Significance of The Interaction

Over the low-lying, flat plain of the Neches-Trinity Coastal basin, water may be present year round in the Taylor Bayou, East Bay Bayou, Oyster Bayou and Double Bayou. Since the entire basin is underlain by the GCAS outcrop, groundwater should contribute to the streamflow as baseflow. However, the perennial condition is primarily the result of high annual rainfall, rice field returned flow, and tidal influences. As such, groundwater contribution to streamflow may be considered a low priority.

Table 3.7.1
Surface Water and Groundwater Interaction, Neches-Trinity Coastal Basin.

Reach	Water Quality Segment	SW/GW Interaction	Aquifer	Probability/ Comment
Taylor Bayou	0701	Yes, gaining	Gulf Coast aquifer: the entire watershed is on the aquifer outcrop.	Low: stream flow is mainly composed of irrigation return flow from rice fields, heavy rainfall and tidal influences.

3.7.3 References

TWC, 1963. Reconnaissance Investigation of the Ground-Water Resources of the Gulf Coast Region, Texas, Texas Water Commission, Bulletin 6305, June 1963.

TWDB, 1997. Water for Texas, Texas Water Development Board, August,1997.

3.8 THE TRINITY RIVER BASIN

3.8.1 Hydrologic Characteristics

The Trinity River Basin is bounded on the north by the Red River Basin, on the west by the Brazos River Basin, the Sulfur, Sabine, and Neches River Basins to the east, and on the south by the San Jacinto and Trinity-San Jacinto River Basins in east Texas (Figure 3.8.1). Main tributaries of the Trinity River are the Clear Fork, the West Fork, the Elm Fork, the East Fork, Chambers Creek, and Richland Creek. The total drainage area of the basin is approximately 17,930 square miles and includes all or part of 37 counties (TWC, 1963). The basin altitudes range from sea level, at the river mouth to about 1,200 feet above sea level in the upper reaches. Due to the basin's large areal extent, the Trinity River Basin was divided into three regions.

Region I

Region I constitutes the upper watershed of the Trinity River Basin to the confluence of Chambers Creek. The south regional boundary is the south county line of Henderson and Navarro Counties. The total drainage area for the region is 10,388 square miles. The topography consists of alternating treeless prairies and rolling timbered hills. The region exhibits a warm, humid climate with mean annual precipitation ranging from slightly less than 27 inches in the westernmost part of the region to about 41 inches in the eastern part of the region (TWC, 1963).

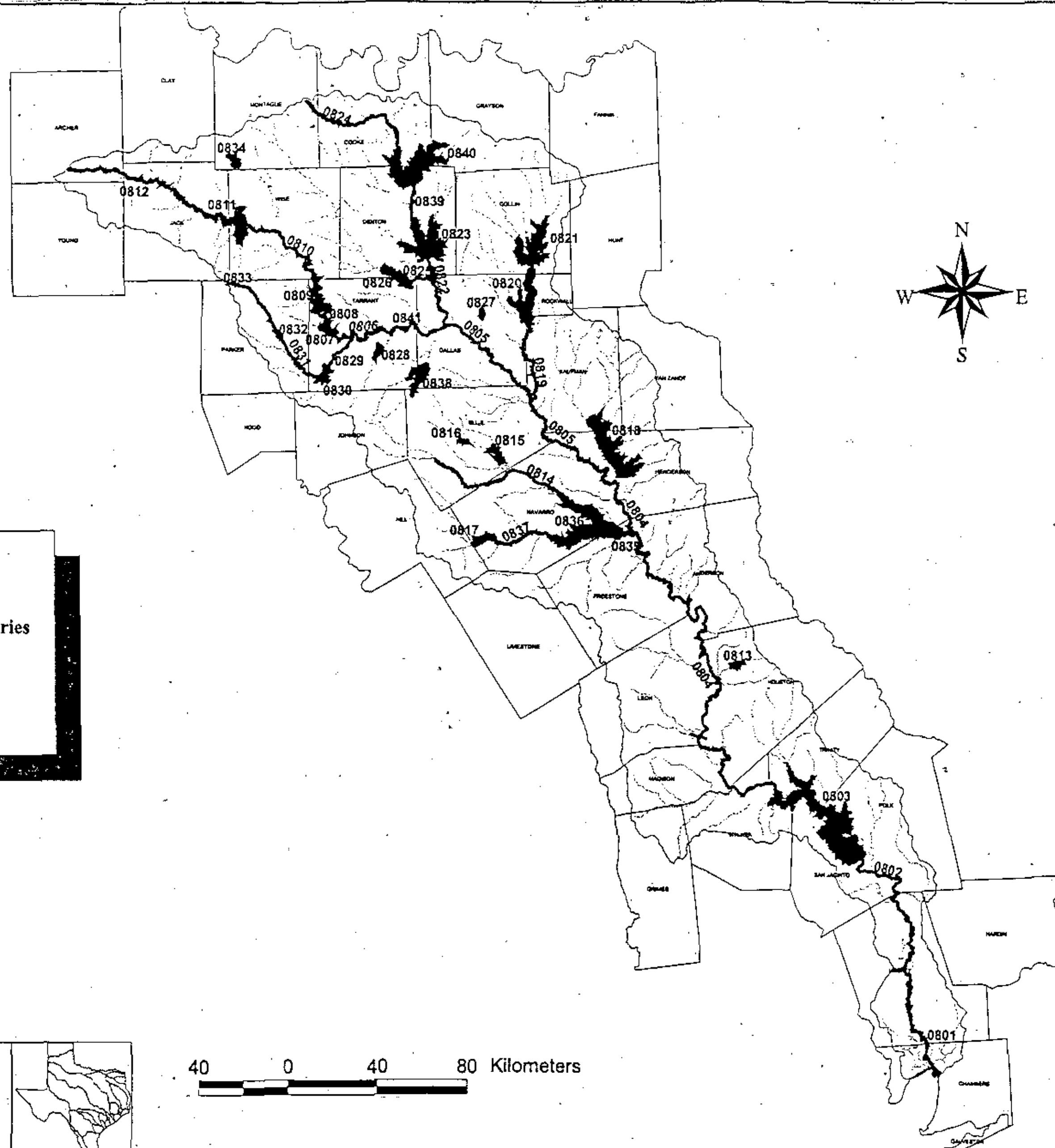
Region II

Region II constitutes the middle drainage area of the Trinity River Basin. The total drainage area for the region is 5,155 square miles. The topography consists of mostly flat to gently rolling hills. The eastern portion of the region consist of heavily timbered gently rolling hills. The region exhibits a warm, humid climate with mean annual precipitation ranging from 38 to 46 inches (TWC,1963).

Region III

Region III constitutes the lower drainage area of the Trinity River Basin from north county line of Trinity and San Jacinto Counties to Trinity Bay. The total drainage area for the region is 2,387 square miles. The topography consists of heavily timbered gently rolling hills becoming relatively flat near the coast. The region exhibits a warm, humid climate with mean annual precipitation ranging from 45 to 52 inches (TWC,1963).

The geology of the Trinity River Basin consist of rocks and sediments from the Pennsylvanian to the Quaternary Periods (Figure 3.8.2). Throughout the basin the geologic formation dips generally to the east with the exception of the Pennsylvanian-age deposits which dip to the northwest. The history of the basin has undergone three major geological events. During the Pennsylvanian time, the sea transgressions and regressions deposited alternating sequences of nearshore sands, and marine shales and limestones.



Key to Features

- TNRCC Designated Segment Boundaries
- TNRCC Designated Segments
- Trinity River Basin

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FIGURE 3.8.1

TRINITY RIVER BASIN
TNRCC Designated Stream Segments

Source: TNRIS/TNRCC Water Resource Management Division

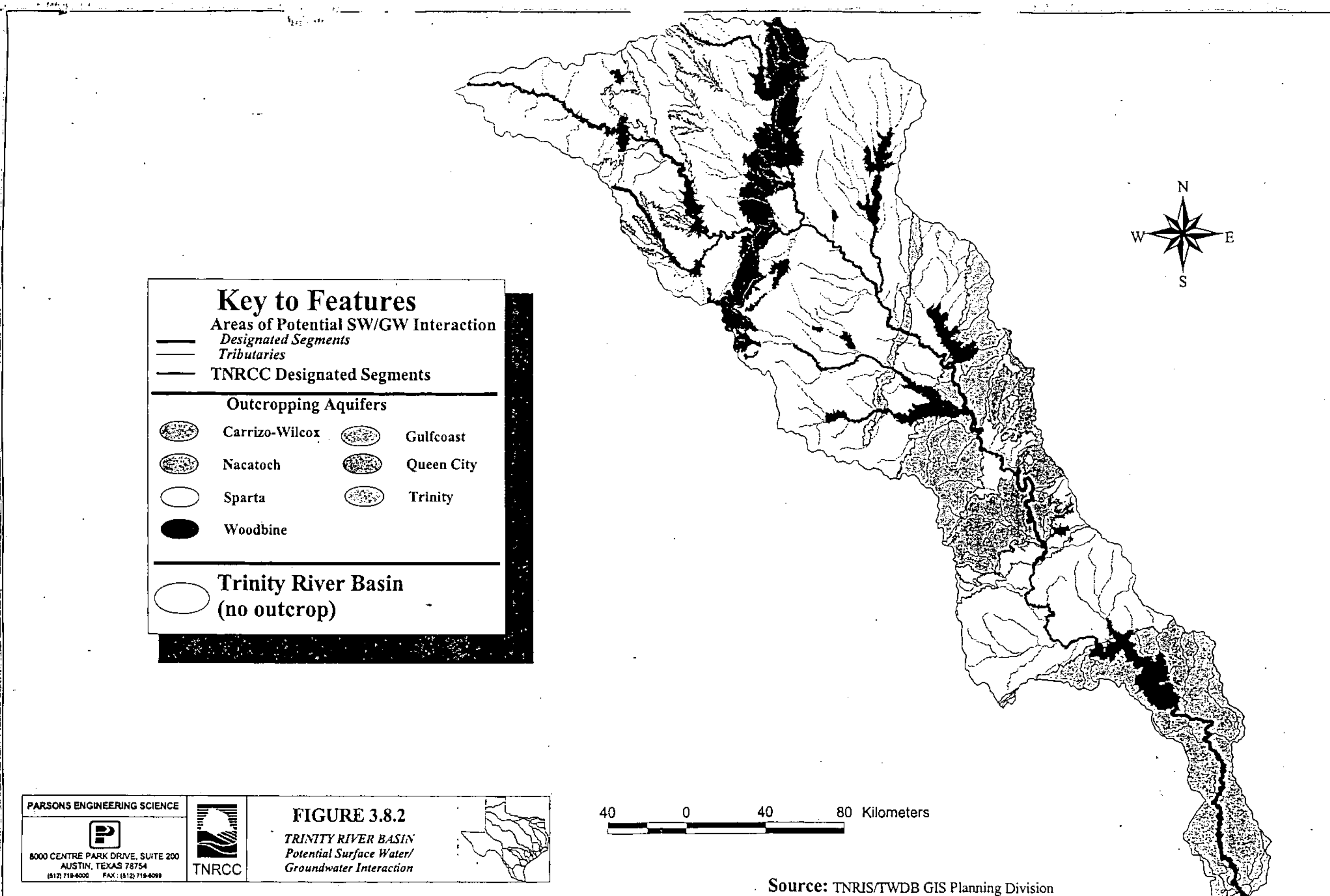

FIGURE 3.8.2

TRINITY RIVER BASIN
Potential Surface Water/ Groundwater Interaction

Following the Pennsylvanian deposits, uplifting occurred causing a regional northwest dip. Erosion occurred allowing sediment from the Cretaceous Period to be deposited. The Cretaceous deposits followed a similar pattern as in the Pennsylvanian time. Following the Cretaceous deposits, another uplifting event occurred causing a regional dip to the east.

Erosion again occurred allowing deposits from the Tertiary and Quaternary periods to be laid. The history of the Tertiary and Quaternary periods is a repetitive series of marine transgressions and regressions therefore depositing an alternating sequence of marine and continental sediments. The marine sediments are characterized by clay, shale, marl, and minor amounts of sand which account for poor groundwater bearing properties. The continental deposits consist mainly of sand with small amounts of shale, clay, and lignite; these deposits are the major groundwater bearing units of the basin (TWC, 1963).

Major Aquifers

The stratigraphic units which make up the primary aquifers consist of the Travis Peak Formation, Glen Rose Formation, and the Paluxy Formation (Trinity aquifer), Carrizo Formation and Wilcox Group (Carrizo-Wilcox aquifer), Sparta Formation (Sparta aquifer), and the Catahoula Sandstone, Oakville Sandstone, Lagarto Clay, Goliad Sand, Willis Sand, Lissie Formation, and Beaumont Clay (Gulf Coast aquifer).

The Trinity Group aquifer is the primary aquifer in Region I of the Trinity River Basin (Figure 3.8.2). The aquifer is comprised of three geologic units. The outcrop of the Trinity Group aquifer is considered undifferentiated due to the transitional irregularities of the Travis Peak, Glen Rose, and Paluxy Formations. The Travis Peak and Paluxy Formations are primarily fine-grained sand with interfingering of clay, shale, and gravel. The Glen Rose Formation consists predominantly of limestone making the Trinity Group aquifer hydraulically separated downdip. The natural gradient flows generally downdip. The undifferentiated outcrop is located in the upper reaches of Region I south of Bridgeport Reservoir in Montage, Parker, and Wise Counties. The outcrop is in a region of sandy, rolling hills with natural growth mostly post oak and soils that are fairly permeable (TWC, 1963).

The Carrizo-Wilcox aquifer is the primary source of groundwater in Region II of the Trinity River Basin. The aquifer is comprised of two geologic units: the Carrizo Formation and the Wilcox Group. Both units are predominantly comprised of sand, although the Wilcox Group does contain interbedded layers of shale, clay and minor amounts of lignite. The natural gradient of the aquifer is generally downdip. The Carrizo-Wilcox aquifer outcrops in the north central portions of Region II in Firestone and Henderson Counties including portions of Navarro and Anderson Counties. Recharge of the aquifer occurs in the outcrop areas where the surface soils consist of loose sandy soils timbered with oak trees. Groundwater is discharged naturally from the aquifer by springs and seeps (TWC, 1963).

The Gulf Coast aquifer is located within Region III of the Trinity River Basin. The aquifer is made up of seven geological formations each of which are based on its physical properties. The Gulf Coast aquifer is a complex network of sand, silts , and clays. The regional dip of the aquifer as well as the water quality may be abruptly changed in local areas due to the occurrence of salt domes. The aquifer generally outcrops over all of Region III. Recharge of the aquifer is generally very good due to large amounts of rainfall within the outcropped area (TWC, 1963).

Minor Aquifers

The stratigraphic units, which make up the secondary aquifers are the Woodbine Group (Woodbine aquifer), the Queen City Formation (Queen City aquifer) and the Sparta Sand aquifer.

The Woodbine aquifer is located within Region I of the Trinity River Basin (Figure 3.8.1). The geology of the aquifer consists of interbedded sand and sandstone with laminated clay. The sands of the aquifer range from loose to consolidated and represent approximately 50 percent of the of the formation's thickness. The natural gradient of the aquifer flows down dip to the southeast. The aquifer outcrops along the middle portion of Region I and east of the Trinity aquifer outcrop. The Woodbine outcrop runs along a north-south band of Cooke, Denton, and Tarrant Counties. The surface soils within the outcrop area are sandy and are fairly permeable (TWC, 1963).

The Queens City aquifer is located within Region II of the Trinity River Basin (Figure 3.8.1). The geology of the aquifer consists of sand with interbedded shale and sandy shale. Generally, the movement of groundwater within the Queens City aquifer is controlled by the elevation of the land surface and therefore moves from the basin boundaries toward the Trinity River and its tributaries. The aquifer outcrops along the middle portion of Region II. The outcrop area consists of shale that grades to a loose sand. Recharge of the aquifer is generally very good within the sandy unit due to its permeable characteristics and the amount of rainfall within the area (TWC, 1963).

The Sparta aquifer is located within the southern reaches of Region II of the Trinity River Basin. The geology of the aquifer consists of sand with interbedded layers of clay and shale. Groundwater within the Sparta aquifer moves south and southeast down dip of the formation. The aquifer outcrops in a narrow path across the south central part of Region II. Recharge of the aquifer occurs along the loose sandy soil outcrop area. Groundwater is discharged naturally from the aquifer by springs and seeps (TWC, 1963).

Minor Aquifers

In addition to the six major aquifers, five minor aquifers (Nacatoch Formation, Yegua Formation, Cook Mountain Formation, Jackson Group, and the Alluvium) exist within the Trinity River Basin. The Nacatoch Formation is present in both Regions I and II, but only considered an aquifer within Region II (Figure 3.8.2). The Cook Mountain, Yegua and Jackson Formations exist in Regions II in thin (approximately 5 miles) sections along the southern portion of the region. All three formations have small narrow outcrops and have little effect within the Trinity River Basin. Alluvial deposits along the Trinity River and its tributaries furnish water for small industries, livestock, and domestic purposes.

Reservoirs

There are twenty (20) lakes within the Trinity River Basin. Four of the lakes (Bridgeport Reservoir, Eagle Mountain Reservoir, Cedar Creek Reservoir, and Lake Livingston) are located along the Trinity River while the remaining lie along tributaries. The lakes within the Trinity River Basin are used for flood control, recreation, and drinking water.

3.8.2 Significance of The Interaction

The Trinity River Basin is comprised of the Trinity River and its six main tributaries: the Clear Fork, the West Fork, the Elm Fork, the East, Chambers Creek, and Richland Creek. Several reaches of the Trinity River and its tributaries flow through or headwater within outcrop areas of both the major and minor aquifers in the basin. These reaches have a low to high potential to act as recharge zones for the aquifers. Resources available for review were inconclusive as to whether any portion of the basin could provide a significant gain to the river system. The following table summarizes the surface water and groundwater interaction within the Trinity River Basin.

Table 3.8.1
Surface Water and Groundwater Interaction, Trinity River Basin.

Reach	Water Quality Segment	SW/GW Interaction	Aquifer	Probability/ Comment
Trinity River, Bridgeport Reservoir and above	0812, 0811, & 0834	No	Over non-aquifer outcrop area.	Low, area of Pennsylvanian age sediment
Trinity River, Fork of Clear Fork of Trinity River to Bridgeport Reservoir	0807, 0808, 0809, & 0810	Yes, gaining or losing	Trinity aquifer: outcrop area provides interaction potential.	High: large outcrop area for Trinity, and large surface bodies of water present.

Table 3.8.1 (Continued)
Surface Water and Groundwater Interaction, Trinity River Basin.

Reach	Water Quality Segment	SW/GW Interaction	Aquifer	Probability/ Comment
Trinity River, Cedar Creek Reservoir to the Clear Fork of Trinity River	0805, 0841, & 0806	Yes, losing and gaining	Woodbine aquifer and Nacatoch Formation: outcrops provide interaction potential.	Medium: narrow outcrop, but surface lithology suitable for aquifer recharge.
Trinity River, Coast up to Cedar Creek Reservoir	0801, 0802, 0803, 0813, 0804 & 0818	Yes, gaining and losing	Carrizo-Wilcox, Queen City, Sparta, and Gulf Coast aquifers: outcrops along these segments.	High, large outcrop areas are suitable for recharge near large surface water bodies. Losing at upstream portion of the outcrop and the lower portion of reservoir.
Elm Fork of the Trinity River	0822, 0825, 0826, 0823, 0839, 0840, & 0824	Yes, gaining	Woodbine aquifer: outcrops along these segments.	High: long, narrow, sandy surface outcrop and large bodies of water within outcrop area
Clear Fork of the Trinity River	0829, 0830,0831, 0832, & 0833	Yes, possible gaining during certain times of the year	Trinity Group: outcrops are along the river.	High: headwaters within the outcrop area, suitable lithology for recharge
East Fork of the Trinity River	0819, 0820, & 0821	No, but possible interaction along alluvial deposits.	Over non-outcrop areas.	Low to medium: possible recharge to alluvium deposits due to large bodies of water.
Chambers Creek and Richland Creek, from above Richland-Chambers Reservoir to headwaters	0814, 0815, 0816, 0837, & 0817	No, but possible along sands or alluvial deposits.	Nacatoch Formation: creeks are over thin-outcrop area.	Low to moderate: possible recharge to Nacatoch and alluvium deposits due to bodies of water.
Chambers Creek and Richland Creek, from Trinity River through Richland-Chambers Reservoir	0835 & 0836	Yes, gaining	Carrizo-Wilcox aquifer: outcrop provides potential for interaction.	High: large outcrop areas which are suitable for recharge, large bodies of water are within outcrop areas.
Misc. Reaches	0828, 0838, & 0827	No, but possible interaction along alluvial deposits.	Over non-outcrop areas	Low: possible recharge to alluvium deposits

3.8.3 References

TWC,1963. Reconnaissance Investigation of the Ground-Water Resources of the Trinity River Basin, Texas, Texas Water Commission, Bulletin 6309, September 1963.

3.9 THE TRINITY-SAN JACINTO COASTAL BASIN

3.9.1 Hydrologic Characteristics

The Trinity-San Jacinto Coastal Basin is bounded on the east by the Trinity River Basin and on the west by the San Jacinto River Basin (Figure 3.9.1). The southern extent of the basin is bordered by Galveston Bay. Total drainage area of the basin is 247 square miles (TWDB, 1997). The basin is located in the West Gulf Coast section of the Coastal Plains province, which is predominantly a smooth, featureless, depositional plain rising from sea level to an altitude of about 200 feet. The basin exhibits a moist subhumid climate with a mean annual rainfall of about 48 inches (TWC, 1963).

The sediments that are exposed on the land surface and in the surface water channels throughout the Trinity-San Jacinto Coastal Basin consist of beds, lenses, and stringers of gravel and coarse to fine sand interbedded with silt and clay beds and lenses. These sediments form a series of gently dipping truncated wedges which thicken toward the coast, causing each wedge to have a slightly steeper dip than the overlying wedge. At depth, the lithology of these sediments become more dominantly silt and clay (TWC, 1963).

Due to the shallow depths to groundwater and the surficial exposure of sediments in the outcrop of the Gulf Coast Aquifer System (GCAS), it is expected that groundwater would generally discharge into drainage-ways and coastal embayment throughout the basin.

Regions

The Trinity-San Jacinto Coastal Basin is treated as one hydrologic unit.

Major Aquifers

The Trinity-San Jacinto Coastal Basin is underlain by the Gulf Coast Aquifer System (GCAS) as shown in Figure 3.9.2. The GCAS is a complex network of interbedded sediments which have been segregated into four generally recognized water producing formations. Aggregately, these formations form a large leaky artesian aquifer system, the GCAS, that provides groundwater for agricultural, industrial, and municipal uses. The Lissie Formation and the Beaumont Clay are the two local formation that make up the uppermost portion of the GCAS that outcrop in the Trinity-San Jacinto Coastal Basin. The Lissie Formation is composed mainly of beds and lenses of coarse to fine light-colored sand, grading into and interbedded with sandy clay, clay, and gravel. The Lissie Formation, along with the Goliad Sand and Willis Sand constitute the greatest source of groundwater throughout the basin. The aquifer is recharged at the surface and the water moves downdip through the sand beds of the Lissie Formation for great distances from the outcrop and constitutes the only usable groundwater of sufficient quantity for municipal and industrial use in the region (TWC, 1963).

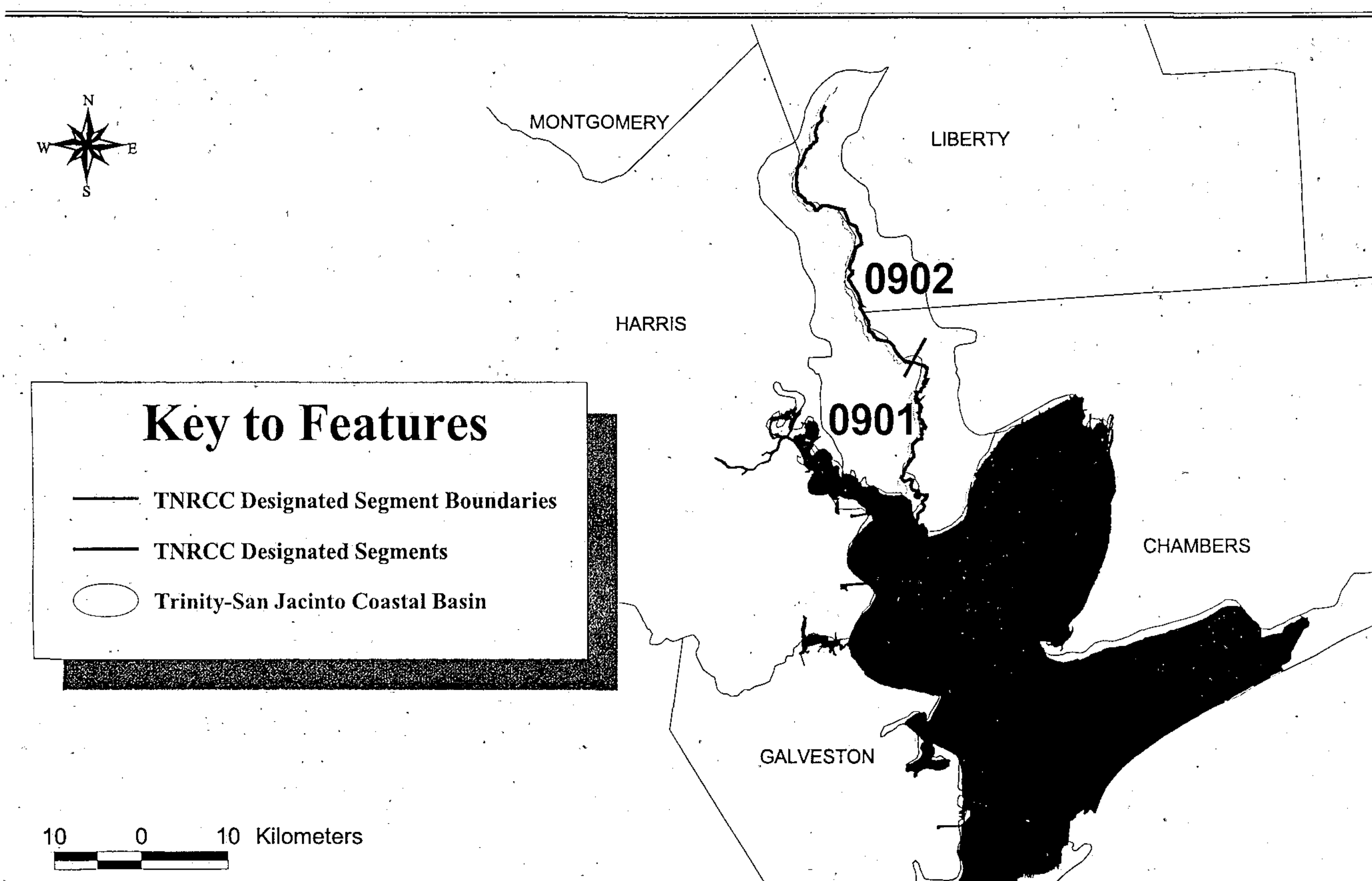

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FIGURE 3.9.1

TRINITY - SAN JACINTO COASTAL BASIN
TNRCC Designated Stream Segments

Source: TNRIS/TNRCC

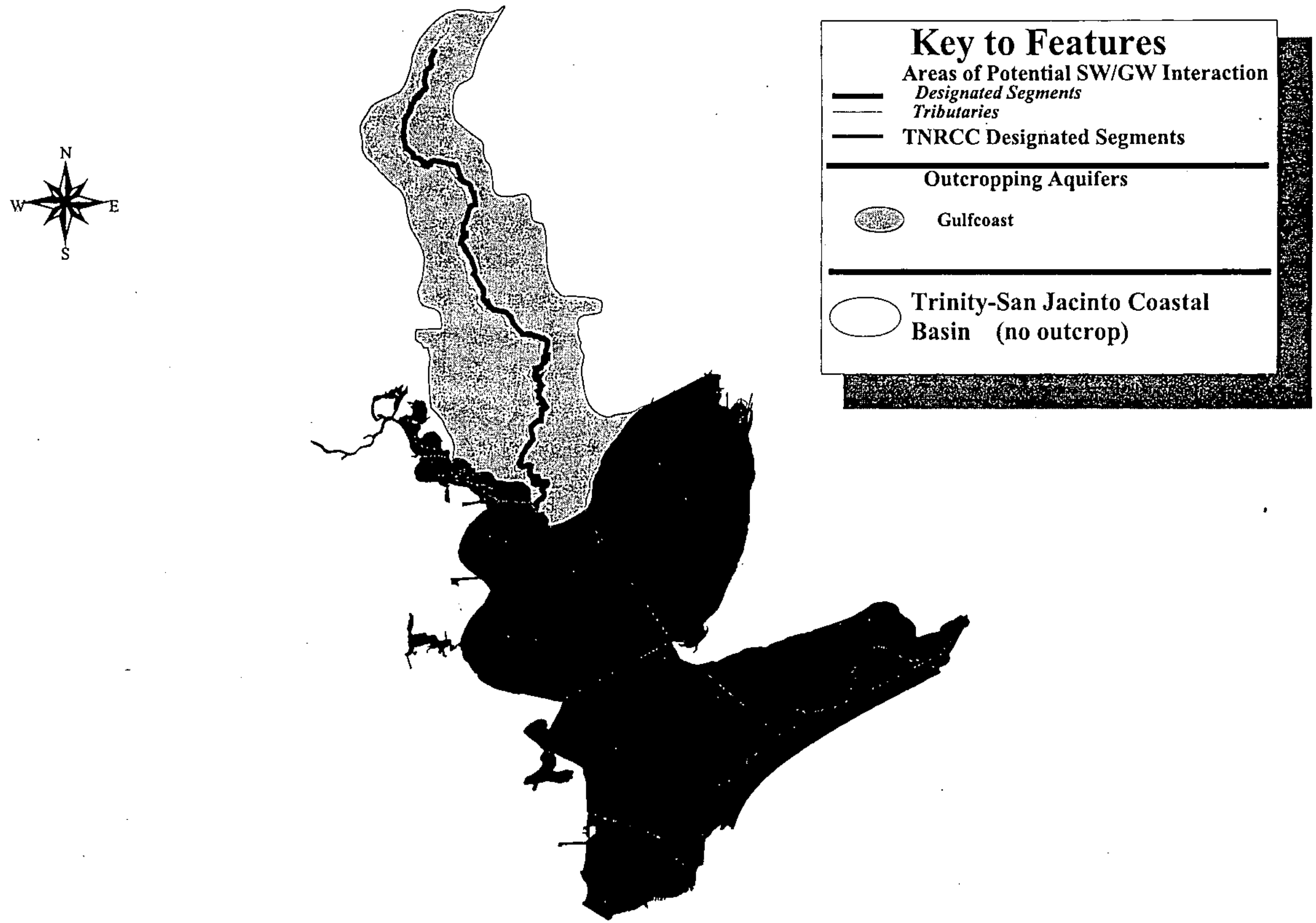

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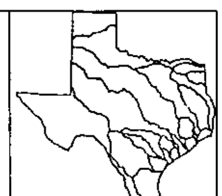
FIGURE 3.9.2

TRINITY-SAN JACINTO COASTAL BASIN Potential Surface Water/ Groundwater Interaction



Source: TNRIS/TWDB GIS Planning Division

The Beaumont Clay is an aquifer in a large part of the basin between the Nueces to the west and Sabine Rivers to the east. The Beaumont Clay is principally a poorly bedded calcareous clay of various colors, containing thin stringers and beds of silt and fine sand. Wells tapping sand beds in the Beaumont Clay yield small to moderate amounts of water throughout the basin. The upper part of the Beaumont Clay, which outcrops in the Trinity-San Jacinto Coastal Basin, fronts many lagoons and bays along the coast and extends inland adjacent to the major river valleys as alluvial plains. The formation is composed here of interbedded, unconsolidated, light-colored sands and clays and ranges in thickness from 0 to 200 feet (TWC, 1963).

Minor Aquifers

There are no minor aquifer systems in the Trinity-San Jacinto Coastal Basin.

Reservoirs

There are no storage reservoirs in the Trinity-San Jacinto Coastal Basin.

3.9.2 Significance of The Interaction

Cedar Bayou is the longest stream in the Trinity-San Jacinto Coastal Basin. It discharges into the Galveston Bay east of Baytown. The length of Cedar Bayou, or most creeks in the Central Plains, is less than 50 miles. Goode Bayou is much shorter than Cedar Bayou, and also discharges into Galveston Bay west of Baytown. Because the entire basin is underlain by the GCAS outcrop, groundwater should discharge to Cedar Bayou when the creek cuts into the shallow watertable. However, groundwater that contributes to streamflow may not be significant due to high rainfall and large amounts if irrigation return flow from rice fields. Irrigation water is imported from the Trinity River.

Table 3.9.1
Surface Water and Groundwater Interaction, Trinity San Jacinto Coastal Basin.

Reach	Water Quality Segment	SW/GW Interaction	Aquifer	Probability/ Comment
Cedar Bayou	0901, 0902	Yes, gaining	Gulf Coast aquifer: the entire watershed is on the outcrop.	Low: stream flow is maintained mainly by rice field return water and rainfall.

3.9.3 References

TWC, 1963. Reconnaissance Investigation of the Ground-Water Resources of the Gulf Coast Region, Texas, Texas Water Commission, Bulletin 6305, June 1963.

TWDB, 1997. Water for Texas, Texas Water Development Board, August, 1997.

3.10 THE SAN JACINTO RIVER BASIN

3.10.1 Hydrologic Characteristics

The San Jacinto River Basin is bounded on the east by the Trinity River Basin and on the west by the Brazos River Basin (Figure 3.10.1). The southern extent of the basin is bordered Galveston Bay. Total drainage area of the basin is 2,800 square miles (TWDB, 1997). Tributaries are, from east to west, Luce Bayou, East Fork, Peach Creek, Caney Creek, West Fork, Lake Creek, Spring Creek, Cypress Creek, and Buffalo Bayou. Buffalo Bayou drains the city of Houston. The rest of the creeks discharge directly into Lake Houston. The basin is located in the West Gulf Coast section of the Coastal Plains province, which is predominantly a smooth, featureless, depositional plain rising from sea level to an altitude of about 200 feet. The basin exhibits a moist subhumid climate with a mean annual rainfall of about 44-46 inches (TWC, 1963). For rural watersheds, the average portion of rainfall becomes of streamflow is 11 inches (East Fork above Lake Houston, i.e., 280 cfs) to 13 inches (Spring Creek at I-45, i.e., 224 cfs) (USGS, 1991).

The sediments that are exposed on the land surface and in the surface water channels throughout the San Jacinto River Basin consists of beds, lenses, and stringers of gravel and coarse to fine sand interbedded with silt and clay beds and lenses. These sediments form a series of gently dipping truncated wedges which thicken toward the coast, causing each wedge to have a slightly steeper dip than the overlying wedge. At depth, the lithology of these sediments become more dominantly silt and clay (TWC, 1963).

Regions

The San Jacinto River basin is treated as one hydrologic unit.

Due to the shallow depths to groundwater and the surficial exposure of sediments in the outcrop of the Gulf Coast Aquifer System (GCAS), it is expected that groundwater would generally discharge into drainage-ways and coastal embayment throughout the basin.

Major Aquifers

The San Jacinto River Basin is underlain by the GCAS as shown in Figure 3.10.2. The GCAS is a complex network of interbedded sediments which have been segregated into four generally recognized water producing formations. Aggregately, these formations form a large leaky artesian aquifer system, the GCAS, that provides groundwater for agricultural, industrial, and municipal uses.

The principal formation of the GCAS in the northern third of the basin are the Catahoula, Oakville, and Lagarto. These formations yield moderate to large quantities of water to wells in the northern portion of the San Jacinto Basin.

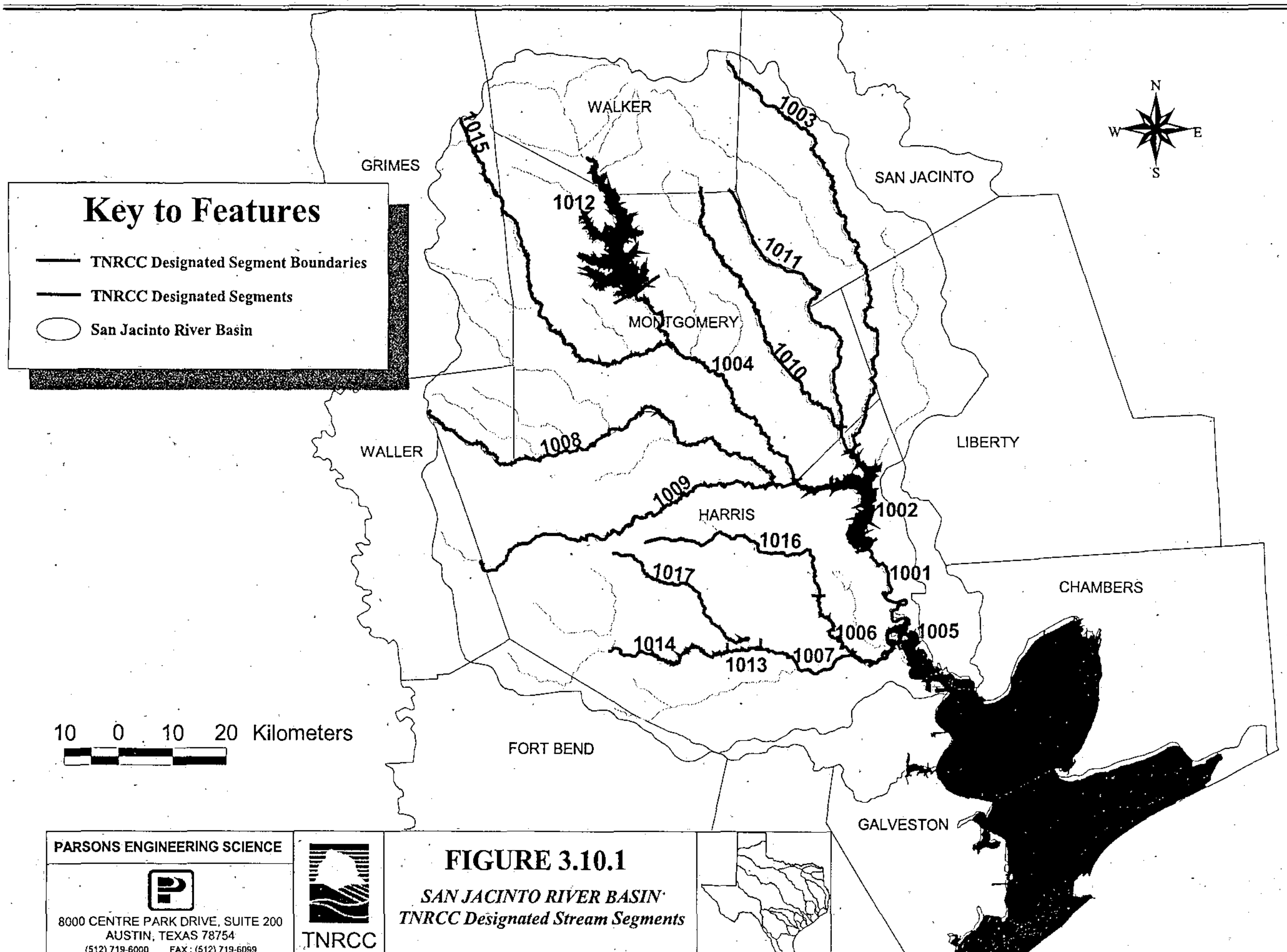


FIGURE 3.10.1

SAN JACINTO RIVER BASIN
TNRCC Designated Stream Segments

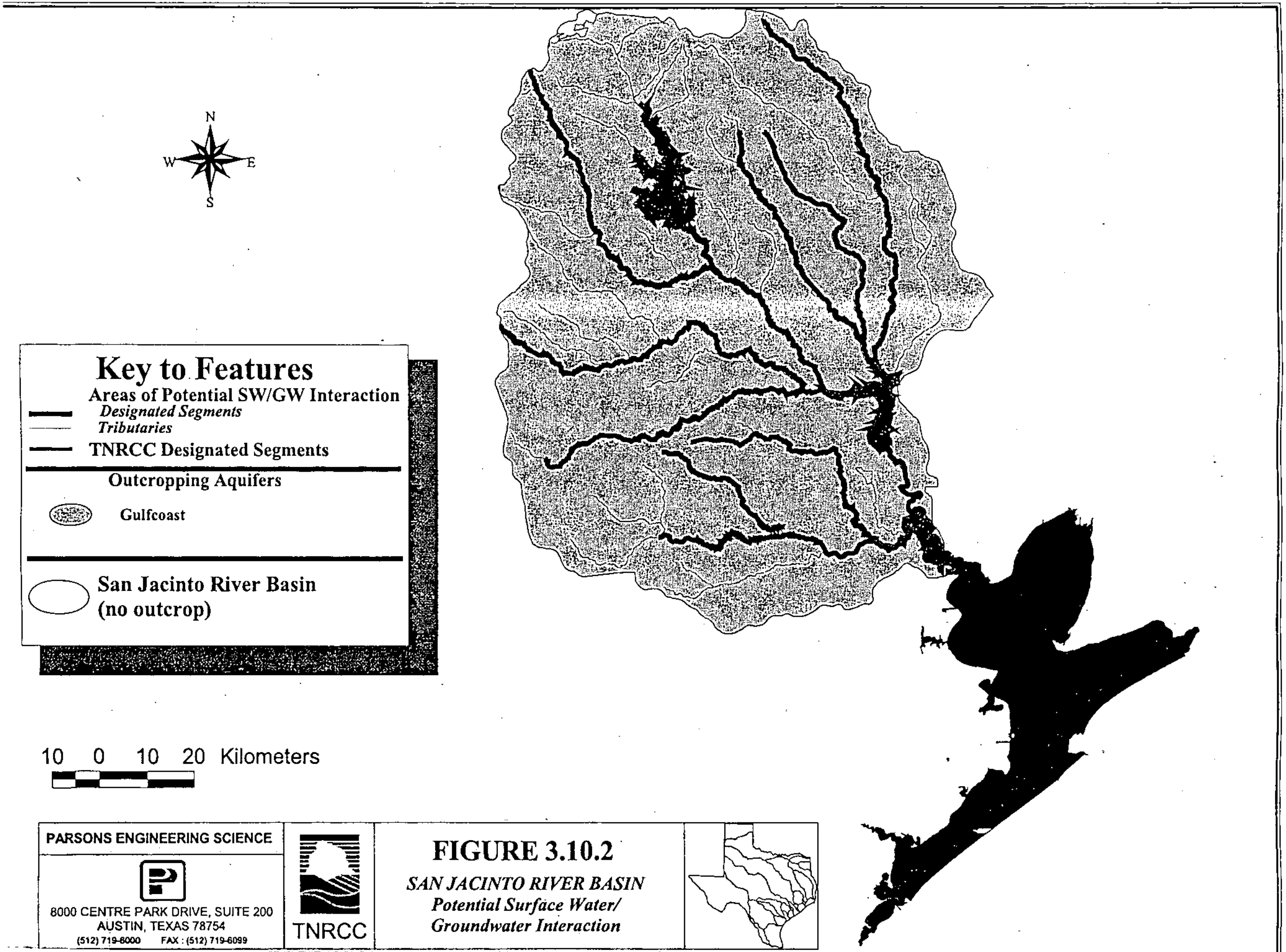


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FIGURE 3.10.2

SAN JACINTO RIVER BASIN
Potential Surface Water/
Groundwater Interaction

The Goliad Sand, Willis Sand, and Lissie Formation are the local formations of the GCAS that outcrop in the central third of the San Jacinto Coastal Basin. The Goliad Sand is comprised of bentonitic clay interbedded with reddish colored sand and gravel which are cemented with lime. The Goliad ranges in thickness from 0 to 500 feet. The Willis Sand is dominantly a fine to coarse sand containing gravel, silt, and clay intimately mixed with the sand or as lenses interbedded with the sand. The Willis Sand ranges in thickness from 0 to 400 feet. The Lissie Formation is composed mainly of beds and lenses of coarse to fine light-colored sand, grading into and interbedded with sandy clay, clay, and gravel. The Lissie Formation, along with the Goliad Sand and Willis Sand constitute the greatest source of groundwater throughout the region. The aquifer is recharged at the surface and the water moves downdip through the sand beds of the Lissie Formation for great distances from the outcrop and constitutes the only usable groundwater of sufficient quantity for municipal and industrial use in the region (TWC, 1963).

The Beaumont Clay is the principal formation of the GCAS in the southern third of the basin. The Beaumont Clay is principally a poorly bedded calcareous clay of various colors, containing thin stringers and beds of silt and fine sand. Wells tapping sand beds in the Beaumont Clay yield small to moderate amounts of water throughout the basin. Permeability of the Beaumont Clay is considered to be low. The upper part of the Beaumont Clay, which outcrops in the San Jacinto Coastal Basin, fronts many lagoons and bays along the coast and extends inland adjacent to the major river valleys as alluvial plains. The formation is composed here of interbedded, unconsolidated, light-colored sands and clays and ranges in thickness from 0 to 200 feet (TWC, 1963).

Lands in the lower portion of the San Jacinto River Basin include fresh-water marshes and swamps that are not subjected to salt-water flooding except during very high hurricane surge floods. These lands have a permanently high water table that essentially intersects the ground surface, have depressed relief, and are subject to fresh water flooding. Permeability is very low and internal drainage very slow; water holding capacity is high, and load bearing strength is very poor (Fisher, et al, 1972).

Minor Aquifers

There are no minor aquifer systems in the San Jacinto River basin.

Reservoirs

There are two storage reservoirs in the San Jacinto River basin: Lake Conroe and Lake Houston. Lake Conroe (capacity, 532,000 acre feet) is located on the outcrop of the GCAS, specifically the Willis Sand and Oakville Formations and is identified as stream segment 1012. The lithology of the Willis Sand and Oakville Formation underlying Lake Conroe indicates that the permeability is moderate to high and interaction between the aquifer and the reservoir would be likely. Lake Houston (capacity, 146,700-acre feet), stream segment 1002, is also located on the outcrop of the GCAS. Since Lake Houston is underlain by the Beaumont Formation which is of low permeability and therefore it is anticipated that the interaction between the reservoir and the underlying aquifer would be minimal.

3.10.2 Significance of The Interaction

Although the streamflow increases downstream is an indication of groundwater contribution. The increase in streamflow could also be derived from more surface runoff from a larger watershed in a subhumid region, dam seepage, sewage discharges from city and town, and from irrigation return flow from rice fields. In Houston, it is known that the groundwater withdrawal caused subsidence. This would indicate that groundwater was drawn significantly below land surface and groundwater discharge into streams and bayous would be very limited or even ceased. By the same logic, groundwater withdrawal would induce streamflow loss. Therefore, one would assume that there is the surface water/groundwater interaction because the entire watershed in under the outcrop of the Gulf Coast aquifer. Yet the magnitude of the interaction can not be determined with the current literature review and is to be determined based on future seepage runs and water balance studies

Table 3.10.1
Surface and Groundwater Interaction, San Jacinto River Basin.

Reach	Water Quality Segment	SW/GW Interaction	Aquifer	Probability/ Comment
San Jacinto River above Lake Houston: East Fork, Peach Creek, Caney Creek	1003, 1011, 1010	Yes, gaining	Gulf Coast aquifer: the entire watershed is over the aquifer.	Medium: due to subhumid region, the Gulf Coast aquifer would reject recharge in this basin.
San Jacinto River above Lake Houston: West Fork, Spring Creek, Cypress Creek	1002, 1004, 1012, 1015, 1008, 1009	Yes, gaining or losing	Gulf Coast aquifer: the entire watershed is over the aquifer. Lake Conroe and Houston may recharge groundwater and then show up downstream as baseflow.	Medium: due to subhumid region, the Gulf Coast aquifer would reject recharge in this basin.
San Jacinto River below Lake Houston and above tide	1001	Yes, gaining or potentially losing	Gulf Coast aquifer: the entire watershed is over the aquifer. Lake Conroe and Houston may recharge groundwater and then show up downstream as baseflow.	Medium: due to subhumid region, the Gulf Coast aquifer would reject recharge in this basin. However, regional groundwater withdrawal would induce stream loss to aquifer.
Buffalo Bayou	1006, 1007	Yes, gaining	Gulf Coast aquifer: the entire watershed is over the aquifer. Lake Conroe and Houston may recharge groundwater and then show up downstream as baseflow.	Medium: due to subhumid region, the Gulf Coast aquifer would reject recharge in this basin.

3.10.3 References

Fisher, W.L., McGowen, J.H., Brown, Jr., L.F., and Groat, C.G, 1972. Environmental Geologic Atlas of the Texas Coastal Zone - Galveston-Houston Area, University of Texas Bureau of Economic Geology, 1972.

TWC, 1963. Reconnaissance Investigation of the Ground-Water Resources of the Gulf Coast Region, Texas, Texas Water Commission, Bulletin 6305, June 1963.

TWDB, 1997. Water for Texas, Texas Water Development Board, August, 1997.

USGS, 1991. Water Resources Data, Water Year 1991.

3.11 THE SAN JACINTO-BRAZOS COASTAL BASIN

3.11.1 Hydrologic Characteristics

The San Jacinto-Brazos Coastal Basin is bounded on the east by the San Jacinto River Basin and on the west by the Brazos River Basin (Figure 3.11.1). Galveston Bay borders the southern extent of the basin. Total drainage area of the basin is 1,440 square miles (TWDB, 1997). Drainage channels that discharge directly into Galveston Bay are Armand Bayou, Clear Creek, Dickinson Bayou, Chocolate Bayou, Bastrop Bayou, and Oyster Creek. The basin is located in the West Gulf Coast section of the Coastal Plains province, which is predominantly a smooth, featureless, depositional plain rising from sea level to an altitude of about 200 feet. The basin exhibits a moist subhumid climate with a mean annual rainfall of about 48 inches (TWC, 1963).

The sediments that are exposed on the land surface and in the surfacewater channels throughout the San Jacinto-Brazos Coastal Basin consists of beds, lenses, and stringers of gravel and coarse to fine sand interbedded with silt and clay beds and lenses. These sediments form a series of gently dipping truncated wedges, which thicken toward the coast, causing each wedge to have a slightly steeper dip than the overlying wedge. At depth, the lithology of these sediments become more dominantly silt and clay (TWC, 1963).

Regions

The San Jacinto-Brazos Coastal Basin is treated as one hydrologic unit.

Due to the shallow depths to groundwater and the surficial exposure of sediments in the outcrop of the Gulf Coast Aquifer System (GCAS), it is expected that groundwater would generally discharge into drainage ways and coastal embayment throughout the basin.

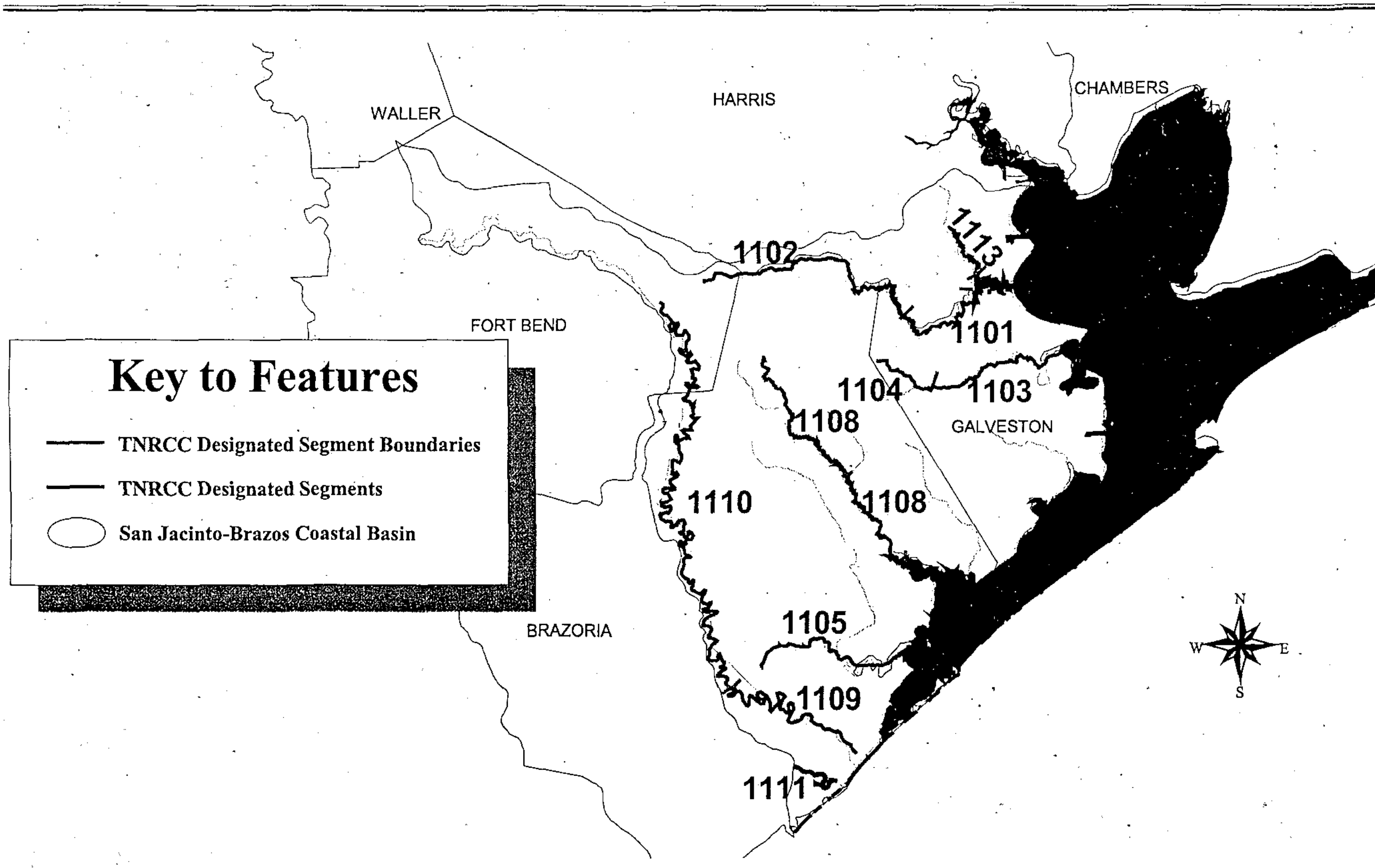

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FIGURE 3.11.1
SAN JACINTO - BRAZOS COASTAL BASIN
TNRCC Designated Stream Segments

10 0 10 20 Kilometers

Major Aquifers

The San Jacinto-Brazos Coastal Basin is underlain by the Gulf Coast Aquifer System (GCAS) as shown in Figure 3.11.2. The GCAS is a complex network of interbedded sediments, which have been segregated into four generally, recognized water-producing formations. Aggregately, these formations form a large leaky artesian aquifer system of the GCAS and provides groundwater for agricultural, industrial, and municipal uses. The Lissie Formation and the Beaumont Clay are the two local formations that make up the uppermost portion of the GCAS that outcrop in the San Jacinto-Brazos Coastal Basin. The Lissie Formation is composed mainly of beds and lenses of coarse to fine light-colored sand, grading into and interbedded with sandy clay, clay, and gravel. The Lissie Formation, along with the Goliad Sand and Willis Sand constitute the greatest source of groundwater throughout the region. The aquifer is recharged at the surface and the water moves downdip through the sand beds of the Lissie Formation for great distances from the outcrop and constitutes the only usable groundwater of sufficient quantity for municipal and industrial use in the region (TWC, 1963).

The Beaumont Clay is an aquifer in a large part of the region between the Nueces and Sabine Rivers. The Beaumont Clay is principally a poorly bedded calcareous clay of various colors, containing thin stringers and beds of silt and fine sand. Wells tapping sand beds in the Beaumont Clay yield small to moderate amounts of water throughout the basin. The upper part of the Beaumont Clay, which outcrops in the San Jacinto-Brazos Coastal Basin, fronts many lagoons and bays along the coast and extends inland adjacent to the major river valleys as alluvial plains. The formation is composed here of interbedded, unconsolidated, light-colored sands and clays and ranges in thickness from 0 to 200 feet (TWC, 1963).

The land within the San Jacinto-Brazos Coastal Basin include areas that are dominantly clay and mud and areas that are dominantly clayey sand and silt. The areas that are dominantly clay and mud form the coastal upland areas and are of low permeability , poor drainage, and level to depressed relief. Geologic units for these areas include inter-distributary muds, barrier-strand plain-chenier swales, abandoned channel-fill muds, overbank fluvial muds, and mud filled coastal lakes and tidal creeks. The areas that are dominantly clayey sand and silt are located along the creeks and drainage ways within the basin. These areas are moderate permeability and drainage and level relief with local mounds and ridges. Geologic units in these areas include meander-belt sands, alluvium, levee, crevasse splay, distributary sands, bay-margin sand and mud, and distributary delta front sands (Fisher, et al, 1972).

Minor Aquifers

There are no minor aquifer systems in the San Jacinto-Brazos Coastal Basin.

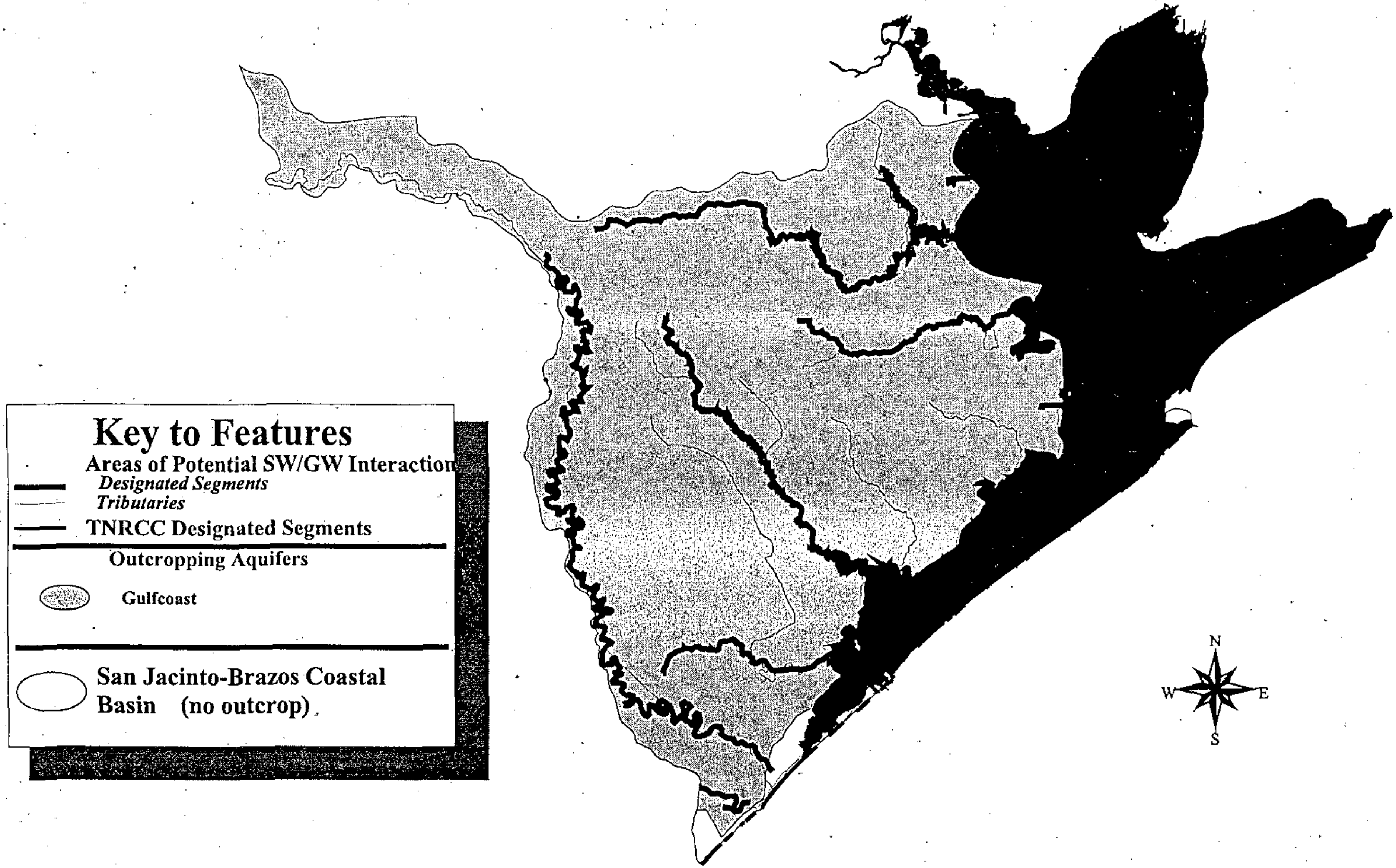

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FIGURE 3.11.2
SAN JACINTO-BRAZOS COASTAL BASIN
Potential Surface Water/ Groundwater Interaction

10 0 10 20 Kilometers

Reservoirs

There are no storage reservoirs in the San Jacinto-Brazos Coastal Basin.

3.11.2 Significance of The Interaction

The hydrologic condition is similar to the San Jacinto River basin with high rainfall and low evaporation, irrigation return flow, sewage discharge, and groundwater withdrawal. The Gulf Coast aquifer underlies the entire watershed. Due to coastal basin, the streams and bayous are shorter than those of inland. However, there are surface water/groundwater interaction in the San Jacinto-Brazos Coastal Basin. Historical subsidence caused by groundwater withdrawal may change an effluent reach to an influent reach. One can postulate this even though existing literature do not specifically stated this. However, USGS (1991) stated the Chocolate Bayou near Alvin had an average flow of 106 cfs with a watershed area of 87.7 square miles. From April to June, Chocolate Bayou has the highest flow, but low flow component from April to October is mainly from rice-field irrigated with water diverted from the Brazos River.

Table 3.11.1
Surface Water and Groundwater Interaction, San Jacinto Brazos Coastal Basin.

Reach	Water Quality Segment	SW/GW Interaction	Aquifer	Probability/ Comment
Armand Bayou	1113	Yes, gaining or losing	Gulf Coast aquifer: underlies entire watershed.	Medium
Clear Creek	1101,1102	Yes, gaining or losing	Gulf Coast aquifer: underlies entire watershed.	Medium
Dickinson Bayou	1103,1104	Yes, gaining or losing	Gulf Coast aquifer: underlies entire watershed.	Medium
Chocolate Bayou	1105,1106	Yes, gaining or losing	Gulf Coast aquifer: underlies entire watershed.	Medium: USGS reported high to low flow periods.
Oyster Bayou	1109,1110, 1112	Yes, gaining or losing	Gulf Coast aquifer: underlies entire watershed.	Medium: the meandering feature indicates shallow groundwater along the creek banks.

3.11.3 References

Fisher, W.L., McGowen, J.H., Brown, Jr., L.F., and Groat, C.G, 1972. Environmental Geologic Atlas of the Texas Coastal Zone - Galveston-Houston Area, University of Texas Bureau of Economic Geology, 1972.

TWC, 1963. Reconnaissance Investigation of the Ground-Water Resources of the Gulf Coast Region, Texas, Texas Water Commission, Bulletin 6305, June 1963.

TWDB, 1997. Water for Texas, Texas Water Development Board, August,1997.

USGS, 1991. Water Resources Data, Texas, Water Year 1991.

3.12 THE BRAZOS RIVER BASIN

3.12.1 Hydrologic Characteristics

The Brazos River Basin in Texas extends from the New Mexico State line in Bailey County southeastward, toward Brazoria County and the Gulf of Mexico 615 miles away. The basin ranges in width from 1 to 120 miles, encompassing approximately 45,573 square miles (TWC, 1963). Of which, 43,000 square miles are in Texas. It is bounded by the Texas-New Mexico border to the west, on the north by the Red River Basin, on the east by the Trinity and San Jacinto Basins, and on the south by the Colorado River Basin (Figure 3.12.1). The basin rocks are generally composed of gravel, silt, and caliche (with some gypsum and anhydrite beds) in the High Plains, sandstones, shales, and limestone in the Central Texas part, and sandstones, silts, and clays in the Coastal Plains. The source of the groundwater recharge is primarily precipitation on most aquifers within the Brazos River Basin.

The climate of the Brazos River Basin in Texas varies from humid in the eastern portion to semiarid in the western portion, with rainfall averaging between 48 inches in the eastern part of the Coastal Plain to 16 inches in the western part of the High Plains (TWC, 1963).

Brazos River Basin represents a geologic history resulting from repeated advance and retreats of shallow seas. This resulted in a series of clastic sediments of sandstones, shales, clays, gravels and evaporitic deposits. The basin is characterized by the flat, elevated surface of the High Plains; gently sloping plains dissected by entrenched streams in the Osage Plains; the heavily dissected area of Central Texas section; and the hilly-gently rolling country of the inland part of the West Gulf Coastal Plain, which becomes nearly flat land along the Gulf of Mexico (TWC, 1963). Rocks outcropping in the basin range in age from Ordovician to Recent. The dip of the rocks generally increase in gradient toward the Gulf of Mexico, with the thickening of the clastic deposits due to growth faulting and sediment loading.

Regions

The Brazos River Basin stretches along the entire length of Texas, encompassing several different regions of the state. The basin resides in the following physiographic sections of Texas: Great Plain, Osage Plain, and the Coastal Plain Provinces. Its headwaters begin in eastern New Mexico at an altitude of 4,150 feet msl, where it flows southeasterly across the High Plains toward the Gulf of Mexico (TWC, 1963).

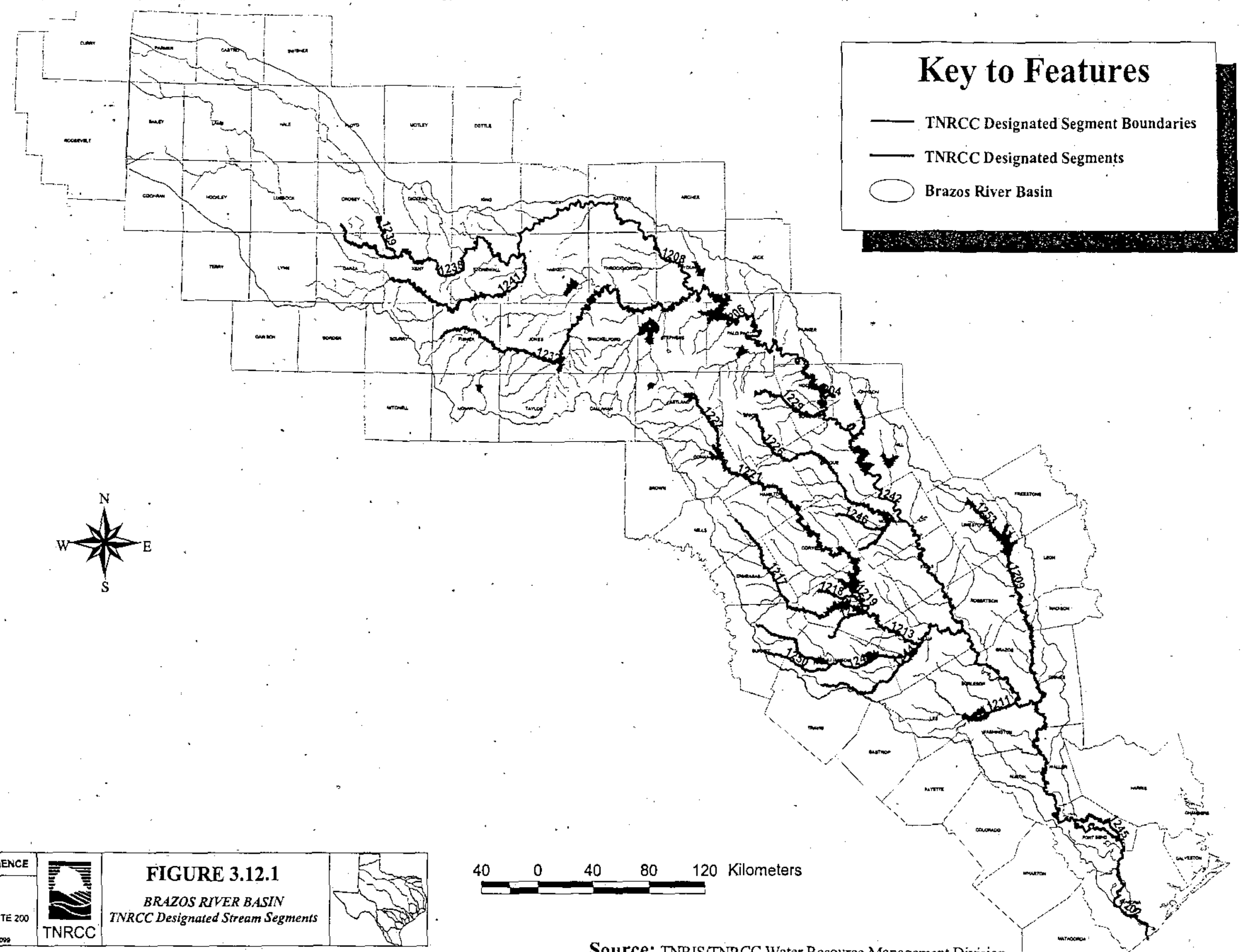

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FIGURE 3.12.1

BRAZOS RIVER BASIN
TNRCC Designated Stream Segments

Source: TNRIS/TNRCC Water Resource Management Division

Primary Aquifers

There are three major aquifers in the Brazos River Basin: the Ogallala of the High Plains Province, the Tertiary Group of the West Coastal Plains, and the Quaternary Alluvium that exists the entire length of the basin.

Ogallala Formation

Ogallala Formation is only primary aquifer in the High Plains Province (Figure 3.12.2). It covers approximately 7,500 square miles in the Brazos River Basin. It is composed of Pliocene-age clays, silts, sands, gravels, and caliche that unconformably overlie Triassic- and Cretaceous-age rocks. The formation thickens from pinch-out at the southern boundary to a thickness of 400 to 500 feet in the north. The formation dips gently toward the southeastward at a rate up to 10 feet per mile. The angle of dip generally increases with depth, as does total thickness of the unit. The groundwater derived from the Ogallala Formation is utilized in public supply, irrigation, industrial and domestic purposes.

The climate is semiarid in western part of the basin (High Plains and Osage Plains). Groundwater in the Ogallala occurs under water-table conditions. The area of the basin in the High Plains contributes virtually no runoff to the river. Approximately 90% of the groundwater withdrawal from the Ogallala Formation is in the High Plains. This is due to semiarid climate in west Texas. Surface water supplies are not adequate, therefore demand is high for irrigation by farmers. In the more humid eastern side of the basin closer to the Coastal Plain, groundwater is used on a supplemental basis only during dry conditions (greater precipitation allows for dry farming techniques).

Tertiary Group

The Tertiary Group is not only the most prolific aquifer in the West Gulf Coastal Plain, but the entire Brazos River Basin. These units range in age from Cretaceous to recent, and are comprised of limestone, shale, siltstone, and clays.

Carrizo Sand and Wilcox Formation Group (Undifferentiated)

The Carrizo Sand and Wilcox Formation are comprised of sandstones with interbedded clay layers. They dip from 80 to 90 feet per mile southeast toward the Gulf Coast and total thickness of the unit increase with depth. Groundwater quality is fresh to slightly saline, suitable for industry with minimal treatment. It is also used for domestic and livestock purposes. Carrizo Sand and Wilcox Formation range in thickness from zero at the outcrop to 4,340 feet thick, dipping to the east in southeast Washington County. Recharge is by precipitation. Water quality is fresh to slightly saline.

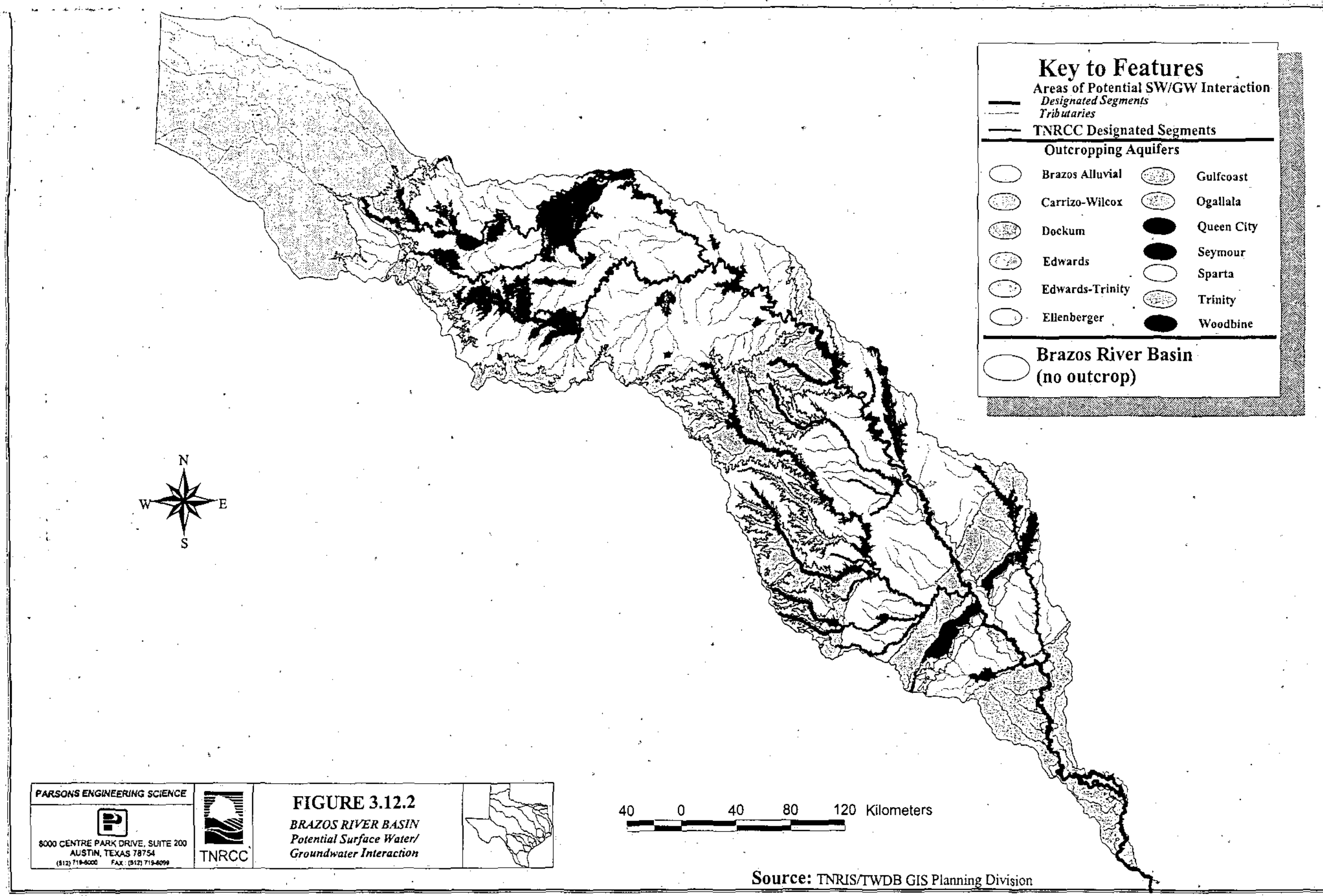

FIGURE 3.12.2

BRAZOS RIVER BASIN
Potential Surface Water/
Groundwater Interaction

Catahoula Sandstone, Oakville Sandstone, Lagarto Clay (Undifferentiated)

The Catahoula Sandstone, Oakville Sandstone, Lagarto Clay units are the primary aquifer of the Gulf Coast Region, ranging up to 4,100 feet thick. Water quality ranges from fresh to slightly saline, and moderately to very hard composition. The aquifer consists of alternating clays and shales with coarse sandstones. These units thicken downdip to a maximum of 4,100 feet thick.

Goliad Sand, Willis Sand, and Lissie Formation (Undifferentiated)

These units range in thickness from 0 to 1,700 feet, dipping 20 to 45 feet per mile and thickening toward the Gulf coast. The Goliad Sand, Willis Sand, and Lissie Formation are mostly overlain by the Beaumont Clay and Quaternary Alluvium.

Quaternary Alluvium

Quaternary alluvium occurs in a narrow belt between old rocks but along the Brazos River Valley. The alluvium is present along most of the Brazos River, outcropping over the older rocks in 1 to 7 mile widths. The alluvium consists of gravels, sands, silts and clays, that occur in a gradational depositional pattern. Alluvium was deposited by streams, but reworked by wind action. Deposits occur as terraces or flood-plain deposits along and upland of the river valley. Sands, gravel, silts, and clays range from 16 to 200 feet thick near the coast. Saturated thickness of groundwater is 4 to 84 feet, though near the cost saturated thicknesses are equivalent to total thickness of alluvium. Water quality ranges from fresh to slightly saline.

Secondary Aquifers

There are eight minor aquifer systems in the Brazos River Basin: Dockum Group, Trinity Group, Cook Mountain, Yegua Formation, Mount Selman Formation, Midway Group, Jackson Group, and the Beaumont Clay. There are no primary aquifers in central Texas Sections.

Dockum Group

The Dockum Group ranges in thickness from zero to 1,600 feet. Late Triassic in age, it underlies the entire High Plains region, though it does not produce water except east of the escarpment. Groundwater is both low in quality (moderately saline) and quantity, serving limited irrigation, public supply, and industrial uses. The group is comprised of shales, sandy shales, sandstones, and conglomerates.

Trinity Group

The Trinity Group, Cretaceous in age, is approximately 2,350 feet thick. The group includes Travis Peak Formation (the main aquifer of the group), Glen Rose Limestone, and the Paluxy Sandstone. The group is composed of sandstones, limestones, clays, and interbedded shales. Water quality ranges from fresh to slightly saline.

Cook Mountain

This formation ranges in thickness from zero to 700 feet thick in widths ranging from 1 to 7 miles. The formation is composed of 90% clay, shale, and sandy shale, 9 % glauconitic sand, and 1 % limestone concretions. The water quality degrades downdip with increasing mineralization.

Yegua Formation

The Yegua Formation outcrops between 4 and 22 miles wide, and the maximum thickness is 1,000 feet. It is composed of heterogeneous sands, shales, lignite, and carbonaceous clays. The water quality is moderately saline.

Mount Selman Formation

This formation ranges in thickness from zero to 1,200 feet. Its outcrop is 5 to 10 miles wide. Water quality is moderately saline, having a hard water composition. It is used primarily for domestic and livestock purposes. The Mt. Selman Formation is divided up into three components: Reklaw Member, Queen City Sand, and Weches Greensand Member.

Midway Group

Paleocene in age, the Midway Group is composed of glauconitic sand, silt and calcareous clays. It ranges in thickness from zero to 900 feet. This minor aquifer only produces locally small amounts of useable groundwater.

Sparta Sand

The Sparta Sand outcrops in 1 to 6 mile widths, ranging in thickness from 250 to 300 feet. This minor aquifer supplies moderate water quantities to public supply, industrial, and irrigation with good overall quality of water.

Jackson Group

This minor aquifer outcrops between 7 to 9 miles in width, and ranges in thickness from zero to 200 feet thick. It is composed of clays, silts, and bentonitic clay lenses. This aquifer supplies moderate amounts of water to ranches and farms above 400 feet, with deeper water becoming too saline.

Beaumont Clay

The Beaumont Clay is a poorly bedded calcareous clay containing sand and silt stringers (clay composition is 80-90%). It is approximately 1,300 feet thick, dipping 20 feet per mile toward the Gulf Coast.

Reservoirs

There are three storage reservoirs on the Brazos River main stem: Lake Whitney in Bosque County (Washita and Fredericksburg, Undifferentiated), Lake Granbury in Hood County (Trinity Group), and Possum Kingdom Lake in Palo Pinto County (Strawn Group).

3.12.2 Significance of the Interaction

The High Plains Region of the Brazos River Basin provides no runoff into the Brazos River. The arid conditions, in addition to the greater depths to the top of the water table, makes influent streams. The primarily reaches of groundwater effluent would be located in the Gulf Coastal Plain region of the basin. Adequate precipitation, along with minimal irrigation in farming practices, allow an elevated water table to interact with the surface water from the river system. Areas likely for the water availability modeling of the river are thus in the Tertiary outcrops on the Gulf Coastal Plains.

The Carrizo Sand and Quaternary Alluvium outcrops in Milam and Robertson Counties along the Brazos River. The Brazos River intersects Little Creek in Hearne, Texas, between water segments 1211 and 1242.

Another potential surface water/groundwater interaction site would be in Navasota, Texas, where the Navasota Creek from the east and Yegua Creek from the west intersect the Brazos River in Washington and Grimes Counties. Quaternary Alluvium, Lagarto Clay, Oakville Sandstone, and Catahoula Sandstone outcrops at this location, water segment 1202.

Table 3.12.1
Surface Water and Groundwater Interaction, Brazos River Basin

Reach	Water Segment	SW/GW Interaction	Aquifer	Probability/ Comment
From Lake Whitney Dam to Navasota River	1242	Yes, gaining	Carrizo Sand and Quaternary Alluvium aquifers.	Medium: due to small recharge area and intersection of streams.
Brazos River below Navasota River	1201, 1202	Yes, gaining	Outcrops of Quaternary Alluvium, Gulf Coast, and Tertiary Group aquifers.	High: due to incoming streams and large recharge outcrop zone.

Other potential sites for interaction modeling would be in Central Texas, where the topography is hilly and stream valleys are incised into the surrounding bedrock. Groundwater springs and seeps from the Trinity and Edwards aquifers potentially sustain perennial streamflow of San Gabriel Lampasas and Leon Rivers. These rivers form the Little River which discharges into the Brazos River west of Hearne in Robertson County.

3.12.3 References

TWC, 1963, Reconnaissance Investigation of the Ground-Water Resources of the Brazos River Basin, Texas, Texas Water Commission, Bulletin 6310, December 1963.

TWDB, 1967, Ground Water in the Floodplain Alluvium of the Brazos River, Whitney Dam to Vicinity of Richmond, Texas, Texas Water Development Board, Report 41, March 1967.

3.13 THE BRAZOS-COLORADO COASTAL BASIN

3.13.1 Hydrologic Characteristics

The Brazos-Colorado Coastal Basin is bounded on the east by the San Jacinto River Basin and on the west by the Brazos River Basin (Figure 3.13.1). The southern extent of the basin is bordered by Matagorda Bay. Total drainage area of the basin is 1,850 square miles (TWDB, 1997). Major streams are San Bernard River and Caney Creek. The basin is located in the West Gulf Coast section of the Coastal Plains province, which is predominantly a smooth, featureless, depositional plain rising from sea level to an altitude of about 200 feet. The basin exhibits a moist subhumid climate with a mean annual rainfall of about 40-44 inches (TWC, 1963).

According to USGS (1991) that The San Bernard River at Wharton and Fort Ben County line southeast of the city of Wharton has a 37-year average of 483 cfs discharge with a watershed area of 727 square miles. This upper reach covers about one-half of the San Bernard River watershed. There is no USGS gaging station on Caney Creek. Although Caney Creek is shorter than the San Bernard River, it indicates an old stage with shorter wave length of its meanders. Thus, the probability of surface water and groundwater interaction exists. (A river is classified as young, mature, and old based on erosion cycle. In the young stage, the river cuts downward rapidly with a V-shaped valley and high gradient. At maturity, the river reaches its maximum efficiency in carrying sediment. At old stage, the river meanders in a broad flood plain.)

The sediments that are exposed on the land surface and in the surface water channels throughout the Brazos-Colorado Coastal Basin consist of beds, lenses, and stringers of gravel and coarse to fine sand interbedded with silt and clay beds and lenses. These sediments form a series of gently dipping truncated wedges which thicken toward the coast, causing each wedge to have a slightly steeper dip than the overlying wedge. At depth, the lithology of these sediments become more dominantly silt and clay (TWC, 1963).

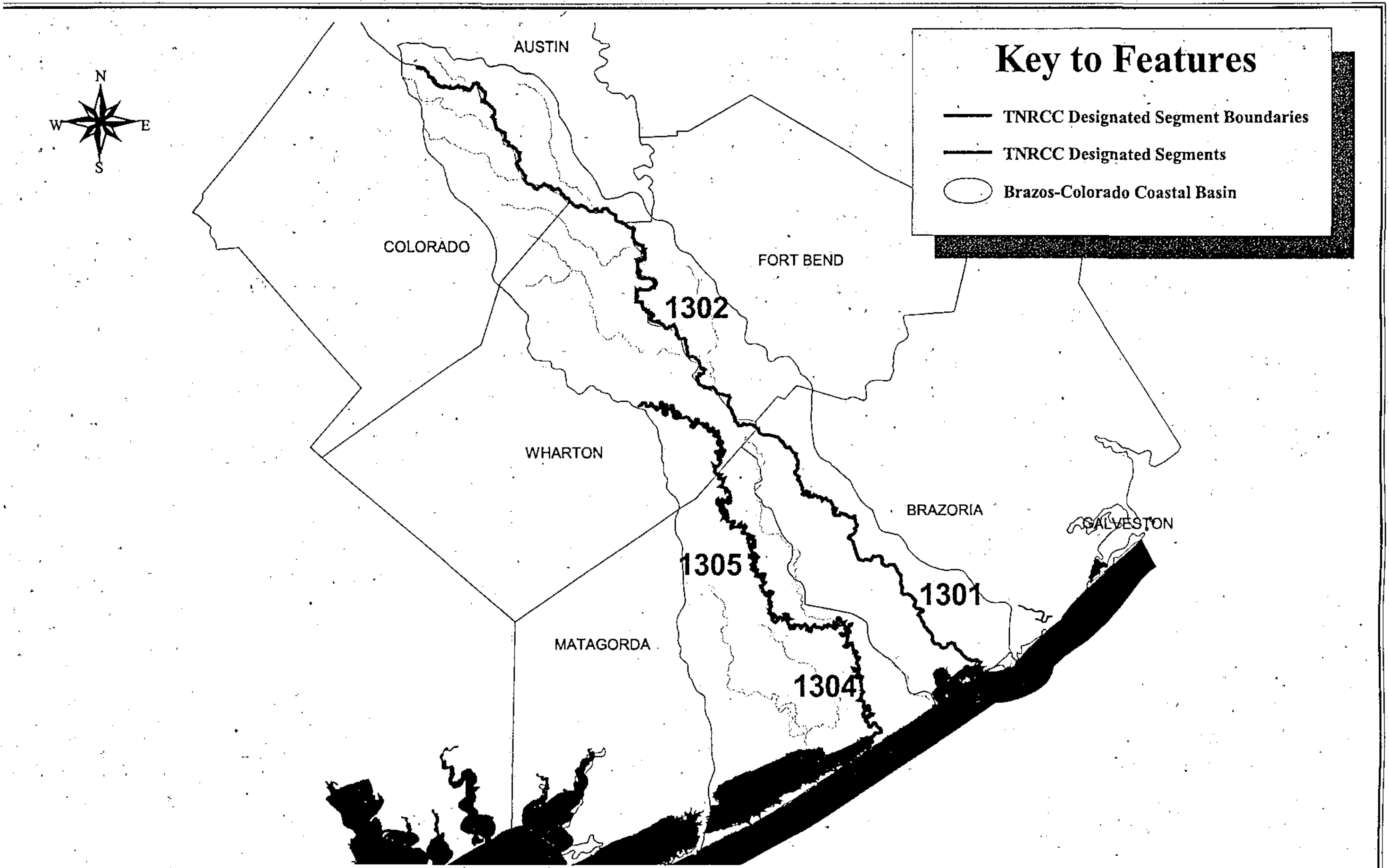

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FIGURE 3.13.1
BRAZOS-COLORADO COASTAL BASIN
TNRCC Designated Stream Segments

20 0 20 Kilometers

Regions

The Brazos-Colorado Coastal Basin is treated as one hydrologic unit.

Due to the shallow depths to groundwater and the surficial exposure of sediments in the outcrop of the Gulf Coast Aquifer System (GCAS), it is expected that groundwater would generally discharge into drainage-ways and coastal embayment throughout the basin.

Major Aquifers

The Brazos-Colorado Coastal Basin is underlain by the GCAS as shown in Figure 3.13.2. The GCAS is a complex network of interbedded sediments which have been segregated into four generally recognized water producing formations. Aggregately, these formations form a large leaky artesian aquifer system, the GCAS, that provides groundwater for agricultural, industrial, and municipal uses. The Lissie Formation and the Beaumont Clay are the two local formation that make up the uppermost portion of the GCAS that outcrop in the Brazos-Colorado Coastal Basin. The Lissie Formation is composed mainly of beds and lenses of coarse to fine light-colored sand, grading into and interbedded with sandy clay, clay, and gravel. The Lissie Formation, along with the Goliad Sand and Willis Sand constitute the greatest source of groundwater throughout the region. The aquifer is recharged at the surface and the water moves downdip through the sand beds of the Lissie Formation for great distances from the outcrop and constitutes the only usable groundwater of sufficient quantity for municipal and industrial use in the region (TWC, 1963).

The Beaumont Clay is an aquifer in a large part of the region between the Nueces and Sabine Rivers. The Beaumont Clay is principally a poorly bedded calcareous clay of various colors, containing thin stringers and beds of silt and fine sand. Wells tapping sand beds in the Beaumont Clay yield small to moderate amounts of water throughout the basin. The upper part of the Beaumont Clay, which outcrops in the Brazos-Colorado Coastal Basin, fronts many lagoons and bays along the coast and extends inland adjacent to the major river valleys as alluvial plains. The formation is composed here of interbedded, unconsolidated, light-colored sands and clays and ranges in thickness from 0 to 200 feet (TWC, 1963).

The land within the Brazos-Colorado Coastal Basin include areas that are dominantly clay and mud and areas that are dominantly clayey sand and silt. The areas that are dominantly clay and mud form the coastal upland areas and are of low permeability , poor drainage, and level to depressed relief. Geologic units for these areas include inter-distributary muds, barrier-strand plain-chenier swales, abandoned channel-fill muds, overbank fluvial muds, and mud filled coastal lakes and tidal creeks. The areas that are dominantly clayey sand and silt are located along the creeks and drainage ways within the basin. These areas are moderate permeability and drainage and level relief with local

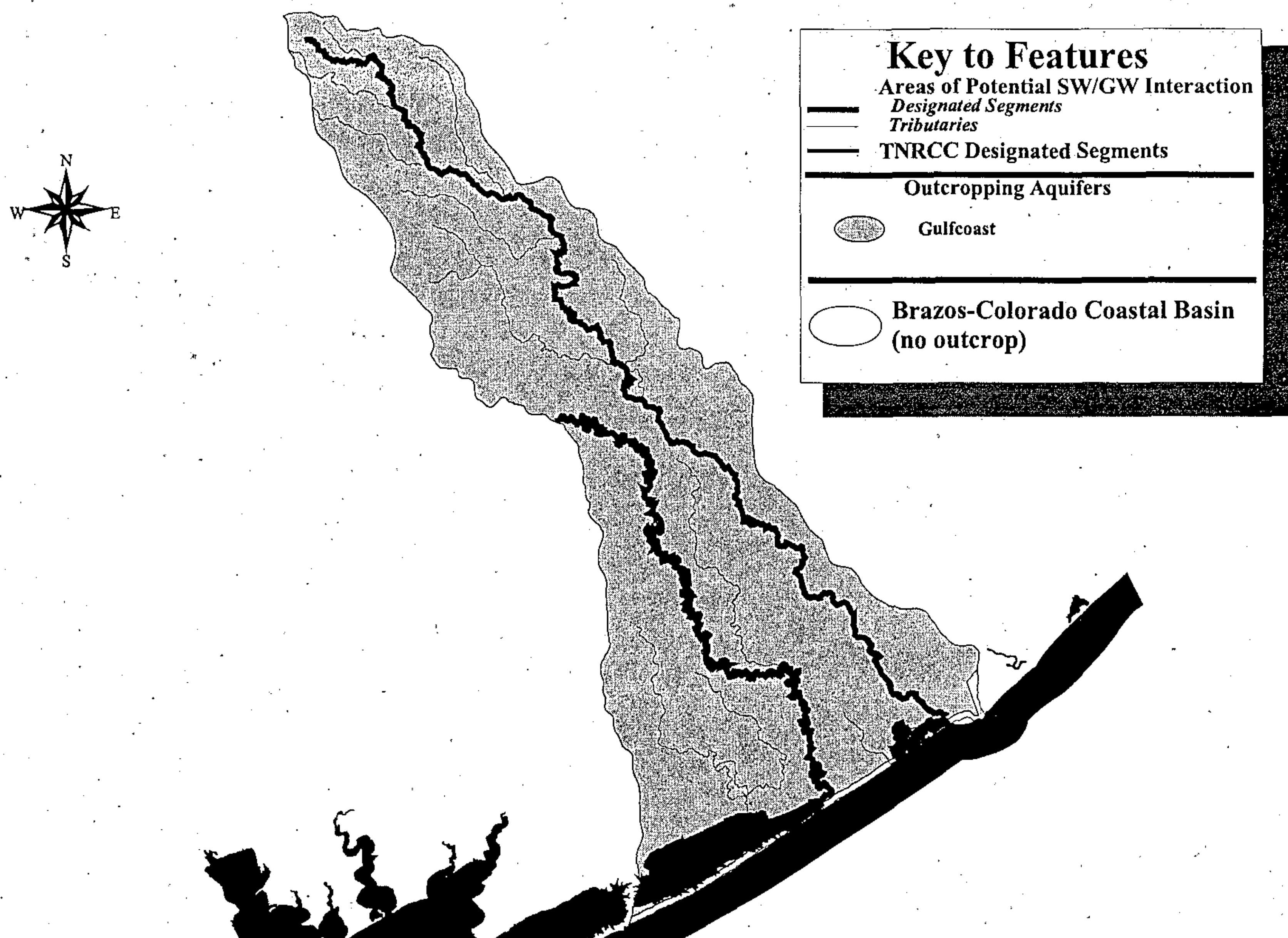

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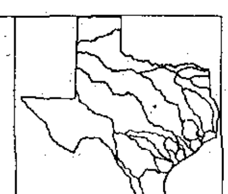
FIGURE 3.13.2
BRAZOS-COLORADO COASTAL BASIN
Potential Surface Water/ Groundwater Interaction



mounds and ridges. Geologic units in these areas include meander-belt sands, alluvium, levee, crevasse splay, distributary sands, bay-margin sand and mud, and distributary delta front sands (Fisher, et al, 1972).

Minor Aquifers

There are no minor aquifer systems in the Brazos-Colorado Coastal Basin.

Reservoirs

There are no storage reservoirs in the Brazos-Colorado Coastal Basin.

3.13.2 Significance of The Interaction

It is very possible that the Gulf Coast aquifer may contributes to baseflow when the San Bernard River and Caney Creek cut into the water table of the aquifer. The Gulf Coast aquifer underlies the entire basin. As stated in the aforementioned coastal basins, coastal streams may yield perennial flows from abundant rainfall, irrigation return flow from rice fields, and groundwater discharge. In light of that the upper San Bernard River yields an annual flow of 483 cfs, surface water, groundwater could contribute baseflow to the San Bernard River and Caney Creek.

Table 3.13.1
Surface Water and Groundwater Interaction, Brazos-Colorado Coastal Basin

Reach	Water Quality Segment	GW/SW Interaction	Aquifer	Probability/ Comments
San Bernard River from Headwaters to the Gulf	1301,1302	Yes, gaining	Gulf Coast aquifer: underlies entire basin.	Medium: perennial stream flows may be due to groundwater, or other sources such as irrigation return flow.
Caney Creek from Headwaters to East Matagorda Bay	1304,1305	Yes, gaining	Gulf Coast aquifer: underlies entire basin.	Medium: perennial stream flows may be due to groundwater, or other sources such as irrigation return flow.

3.13.3 References

Fisher, W.L., McGowen, J.H., Brown, Jr., L.F., and Groat, C.G, 1972. Environmental Geologic Atlas of the Texas Coastal Zone - Galveston-Houston Area, University of Texas Bureau of Economic Geology, 1972.

TWC, 1963. Reconnaissance Investigation of the Ground-Water Resources of the Gulf Coast Region, Texas, Texas Water Commission, Bulletin 6305, June 1963.

TWDB, 1997. Water for Texas, Texas Water Development Board, August,1997.

USGS, 1991. Water Resources Data, Texas, Water Year 1991.

3.14 COLORADO RIVER BASIN

3.14.1 Hydrologic Characteristics

The Colorado River basin (Figure 3.14.1) extends across the central part of the state and covers approximately 40,440 square miles of which 1,870 square miles of the upper watershed is in the state of New Mexico. The watershed includes all or parts of 64 counties and represents about 15.3 percent of the total land-surface area of Texas. Altitudes of the river range from sea level at the mouth to 4,000 feet above mean sea level (msl) at the New Mexico-Texas State line. The average annual precipitation ranges from less than 15 inches at the upper basin of rugged hills and high plain to more than 40 inches near the treeless coastal plain. Lake evaporation rates range from 10 inches per year near the coast to over 70 inches in the High Plains (Mount et al., 1967).

Two primary aquifers that supply large quantities of water are in this basin. They are the Ogallala and the Edwards-Trinity (Plateau) aquifers. Six minor aquifers that provide a large quantity of water to local areas also occur in the basin. They are Edwards-Trinity Cretaceous rocks (outliers), alluvium, Permian rocks, Pennsylvania rocks, Welge Sandstone member of the Wilberns Formation, Precambrian rocks, Trinity Group (North-Central Texas), Edwards Limestone (Balcones fault zone), Queen City Formation, Yega Formation, and Jackson Group (Mount et al., 1967). Figure 3.14.2 shows the locations of the primary and secondary aquifers of the Colorado River basin.

Reservoirs

Reservoir lakes along the main stem of the Colorado River are J. B. Thomas, E. V. Spence (Robert Lee), O. H. Ivie, Buchanan, Inks, L. B. Johnson, and Travis and in Austin, Austin and Town Lakes. Major reservoirs along the tributaries are Colorado City and Champion Creek near Colorado City, Oak Creek and Ballinger near Ballinger, New Lake near Winteres, Twin Buttes, Nasworthy, and O. C. Fisher along the Concho River near San Angelo, Coleman and Brownwood along Pecan Bayou (TDWR, 1984; TNRCC, 1996).

Region I

Based on hydrogeology, climate, vegetation, and size consideration, the Colorado River is divided into three regions at the Runnels-Coke County-line just above the E.V. Spencer (Robert Lee) Reservoir and at the confluence with Onion Creek below Austin in Travis County (Mount et al, 1967). Region I is the upper watershed encompassing 12,280 square miles. The land altitude ranges from 2,000 ft msl in eastern Mitchell County to 4,000 ft at the state line in Cochran County. About 6,400 square miles of the Southern High Plains contributes no runoff to the Colorado River. Drainage of the plains is very poorly developed, consisting of wide, shallow, and poorly defined valleys or draws.

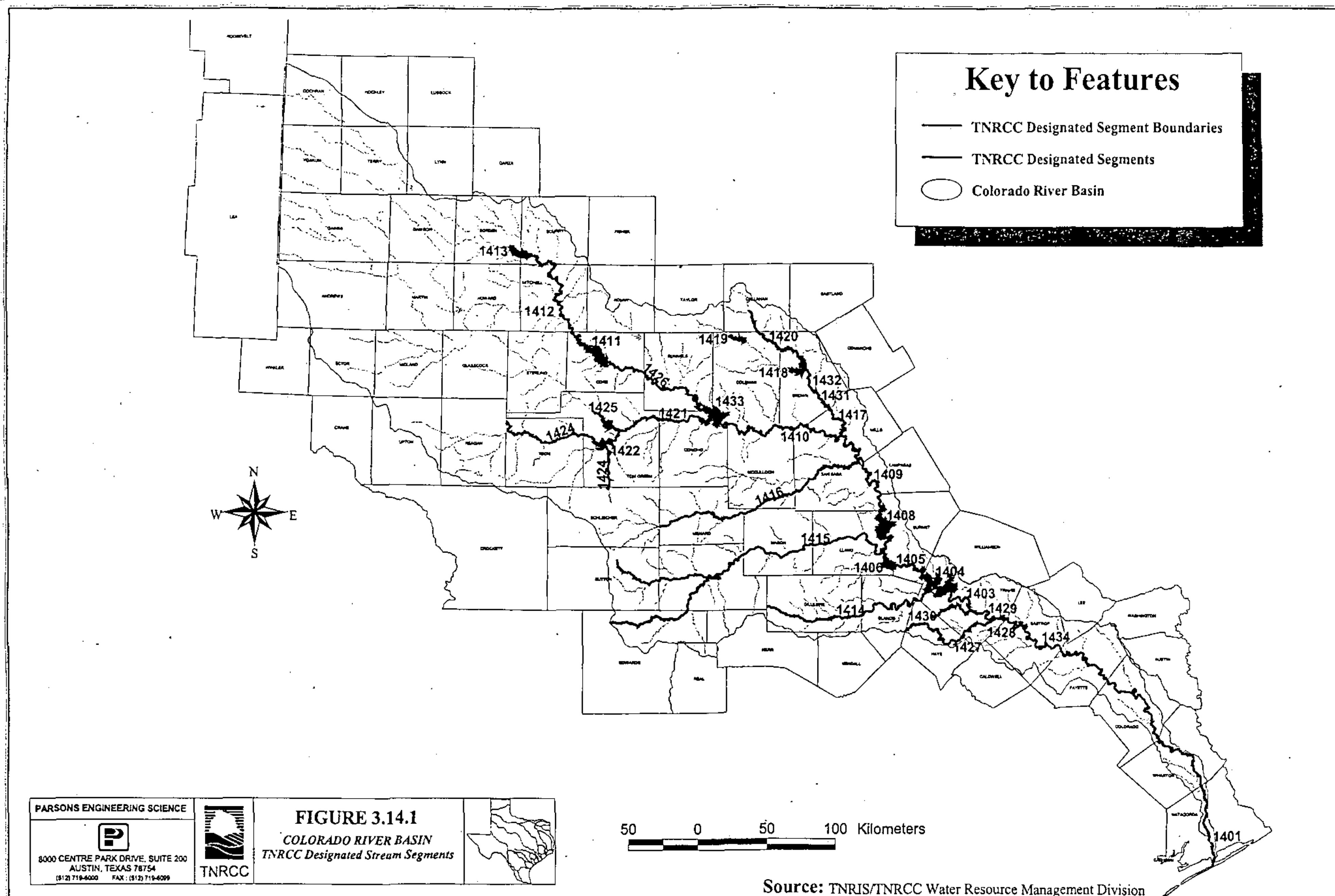


FIGURE 3.14.1

COLORADO RIVER BASIN

TNRCC Designated Stream Segments

Surface water accumulated in the draws ordinarily flows for only a short distance before lost by seepage and evaporation. This is a significant regional hydrologic feature. Moreover, the Colorado River and its majority tributaries have salinity problem due to brine production from oil and gas fields or seeps from such fields and geologic formations that contain high salinity groundwater along the draws or riverbanks. A major tributary in this region is Beals Creek with its tributaries of Sulphur Springs Draw, Mustang Creek, and Johnson Draw.

Region II

Further downstream, in Region II, the streams become perennial in general, except those ephemeral tributaries in the upper headwaters. The middle Colorado River basin is characterized by high-relief escarpment of the Edwards Limestone to the northwest and the low-relief hills of Austin Chalk and Taylor Marl to the southeast. The altitude ranges from 700 ft msl at Lake Travis to 2,900 ft msl in Upton County to the west. The North Central Plains extends from Region I into Region II covering area west of Brown and McCulloch Counties. In Region II, the North Central Plains consists of bench topography covered with mesquite and prairie grasses. About 20 miles south of the Colorado River in Region II, the topography changes to more rugged Edwards Plateau and the "Hill Country." The Edwards Plateau occupies the southwestern part of Region II west and north of Gillespie County, and is generally flat and featureless on its high parts except for occasional sink holes formed by dissolution of the limestone bedrock. Where drainage has developed, streams cut through the limestone, forming canyons of considerable relief. The Hill Country is situated east of the Edwards Plateau and is generally an area of steep hills with cedar-covered slopes.

Region II occupies about 24,550 square miles. Major tributaries are the Concho, San Saba, Llano, and Pedernales Rivers. Annual rainfall is about 15 inches in Upton County to 32 inches in Travis County. Most of the rainfall occurs in spring and summer months. Lake evaporation is about 70 inches per year in the west and 40 inches per year in the east. Barton Creek and Onion Creek, minor tributaries, drain the Hill Country and the Balcones fault zone (BFZ). Barton Springs originates from the Edwards aquifer and contributes on average 56 cubic feet per second (cfs) to the streamflow of Barton Creek (Kuniansky and Holligan, 1994).

Region III.

Region III begins downstream of the confluence with Onion Creek, which is the east-most tributary that drains the Hill Country and the BFZ. The boundary between the hill country and the Gulf Coast Plain is sharply marked by the northeast-southwest trending Balcones escarpment which passes through the City of Austin. The coastal plain is flat and features many poorly drained areas. Altitude ranges from msl at the mouth to about 800 ft in Hays County. Region III drains 1,740 square miles. Average rainfall is 32

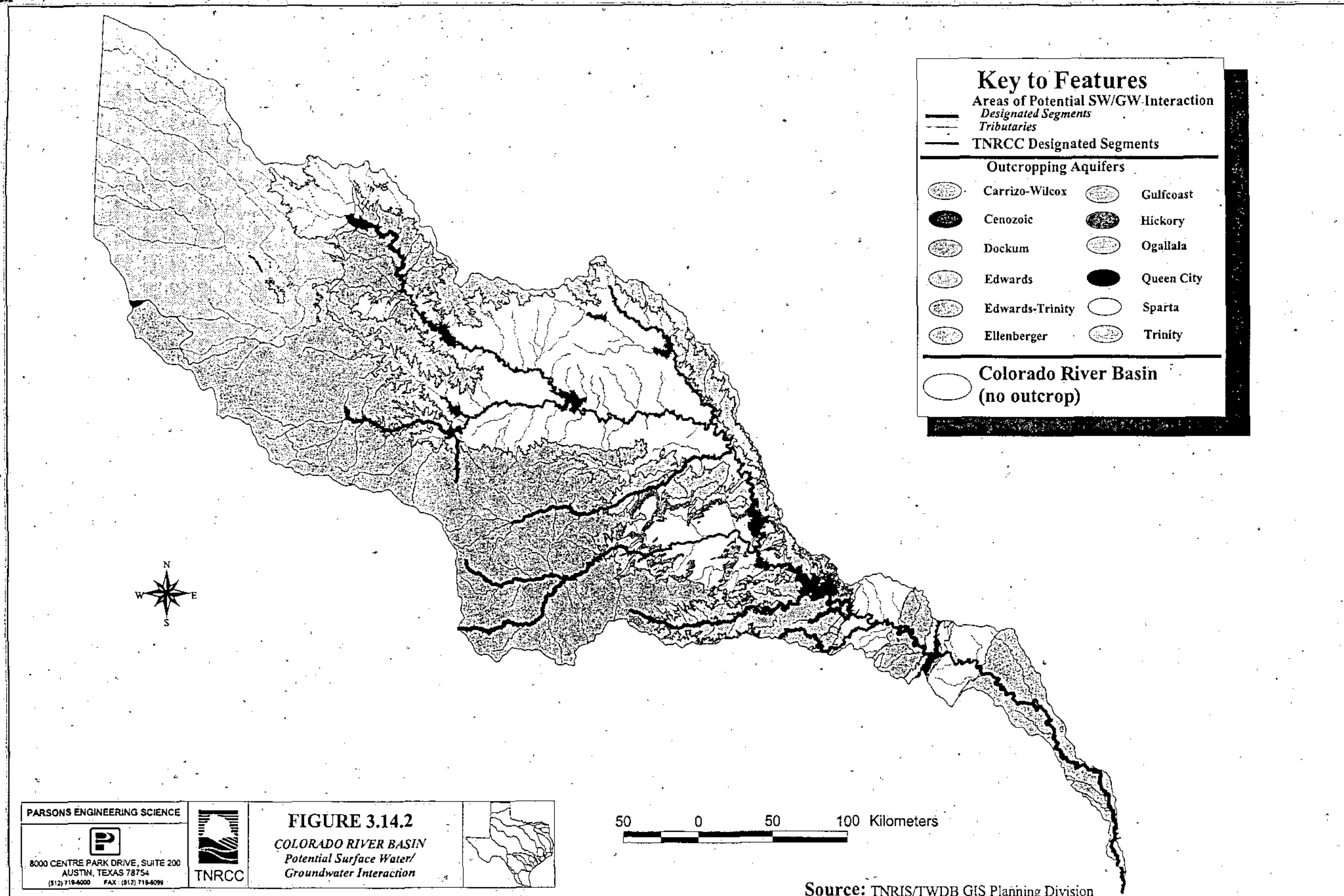


FIGURE 3.14.2

COLORADO RIVER BASIN
Potential Surface Water/
Groundwater Interaction

inches in Travis County to 40 inches in Matagorda County by the coast. Average annual lake evaporation is about 40 inches in Travis County and 10 inches at the coast.

Aquifers

The Upper Colorado River Basin—Region I

In Region I, Ogallalla and Edwards-Trinity (Plateau) are the two main aquifers. Secondary aquifers are the Edwards-Trinity (High Plains) and the Santa Rosa. The Ogallala aquifer is the basal portion of the Ogallala Formation and is the major water source for irrigation and cities. It covers 7,500 square miles in Region I. Saturated thickness is generally between 72 and 350 feet below land surface, averaging less than 100 ft, and is predominately sand. Annual recharge is about 80,000 acre-feet per year (afy) with horizontal inflow from New Mexico, the total recharge is about 120,000 afy. Discharge is through wells and evapotranspiration (Mount et al., 1967). Aquifer contribution to the Colorado River and its tributaries is minimal.

South of the Ogallala is the Edwards-Trinity (Plateau), occupying Ector, Midland, and Glasscock Counties with minor portions in Andrews, Upton, and Howard Counties. The major Edwards-Trinity aquifer occurs in Region II. In Region I, it occupies only 1,500 square miles. This aquifer is composed of the saturated Comanche Peak, Edwards Limestones, and the Paluxy Sand. The average thickness is about 140 feet Groundwater discharge is through pumping and evapotranspiration (Mount et al, 1967).

Underneath the Ogallala aquifer is the Edwards-Trinity (High Plains) aquifer. In Region I, the Paluxy Sand portion of the Edwards-Trinity (High Plains) occurs generally between 300 and 400 ft below the land surface. The relatively thick Kiamichi Clay separates the Ogallala aquifer from the Comanche Peak and Edwards Limestones aquifer. The aquifer is under artesian condition. While at the outcrop in Border and Dawson Counties, the Ogallala aquifer is in water-table condition. Discharge of this aquifer is to the overlying Ogallala aquifer, wells, and springs at the base of the eastern escarpment of the Comanche Peak and Edwards Limestones in Dawson and Borden Counties.

The Santa Rosa Formation crops out east of the Colorado River in parts of Scurry, Mitchell, and Nolan Counties. The eastern part consists of a lower and an upper sand separated by shale. Groundwater moves toward the Colorado River and its tributaries. The western part of Santa Rosa lies in Gaines, Andrews, (under Ogallala) and Ector (under Edwards-Trinity (Plateau)) Counties. The western part outcrops in New Mexico to the west. The Santa Rosa of the Dockum Group is older than Paluxy Sand and is composed of interbedded lenses of sand, sandstone, gravel, and shale. Average thickness is about 200 feet This aquifer is under artesian conditions except in and near its outcrop. Groundwater discharge from the Santa Rosa aquifer is through springs and seeps in its eastern extremity in Mitchell, Nolan, and Scurry Counties. Water is also lost through evapotranspiration and from pumping wells. In the western part, the Santa Rosa aquifer discharges into the overlying Chinle Formation of the Dockum Group.

The Middle Colorado River Basin—Region II

Edwards-Trinity (Plateau) is the major aquifer extending from Region I into Region II. It occurs in 18 counties south of the Colorado River in Region II. The secondary aquifers are the Ellenburger-San Saba and Hickory surrounding the Llano uplift which is centered in Llano County. Other aquifers with limited extent are alluvium, Permian rocks, Pennsylvanian rocks, the Welge Sandstone of Wilberns Formation, Precambrian rocks, and the Trinity Group.

The Edwards-Trinity (Plateau) is composed of the Edwards and associated limestones (Comanche Peak, Edwards, and Georgetown) and sands of the Trinity Group. Well developed solution openings are common in the Edwards. Thickness of the Edwards may exceed 500 ft in the southern part of the high plateau where the Edwards is overlain by shale and limestone. Where the Edwards is exposed in the surface, sinkholes are characteristic and serve as recharge areas. Below and hydraulically connected to the Edwards is the Paluxy Sand in the northwestern part of Region II. The Hensell Sand in the southern part is separated from the Edwards by the Glen Rose Formation and the Walnut Clay. Both sands are hydraulically connected with the unconformably underlying, water-bearing rocks of Cambrian and Ordovician age. Edwards and Trinity rocks dip to the southeast at approximately 50 ft per mile (Mount et al, 1967).

Groundwater in the Edwards-Trinity (Plateau) moves from northwest to southeast in the region. It also moves locally to surface drainage courses where groundwater is discharged to support the baseflow. Baseflow studies indicate that the Edwards-Trinity aquifer produces perennial flow for the Llano (Holland Mendieta, 1965) and Pedernales Rivers (Holland and Hughes, 1964). The Llano River becomes perennial at Junction and the Pedernales River, ten miles west of Fredericksburg. Kuniansky and Holligan (1994) did a regional aquifer systems analysis using computer modeling. Their results of simulations indicated that the Edwards-Trinity (Plateau) aquifer discharges into the Concho, San Saba, Llano, Pedernales, and Colorado Rivers.

The Ellenburger-San Saba aquifer is composed of two different units: the Ellenburger of Ordovician limestone and the San Saba of Cambrian limestone. Because of the difficulty in distinguishing the two, they are considered one aquifer. This aquifer dips away from the Llano uplift on all sides and is absent over much of the uplift area due to erosion. Because of intensive faulting, structural conditions are very complex. This aquifer is presumed to extend less than 20 miles from the outcrop on all sides of the uplift. Depths to the top of the aquifer vary from land surface to more than 2,000 feet below land surface in northern McCulloch County. According to the geologic map, the Colorado River cuts into the Ellenburger-San Saba outcrop above Lake Buchanan in Lampasas, San Saba, Burnet, and Llano Counties. Baseflow of many of the streams in the Llano uplift are supported substantially by the Ellenburger-San Saba aquifer (Mount et al., 1967).

Similar to the Ellenburger-San Saba Limestones, the underlying Hickory Sandstone crops out intermittently around the periphery of the Precambrian core of the Llano Uplift in Llano County. The average dip of the Hickory Sandstone is about 100 feet per mile. However, abrupt changes in dip may occur locally near faults. The average thickness is 400 feet but only 50 to 75 percent of this thickness can be depended upon to bear water. It outcrops only on the north and west sides of the Llano uplift and within the ring of the Ellenburger-San Saba outcrop. No major streams transverse through the Hickory outcrop.

Alluvial deposits consisting mostly of gravel along the Colorado River and its tributary in Region II. This is a one to two mile wide band with a possible thickness to 170 feet (Thompson, 1967; Walker , 1967; Wilson, 1973). The main trunk of the Colorado River in Region II is over the Permian rocks underneath the Alluvium deposits. Over the Llano uplift, the deposits are thin with as much as a 20-foot stringer of sand and gravel in Coleman County (Walker 1967) and 50 feet in Brown County (Thompson 1967). In the central part of the Llano uplift, stream gravels derived from the granitic terrain are usually the only reliable source of groundwater for domestic use. The deposits along the Concho River west of San Angelo reaches to a thickness of 250 feet and are hydraulically connected with the Edwards-Trinity (Plateau) aquifer (Mount et al., 1967). The man-made lakes, no doubt, are hydraulically connected to the alluvium deposits, and possibly, in turn, connected to the bedrock water-bearing units underneath the alluvium.

Other minor water-bearing units are Permian rocks, Pennsylvanian rocks, Welge Sandstone, Precambrian rocks, and Trinity Group. Except the Standpipe Limestone and the Bullwagon Dolomite in eastern Tom Green County and western Runnels County, the Permian rocks are tight or yield only small amount of mineralized water to wells. For Pennsylvanian rocks, the sands of Strawn Group yield small amounts of water for domestic and livestock wells in the outcrop area in Brown, Mills, San Saba, and McCulloch Counties along the Colorado River by the Llano uplift. The cities of San Saba and Richland Springs obtain water from large springs in the Marble Falls Limestone. The Upper Cambrian Welge Sandstone is about 20 feet thick and yields small amounts of water where it crops out in the Llano uplift.

The Lower Colorado River Basin—Region III

Region III of the Colorado River basin does not possess a primary groundwater resource. From the statewide view of water resources, the Carrizo-Wilcox Sand is a major aquifer. However, because of its limited extent imposed by the basin boundaries, it's a secondary aquifer for Region III. There are two aquifers: the Carrizo-Wilcox Sand to the west in Bastrop and Fayette Counties and the Gulf Coast to the east in Fayette, Colorado, Wharton, and Matagorda Counties. Other minor aquifers in Region III are the Queen City Formation, the Yegua Formation, the Jackson Group, and the Alluvium, in ascending order.

The Gulf Coast aquifer consists of sands of the Catahoula, Oakville, Lagarto, Goliad, Lissie, and Beaumont units. The Miocene Catahoula Sandstone-Oakville Sandstone-Lagarto Clay unit crops out in southeastern Fayette County and northwestern Colorado County. Both Catahoula and Lagarto contain massive clay, which limits the development potential. The Oakville Sandstone that overlies the Catahoula, is a massive sand with minor interbeds of clays. The Pliocene Goliad Sand and the Pleistocene Lissie Formation unit crop out in a narrow band near Columbus in Colorado County on either side of the Colorado River. The Goliad Sand is a coarse grained sand interbedded with gravel and clay. The Lissie Formation is composed of massive beds and lenses of sand which grade into interbedded gravel and clay. This unit is the most prolific portion of the Gulf Coast aquifer. Near the coast, the Pleistocene Beaumont Clay yields water from sand stringers and beds of silt and fine sand (Mount et al., 1967; Baker, 1979; Hammond, 1969; Loskot et al, 1982; and Rogers, 1967).

Where the sands of the Gulf Coast aquifer appear at the surface, water-table conditions exist. Because the rocks dip toward the gulf at about 50 ft per mile, the aquifer becomes a confined condition downdip from the outcrop areas. Most of the aquifer is under artesian conditions. Due to salt water intrusion, freshwater of the aquifer is shallower at the mouth (at about 600 ft depth) but is deeper inland. Groundwater discharge is through wells and seeps along drainage courses and through upward leakage into overlying formations. However, Mount et al. (1967) considered that at maximum groundwater development, recharge at the outcrop would be greater than the amount needed for withdrawal. Thus, there would be no depletion of groundwater that would decrease baseflow.

The Carrizo-Wilcox Sand crops out in a broad band through a large part of Bastrop County. Beds dip at 100 to 150 ft per mile in Fayette County to the east. Thickness varies to zero at the outcrop to about 2,500 feet in the southeastern part of Bastrop County. The Carrizo-Wilcox is composed of lenses of sand and clay with beds of lignite that occur mostly in the lower part of the Wilcox. Near the surface, the sands are generally cemented with iron precipitate. The Wilcox is divided into Sabinetown, Rockdale, and Seguine Formations with the Rockdale Formation being the most prolific. The Carrizo Formation overlies the Wilcox Group and is composed entirely of unconsolidated sands.

In the outcrop area, the Carrizo-Wilcox aquifer is under a water-table condition. Artesian conditions are encountered downdip from the outcrop. The aquifer is bounded by tight clay of the Midway Group from below and tight clay of the Recklaw Formation from above. Groundwater moves toward topographic lows as seeps and baseflow and in the direction of a regional dip toward the coast. Even though the recharge to the aquifer is large, much of the potential recharge is rejected (Mount at al., 1967 and Follett, 1970).

Minor aquifers are Queen City Sand, Yega Formation, and Jackson Group. The Queen City Sand overlies the Recklaw Formation and outcrops as a 4-mile wide band paralleling to the coast in the southern part of Bastrop County. It supplies groundwater to

Smithville, in Bastrop County. The outcrop of the Yega Formation parallels to the Queen City Sand as a band along the Bastrop and Fayette County line (Rogers, 1967d) The City of Flatonia in southern Fayette draws water from the Yega Formation. The Jackson Group crop out as a band east of the Yega Formation outcrop. Because the Jackson is associated with volcanic activity, it can not furnish adequate water for a large well. However, its lenticular sands in the upper portion provide water for La Grange in Fayette County.

As in Region II, the alluvial and terrace deposits are more prominent in Region III along the Colorado River. Its width varies from about five miles east of Austin in Travis County to over ten miles north of Bay City in Matagorda County. It is obvious that there is the hydrologic communication between these deposits and the Colorado River. Because the Colorado River flows to the Gulf relatively perpendicular to the outcrops of the geologic formations, the River and its associated alluvium and terrace deposits may recharge the aquifers. According to Mount et al (1967), only Bastrop draws its water supply from the alluvium deposits in Region III (Follett, 1970). This may reduce streamflow.

3.14.2 Significance of Interaction

Region I

In the semi-arid Region I, encompassing from the headwaters of the west to the confluence of the River in Coke-Runnels County line, groundwater contributes an insignificant amount of baseflow to the Colorado River and its tributaries. As stated previously, because about 50% of Region I contributes no surface runoff, the recharge to groundwater derived from surface runoff can be considered minimal. Potential surface water and groundwater interaction is limited to the reach between Colorado City and Champion Creek Lakes in Mitchell County and J. B. Thomas Lake in Borden and Scurry Counties. No dam is 100% seepage free. These man-made lakes create perennial streamflow downstream from the dams and probably also increase bank storage and the underlying groundwater reservoir. Due to brine disposals from the oil fields and salt seeps, the Colorado River in Borden County has salinity problem, limiting its use for domestic consumption and groundwater recharge.

The August1918 channel gain and loss survey (Manford, Dixon, and Dent, 1960) found that there was no flow from Robert Lee down stream to Pecan Bayou in Region II. One can therefore surmise that there would be no streamflow for the Colorado River above Robert Lee, indicating that the river has the potential of losing water between Lake J. B. Thomas and E. V. Spence. It should be noted that there was smaller discharge in the downstream gaging station than that of the upstream gaging stations during low flow period, meaning the river recharges the underlying aquifer. It is possible that the decrease in streamflow is caused by evapotranspiration from phreatophytes along the flood plain of the lower reaches. Baker et al., documented that little or no water was contained in the alluvial sediments prior to vegetation clearing [Baker et al (1963, page 97)]. After the removal of phreatophytes, the water table rose in the alluvium. Since late in the 19th century, when crop farming was began, the water table has risen at least 20 feet in the alluvium southwest of Vernon and 60 feet in part of Knox County from about 1900 to 1933.

Region II

Unlike Region I, the Colorado River is perennial in Region II. According to the computer simulations of Kuniansky and Holligan (1994), the streamflow of the Colorado River is intimately related to the aquifers of the region. The Edwards-Trinity (Plateau) aquifer feeds springs and baseflow of the Concho, San Saba, Llano, and Pedernales River. The Glen Rose Limestone of the Trinity Group, the Edwards Limestone of the Hill Country, and the BFZ contribute baseflow to Barton Creek and Onion Creek in and east of Austin. Onion Creek also recharges the Edwards aquifer where it crosses the BFZ.

However, immediately below the springs, the streams may losing water. For example, in Concho River, Spring Creek was fed by Seven Springs, Dove Creek was fed by Dove Creek Spring, and the South Concho River was fed by the Main Springs (Manford, Dixon, and Dent, 1960). In 1918, the Middle Concho River above Spring Creek was dry, but between the confluence with Spring Creek to the confluence with the South Concho River, the Middle Concho River gained 2 cfs in 2 miles. The North Concho from Sterling City to Water Valley gained 1 cfs but lost 2 cfs from Water Valley to the mouth. The South Concho River gained 12 cfs from Christoval to the confluence with the North Concho River. About ¼ miles below the South and North Concho River confluence, the Concho began to lose water. At its mouth with the Colorado River about 51 river miles downstream, there was no flow registered on March 27, 1918. This condition is in contrary with the USGS 1991 gaging data which indicate that the Concho River had an average discharge of 158 cfs at San Angelo and 210 cfs at Paint Rock, a gaining of 52 cfs prior to major reservoirs construction. After reservoir construction, the average discharge of the Concho River was 21 cfs at San Angelo and 59 cfs at Paint Rock, an increase of 38 cfs. Consideration would be giving in comparing the 1918 and the 1991 data. The 1918 data were collected at one time in March during low flow period while the 1991 were average of several years' annual flow data.

As stated before, the August 1918 gain and loss survey reported no flow from Robert Lee down to the mouth with Pecan Bayou for 164 river miles (Manford, Dixon, and Dent, 1960). Pecan Bayou contributed 0.2 cfs to the Colorado River. The San Saba River added 2.9 cfs, increasing the Colorado River flow below the confluence to 5.2 cfs. The river lost water between the mouth of the San Saba River and Bluffton-Kingsland road, about 55 miles. From there to the mouth of the Llano River, streamflow increased from 2.6 cfs to 3.7 cfs. Then, discharge increased to 9 cfs above the mouth of the Pedernales River. Pedernales River had no flow at its mouth. The river lost water for the next 12 miles to 6.6 cfs at Watsons Ford. Three miles downstream at Cameron Road, the river was gaged at 8 cfs. For another 12 miles, below Austin Dam, the discharge was 20.5 cfs.

Two miles below the dam, Barton Creek was flowing at a rate of 14.3 cfs. Due to a diversion, the river was 26.9 cfs at Austin gaging station one mile below Barton Creek. Sixteen miles downstream at Platts Ferry below Austin, the river flowed at 51.1 cfs, indicating a gaining reach. The Colorado River above Onion Creek was gaged at 48.4 cfs, indicating a losing reach.

The two-mile band of alluvium deposits along the river from Mitchell County to the west to Travis County to the east may also regulate the streamflow. Seepage derived from the man-made lakes becomes underflow and appears in the stream channels downstream from the dams. The Kuniansky and Hollingan (1994) groundwater modeling is part of the USGS regional aquifer assessment. Thus, major wellfield development in the Edwards-Trinity (Plateau) in the future would reduce the streamflow of the Colorado River and its tributaries. On the other hand, the Colorado River and its tributaries may not recharge the Edwards-Trinity (Plateau) aquifer because the perennial reaches are at lower elevations below the outcrop of the Edwards-Trinity rocks .

Region III

The Colorado River is perennial in Region III. The perennial condition is derived from baseflow due to aquifer discharge, seepage and reservoir release from a chain of dams upstream of Austin, and wastewater discharges from the cities along the river. The wellfield of the City of Bastrop draws water from the alluvium deposits and will induce recharge from the Colorado River to the alluvium aquifer. Moreover, Region III in the basin is a long, narrow band of watershed. In the outcrop areas, the groundwater divide may coincide with the surface watershed divide of the Colorado River. In other places, the two divides may not coincide. Therefore, there is the possibility that with extensive development of wellfields in other watersheds in the future, the groundwater divides may shift and decline. Consequently, this might impact the baseflow (and the discharge) of the Colorado River. The other watersheds are the Brazos-Colorado Coastal Basin, the Colorado-Lavaca Coastal Basin, and the Lavaca River Basin.

The USGS (1991) gaging data for the Colorado River at Austin is 1,918 cfs and at Columbus, 2,814 cfs. Annual flow at Wharton is 2,595 cfs and at Bay City, 34 miles downstream, 2,314 cfs. This 500 cfs reduction is due to irrigation diversions.

Table 3.14.1
Surface Water and Groundwater Interaction, Colorado River Basin

Reach	Water Quality Segment	Surface water-Groundwater Interaction	Aquifer	Probability/ Comments
Colorado River above Lake J.B. Thomas	1413	Yes, losing	Ogallala and Edwards-Trinity Plateau aquifers: depth to aquifers are below streambeds; ephemeral streams in semi-arid area indicate losing flow conditions; USGS gaging station data above lake indicates streamflow only in August and September.	High: however, just above the lake, salt seeps contribute small baseflow
Below Lake J. B. Thomas and above E. V. Spence Reservoir	1412	Yes, gaining or losing.	Ogallala, Edwards-Trinity Plateau, and Santa Rosa aquifers: seepage from lakes; flow is regulated by Lake JB Thomas. Three USGS gaging station data indicated there were no flows, i.e., losing conditions; Coke County (Wilson 1973) groundwater report indicates gaining conditions. Mount et al. (1967) stated that south of Colorado City, Santa Rosa aquifer outcrop contributes baseflow.	Medium. Lake Colorado on Morgan Creek and Champion Creek Reservoir on Champion Creek may also provide seepage.
Between E. V. Spence Reservoir and the confluence with Concho River (O. H. Ivie Reservoir)	1411, 1426 & 1433	Yes, gaining or losing.	Ogallala, Edwards-Trinity Plateau, and Santa Rosa aquifers: prior to Spence Reservoir, the river had more flow than below. Flow increased downstream; also had no flow days.	Medium: Low permeable Permian rock outcrops might not contribute significant amount of baseflow. Also wastewater from cities may augment flow.
Concho River	1424, 1423, 1422, 1425 & 1421	Yes, gaining at springs and losing to the mouths.	Edward-Trinity (Plateau) aquifer: Concho River is gaining along the main stem probably due to springs from the base of aquifer. Dove Creek Spring between the South and Middle Concho flows at 16.4 cfs.	Medium.

Table 3.14.1 (Continued)
Surface Water and Groundwater Interaction, Colorado River Basin

Reach	Water Quality Segment	Surface water-Groundwater Interaction	Aquifer	Probability/ Comments
Below O. H. Ivie Reservoir and above Pecan Bayou	1410	Yes, gaining or losing	Edward-Trinity (Plateau) aquifer on the west side of the river only: annual streamflow increased below O. H. Ivie Reservoir from 215 cfs to 272 cfs west of US Highway 377. Below San Saba river, discharge was 1,340 cfs. Pecan Bayou and San Saba River flowed at 134 cfs and 222 cfs, respectively, at mouths with the Colorado River	Medium: in general the river flows over outcrops of the Permian and Pennsylvanian rocks which are not water bearing. The 1918 low flow survey indicated no flow between Robert Lee and Pecan Bayou, but gaining between Pecan Bayou and San Saba River.
Pecan Bayou	1420, 1418, 1417, 1419	Yes, gaining and losing	Trinity aquifer partial outcrop: outcrops at east-half of Brown County. The bayou cuts though the Strawn Group below Lake Brownwood to its mouth with the River. Groundwater may contribute to streamflow below the lake. Above the lake, the stream may be losing.	Medium: Pecan Bayou is regulated by four reservoirs upstream from the city of Brownwood. Dam seepage may contribute perennial flow but be misinterpreted as baseflow from aquifer.
San Saba River	1416	Yes, gaining	Trinity-Edwards (Plateau) aquifer: discharge from springs and seeps and outcrop of the aquifer. However, faults created by the Llano Uplift might cause river losing to the Ordovician limestones.	High
Llano River	1415	Yes, gaining	Edwards-Trinity (Plateau) aquifer water-bearing outcrops sustained the river from springs above Junction in Kimble County (Holland and Mendieta, 1965).	High
Pedernales River	1414	Yes, gaining	Edwards-Trinity (Plateau) aquifer water-bearing outcrops sustained the river from springs above Junction in Kimble County (Holland and Mendieta, 1965) (Holland and Hughes, 1964).	High

Table 3.14.1 (Continued)
Surface Water and Groundwater Interaction, Colorado River Basin

Reach	Water Quality Segment	Surface water-Groundwater Interaction	Aquifer	Probability/ Comments
Colorado River between San Saba River and Onion Creek	1409, 1408, 1407, 1406, 1405, 1404, 1403	Yes, gaining	Ordovician limestone aquifers, Glen Rose aquifer, and the Edwards aquifer: These water-bearing units discharge to the river.	High: Dam seepage from the lake chain (Lake Buchanan, Inks Lake, Lake LBJ, Lake Marble Falls, Lake Travis, Lake Austin, and Town Lake) may also contribute perennial flow of the river.
Onion Creek	1427	Yes, gaining	Edwards aquifer: discharge conditions.	High
Colorado River below Onion Creek to its mouth	1402, 1401	Yes, gaining	Gulf Coast and Carrizo-Wilcox Sand aquifers: discharge conditions.	High

3.14.3 References

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3.15 THE COLORADO-LAVACA COASTAL BASIN

3.15.1 Hydrologic Characteristics

The Colorado-Lavaca Coastal Basin is bounded on the east by the Colorado River Basin and on the west by the Lavaca-Guadalupe Coastal Basin and the Lavaca River Basin (Figure 3.15.1). The total drainage area of the basin is 939 square miles which drains into Matagorda Bay (TWDB, 1997). Major drainage systems are Tres Palacios Creek to the east, the East and West Carancahua Creeks in the middle, and Cox Creek to the west. Tres Palacios Creek discharges into the Tres Palacios Bay; Carancahua Creek, Carancahua Bay; and Cox Creek, Lavaca Bay. The basin is located in the West Gulf Coast section of the Coastal Plains province, which is predominantly a smooth, featureless, depositional plain rising from sea level to an altitude of less than 400 feet at the distal extent of the interior boundary in the northeastern portion of the basin (TWDB 1979). The basin exhibits a wet subhumid climate with a mean annual rainfall of about 40

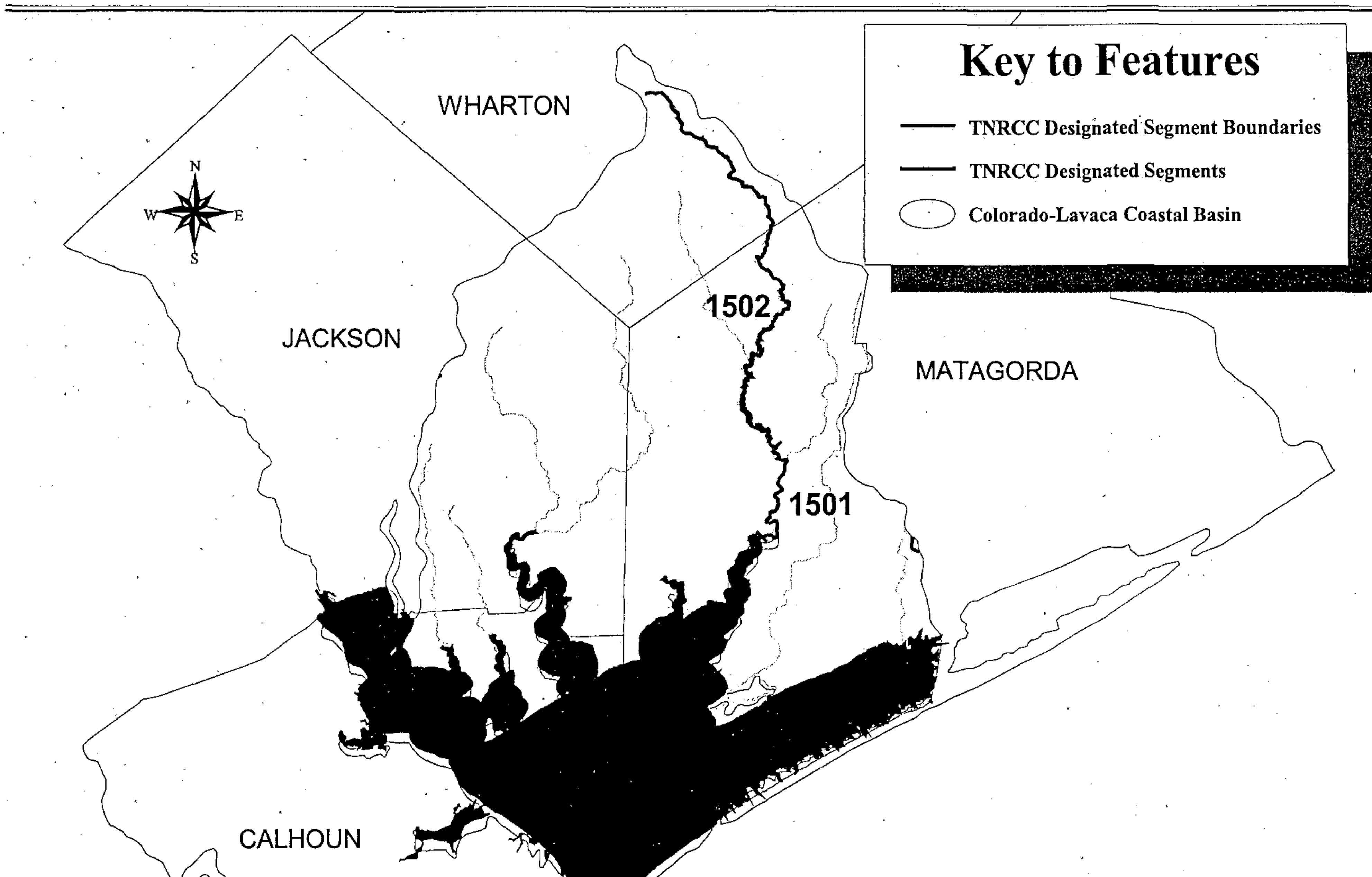

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FIGURE 3.15.1

COLORADO-LAVACA
COASTAL BASIN
TNRCC Designated Stream Segments

10 0 10 Kilometers

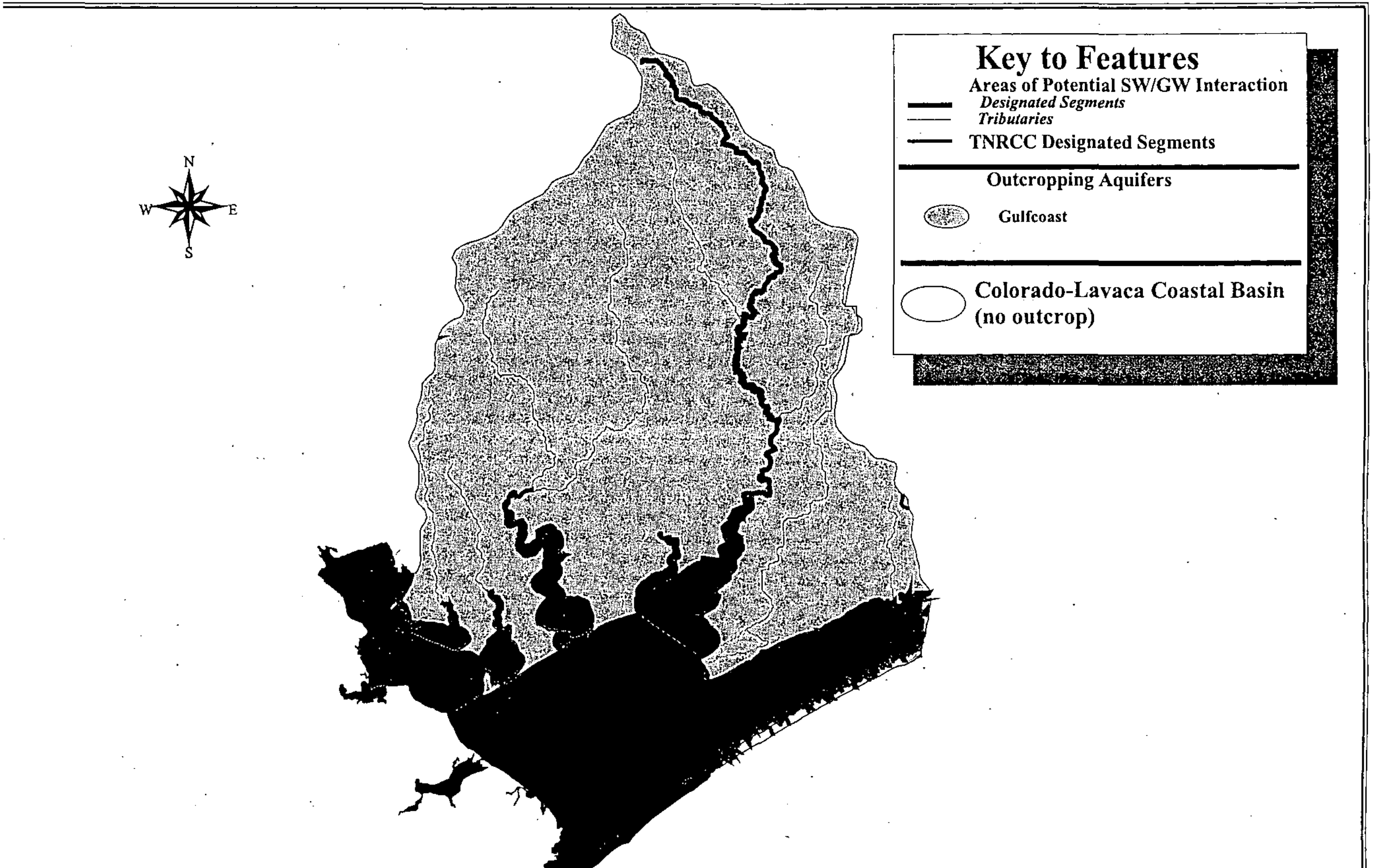

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FIGURE 3.15.2
COLORADO-LAVACA COASTAL BASIN
Potential Surface Water/ Groundwater Interaction

10 0 10 Kilometers

Source: TNRIS/TWDB GIS Planning Division

3.15.2 Significance of The Interaction

Since the entire basin is underlain by the Gulf Coast aquifer outcrop, there is surface water and groundwater interaction. However, the portion of groundwater contribution to streamflow may not be significant relative to the high annual rainfall and the rice field irrigation return flow. The irrigation water is imported from the Colorado River Basin.

Table 3.15.1
Surface Water and Groundwater Interaction, Colorado Lavaca Coastal Basin

Reach	Water Quality Segment	SW/GW Interaction	Aquifer	Probability/ Comments
Tres Palacios Creek	1501,1502	Yes, gaining	Gulf Coast aquifer: underlies creek area.	Low: tail water from rice fields may mask groundwater effluent.
West and East Carancahua Creek	NA	Yes, gaining	Gulf Coast aquifer: underlies creek area.	Low: tail water from rice fields may mask groundwater effluent.
Cox Creek	NA	Yes, gaining	Gulf Coast aquifer: underlies creek area.	Low: tail water from rice fields may mask groundwater effluent.

3.15.3 References

Slade, R., U.S. Geological Survey, Texas District Office, personal communication, June 1999.

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TWDB, 1997. Water for Texas, Texas Water Development Board, August, 1997.

USGS, 1991. Water Resources Data, Texas, Water Year 1991.

3.16 THE LAVACA RIVER BASIN

3.16.1 Hydrologic Characteristics

The Lavaca River basin is bounded on the north and east by the Colorado River basin, on the west by the Guadalupe River basin, on the southeast by the Colorado-Lavaca Coastal Basin, and on the southwest by the Lavaca-Guadalupe Coastal Basin (TNRCC, 1996). Headwaters of the Lavaca River originate in southern Fayette County and flow into

Lavaca Bay (Figure 3.16.1). About 60 percent of the basin is drained by the Navidad River and its principal tributary Mustang Creek. The Navidad River headwaters also originate in Fayette County, and flows to Lake Texana. About 40 percent of the basin is drained by the Lavaca River. The confluence of the Lavaca and Navidad Rivers is about two miles east of Vanderbilt in Jackson County and below the dam of Lake Texana. Total drainage area of the Lavaca River in Texas is 2,309 square miles.

The basin is located in the West Gulf Coast section of the Coastal Plains province, which drains a coastal prairie north of the San Antonio-Matagorda Bay area. The area is predominantly a smooth, featureless, depositional plain rising from sea level to an altitude of less than 400 feet at the distal extent of the interior boundary in the northeastern portion of the basin (TWDB 1979). The basin exhibits a predominantly wet subhumid climate with a mean annual rainfall of about 38 inches (TWC, 1963).

Regions

The Lavaca River basin is treated as one hydrologic unit.

Major Aquifers

The Lavaca River basin is underlain by the Gulf Coast Aquifer System (GCAS) as shown in Figure 3.16.2. The GCAS is a complex network of interbedded sediments which have been segregated into four generally recognized water producing formations. Aggregately, these formations form a large leaky artesian aquifer system, the GCAS, that provides groundwater for agricultural, industrial, and municipal uses.

The Chicot aquifer, which is the upper or down-dip most component of the GCAS, outcrops throughout most of the Lavaca River basin and is hydrologically interconnected with the underlying by Evangeline aquifer.(TWDB, 1979). The Evangeline aquifer outcrops in the northwestern portion of the basin. The thickness of fresh to slightly saline water within the aquifer ranges from about 200 feet in the northwestern portion of the basin to about 800 feet in the central portion of the basin (TWC, 1963). Surface water channels are sufficiently entrenched into the surficial sediments to allow shallow groundwater to discharge into them (Ray Slade, personal communication, 1999).

Minor Aquifers

There are no minor aquifer systems in the Lavaca River basin.

Reservoirs. Lake Texana (Palmetto Bend Reservoir), located about 12 river miles above Lavaca Bay, is constructed on the main stem of the Navidad River, Mustang and Sandy Creeks. Lake Texana is the only water supply reservoir in the basin and is primarily used to meet required water releases for bay and estuary inflow needs. Since most of the municipal water supply requirements are met with groundwater, future uses of stored

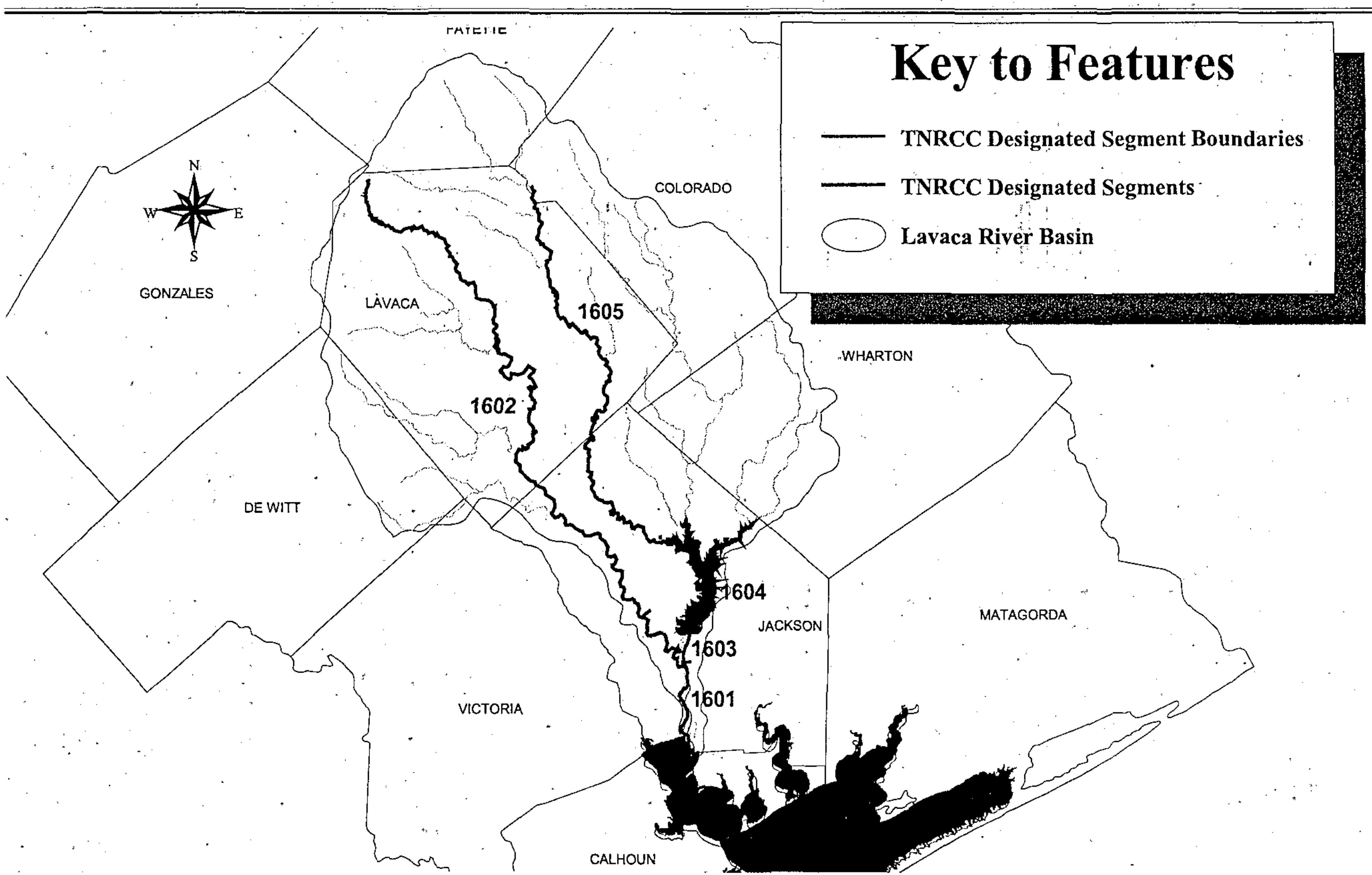

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FIGURE 3.16.1

LAVACA RIVER BASIN
TNRCC Destgnated Stream Segments

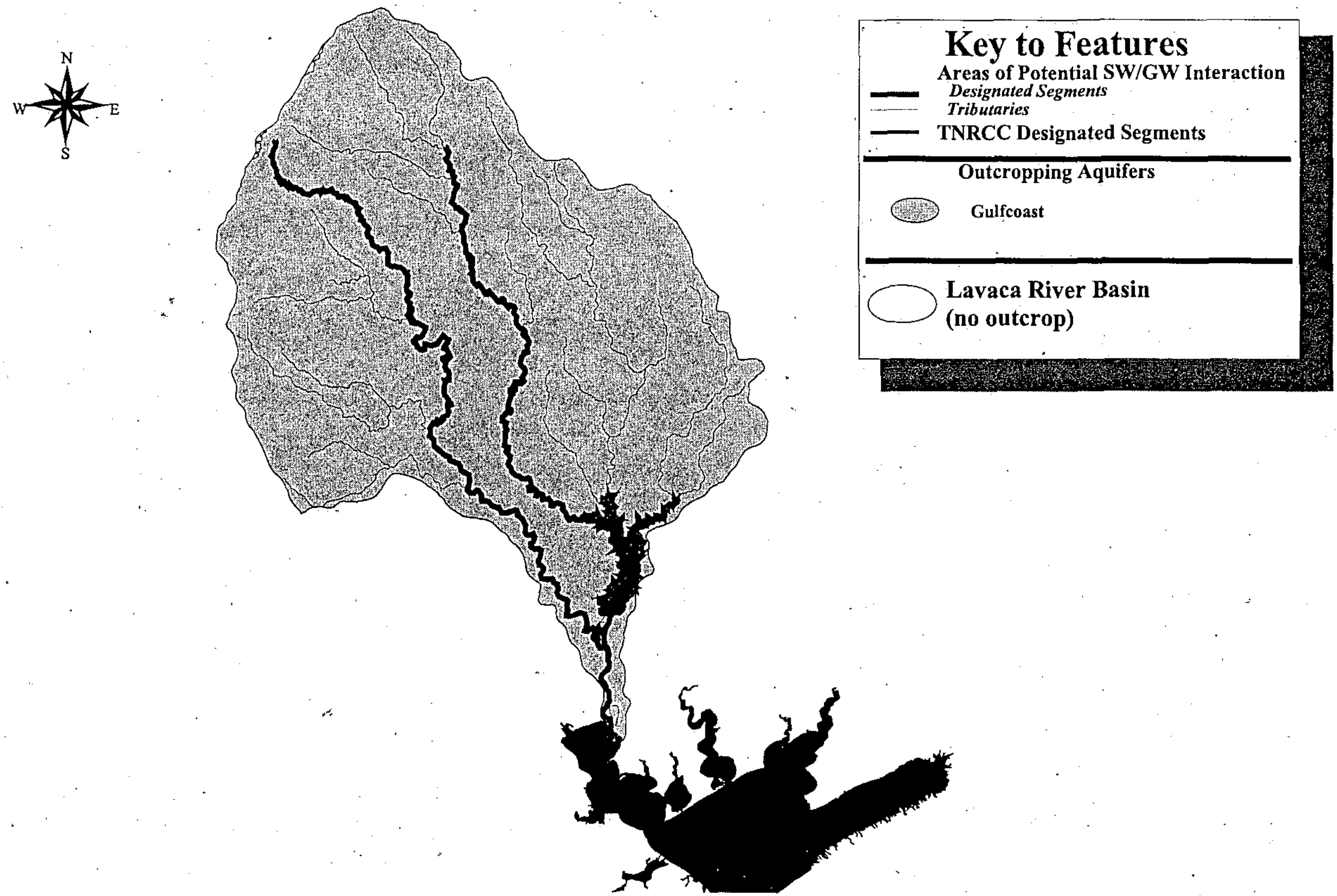

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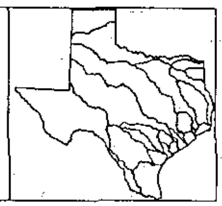
FIGURE 3.16.2

LAVACA RIVER BASIN
Potential Surface Water/ Groundwater Interaction



water in Lake Texana may include interbasin transfers. In 1974, 96 percent of the 323,600 acre feet in-basin water use was for irrigation. The majority of the source is from groundwater (TDWB 1977).

3.16.2 Significance of The Interaction

Shallow groundwater is generally expected to discharge into river channels and drainage-ways throughout the basin due to the shallow depths to groundwater, low hydraulic gradients in the shallow water bearing strata present in the outcrop zone, and the surficial exposure of sediments in the outcrop of the GCAS. However, the expected rates of groundwater inflow into surface water channels is believed to be insignificant for purposes of future water availability modeling. As well, the probability of inflows into or out of the Lake Texana from groundwater flow is expected. Future water availability models would likely discover that model calibration is best suited to considering Lake Texana as a constant head boundary relative to groundwater.

Table 3.16.1
Surface Water and Groundwater Interaction, Lavaca River Basin

Reach	Water Segment	SW/GW Interaction	Aquifer	Probability/ Comments
West Mustang Creek and Sandy Creek above Lake Texana	NA	Yes, gaining	Gulf Coast aquifer: underlies basin. Expected that shallow groundwater would discharge to surface water.	Medium: however, rice fields return water may mask groundwater discharge to creeks.
Navidad River from Lake Texana to headwaters	1063, 1604	Yes, gaining	Gulf Coast aquifer: underlies basin. Expected that shallow groundwater would discharge to surface water.	Medium: groundwater should discharge to river, but Lake Texana may recharge groundwater due to constant head.
Lavaca River from bay to headwaters	1601, 1602	Yes, gaining	Gulf Coast aquifer: underlies basin. Expected that shallow groundwater would discharge to surface water.	High: USGS upper and lower gaging stations indicating six-fold increase of streamflow downstream.

3.16.3 References

Slade, R., U.S. Geological Survey, Texas District Office, personal communication, June 1999.

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3.17 THE LAVACA-GUADALUPE COASTAL BASIN

3.17.1 Hydrologic Characteristics

The Lavaca-Guadalupe Coastal Basin is bounded on the east by the Lavaca River Basin and the Colorado-Lavaca Coastal Basin, and on the west by the Guadalupe River Basin and San Antonio-Nueces Coastal Basin (Figure 3.17.1). The southern extent of the basin is bordered on the southwest by San Antonio Bay and on the southeast by Lavaca Bay and Matagorda Bay. Total drainage area of the basin is 998 square miles (TWDB, 1997). The basin is located in the West Gulf Coast section of the Coastal Plains province, which is predominantly a smooth, featureless, depositional plain rising from sea level to an altitude of about 200 feet (TWDB, 1979). The basin exhibits a wet to dry subhumid climate with a mean annual rainfall of about 35 inches (TWC, 1963).

The sediments that are exposed on the land surface and in the surface water channels throughout the Lavaca-Guadalupe Coastal Basin consists of beds, lenses, and stringers of gravel and coarse to fine sand interbedded with silt and clay beds and lenses. These sediments form a series of gently dipping truncated wedges, which thicken toward the coast, causing each wedge to have a slightly steeper dip than the overlying wedge. At depth, the lithology of these sediments become more dominantly silt and clay (TWC, 1963). Surface water channels are sufficiently entrenched into the surficial sediments to allow shallow groundwater to discharge into them (Ray Slade, personal communication, 1999).

Arenosa Creek with its tributaries (Gracitas Creek, Marcado Creek, Arroyo Palo Alto and Placedo Creek) discharge into Lavaca Bay, north of Port Lavaca. USGS data (1991) indicates that Gracitas Creek at US Highway 59 has an annual discharge of 50.1 cfs and Placedo Creek, east of Placedo, has an annual discharge of 63.1 cfs. This basin encompasses the southern end of the rice producing area in Texas and receives irrigation water imported from the Guadalupe River.

Regions

The Lavaca-Guadalupe Coastal Basin is treated as one hydrologic unit.

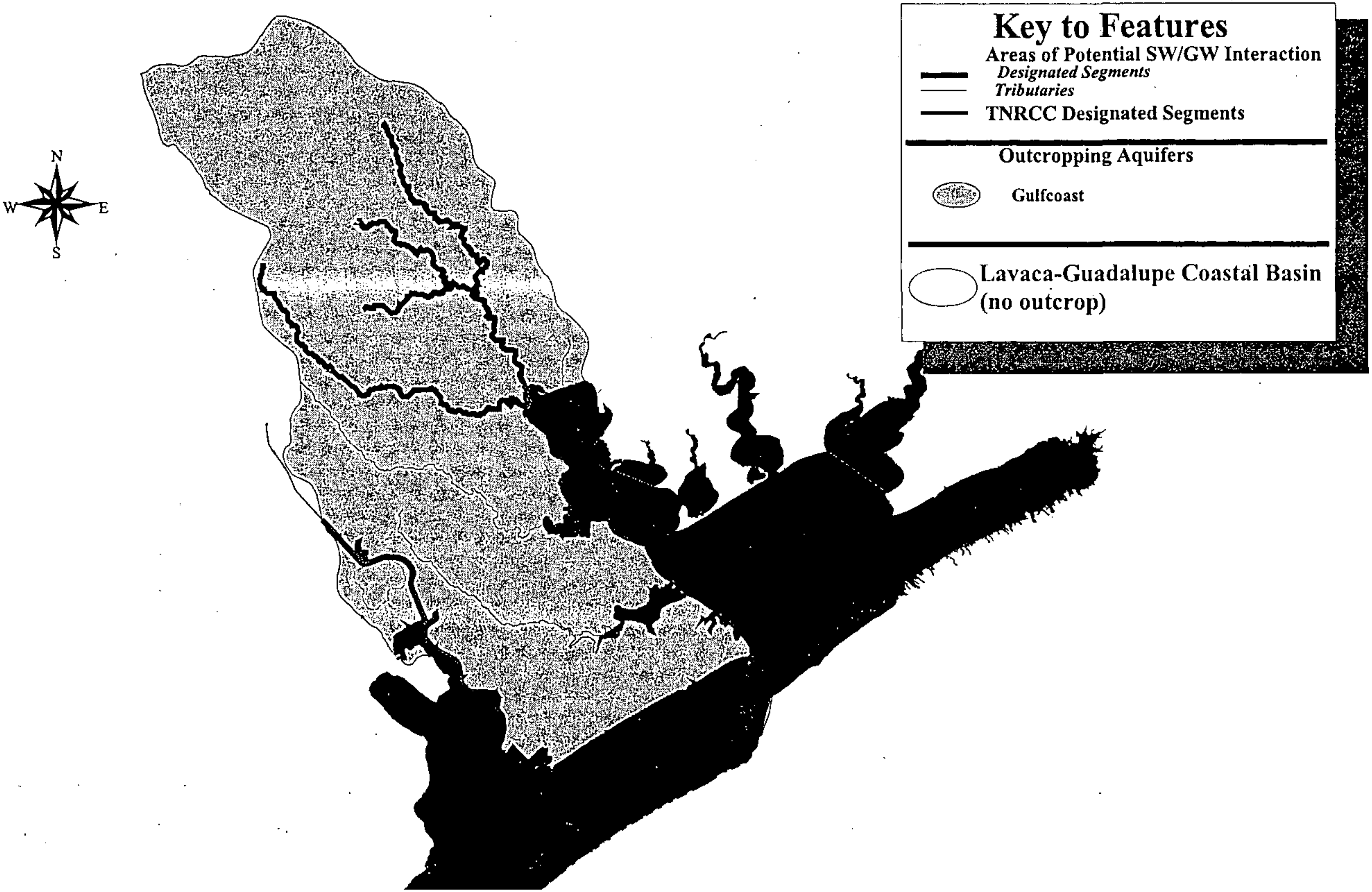

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FIGURE 3.17.2

LAVACA-GUADALUPE COASTAL BASIN
Potential Surface Water/ Groundwater Interaction

4 0 4 8 Kilometers

Source: TNRIS/TWDB GIS Planning Division

Major Aquifers

The Lavaca-Guadalupe Coastal Basin is underlain by the Gulf Coast Aquifer System (GCAS) as shown in Figure 3.17.2. The GCAS is a complex network of interbedded sediments which have been segregated into four generally recognized water producing formations. Aggregately, these formations form a large leaky artesian aquifer system, the GCAS, that provides groundwater for agricultural, industrial, and municipal uses.

The Chicot aquifer, which is the upper or down-dip most component of the GCAS, outcrops within the entire Lavaca-Guadalupe Coastal Basin and is hydrologically interconnected with the underlying by Evangeline aquifer (TWDB, 1979). The thickness of fresh to slightly saline water within the aquifer ranges from less than 200 feet near the coast to more than 800 feet in the northern portion of the basin east of Victoria (TWC, 1963). Due to the shallow depths to groundwater and the surficial exposure of sediments in the outcrop of the GCAS, it is expected that groundwater would generally discharge into drainage ways and coastal embayment throughout the basin.

Minor Aquifers

There are no minor aquifer systems in the Lavaca-Guadalupe Coastal Basin.

Reservoirs

There are no storage reservoirs in the Lavaca-Guadalupe Coastal Basin.

3.17.2 Significance of The Interaction

There are no fresh water stream flows or river segments that have been identified for water availability modeling. Therefore, for purposes of this report, there are no significant surface water/groundwater interaction areas in the Lavaca-Guadalupe Coastal Basin.

Table 3.17.1
Surface Water and Groundwater Interaction, Lavaca-Guadalupe Coastal Basin

Reach	Water Segment	SW/GW Interaction	Aquifer	Probability/ Comments
Gracitas and Placedo Creek above bay	NA	Yes, gaining	Gulf Coast aquifer: outcrop.	Medium

3.17.3 References

Slade, R., U.S. Geological Survey, Texas District Office, personal communication, June 1999.

TWC, 1963. Reconnaissance Investigation of the Ground-Water Resources of the Gulf Coast Region, Texas, Texas Water Commission, Bulletin 6305, June 1963.

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3.18 THE GUADALUPE RIVER BASIN

3.18.1 Hydrologic Characteristics

The Guadalupe River basin is bounded on the north by the Colorado River Basin, on the east by the Lavaca River Basin and Lavaca-Guadalupe Coastal Basin, and on the west and south by the Nueces and San Antonio River Basins. Total basin drainage is 6,070 square miles. Headwaters of the Guadalupe River form in southwestern Kerr County at 2,360 feet msl. The river flows easterly to Gonzales and then southeasterly into the San Antonio Bay. Major tributaries are the Blanco and San Marcos Rivers (Figure 3.18.1).

The Blanco River originates in northern Kendall County at 1,900 feet msl and flow easterly, joining the San Marcos River two miles southeast of San Marcos at 545 feet msl. The San Marcos River originates at San Marcos from the flow of the San Marcos Springs, and joins the Guadalupe River at Gonzales at 252 feet msl.

The South Fork of the Guadalupe River originates in southwestern Kerr County and joins the North Fork at Hunt, about 10 miles west of Kerrville, at 1,735 feet msl, in Kerr County. From Hunt to Kerrville, the river channel is incised into the upper member of the Glen Rose Limestone; the river meanders through its narrow valley, flowing intermittently over rapids or through long pools of natural or man-made origin. The channel bed is composed alternately of limestone and of highly porous alluvial deposits. From Kerrville to Comfort in Kendall County, at 1,370 feet msl, the topography is rolling, and the alluvial valleys widen. (Kuntz and Smith, 1965). In the vicinity of Kendall and Comal County line, the river cuts into the Travis Peak Formation, which is older than the Glen Rose Limestone, west of the US Highway 281. East of US Highway 281, the river resumes flow over the Glen Rose Limestone outcrop. Below Canyon Lake, the river flows over the Edwards Limestone which is also the Balcones fault zone (BFZ) (Holland, 1965). The Comal River originates west of New Braunfels and becomes perennial from the flow of the Comal Springs in Landa Park in New Braunfels. The

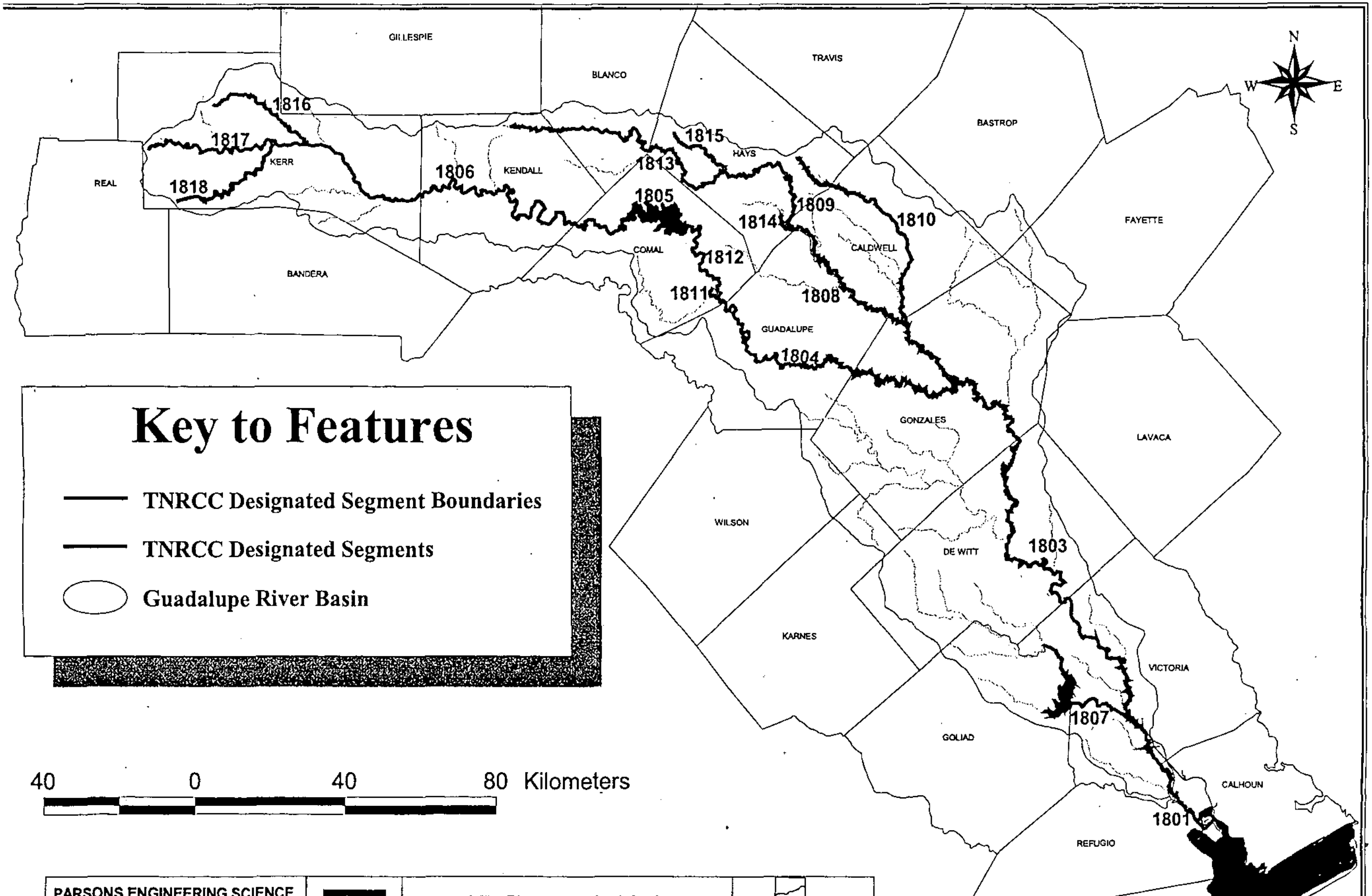

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FIGURE 3.18.1

GUADALUPE RIVER BASIN
TNRCC Designated Stream Segments

Comal River joins the Guadalupe River west of Interstate Highway 35 (I-35) at 583 feet msl. About five miles south of Victoria in Victoria County, Coleto Creek joins the Guadalupe River at 20 feet msl. The river debauches into the San Antonio Bay, about ten miles north of the Aransas National Wildlife Refuge.

Regions

The Guadalupe River basin is divided into two hydrologic units. Region I is the Edwards Plateau including the BFZ and Region II, the West Gulf Coast Plain (TWDB, 1977, Alexander; Meyers, and Dale, 1964). Demarcation of the regions is generally along U.S. Highway I-35.

As stated before, upper reaches of the Guadalupe River basin are underlain by the Cretaceous-age (65 to 140 mya) limestone which forms the Edwards Plateau (Figure 3.18.2). East and south of the Plateau are the upper Cretaceous chalk, limestone, and clay. The extensive BFZ separates the Edwards Plateau from the West Gulf Coast Plain. Over the West Gulf Coastal Plain, Tertiary-age (2 to 65 mya) sand, silt, clay, glauconite, volcanic ash and lignite dip southeasterly toward the Gulf. In turn, these strata are overlain by clay, silt, and sand of the Pleistocene-age Beaumont Formation in the coastal area. Throughout the basin, alluvial sediments and terrace deposits of Recent age occur along streams and cap the upland areas.

Annual precipitation in Region I is 30 inches and in Region II is 40 inches. The net lake evaporation rate is 25 inches by the coast and 49 inches in the northwest of the basin in Kerr County.

Major Aquifers

Three major aquifers occur in Region I and two in Region II (TWDB, 1977). In the Edwards Plateau, the Edwards-Trinity (Plateau) aquifer occurs in a small area in the northern part of the basin. It consists of the Comanche Peak, Edwards, and Georgetown Limestones and sand of the Trinity Group. The upper part of the aquifer is made up of various types of limestones with secondary porosity resulting from fractures and solution cavities. The lower part consists of interbedded fine sand and clay. Total thickness reaches to 500 feet. Most existing wells are low yield, but well yields of 250 to 500 gpm are possible where there is sufficient saturated thickness. The aquifer receives recharge from precipitation falling over the outcrops. The water is discharged chiefly through seeps and springs at the contact between Edwards and the underlying Glen Rose Limestone. The Edwards Plateau aquifer is typically in a water-table condition and groundwater flows south and southeastward.

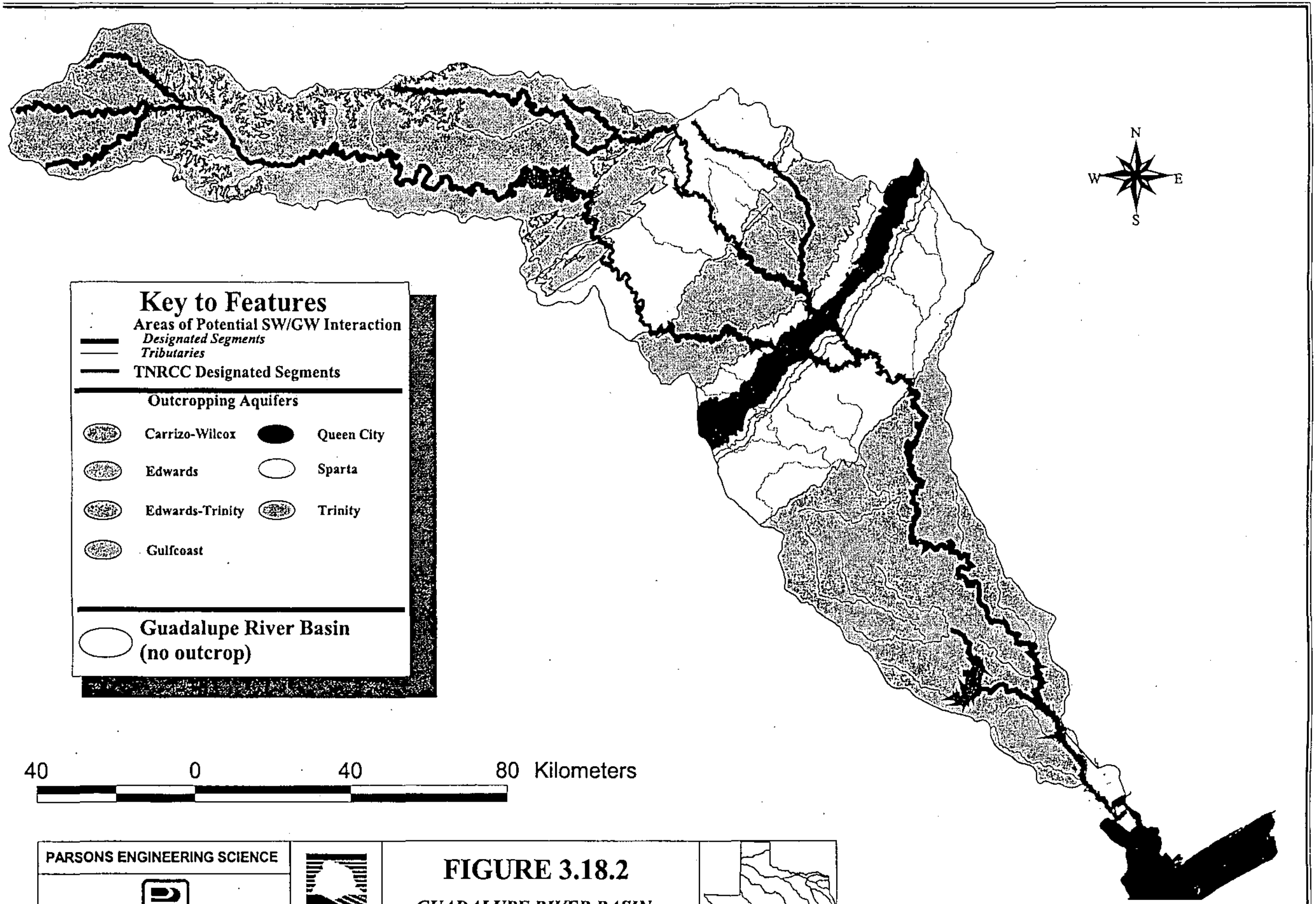

FIGURE 3.18.2

GUADALUPE RIVER BASIN
Potential Surface Water/
Groundwater Interaction

Between the BFZ and the Edwards Plateau is the Hill Country and the outcrop of the Upper Glen Rose Limestone. The Upper Glen Rose is the Upper Trinity aquifer. The Middle Trinity aquifer is composed of the Lower Glen Rose Limestone, the Bexar Shale, the Cow Creek Limestone, and the lowest stratum, the Hammett Shale which is a non-water-bearing unit. The Lower Trinity aquifer consists of Sligo Limestone and Hosston Sand (Ashworth, 1983). The Middle Trinity aquifer outcrops in a small area along the Guadalupe River west of US Highway 218. However, the Upper Glen Rose Limestone has low permeability and has two seams of anhydrite which renders the Upper Glen Rose with a high total dissolved solids (1,130 to 4,140 mg/l) (Alexander, Myers, and Dale, 1964, page 52).

The Edwards and associated limestones (Georgetown, Edwards, and Comanche Peak) form the Edwards aquifer in the BFZ. The Edwards aquifer was named the Balcones aquifer by Alexander, Myers and Dale (1964). The aquifer consists of various types of limestone interbedded with thin marl and shale. Secondary porosity, consisting fractures and solution cavities, has developed in the limestone. Well yield averages at 500 gpm and can reach 1,500 gpm. Because of the northeast-southeast trending faults, groundwater flow is controlled by the faults. Even the water of the Edwards aquifer in the Nueces and San Antonio River basins flows northeast and discharges in the Comal and San Marcos Springs of the Guadalupe River basin (Kuniansky and Holligan, 1994, Plate 3). The 1934-1996 average discharge of the Comal Springs is 286 cfs or about 207,065 afy. For the same period, the San Marcos Springs issued 186 cfs (134,665 afy) (DOD, 1998, page 3-14).

In Region II, the major aquifers are the Carrizo-Wilcox and the Gulf Coast. The outcrop of Carrizo-Wilcox occurs along a east-west band of 5 to 15 miles from Luling in Caldwell County to Floresville in Wilson County (Figure 3.18.2). In the outcrop area the Wilcox is 150 feet thick and the Carrizo, 200 feet. In general, the water in the Carrizo-Wilcox aquifer moves southeastward parallel to the dip of the aquifer.

The Gulf Coast aquifer occurs over the entire southern part of the basin. It is made up of Catahoula Tuff, Oakville Sandstone, Lagarto Clay, Goliad Sand, Lissie Formation, and Beaumont Clay, in ascending order. They are interconnected hydrologically and considered as one aquifer. The aquifer crops out in eastern Gonzales and Karnes Counties as its western extent. As with the Carrizo-Wilcox aquifer, this aquifer dips coastward. The movement of groundwater is southeastward in the direction of the dip. Recharge is from rainfall over the outcrop areas and seepage from streams that cross the outcrops. The principal discharge is by seepage upward to the surface where the water is lost by evapotranspiration and, to a lesser extent, by seepage into streams and discharge through wells (Alexander, Myers, and Dale, 1964).

Minor Aquifers

TWDB (1977) lists Hickory and Ellenburger-San Saba aquifers as minor aquifers in the Guadalupe River basin. The Hickory aquifer is Cambrian in age (500-570 mya) sandstone. The San Saba Dolomite is upper Cambrian in age. The Ellenburger Dolomite formed in the Ordovician-age (425-500 mya). Since these two aquifers do not crop out in Region I, this interaction with streamflow is minimal in the Guadalupe River basin. (They crop out in the Colorado River basin in Blanco and Gillespie Counties north of Kerr and Kendall Counties.)

In Region II, the Queen City Sand aquifer occurs in a narrow band across the middle part of the Guadalupe River basin in western Gonzales County. The aquifer is consisted of interbedded sand and shale with a maximum thickness of 400 feet. Well yields are less than 200 gpm but locally can reach 400 gpm. The principal recharge is precipitation on the outcrop and seepage from streams crossing the outcrop. The natural discharge of groundwater is by seepage into other subsurface formations and by evapotranspiration in the outcrop.

The Sparta Sand aquifer crops out along a narrow band east of the Queen City Sand in Gonzales County. Recharge and discharge of the Sparta aquifer is similar to the Queen City Sand.

The recent alluvium deposits and Leona Formation occur along the Marcos River between San Marcos and Lockhart. It should be noted that the Leona Formation and alluvium situate on the same east-west band where the Midway Formation outcrops. The Midway is an aquitard, not yielding water to a well.

Reservoirs

The only reservoir along the main stem of the Guadalupe River is the Canyon Lake west of New Braunfels. The Coleto Creek Reservoir is built on the Coleto Creek southwest of Victoria.

3.18.2 Significance of The Interaction

Region I. The Guadalupe River in Region I is an effluent stream. The Edwards-Trinity (Plateau) aquifer contributes baseflow from springs and seeps where the river is incised into the saturated zone or where the aquifer is in contact with the upper Glen Rose Limestone. Kunz and Smith (1965) performed a baseflow study in March 1965 when evapotranspiration and rainfall are in a minimum. Both of the North and South Forks had perennial flow above Hunt, about ten miles west of Kerrville. At the Kerr Wildlife Management Area the North Fork registered a flow of 15.8 cfs. At 11.6 miles above Hunt, the South Fork was gaged at 10.1 cfs. Below the confluence, and Hunt, the Guadalupe River had a discharge of 47.9 cfs. Thirty-three miles downstream below Comfort, the river flowed at a rate of 120 cfs. Between Hunt and Comfort, the river flows over the outcrop of the upper Glen Rose Limestone.

Holland (1965) and Manford, Dixon, and Dent (1960) performed channel gain and loss studies between Comfort and New Braunfels. This stretch of river is unique because there are seven major faults cut across the river. In general, the BFZ is the major recharge zone for the Edwards aquifer. However, Holland's investigation indicated that the river flowed at 92.1 cfs near the Kendall and Comal County line to 135 cfs above the Comal River at New Braunfels in March 1962. The distance between these two measurement points is 57 river miles. The river gained 43 cfs. Manford, Dixon, and Dent (1960) concluded that "between Spring Branch (near Kendall and Comal County line in Comal County) and New Braunfels, stream losses and gains are insignificant."

The headwaters of the Blanco River also originate in the Edwards Plateau in Kendall County. The river flows eastward over the upper Glen Rose Limestone in Blanco and Hays Counties before entering the BFZ where the Edwards Limestone outcrops in Hays County west of I-35. Manford, Dixon, and Dent (1960) indicated that the Blanco River had no flow from a place near the Blanco and Hays County line to 13.6 miles downstream and below Little Blanco River mouth in January 1955. At Wimberly, the discharge was 10.5 cfs. This flow derives from springs 11 miles above Wimberly and spring-fed Cypress Creek. There was little or no loss of water from the Blanco River until it reached the mouth of Halifax Creek, where it disappeared completely in the outcrop of the Edwards Limestone. Halifax Creek joins the Blanco River at where the river makes a sharp turn from eastward flow to southeastward west of Kyle. From Halifax Creek to I-35, about ten river miles, the Blanco River had no flow. Manford, Dixon, and Dent (1960) concluded that this river water emerges at the San Marcos Springs. The Blanco River joins the San Marcos River east of San Marcos. As stated before the San Marcos River derives its perennial flow from the San Marcos Springs in San Marcos. The average discharge of the San Marcos Springs from 1934-1996 is 186 cfs.

Region II Southeast of I-35, the San Marcos and Guadalupe Rivers flow over the Midway Group. Because the Midway is not a water-bearing unit, the postulation is that there is no gain or loss over this outcrop. East of the Midway, the Carrizo-Wilcox Sands outcrop as a ten to 15 mile wide band, about perpendicular to the river channels. The rivers may lose or gain from this aquifer (Alexander, Myers, and Dale, 1964). Further east, both rivers flow over the outcrops of minor aquifers. The San Marcos River joins the Guadalupe River west of Gonzales in Gonzales County. Near the southeast Gonzales County line, the Guadalupe River enters into the Gulf Coast aquifer zone. The surface water and groundwater interaction is similar to where the river crosses the Carrizo-Wilcox aquifer outcrop areas.

Table 3.18.1
Surface Water and Groundwater Interaction, Guadalupe River Basin.

Reach	Water Quality Segment	SW/GW Interaction	Aquifer	Probability/ Comments
Guadalupe River above New Braunfels	1811, 1812, 1805, 1806, 1816, 1817, 1818	Yes, gaining	Edwards-Trinity (Plateau) and Edwards aquifers: discharge from springs and seeps and discharge from the Comal Springs.	High: based on publications and gaging stations.
Guadalupe River below New Braunfels and above the mouth with the San Marcos River	1804	Yes, gaining or losing	Carrizo-Wilcox aquifer: no interaction where the river traverses over the Midway Clay outcrop. May lose or gain outcrop.	Medium
Guadalupe River below the San Marcos River and the San Antonio Bay	1803, 1802, 1801, and 1807	Yes, gaining	Gulf Coast aquifer: springs and seeps.	High: based on publications and gaging stations.
San Marcos River above San Marcos	1814	Yes, gaining	Edwards aquifer: sustained by flow from San Marcos Springs.	High: based on publications and gaging stations.
Blanco River above San Marcos	1809, 1813, 1815	Yes, gaining and losing	Edwards aquifer: gaining from springs in Segment 1813 and 1815 but losing in segment 1809.	High: based on publications and gaging stations.
San Marcos River above Guadalupe River	1808, 1810	Yes, gaining and losing	Carrizo-Wilcox aquifer: the river flows over the outcrop, which may contribute to baseflow.	Medium

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3.19 THE SAN ANTONIO RIVER BASIN

3.19.1 Hydrologic Characteristics

The San Antonio River is bounded on the north and east by the Guadalupe River basin; on the south and west by the Nueces River basin and the San Antonio-Nuceses Coastal basin. Total drainage area is 4,180 square miles. Major tributaries include the Medina River, Leo Creek, Salado Creek, and Cibolo Creek (Figure 3.19.1).

Olmos Creek originates at 950 feet msl, northwest of San Antonio and flows into Olmos Dam in San Antonio. About one mile downstream from the dam, the San Antonio River is formed from the flow of San Antonio Springs at a streambed elevation of 665 feet msl. Major tributaries to the San Antonio River are the Medina River, Salado Creek, and Cibolo Creek.

Headwaters of Salado Creek form in Fair Oaks Ranch and Camp Bullis, northwest of San Antonio. It flows southeastward to the San Antonio Airport and then turns south draining runoff from the east side of the city of San Antonio inside loop I-410. The springs and artesian wells in Fort Sam Houston north of I-10 feed Salado Creek and make it perennial. Salado Creek joins the San Antonio River near Southton.

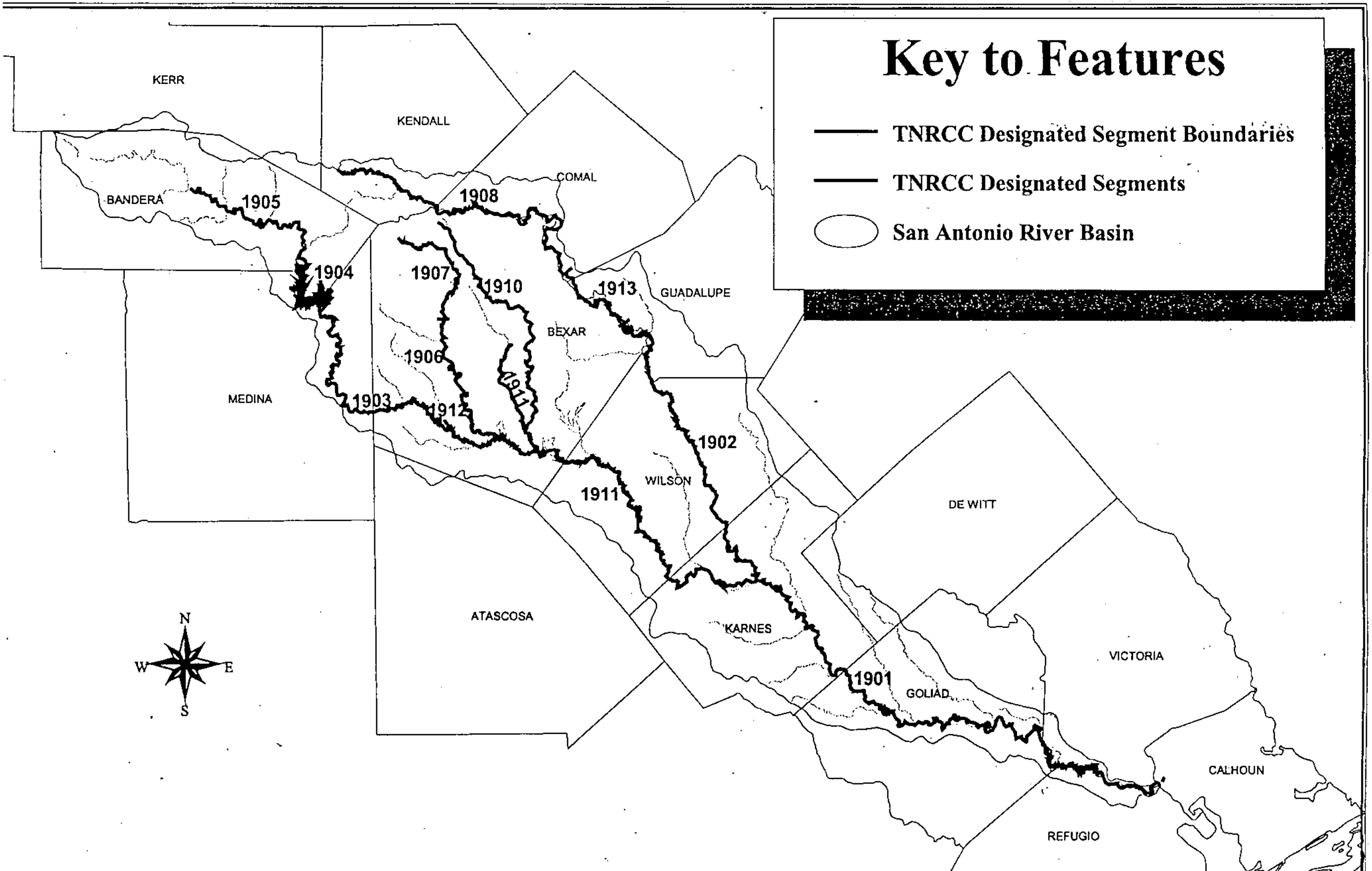


FIGURE 3.19.1

SAN ANTONIO RIVER BASIN
TNRCC Designated Stream Segments

PARSONS ENGINEERING SCIENCE

8000 CENTRE PARK DRIVE, SUITE 200
AUSTIN, TEXAS 78754
(512) 719-6000 FAX : (512) 719-6099

TNRCC

The North Prong Medina River originates in northwestern Bandera County at 2,200 feet msl. The West Prong Medina River starts in western Bandera County at 1,800 feet msl and flows eastward to join the West Prong near the city of Medina at a streambed elevation of 1,422 feet msl. Headwaters of Leon Creek form about 7 miles southeast of Boerne in Kendall County at 1,550 feet msl. Leon Creek flows southeast and joins the Medina River south of San Antonio and west of I-35, near the Braung Lake at 460 feet msl (TWDB, 1977). The Medina River drains 1,317 square miles (USGS, 1991).

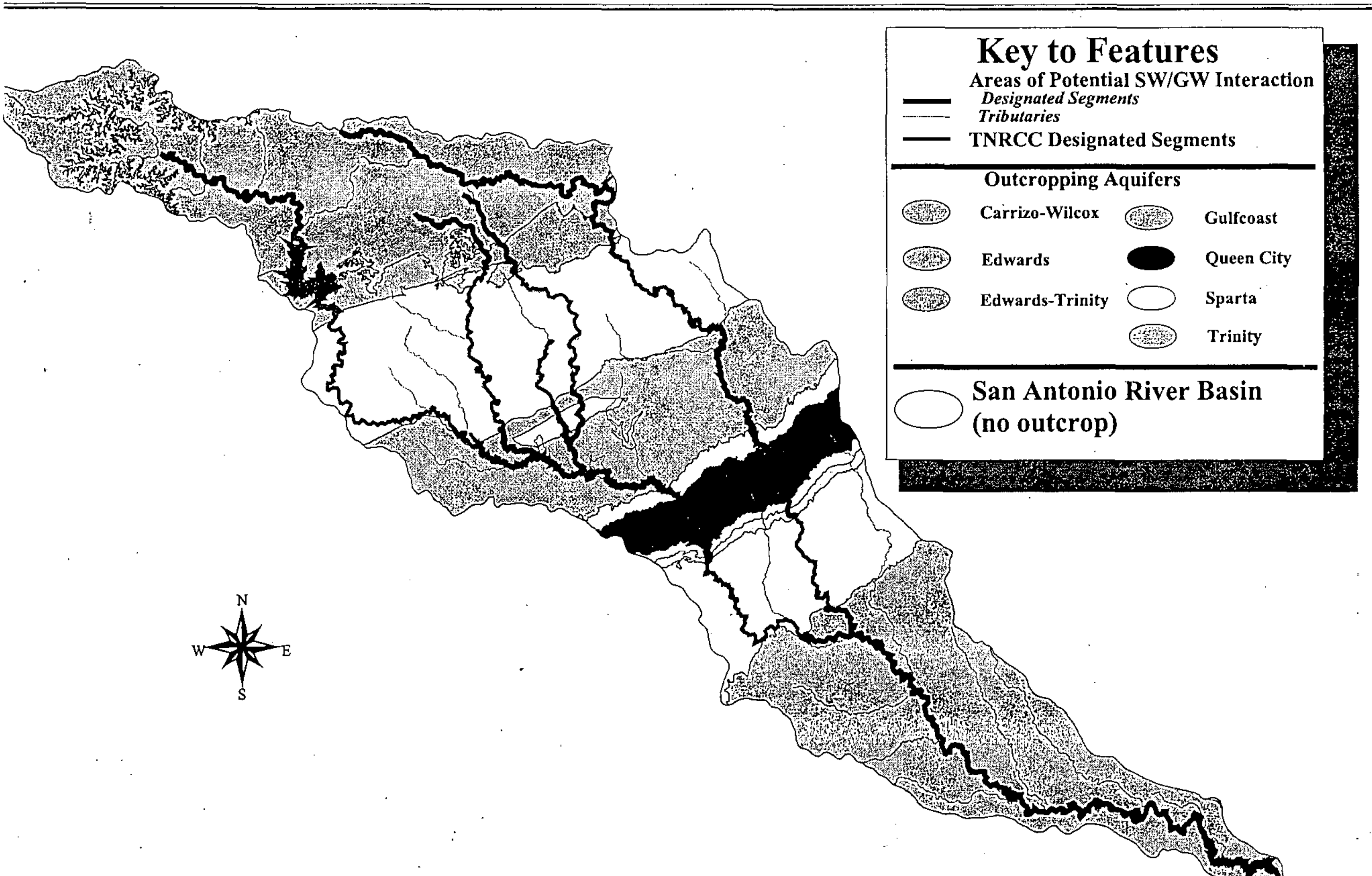
Headwaters of Cibolo Creek originate in southwest Kendall County at 1,900 feet msl. The creek flows intermittently southeastward, joining the San Antonio River north of Karnes City in central Karnes County. Cibolo Creek drains 827 square miles.

Regions

The San Antonio River basin is divided into the Edwards Plateau and the West Gulf Coast Plain. Region I is the Hill Country (and Edwards Plateau) including the BFZ and Region II, the West Gulf Coast Plain (TWDB, 1977, Alexander, Meyers, and Dale, 1964).

As stated before, upper reaches of the San Antonio River basin are underlain by the Cretaceous-age (65 to 140 mya) limestone, which forms the Edwards Plateau and the Hill Country (Figure 3.19.2). Outcrops in the Hill Country are Edwards Limestone and the older upper Glen Rose Limestone. East and south of the BFZ are the upper Cretaceous chalk, limestone, and clay. The width of the BFZ in San Antonio is about 20 miles. The outcrop of the Edwards Limestone within the BFZ is about 5 to 8 miles wide north of San Antonio. This limestone outcrop is the principal groundwater recharge zone for the Edwards aquifer. The extensive BFZ separates the Hill Country from the West Gulf Coast Plain. Over the West Gulf Coastal Plain, Tertiary-age (2 to 65 mya) sand, silt, clay, glauconite, volcanic ash and lignite dip southeasterly toward the Gulf. In turn, these strata are overlain by clay, silt, and sand of the Pleistocene-age Beaumont Formation in the coastal area. Throughout the basin, alluvial sediments and terrace deposits of Recent-age occurs along streams and cap the upland areas.

Annual precipitation in the basin is 26 inches in the northwest and 36 inches in the south near the coast. The average net lake evaporation is 25 inches near the coast to 37 inches in the west. Due to the mild winter, the San Antonio, Guadalupe, and Nueces River basins constitute the Winter Garden area of the Texas (Klemt, Duffin, and Elder).



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TNRCC

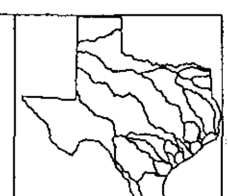

FIGURE 3.19.2

SAN ANTONIO RIVER BASIN
Potential Surface Water/
Groundwater Interaction

Major Aquifers

Three major aquifers occur in Region I and two in Region II. (TWDB, 1977). In the Edwards Plateau, the Edwards-Trinity (Plateau) aquifer occurs in a small area in the northern part of the basin in Bandera and Kerr County. It consists of the Comanche Peak, Edwards, and Georgetown Limestones and sand of the Trinity Group. The upper part of the aquifer is made up of various types of limestone with secondary porosity consisting of fractures and solution cavities. The lower part consists of interbedded fine sand and clay. Total thickness reaches to 500 feet. Most existing wells are low yield, but well yields of 250 to 500 gpm are possible where there is sufficient saturated thickness. It receives recharge from precipitation falling over the outcrops. The water is discharged chiefly through seeps and springs at the contact between Edwards and the underlying Glen Rose Limestone. In general, the Edwards Plateau aquifer is in water-table condition and groundwater flows south and southeastward.

Between the BFZ and the Edwards Plateau is the Hill Country and is also the outcrop of the Edwards and associated limestones, and the Upper Glen Rose Limestone. The Upper Glen Rose is the Upper Trinity aquifer. The Middle Trinity aquifer is composed of the Lower Glen Rose Limestone, the Bexar Shale, the Cow Creek Limestone, and the lowest stratum, the Hammett Shale, which is a non-water-bearing unit. The Lower Trinity aquifer consists of Sligo Limestone and Hosston Sand (Ashworth, 1983). The Middle Trinity aquifer outcrops in a small area along the Guadalupe River west of US Highway 218. However, the Upper Glen Rose Limestone has low permeability and has two seams of anhydrite which renders the Upper Glen Rose with a high total dissolve solids (1,130 to 4,140 mg/l) (Alexander, Myers, and Dale, 1964, page52).

The Edwards and associated limestones (Georgetown, Edwards, and Comanche Peak) form the Edwards aquifer in the BFZ. The Edwards aquifer was named the Balcones aquifer by Alexander, Myers and Dale (1964). The aquifer consists of various types of limestone interbedded with thin marl and shale. Secondary porosity, consisting of fractures and solution cavities, has developed in the limestone. In the limestone outcrop north of San Antonio is the recharge zone and the aquifer is under water table condition. South of the outcrop, the Edwards aquifer underneath the city of San Antonio is under confined condition. Rocks between the Midway Clay and Grayson Shale overlay the Edwards Limestone. Well yield averages at 500 gpm and can reach 1,500 gpm.

Because of the northeast-southeast trending faults, groundwater flow is controlled by the faults. Even the water of the Edwards aquifer in the Nueces and San Antonio River basins flows northeast and discharges in the Comal and San Marcos Springs of the Guadalupe River basin (Kuniansky and Holligan, 1994, Plate 3). North of the San Antonio downtown, the San Pedro and San Antonio Springs used to contribute water to the San Antonio River. Due to regional pumping of the Edwards aquifer, these springs only flow during above normal rainfall season.

In Region II, the major aquifers are the Carrizo-Wilcox and the Gulf Coast. The outcrop of Carrizo-Wilcox occurs along a northeast-southwest band of 5 to 15 miles from Seguine in Guadalupe County to Floresville in Wilson County (Figure 3.19.2). It extends from Floresville northwest to inside the Loop I-410 in south San Antonio. In the outcrop area the Wilcox is 150 feet thick and the Carrizo, 200 feet. In general, the water in the Carrizo-Wilcox aquifer moves southeastward parallel to the dip of the aquifer.

The Gulf Coast aquifer occurs over the entire southern part of the basin. It is made up of Catahoula Tuff, Oakville Sandstone, Lagarto Clay, Goliad Sand, Lissie Formation, and Beaumont Clay, in ascending order. They are interconnected hydrologically and considered as one aquifer. The aquifer crops out in and east of Karnes City in Karnes County. As with the Carrizo-Wilcox aquifer, this aquifer also dips coastward. The movement of groundwater is southeastward in the direction of the dip. Recharge is from rainfall over the outcrop areas and seepage from streams that cross the outcrops. The principal discharge is by seepage upward to the surface where the water is lost by evapotranspiration and, to a lesser extent, by seepage into streams and discharge through wells. (Alexander, Myers, and Dale, 1964).

Minor Aquifers

In Region II, the Queen City Sand aquifer occurs in a narrow band across the middle part of the Guadalupe River basin in western Wilson County. The aquifer is consisted of interbedded sand and shale with a maximum thickness of 400 feet. Well yields are less than 200 gpm but locally can reach 400 gpm. The principal recharge is precipitation on the outcrop and seepage from streams crossing the outcrop. The natural discharge of groundwater is by seepage into other subsurface formations and by evapotranspiration in the outcrop.

The Sparta Sand aquifer crops out along a narrow band east of the Queen City Sand in Wilson County. Recharge and discharge of the Sparta aquifer is similar to the Queen City Sand.

Reservoirs

The only reservoir along the main stem of the Medina River is the Medina Lake southeast of Bandera in Bandera County. The City Public Service (CPS) of San Antonio pumps portion of the San Antonio River flow to Braung and Calaveras Lakes, off-channel lakes, located southeast of San Antonio. Water from these lakes is for power plant cooling and for recreational purpose. These two lakes return portion of their water back to the San Antonio River downstream.

3.19.2 Significance of The Interaction

Region I. In the headwaters of the Medina River, the Edwards-Trinity aquifer contributes to the streamflow through springs and seeps and where the streams cut into the Glen Rose Limestone. Manford, Dixon, and Dent (1960) stated that most of the baseflow developed by this stream comes from the watershed above Bandera; and some water may be absorbed in the channel between Medina and Bandera. The Medina Lake is constructed above the Haby Crossing Fault, one of many faults of the BFZ. The groundwater simulation map of Kuniansky and Kelly (1994) indicates that Medina Lake recharges the Edwards aquifer.

In San Antonio, the San Antonio River was dry at Hildebrand Avenue above the San Antonio Zoo in July 1957 (Manford, Dixon, Dent, 1960). The flow increase to 12 cfs at South Alamo Street, about six miles downstream. The river is sustained by artesian wells and fault-induced springs and seeps of the Edwards aquifer.

During the loss and gain investigation, Cibolo Creek developed a maximum baseflow of 129 cfs, most of which originates in Kendall County (Manford, Dixon, and Dent, 1960). All of this water is lost into sink holes and fissures in the channel from a point two miles below Boerne to a point above Selma, a distance of about 42 miles. The heavy losing sections in Kendall and Comal Counties are on the lower member of the Glen Rose Limestone. From Bulverde to Bracken, the bed of Cibolo Creek is on the upper Glen Rose and the loss in this area is relatively small. Along a five section from Bracken to Selma along U.S. Highway I-35 northeast of San Antonio, the streambed overlies the Edwards limestone, which is honeycombed and broken by many faults. Most of the streamflow enters into the lower Glen Rose limestone and passes laterally through underground channels into the Edwards limestone.

Region II

Southeast of San Antonio, the San Antonio River flows over the Carrizo-Wilcox aquifer outcrop. The Carrizo-Wilcox Sands outcrop as a ten to 15 miles band, about perpendicular to the river channels. The river and its tributaries may lose or gain from this aquifer (Alexander, Myers, and Dale, 1964). Because the pumping (272,000 afy) is more than the natural recharge (100,000 afy), in the Winter Garden area, the San Antonio River and its tributaries flowing over the outcrop will lose more streamflow to groundwater due to water table declines than without excess pumping for irrigation (Klemt, Duffin, and Elder, 1976). Consequently, the aquifer will contribute less baseflow to streams in downstream side.

Further east and southeast, the river flows over the outcrops of minor aquifers (Queen City Sand and Sparta Sand). The San Antonio River merges with Cibolo Creek north of Karnes City in Karnes County. The western extent of the Gulf Coast aquifer begins about five miles west of Karnes City. In general, the Carrizo-Wilcox aquifer, the Coastal aquifer, and the two minor aquifers may contribute baseflow to the San Antonio River.

The USGS (1991) provided the following streamflow data

Gaging Station	Drainage (mi²)	River Miles	Annual Discharge (cfs)
San Antonio River below Medina River	1,734	208	528
San Antonio River near Karnes City	2,113	150.5	426
San Antonio River at Goliad	3,921	66.5	681
Cibolo Creek at Selma	274	15.2	
Cibolo Creek north of Karnes City	827	119	

Table 3.19.1
Surface Water and Groundwater Interaction, San Antonio River Basin.

Reach	Water Quality Segment	SW/GW Interaction	Aquifer	Probability/ Comments
Medina River above Medina Lake	1905	Yes, gaining and losing	Edwards aquifer: gaining between Medina and Bandera but losing from Bandera to Medina lake.	High: lake is located on the Edwards limestone outcrop in the Balcones Fault Zone (BFZ).
Medina Lake and Diversion Lake	1904, 1909	Yes, losing	Edwards aquifer: Major BFZ faults located below Medina Lake that induce leakage to Edwards aquifer.	High: lake leaks to Edwards aquifer through the Medina Lake fault, Diversion Lake fault, and Haby Crossing Fault.
Medina River above San Antonio River	1903, 1912	Yes, gaining	Edwards and Carrizo-Wilcox aquifers: upward leakage from the Edwards aquifer and discharge from the Carrizo-Wilcox Sand aquifer to the river.	Medium: irrigation return water may contribute to the low flow.
Leon Creek	1907,1906	Yes, losing	Edwards, Upper Trinity and Middle Trinity aquifers: not a perennial stream above San Antonio due to geology.	High: headwaters in the lower and upper Glen Rose (Trinity aquifers) near Boerne and pass through BFZ. Flow measured SW of San Antonio at I-35 is from wastewater disposal and city runoff.

Table 3.19.1 (Continued)
Surface Water and Groundwater Interaction, San Antonio River Basin.

Reach	Water Quality Segment	SW/GW Interaction	Aquifer	Probability/ Comments
Salado Creek	1910	Yes, losing and gaining	Edwards, Upper Trinity and Middle Trinity aquifers: not a perennial stream above San Antonio due to geology.	High: headwaters are in the same area as Leon Creek but creek becomes perennial in Fort Sam Houston due to springs and artesian wells discharge.
Cibolo Creek from headwaters to I-35	1908	Yes, losing	Edwards and Middle Trinity aquifers: area of the BFZ.	High: Stream losing water to karsted and faulted lower Glen Rose and Edwards limestones.
Cibolo Creek from I-35 to mouth with San Antonio River	1913, 1902	Yes, losing and gaining	Carrizo-Wilcox aquifer: may lose streamflow when first enters the sand but gains downstream where the sand discharges to creek as springs and seeps.	Medium: Streamflow is also augmented by wastewater discharge.
San Antonio River above Median River	1911	Yes, gaining	Edwards aquifer: springs and artesian wells discharge from the aquifer.	High
San Antonio River below Medina River to mouth with Guadalupe River	1911, 1901	Yes, losing and gaining	Carrizo-Wilcox aquifer: same reason as Cibolo Creek segments 1913 and 1902	Medium: stream flow is augmented by wastewater discharge.

3.19.3 References

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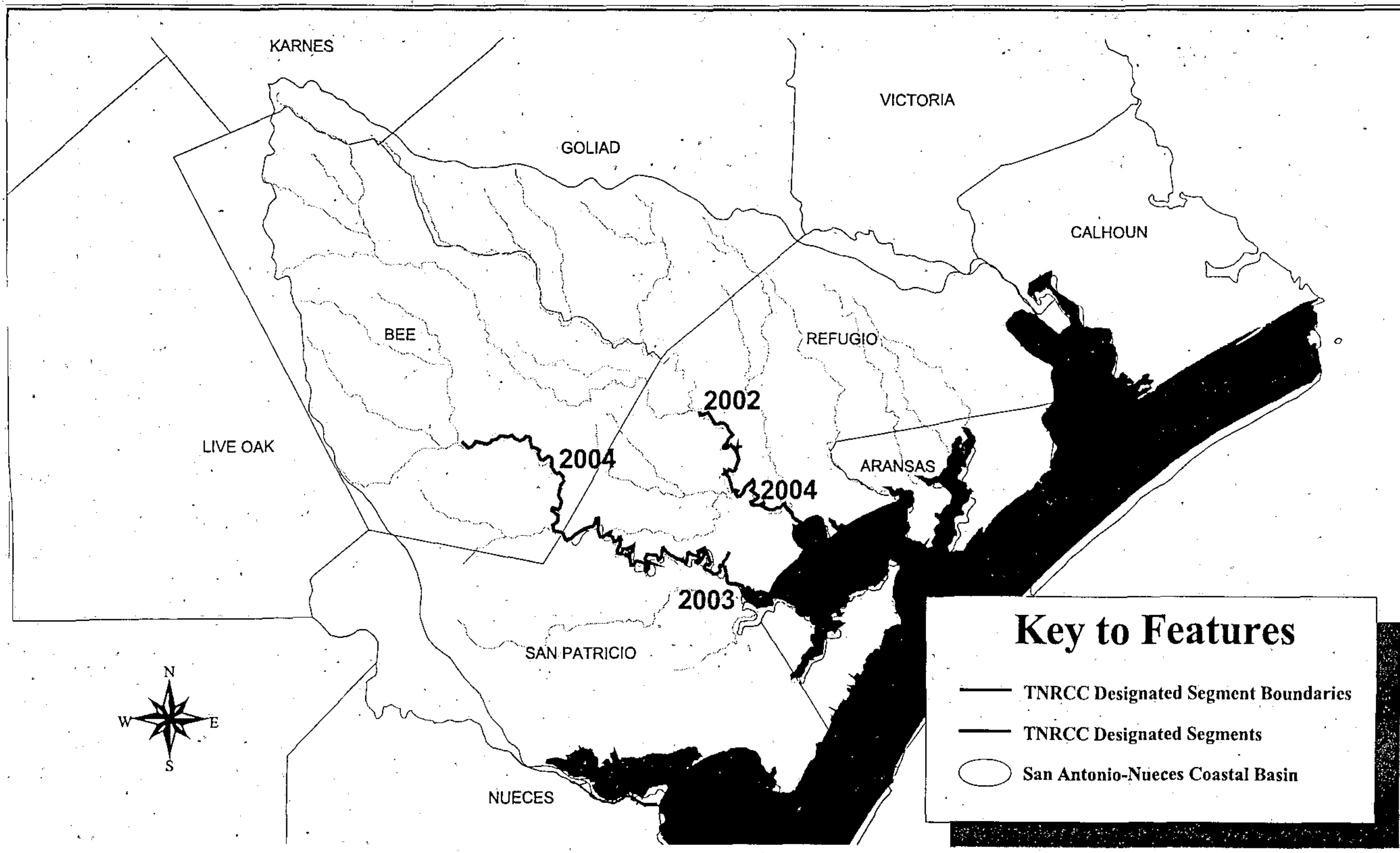
3.20 THE SAN ANTONIO-NUECES COASTAL BASIN

3.20.1 Hydrologic Characteristics

The San Antonio-Nueces Coastal Basin is bounded on the north and east by the San Antonio River Basin and the Lavaca-Guadalupe Coastal Basin and on the west and south by the Nueces River Basin and the Nueces-Rio Grande Coastal Basin (Figure 3.20.1). Total drainage area of the basin is 2,652 square miles, and it drains into Copano Bay which drains to Aransas Bay (TWDB, 1997). The basin is located in the West Gulf Coast section of the Coastal Plains province, which is predominantly a smooth, featureless, depositional plain rising from sea level to an altitude of less than 400 feet at the distal extent of the interior boundary in the northeastern portion of the basin (TWDB 1979).

The basin exhibits a dry subhumid climate with a mean annual rainfall of about 32 inches (TWC, 1963).



10 0 10 Kilometers

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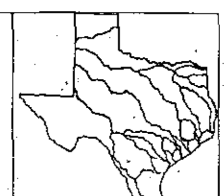
FIGURE 3.20.1

SAN ANTONIO-NUECES COASTAL BASIN

TNRCC Designated Stream Segments



The sediments that are exposed on the land surface and in the surface water channels throughout the San Antonio-Nueces Coastal Basin, consists of beds, lenses, and stringers of gravel and coarse to fine sand interbedded with silt and clay beds and lenses. These sediments form a series of gently dipping truncated wedges which thicken toward the coast, causing each wedge to have a slightly steeper dip than the overlying wedge. At depth, the lithology of these sediments become more dominantly silt and clay (TWC, 1963). Surface water channels are sufficiently entrenched into the surficial sediments to allow shallow groundwater to discharge into them (Ray Slade, personal communication, 1999).

Regions

The San Antonio-Nueces Coastal Basin is treated as one hydrologic unit.

Major Aquifers

The San Antonio-Nueces Coastal Basin is underlain by the Gulf Coast Aquifer System (GCAS), with the exception of the southwestern portion of the basin, as shown in Figure 3.20.2. The GCAS is a complex network of interbedded sediments which have been segregated into four generally recognized water producing formations. Aggregately, these formations form a large leaky artesian aquifer system, the GCAS, that provides groundwater for agricultural, industrial, and municipal uses.

The Chicot aquifer, which is the upper or down-dip most component of the GCAS, outcrops within the southeastern half of the San Antonio-Nueces Coastal Basin and is hydrologically interconnected with the underlying by Evangeline aquifer.(TWDB, 1979). The Evangeline aquifer outcrops in the northwestern portion of the coastal basin and is underlain by the Burkeville confining unit.. The thickness of fresh to slightly saline water within the aquifer ranges from less than 200 feet near the coast to more than 400 feet in the northwestern portion of the basin west of Refugio in Refugio County (TWC, 1963). Due to the shallow depths to groundwater and the surficial exposure of sediments in the outcrop of the GCAS, it is expected that shallow groundwater would generally discharge into drainage-ways and coastal embayment throughout the basin.

Minor Aquifers

There are no minor aquifer systems in the San Antonio-Nueces Coastal Basin.

Reservoirs

There are no storage reservoirs in the San Antonio-Nueces Coastal Basin that would significantly interact with groundwater in the GCAS.

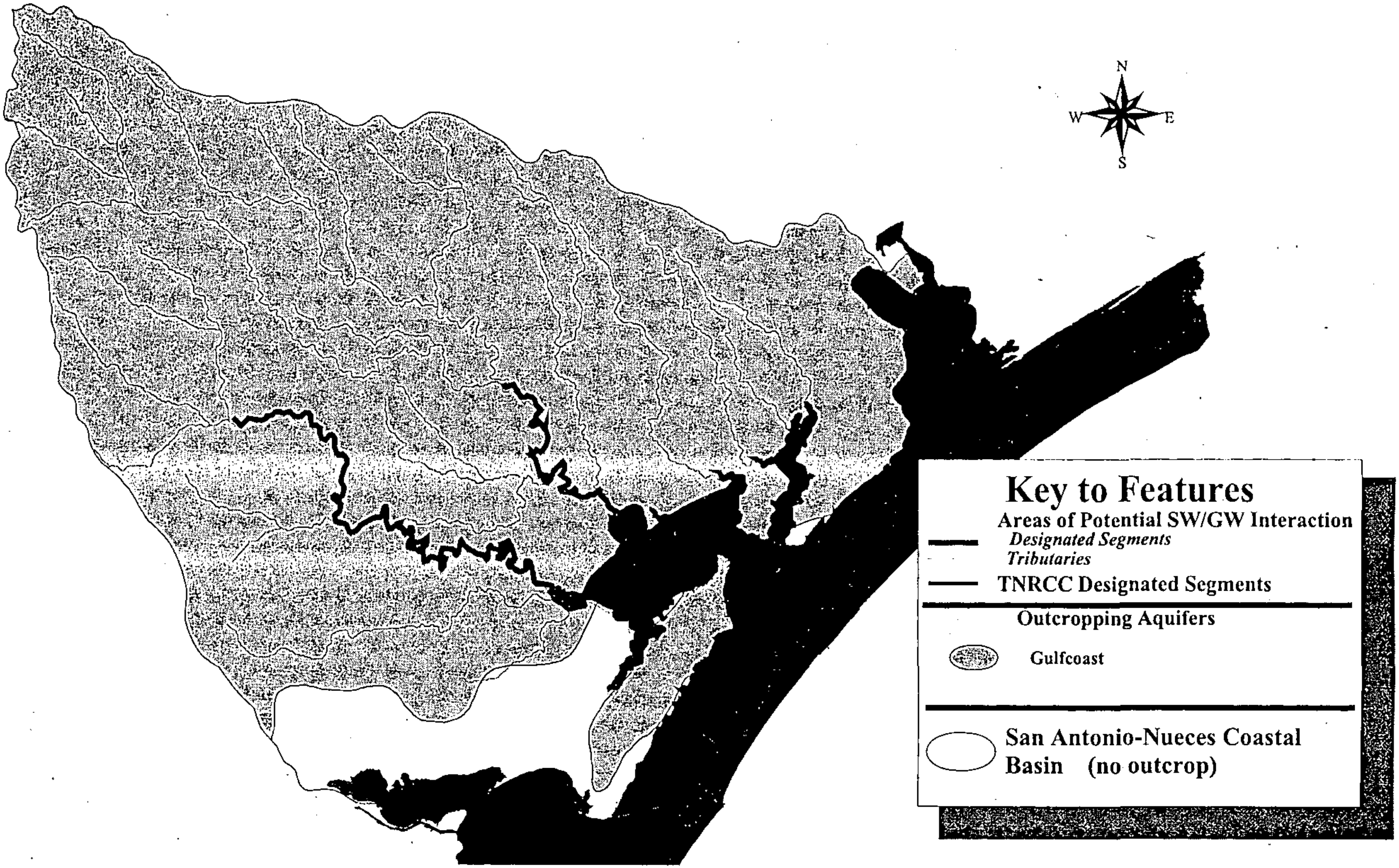


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FIGURE 3.20.2

SAN ANTONIO-NUECES COASTAL BASIN
Potential Surface Water/ Groundwater Interaction

10 0 10 Kilometers

Source: TNRIS/TWDB GIS Planning Division

3.20.2 Significance of The Interaction

There are two minor rivers (the Mission River and the Aransas River) but no watercourses in the basin that maintain significant stream flow (TNRCC, 1996). The Mission River at Refugio in Refugio County covers 609 square miles with an annual flow of 115 cfs. The Aransas River near Skidmore southeast of Beeville has a drainage area of 247 square miles and an annual flow of 35.5 cfs. Portion of the streamflow is supported by sewage discharge from Beeville and the Beeville Naval Air Station USGS, 1991). The Aransas River discharge to the west end of Copano Bay and the Mission River, the middle of Cpano Bay. Toward the east end of the Copano Bay is the Copano Creek. The USGS gaging station north of the Aransas and Refugio County line yields 40.4 cfs. However, in 1991, there was no flow from August to December. This indicates that Copano Creek is intermittent, groundwater effluent is limited to wet seasons. For other small creeks or tributaries to the Mission and Aransas Rivers, the Copano Creek streamflow regime may also apply.

Table 3.20.1
Surface Water and Groundwater Interaction, San Antonio-Nueces River Basin

Reach	Water Segment	SW/GW Interaction	Aquifer	Probability/ Comments
Mission River above Copano Bay	2001, 2002	Yes, gaining and losing	Gulf Coast aquifer: outcrop area.	Medium
Aransas River above Copano Bay	2003, 2004	Yes, gaining and losing	Gulf Coast aquifer: outcrop area.	Medium

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3.21 THE NUECES RIVER BASIN

3.21.1 Hydrologic Characteristics

The Nueces River Basin is bounded on the north and east by the Colorado Guadalupe, and San Antonio River Basins and the San Antonio-Nueces Coastal Basin, and on the this page intentionally left blank west and south by the Rio Grande and the Nueces-Rio Grande Coastal Basins (Figure 3.21.1). Total drainage area is 16,950 square miles. Principal streams include the Atascosa River, the Frio River and its principal tributaries (San Miguel Creek, Hondo Creek, and the Sabinal, Dry Frio and Leona Rivers), and the Nueces River. The Atascosa and Frio Rivers join the Nueces River west of Three Rivers in Live Oak County and above Lake Corpus Christi (TWDB, 1977).

Headwaters of the Nueces River originate in Edwards County east Rocksprings at 2,220 feet msl. The West Nueces River begins also in Edwards County west of Rocksprings at 2,040 feet msl and joins the Nueces River at 952 feet msl northwest of Uvalde in Uvalde County. The Frio River forms in Real County at 2,240 feet msl and joins the Nueces River at 102 feet below Choke Canyon Reservoir southwest of Three Rivers near the US Highway 281.

Regions

Although the TWDB (1977) considers the entire basin as one hydrologic unit for planning purpose. The Nueces River basin has the similar geologic outcrops, climate, and vegetation as the San Antonio and Guadalupe River basins. Both of the latter basins are divided into two regions, the Nueces River basin is also divided into two regions. Region I is north of the BFZ and Region II is south of the BFZ.

As stated before, upper reaches of the Nueces River basin are underlain by the Cretaceous-age (65 to 140 mya) limestone which forms the Edwards Plateau and the Hill Country (Figure 3.21.2). Unlike the San Antonio and Guadalupe River basins where the Glen Rose Limestone outcrop separated the Edwards Plateau to the west from the BFZ, in the Nueces River basin the Edwards Plateau extends south into Uvalde and Kinney Counties in direct contact with the BFZ. Only in the Sabinal River and east, the Edwards Plateau and the BFZ is separated by the Upper Glen Rose Limestone outcrop. An enclave of the Glen Rose Limestone is exposed along the Nueces River in the vicinity of Real, Edwards, and Uvalde County lines.

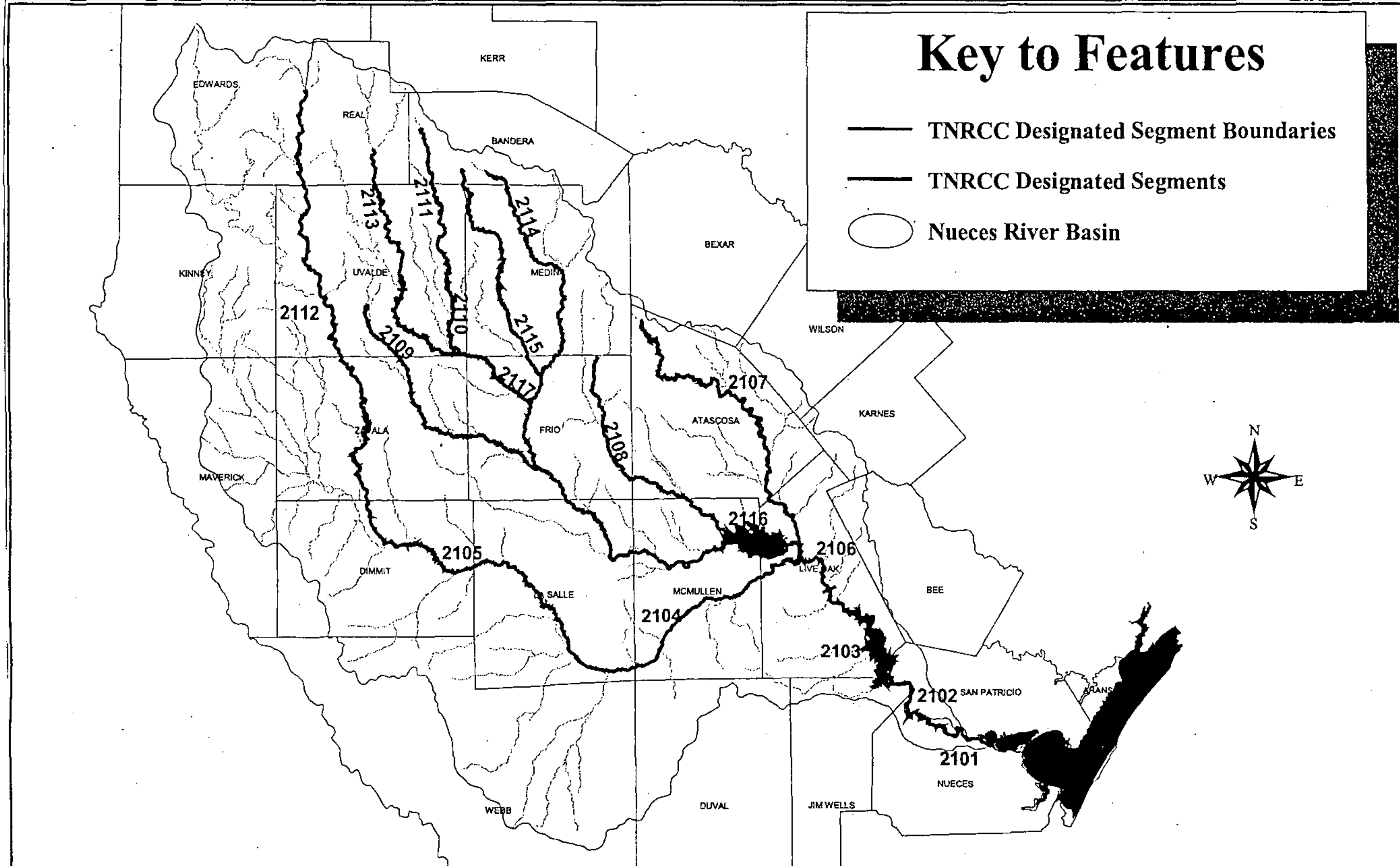

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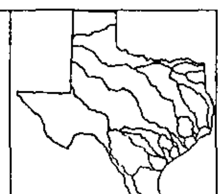
FIGURE 3.21.1

NUECES RIVER BASIN
TNRCC Designated Stream Segments



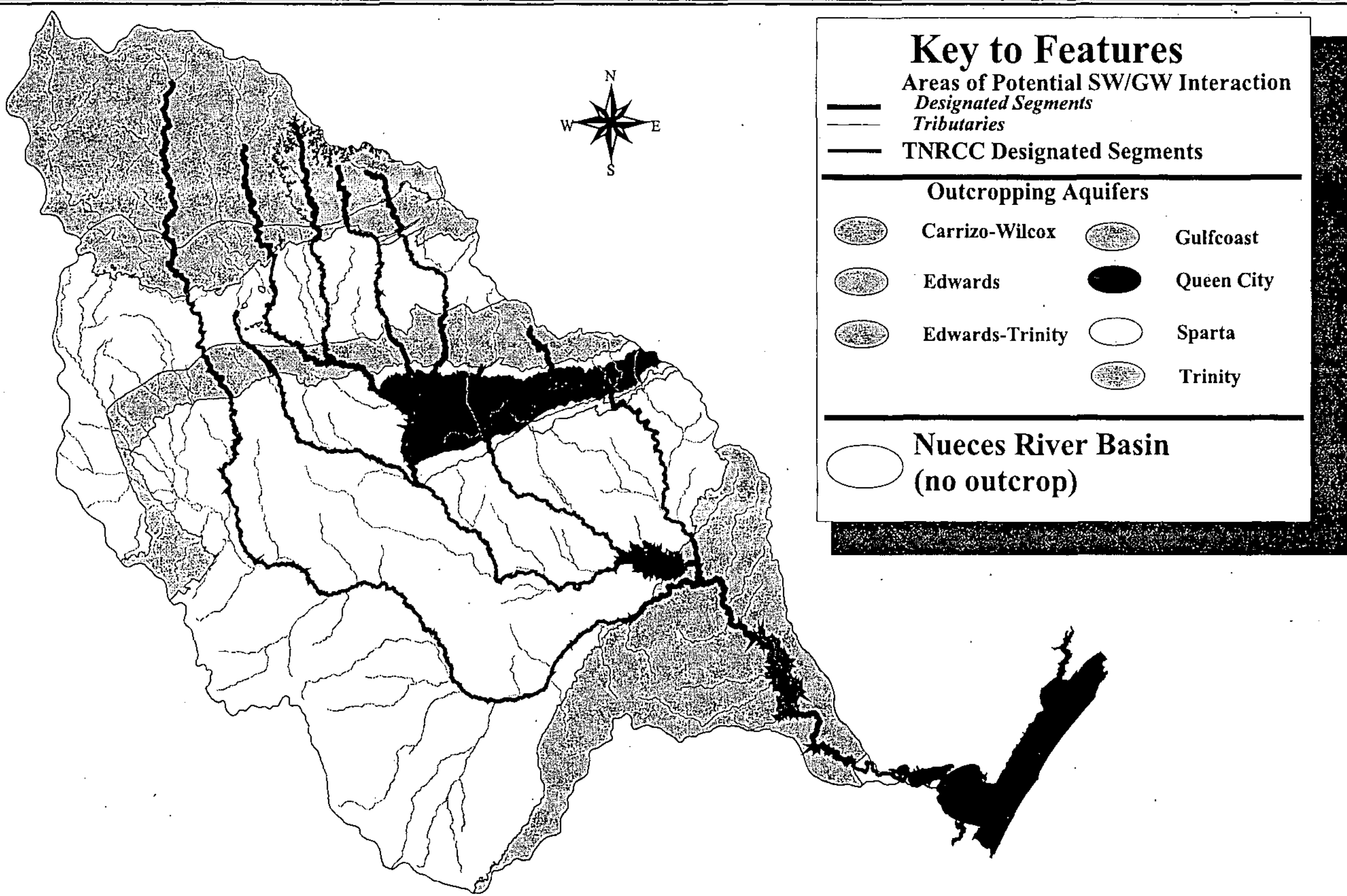


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FIGURE 3.21.2

NUECES RIVER BASIN
Potential Surface Water/ Groundwater Interaction

30 0 30 60 Kilometers

Outcrops in the Hill Country (Real, Bandera and northern Uvalde and Medina Counties) north of the BFZ are Edwards Limestone and the older upper Glen Rose Limestone. South of the BFZ are the upper Cretaceous chalk, limestone, and clay. The width of the BFZ in Medina County is about 30 miles. The outcrop of the Edwards Limestone within the BFZ is about 10 miles wide north of Hondo. This limestone outcrop is the principal groundwater recharge zone for the Edwards aquifer. The extensive BFZ separate the Hill Country from the West Gulf Coast Plain. Over the West Gulf Coastal Plain, Tertiary-age (2 to 65 mya) sand, silt, clay, glauconite, volcanic ash and lignite dip southeasterly toward the Gulf. Along US Highway 90 connecting Hondo, Sabinal, and Uvalde, the Leona Formation overlies the Tertiary rocks of Midway Clay to Grayson Shale and is probably deposited by the rivers (Hondo, Sabinal, Frio, and Nueces) issuing from the Edwards Plateau and Hill Country. South of the Leona Formation, in sequential, is the outcrops of Carrizo-Wilcox Sands, Mount Selman Formation, Cook Mountain Formation, Sparta Sand, Yegua Formation, Jackson Group, Catahoula Tuff, Lagarto Clay, Goliad Sand, and Lissie Formation. These strata, in turn, are overlain by clay, silt, and sand of the Pleistocene-age Beaumont Formation in the coastal area. Throughout the basin, alluvial sediments and terrace deposits of Recent age occurs along streams and cap the upland areas.

Annual precipitation in the basin is 22 inches in the west in Edwards County and 32 inches in south In Corpus Christi near the coast (TDWR, 1984). The average net lake evaporation is 30 inches near the coast to 60 inches in the west.

Major Aquifers

Three major aquifers occur in Region I and two in Region II. (TWDB, 1977). In the Edwards Plateau, the Edwards-Trinity (Plateau) aquifer occurs in Edwards, Real, Bandera and Kerr County. It consists of the Comanche Peak, Edwards, and Georgetown Limestones and sand of the Trinity Group. The upper part of the aquifer is made up of various types of limestones with secondary porosity consisting of fractures and solution cavities. The lower part occurs below the Glen Rose Limestone and consists of interbedded fine sand and clay. Total thickness reaches to 500 feet. Most existing wells are low yield, but well yields of 250 to 500 gpm are possible where there is sufficient saturated thickness. It receives recharge from precipitation falling over the outcrops. The water is discharged chiefly through seeps and springs at the contact between Edwards and the underlying Glen Rose Limestone. The Edwards Plateau aquifer is in water-table condition in general and groundwater flows south and southeastward.

Between the BFZ and the Edwards Plateau is the Hill Country and is also the outcrop of the Edwards and associated limestones and the Upper Glen Rose Limestone. The Upper Glen Rose is the Upper Trinity aquifer. The Middle Trinity aquifer is composed of the Lower Glen Rose Limestone, the Bexar Shale, the Cow Creek Limestone, and the lowest stratum, the Hammett Shale which is a non-water-bearing unit. The Lower Trinity aquifer consists of Sligo Limestone and Hosston Sand (Ashworth, 1983). Only the upper

Glen Rose outcrops in the Nueces River basin. Upper Glen Rose Limestone has low permeability and has two seams of anhydrite which renders the Upper Glen Rose with a high total dissolve solids (1,130 to 4,140 mg/l) (Alexander, Myers, and Dale, 1964, page 52).

The Edwards and associated limestones (Georgetown, Edwards, and Comanche Peak) form the Edwards aquifer in the BFZ. The Edwards aquifer was named the Balcones aquifer by Alexander, Myers and Dale (1964). The aquifer consists of various types of limestone interbedded with thin marl and shale. Secondary porosity, consisting fractures and solution cavities, has developed in the limestone. In the limestone outcrop north of Hondo is the recharge zone and the aquifer is under water table condition. South of the limestone outcrop, the Edwards aquifer underneath the cities of Hondo, Sabinal, and Uvalde is under confined condition. Rocks between the Midway Clay and Grayson Shale overlay and confine the Edwards Limestone. Well yield averages at 500 gpm and can reach 1,500 gpm.

Because of the northeast-southeast trending faults, groundwater flow is controlled by the faults. Even the water of the Edwards aquifer in the Nueces River Basin flows east and then northeast and discharges in the Comal and San Marcos Springs of the Guadalupe River Basin (Kuniansky and Holligan, 1994, Plate 3). In Uvalde County, south of Uvalde, the Leona Springs at the southern edge of the BLZ form the local natural discharge points through faults of the Edwards aquifer. The Leona Springs consist of four groups with discharge varying from zero to 51 cfs (Brune, 1975). According to Kuniansky and Holligan (1994), the Las Moras Springs at Bracketville in Kinney County capture the Edwards aquifer in the Nueces River basin but discharge into the Rio Grande basin. Not like the Leona Springs, the Las Moras Springs never went dry even in the 1956 draught (Brune, 1975).

In Region II, the major aquifers are the Carrizo-Wilcox and the Gulf Coast. The outcrop of Carrizo-Wilcox occurs along a east-west band of 5 to 15 miles from Devine in Medina County to La Pryor in Zavala County (Figure 3.19.2). In the outcrop area the Wilcox is 150 feet thick and the Carrizo, 200 feet. In general, the water in the Carrizo-Wilcox aquifer moves southward parallel to the dip of the aquifer Klemt, Duffin, and Elder, 1976).

The Gulf Coast aquifer occurs over the entire southern part of the basin. It is made up of Catahoula Tuff, Oakville Sandstone, Lagarto Clay, Goliad Sand, Lissie Formation, and Beaumont Clay, in ascending order. They are interconnected hydrologically and considered as one aquifer. The aquifer crops out in and east of Three Rivers in Live Oak County. As with the Carrizo-Wilcox aquifer, this aquifer also dips coastward. The movement of groundwater is southeastward in the direction of the dip. Recharge is from rainfall over the outcrop areas and seepage from streams that cross the outcrops. The principal discharge is by seepage upward to the surface where the water is lost by evapotranspiration and, to a lesser extent, by seepage into streams and discharge through wells. (Alexander, Myers, and Dale, 1964).

Minor Aquifers

In Region II, the Queen City Sand aquifer occurs in a narrow band across the middle part of the Guadalupe River basin in western Wilson County. The aquifer is consisted of interbedded sand and shale with a maximum thickness of 400 feet. Well yields are less than 200 gpm but locally can reach 400 gpm. The principal recharge is precipitation on the outcrop and seepage from streams crossing the outcrop. The natural discharge of groundwater is by seepage into other subsurface formations and by evapotranspiration in the outcrop.

The Sparta Sand aquifer crops out along a narrow band east of the Queen City Sand in Wilson County. Recharge and discharge of the Sparta aquifer is similar to the Queen City Sand.

Reservoirs

Two reservoirs are located in the Nueces River basin. They are Choke Canyon Reservoir and Lake Corpus Christi. Choke Canyon Reservoir is constructed on the Frio River just above its confluence with the Atascosa River over Frio Clay and Jackson Group of clay, sand, and tuff. Further downstream near Mathis, Lake Corpus Christi is built over the Goliad Sand. The storage capacity at the spillway elevation is 743,900 and 241,200 acre feet, respectively, for Choke Canyon and Lake Corpus Christi.

3.21.2 Significance of The Interaction

Region I. In the headwaters of the Nueces River, the Edwards-Trinity aquifer contributes to the streamflow through springs and seeps and where the streams cut into the Glen Rose Limestone. Manford, Dixon, and Dent (1960) stated that most of the baseflow developed by this stream comes from the watershed above Laguna in Uvalde County and some water may be absorbed in the channel between Barksdale in Edwards County and Laguna, a stretch of about 40 river miles. The gain and loss survey of March 1924 indicated that the Nueces River increased its flow from zero cfs 14 miles above Barksdale to 149 cfs at Laguna. About 20 miles downstream from Laguna, the discharge was 1.2 cfs at US Highway 90. Fifteen miles below US90 at La Pryor, the discharge was 26.9 cfs. This is in consistence with the USGS (1991) record that the Nueces River loses water to the alluvium and Leona Formation between Laguna and La Pryor. It should be noted that the West Nueces enters into the Nueces River about half way between US90 and Laguna. The combined loss of the Nueces and the West Nueces is more than 147.8 (149-1.2) cfs.

The Frio River begins north of Leaky in Real County in the Edwards Plateau. Many springs issue from the Edwards and associate limestones to the river. Near the Real-Uvalde County line, springs possibly from the Glen Rose limestone contribute to the river. The river increased from 25 cfs at Leaky to 40.5 cfs 19 miles downstream near Concan in Uvalde County at Highway 127 crossing in June 1945. Seven miles below

Concan, there is no water in the Frio River. (Manford, Dixon, Dent, 1960). The USGS (1991) reported that the 22 miles reach between Concan and the gaging station below US-90 is a losing stream.

During the loss and gain investigation, the Sabinal River gains water from headwaters to the upper USGS gaging station. Eighteen river miles downstream, the USGS operates another gaging station at US-90 highway. Discharge was measured to be 105 cfs at the upper gaging station and immediately dropped 0.25 miles below the gaging station after the river leaves Glen Rose Limestone formation and flows onto Edwards limestone. At US Highway 90, the flow was 40 cfs (Manford, Dixon, and Dent, 1960). The USGS (1991) remarked that the same geologic control of the streamflow loss in the Nueces and Frio Rivers. The average annual streamflow at the upper gaging station is 58.9 cfs and the lower, 15.1 cfs, indicating the Sabinal River loses water to the Edwards Limestone and the Leona Formation.

East of the Sabinal River is Seco Creek. The USGS operates tow gaging stations on Seco Creek. The average annual discharge is 18.7 cfs for the upper station for a drainage area of 45 square miles and 8.35 cfs for the lower station for a drainage area of 168 square miles (USGS 1991). The loss of water can be attributed to the BFZ Edwards limestone and faults.

East of Seco Creek is Hondo Creek. Hondo Creek flows over the Glen Rose Limestone in Bandera County. Both the springs issuing from the Edwards Plateau and the groundwater discharge from the Glen Rose contribute to the streamflow. It increased from 7.11 cfs 12 miles above Tarpley in Bandera County to 58.8 cfs in Tarpley in April 1958. Near Tarpley, a fault separate the Glen Rose from the Edwards. The creek begins to lose water for the next 12 miles until it reaches the USGS gaging station. About 10 of the 12 miles the river flows over the Edwards Limestone. The discharge was 30.1 cfs at the gaging station north of Hondo. Between the gaging station and Hondo, the creek crosses many geologic formations and faults. At Hondo the discharge was 11 cfs (Manford, Dixon, and Dent, 1960).

Region II Southeast of Hondo, all of the rivers in the Nueces River basins flow over the Carrizo-Wilcox aquifer outcrop. The Carrizo-Wilcox Sands outcrop as a ten to 15 miles band, about perpendicular to the river channels. The rivers may lose or gain from this aquifer (Alexander, Myers, and Dale, 1964). Further pumping in the Winter Garden area (Atascosa, Bexar, Caldwell, Dimmit, Frio, Gonzales, Guadalupe, Karnes, La Salle, Live Oak, McMullen, Maverick, Medina, Uvalde, Wedd, Wilson, and Zavala Counties) will enhance the recharge from the rivers flowing over the Carrizo-Wilcox outcrops and reduce the aquifer contribution to the baseflow of the streams in the Nueces River basin (Klemt, Duffin, and Elder, 1976).

Further east and southeast, both rivers flow over the outcrops of minor aquifers (Queen City Sand and Sparta Sand). The Nueces River turns from southeast direction to northeast near La Salle and Duval County line. It merges with the Frio and Atascosa

Rivers near Three Rivers in Live Oak county and resumes southeast flow direction to the Gulf. The Atascosa River originates in the Wilcox Formation north of Devine in Medina County. The western extent of the Gulf Coast aquifer begins about five miles west of Karnes City. In general, the Carrizo-Wilcox aquifer, the Coastal aquifer, and the two minor aquifers may contribute baseflow to the San Antonio River.

Table 3.21.1
Surface Water and Groundwater Interaction, Nueces River Basin.

Reach	Water Quality Segment	SW/GW Interaction	Aquifer	Probability/ Comments
Nueces River above La Pryor	2112	Yes, gaining and losing	Edwards-Trinity (Plateau) aquifer: gaining from the Edwards and Glen Rose limestone above Laguna but losing below Laguna to La Pryor.	High: based on stream flow gauging records.
Nueces River from La Pryor to Corpus Christi Bay	2105, 2104, 2106, 2103, 2102, 2101	Yes, gaining and losing	Carrizo-Wilcox and the Gulf Coast aquifer: flow is over the outcrop areas. May lose at the upgradient portion of the aquifer outcrop and gaining at the downgradient portion.	Medium
Frio River above US Highway 90	2113	Yes, gaining and losing	Edwards-Trinity (Plateau) aquifer: same as Nueces River above La Pryor. Stream loses water between Concan and US Highway 90.	High: based on stream flow gauging records.
Frio River below US Highway 90	2117,	Yes, gaining and losing	Over the West Gulf Coast Plain	Medium
Sabinal River above Hondo Creek	2111, 2110	Yes, gaining and losing	Edwards-Trinity (Plateau), Trinity, and Edwards aquifers: gaining from the aquifers but losing when entering into the BFZ.	High: based on stream flow gauging records.
Hondo Creek above Frio River	2114	Yes, gaining and losing	Edwards-Trinity (Plateau), Trinity, and Edwards aquifers: gaining from the aquifers but losing when entering into the BFZ.	High: based on stream flow gauging records.
Atascosa River above Frio River	2107	Yes, losing and gaining	Carrizo-Wilcox aquifer: may lose streamflow when first enters the sand but gains downstream where the sand discharges to the river as springs and seeps.	Medium

3.21.3 References

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3.22 THE NUECES-RIO GRANDE COASTAL BASIN

3.22.1 Hydrologic Characteristics

The Nueces-Rio Grande Coastal Basin is bounded on the north by the Nueces River Basin and on the west and south by the Rio Grande Basin (Figure 3.22.1). The eastern extent of the basin is bordered by Gulf Inter-coastal Canal. Total drainage area of the basin is 10,442 square miles (TWDB, 1997). The basin is located in the West Gulf Coast section of the Coastal Plains province, which is predominantly a smooth, featureless, depositional plain rising from sea level to an altitude of about 800 feet at the distal extent of the interior boundary in the northwestern portion of the basin (TWDB 1979). The basin exhibits a dry subhumid climate with a mean annual rainfall of about 26 inches (TWC, 1963).

The sediments that are exposed on the land surface and in the surface water channels throughout the Nueces-Rio Grande Coastal Basin consists of beds, lenses, and stringers of gravel and coarse to fine sand interbedded with silt and clay beds and lenses. These sediments form a series of gently dipping truncated wedges which thicken toward the coast, causing each wedge to have a slightly steeper dip than the overlying wedge. At depth, the lithology of these sediments become more dominantly silt and clay (TWC, 1963). Surface water channels are sufficiently entrenched into the surficial sediments to allow shallow groundwater to discharge into them (Ray Slade, personal communication, 1999). However, most streams are intermittent, except in tidally affected reaches (TWDB, 1977).

Regions

The Nueces-Rio Grande Coastal Basin is treated as one hydrologic unit.

Major Aquifers

The Nueces-Rio Grande Coastal Basin is underlain by the Gulf Coast Aquifer System (GCAS) as shown in Figure 3.22.2. The GCAS is a complex network of interbedded sediments which have been segregated into four generally recognized water producing formations. Aggregately, these formations form a large leaky artesian aquifer system, the GCAS, that provides groundwater for agricultural, industrial, and municipal uses.

The Chicot aquifer, which is the upper or down-dip most component of the GCAS, outcrops within the eastern half of the Nueces-Rio Grande Coastal Basin and is hydrologically interconnected with the underlying by Evangeline aquifer in the western portion of the Chicot outcrop zone (TWDB, 1979). The Evangeline aquifer outcrops in the western portion of the coastal basin and is underlain by the Burkeville confining unit.. The thickness of fresh to slightly saline water within the aquifer ranges from less than 200 feet near the coast to more than 400 feet in the southern portion of the basin north of Edinburg (TWC, 1963). Due to the shallow depths to groundwater and the surficial exposure of sediments in the outcrop of the GCAS, it is expected that groundwater would generally discharge into drainage-ways and coastal embayment throughout the basin.

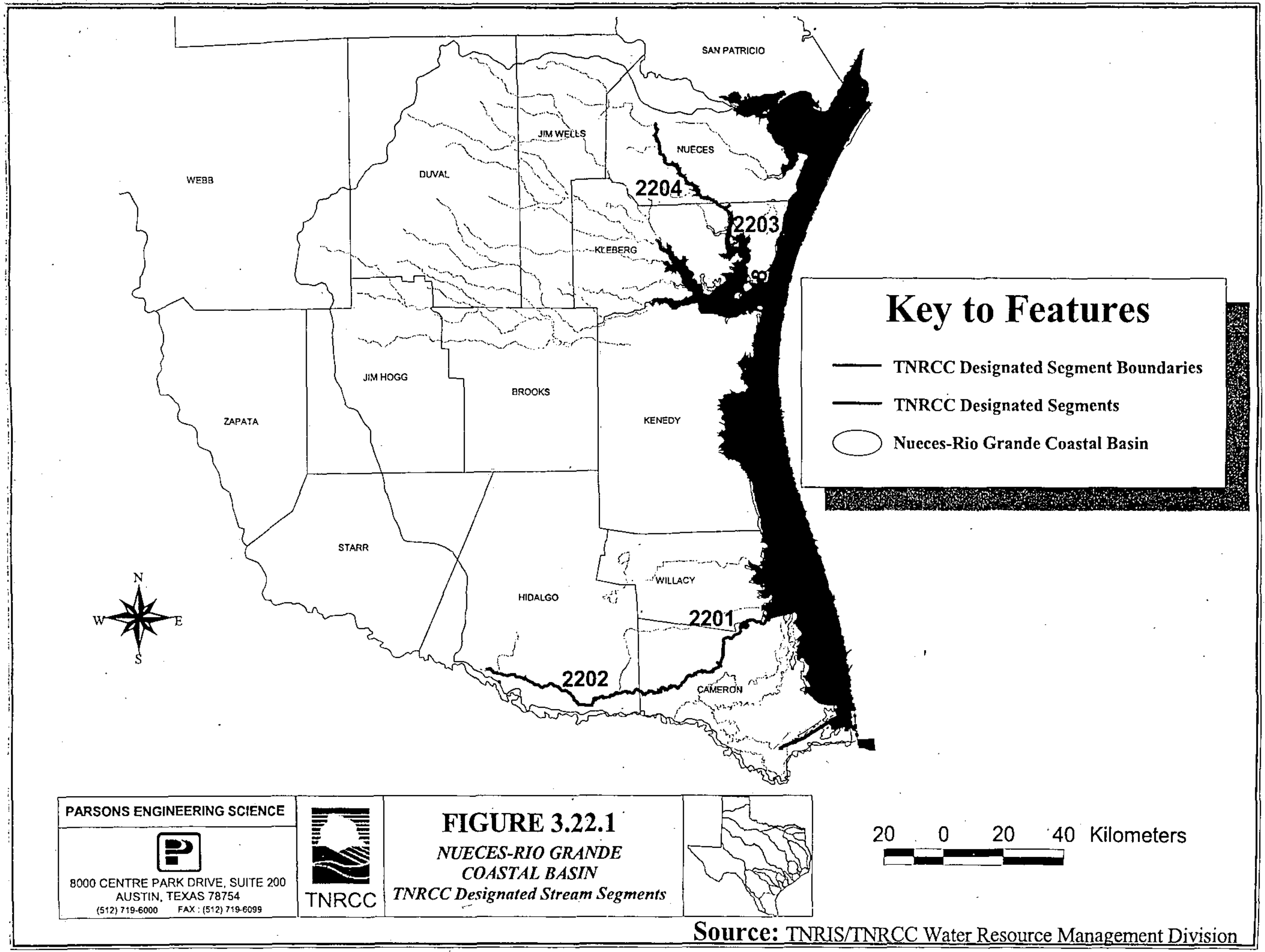


FIGURE 3.22.1

NUECES-RIO GRANDE COASTAL BASIN

TNRCC Designated Stream Segments

Source: TNRIS/TNRCC Water Resource Management Division

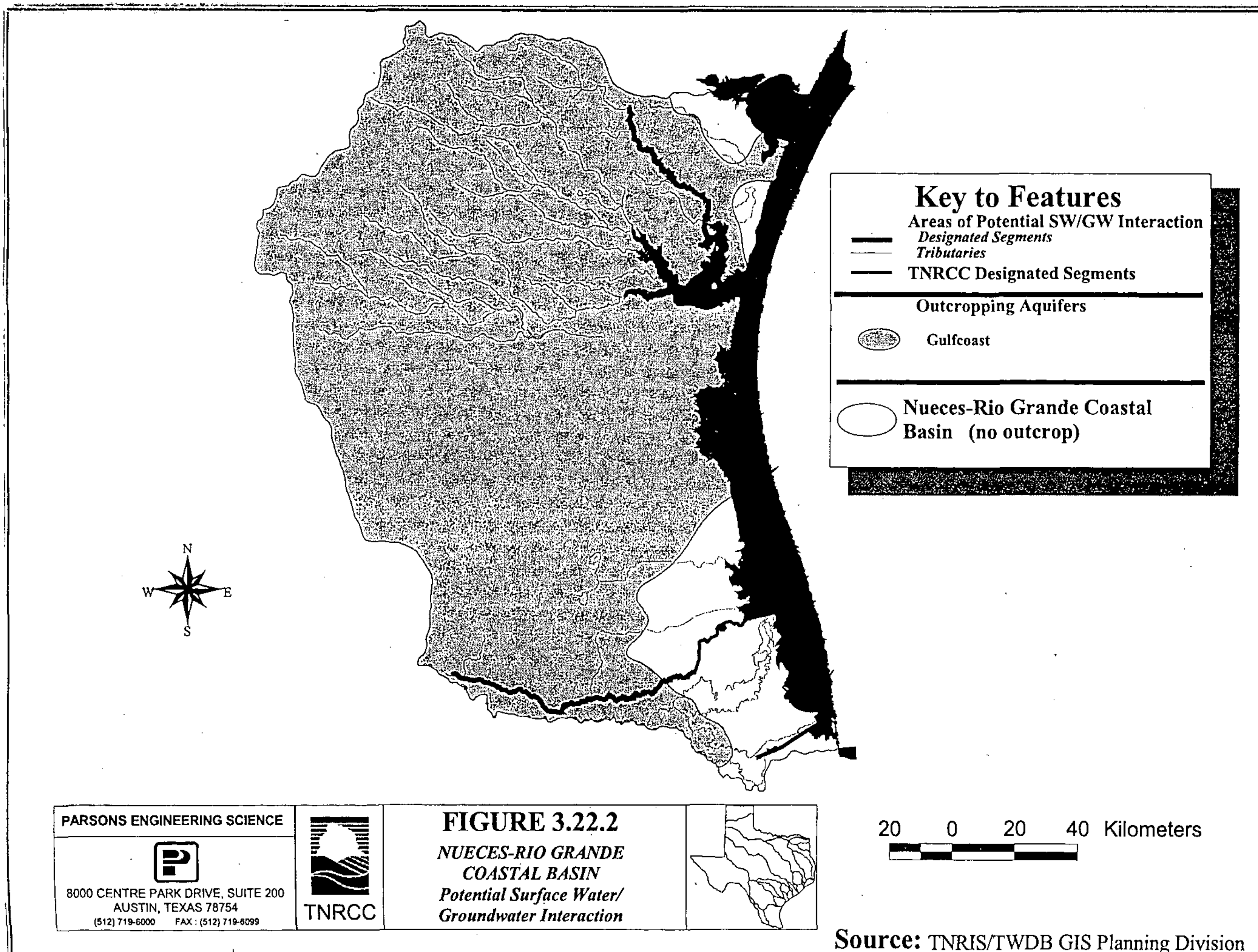
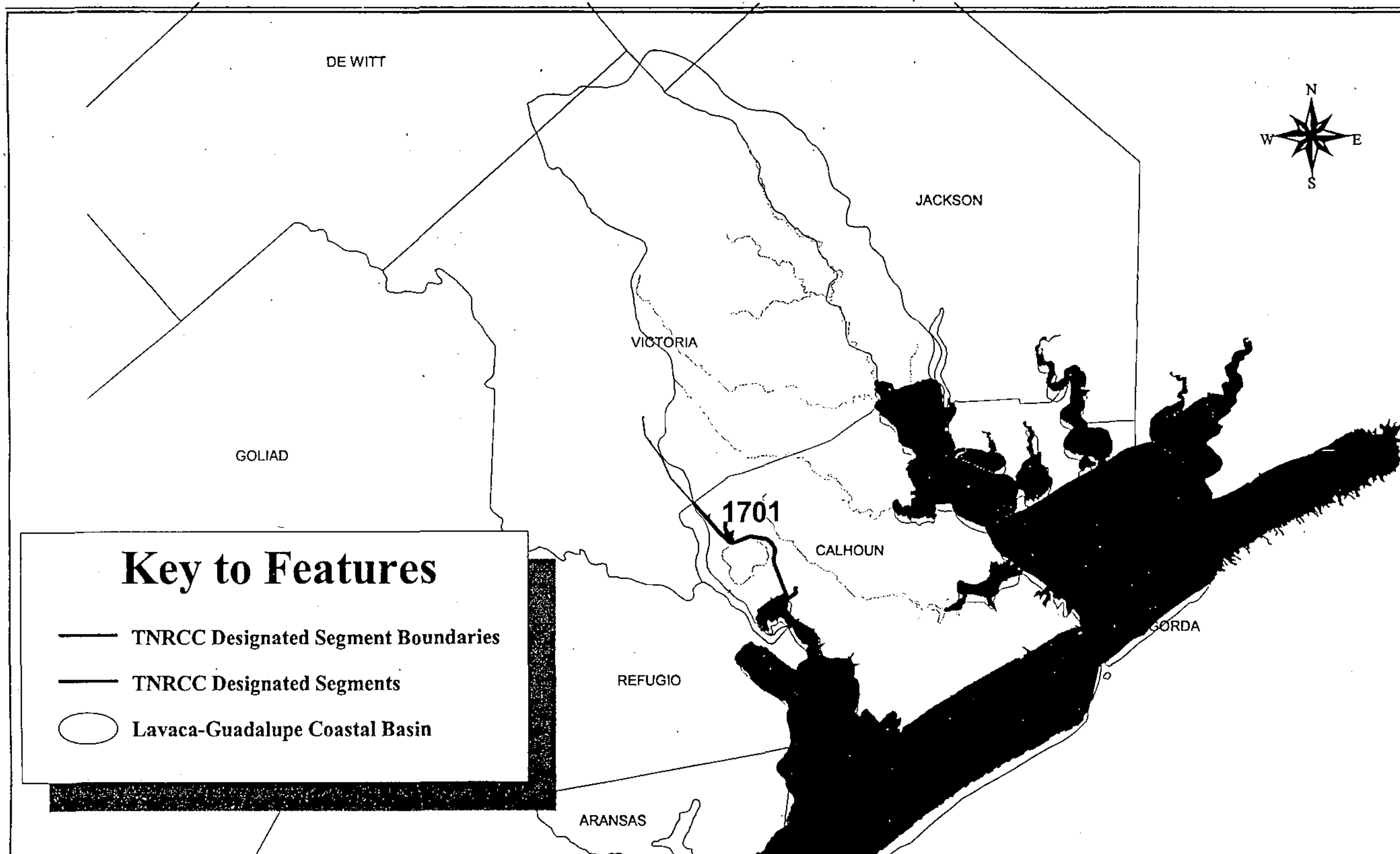


FIGURE 3.22.2

NUECES-RIO GRANDE COASTAL BASIN Potential Surface Water/ Groundwater Interaction



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TNRCC

FIGURE 3.17.1

LAVACA-GUADALUPE COASTAL BASIN
TNRCC Designated Stream Segments

6 0 6 12 Kilometers

Source: TNRIS/TNRCC Water Resource Management Division

Minor Aquifers

There are no minor aquifer systems in the Nueces-Rio Grande Coastal Basin.

Reservoirs

There are no storage reservoirs in the Nueces-Rio Grande Coastal Basin.

3.22.2 Significance of The Interaction

There are no fresh water stream flows or river segments that have been identified for water availability modeling. Therefore, for purposes of this report, there are no significant surface water/groundwater interaction areas in the Nueces-Rio Grande Coastal Basin.

Table 3.22.1
Surface Water and Groundwater Interaction, Brazos River Basin

Reach	Water Quality Segment	SW/GW Interaction	Aquifer	Probability/ Comments
Oso Creek in Corpus Christi	NA	Yes, but insignificant	Chicot aquifer: discharge from oil fields contributes perennial flow.	Low
San Fernado and Los Olmos Creeks above Baffin Bay	NA	Yes, but insignificant	Chicot aquifer: intermittent creeks indicates gaining and losing conditions.	Low
Arroyo Colorado from Laguna Madre to headwater	2201, 2202	Yes, gaining	Chicot aquifer: potentially gaining from irrigation induced high water table, and tail water	Low

3.22.3 References

Slade, R., U.S. Geological Survey, Texas District Office, personal communication, June 1999.

TWC, 1963. Reconnaissance Investigation of the Ground-Water Resources of the Gulf Coast Region, Texas, Texas Water Commission, Bulletin 6305, June 1963.

TWDB, 1997. Water for Texas, Texas Water Development Board, August,1997.

TWDB, 1979. Stratigraphic and Hydrogeologic Framework of Part of the Coastal Plain of Texas, Texas Water Development Board, Report 236, July 1979

TWDB, 1977. Continuing Water Resources Planning and Development for Texas, May 1977.

SECTION 4.0
CONCLUSIONS

This report provides statewide and regional hydrologic information and analysis for 22 of 23 major river basins in the state of Texas. This information furthers the ability of the legislature and public water resource agencies of Texas to form prudent and decisive plans for managing both surface water and groundwater resources. The future availability of water in Texas to meet the projected demands for human consumption, recreation, private and public business interests, and a myriad of critically sensitive environmental uses depends solely upon the ability to understand and manage the hydrologic balance between groundwater and surface water resources.

Surface water in portions of each river basins in the state both lose and/or gain water to or from underlying groundwater systems. Many of these groundwater systems or aquifers discharge water directly into the river basins, which sustains surface water flow in the main stem and tributary channels of a majority of the river basins during dry periods, thereby providing year-round or perennial surface water supplies. Surface water is also available from sources not directly connected to the natural hydrologic cycle through interbasin importation of water and intrabasin wastewater disposal. Regardless of the various sources of surface water within the states' river basins, the amount of water that is exchanged between the surface water and groundwater systems must be better understood.

Generally, the headwaters are losing segments unless they originated from a spring. When a stream flows over the outcrop of an aquifer, this stream segment is potentially a losing segment, at least at the upstream portion. Sometimes in the downstream portion of an outcrop, if the stream is incised into the water table, this segment will be a gaining reach. Toward the river mouth near the Gulf Coast, groundwater usually contributes to the streamflow.

Since it is not possible to assess within the limits of this study every stream in Texas for potential groundwater interaction, attention was focused upon TNRCC designated stream segments (primarily first and second order streams). However, since water rights are often located on smaller tributaries, the potential impacted tributaries were included in the mapping, even if they were not addressed in the body of the analysis report.

Additional information will be required to conduct future analysis and numerical modeling to quantify the degree of surface water interaction with underlying groundwater systems. Basin specific data should include streamflow gain and loss measurements along potentially impacted segments along with aquifer thickness and flow properties to conduct future modeling studies. These surface water/groundwater models should be designed to predict the impact of water availability in either the surface water or the groundwater systems of interest in the event that future demands on the use of water from either system is proposed.

The literature review indicates that there are sufficient evidence that the WAM should consider groundwater component for the river basins across the state of Texas and over the Ogallala aquifer, the Trinity aquifer, Edwards Plateau, the alluviums in the Osage Plains and the Brazos River, and the Balcones fault zone. These river basins are

- The Canadian River
- The Red River
- The Trinity River
- The Brazos River
- The Colorado River
- The Guadalupe River
- The San Antonio River
- The Nueces River

In the east Texas, where the stream flows across the Carrizo-Wilcox, Queen City Sand, and the Gulf Coast aquifers, the probability of the surface and ground water interaction is high. The rivers effected include:

- The Sulphur River
- The Cypress Creek
- The Sabine River
- The Neches River
- The San Jacinto River

For those coastal river basins, even though the volume of discharge is relatively smaller compared to those river basins originating inland, they still have connection with the Gulf Coast aquifer. Because the San Jacinto and the Lavaca River basins are almost completely underlain by the Gulf Coast aquifer, these two river basins also fall into this category.

- The Neches-Trinity Coastal
- The Trinity-San Jacinto Coastal
- The San Jacinto River
- The San Jacinto-Brazos Coastal
- The Brazos-Colorado
- The Colorado-Lavaca Coastal
- The Lavaca River
- The Lavaca-Guadalupe Coastal
- The San Antonio-Nueces Coastal
- The Nueces-Rio Grande Coastal

Table 4.1 presents a representation of river basins and groundwater interactions.

Table 4.1
Occurrence of Aquifer Outcrops within a Major River Basin

Reach	Water Quality Segment	SW/GW Interaction	Aquifer(s) and Reasons for Interaction	Probability (H-M-L)
1. Canadian River Basin				
Canadian River below Lake Meredith and above the Texas-Oklahoma State line	0101	Yes, gaining	Ogallala aquifer: outcrops contribute to stream flow in Hemphill County, sand dune deposits contribute to flow.	High
Lake Meredith	0102	Yes, gaining or losing	Ogallala aquifer: seasonal variation—when lake stage is higher than the water table, losing; otherwise, gaining.	Medium
Canadian River above Lake Meredith	0103	Yes, gaining	Ogallala aquifer: stream flow increases downstream over water bearing geologic units of the Ogallala, Dockum, and Permian rocks.	High
Wolf Creek	0104	Yes, gaining	Ogallala aquifer: baseflow to creek derived from the Ogallala aquifer.	Medium
2. Red River Basin				
North Fork Red River	0224	Yes, gaining or losing.	Ogallala and Alluvium aquifers: Ogallala aquifer discharges along the base of the escarpment. The Alluvium aquifer also discharges along its outcrop. May be losing depending on seasons.	Medium
Salt Fork Red River	0222	Yes, gaining	Ogallala and Alluvium aquifers: Ogallala aquifer discharges along the base of the escarpment. The Alluvium aquifer also discharges along its outcrop. May be losing depending on seasons.	Medium
Prairie Dog Town Red River	0229, 0207	Yes, gaining	Ogallala and Alluvium aquifers: Ogallala aquifer discharges along the base of the escarpment. The Alluvium aquifer also discharges along its outcrop. May be losing depending on seasons.	Medium

Table 4.1 (Continued)
Occurrence of Aquifer Outcrops within a Major River Basin

Reach	Water Quality Segment	SW/GW Interaction	Aquifer(s) and Reasons for Interaction	Probability (H-M-L)
Red River	0206 & 0205	Yes, gaining	Alluvium aquifer: river gains over outcrops of Seymour/alluvial deposits and Permian water-bearing rocks.	High
Pease River	0220	Yes, losing before the confluence with the Middle Pease River, and gaining downstream.	Alluvium aquifer: river gains over outcrops of Seymour/alluvial deposits and Permian water-bearing rocks.	Medium
North Wichita River above Lake Kemp	0218	Yes, gaining	Alluvium aquifer: river gains over outcrops of Seymour/alluvial deposits and Permian water-bearing rocks. Salt seeps are also found.	High
South Wichita River above confluence with the North	0226	Yes, gaining	Alluvium aquifer: river gains over outcrops of Seymour/alluvial deposits and Permian water-bearing rocks. Salt seeps are also found.	High
Little Wichita River above Lake Arrowhead	0213	Yes, losing	Alluvium aquifer: river gains over outcrops of Seymour/alluvial deposits and Permian water-bearing rocks. Salt seeps are also found. However, water table may be higher than the streambeds.	Medium
3. Sulphur River Basin				
North Sulphur River	0305	No, but possible if minor water bearing units outcrop.	Trinity and Woodbine aquifers: River loses over non-water bearing geologic units.	Medium
South Sulphur River	0306	No	Trinity and Woodbine aquifers: River loses over non-water bearing geologic units.	Medium

Table 4.1 (Continued)
Occurrence of Aquifer Outcrops within a Major River Basin

Reach	Water Quality Segment	SW/GW Interaction	Aquifer(s) and Reasons for Interaction	Probability (H-M-L)
Sulphur River	0303	Yes, gaining	Carrizo-Wilcox aquifer: outcrop area provides discharge to river. The upstream Nacatoch Sand may also contribute.	High
Lake Wright Patman	0302	Yes, losing	Carrizo-Wilcox aquifer: the lake is over the non-water bearing Navarro and Midway Clays.	High
Sulphur River	0301	Yes, gaining	Carrizo-Wilcox aquifer: Carrizo-Wilcox Sand outcrops, providing groundwater discharge to the river.	High
White Oak Bayou above Talco	N/A	No, but possible of alluvial or terrace outcrops exist.	Carrizo-Wilcos aquifer: Bayou is over non-water bearing geologic unit Midway Clay.	Medium
White Oak Bayou below Talco	N/A	Yes, gaining	Carrizo-Wilcox aquifer: outcrop provides groundwater discharge to surface water.	High
4. Cypress River Basin				
Big Cypress Creek above Lake Bob Sandlin dam	0405, 0408	Yes, gaining or losing	Carrizo-Wilcox and Cypress aquifers: The creek gains over the aquifer outcrops. Away from the lake, the stream may gain from groundwater; at the lake, the groundwater would gain from the lake.	High
Big Cypress Creek below Lake Bob Sandlin and above Caddo Lake	0404, 0403, & 0402	Yes, gaining or losing	Cypress aquifer: outcrop area of aquifer allows stream to gain from groundwater; but at Lake O' the Pines and Caddo Lake, surface water may recharge groundwater.	High
Little Cypress Creek	0409	Yes, gaining	Cypress aquifer: almost completely flows over aquifer outcrop.	High
Frazier Creek	0407	Yes, gaining or losing	Cypress aquifer: Creek flows over outcrops	High

Table 4.1 (Continued)
Occurrence of Aquifer Outcrops within a Major River Basin

Reach	Water Quality Segment	SW/GW Interaction	Aquifer(s) and Reasons for Interaction	Probability (H-M-L)
Black Bayou	0406	Yes, losing	Cypress aquifer: Bayou is over outcrop area. However, municipal pumping may reduce groundwater contribution.	Medium
5. Sabine River Basin				
Sabine River above confluence with Lake Fork Creek including Lake Tawakoni and Lake Fork Reservoir	0506 upper half, 0507, 0512, & 0515	Yes, losing or gaining	Nacatoch Sand and Carrizo-Wilcox aquifer: River is over aquifer outcrops.	High
Sabine River below confluence with Lake Fork Creek and above Longveiw, Texas including Lake Fork Creek and Big Sandy Creek	0506 lower half & upper half of 0505	Yes, gaining	Queen City aquifer: River is over outcrop areas.	High
Sabine River below Longview, Texas and above Toledo Bend Reservoir including the upper half of the reservoir	0510, 0509, & 0504	Yes, gaining	Carrizo-Wilcox aquifer: River is over aquifer outcrops.	High
Sabine River below Toledo Bend Reservoir to Sabine Lake	0513, 0503, 0501, 0508, & 0511	Yes, losing or gaining	Gulf Coast aquifer: system formations outcrop	Low to Medium
6. Neches River Basin				
Neches River, Lake Palestine and above	0605 & 0606	Yes, gaining	Carrizo-Wilcox and Queen City aquifers: units outcrop along these segments.	High
Neches River, BA Steinhagen to Lake Palestine	0604	Yes, gaining	Queen City, Sparta, Yegua, Jackson, and Gulf Coast aquifers: the formations outcrop along this reach.	Low to Medium

Table 4.1 (Continued)
Occurrence of Aquifer Outcrops within a Major River Basin

Reach	Water Quality Segment	SW/GW Interaction	Aquifer(s) and Reasons for Interaction	Probability (H-M-L)
Neches River, BA Steinhagen to Coast	0603, 0602, 0608, 0607, & 0601	Yes, gaining	Gulf Coast aquifer: outcrop in area of river.	High
Angelina River	0611	No, but potential interaction near alluvial/terrace deposits along the river.	Pecan City and Carrizo-Wilcox aquifer outcrop North of Nacadoches.	Low
Attoyac Bayou	0612	Yes, gaining	Carrizo-Wilcox aquifer: outcrop.	High
Sam Rayburn Reservoir to BA Steinhagen	0610 &0609	Yes, gaining	Yegua, Jackson, and Gulf Coast aquifers: units outcrop	High
7. Neches-Trinity Coastal Basin				
Taylor Bayou	0701	Yes, gaining	Gulf Coast aquifer: the entire watershed is on the aquifer outcrop.	Low
8. Trinity River Basin				
Trinity River, Bridgeport Reservoir and above	0812, 0811, & 0834	No	Over non-aquifer outcrop area.	Low
Trinity River, Fork of Clear Fork of Trinity River to Bridgeport Reservoir	0807, 0808, 0809, & 0810	Yes, gaining or losing	Trinity aquifer: outcrop area provides interaction potential.	High
Trinity River, Cedar Creek Reservoir to the Clear Fork of Trinity River	0805, 0841, & 0806	Yes, losing and gaining	Woodbine aquifer and Nacatoch Formation: outcrops provide interaction potential.	Medium

Table 4.1 (Continued)
Occurrence of Aquifer Outcrops within a Major River Basin

Reach	Water Quality Segment	SW/GW Interaction	Aquifer(s) and Reasons for Interaction	Probability (H-M-L)
Trinity River, Coast up to Cedar Creek Reservoir	0801, 0802, 0803, 0813, 0804 & 0818	Yes, gaining and losing	Carrizo-Wilcox, Queen City, Sparta, and Gulf Coast aquifers: outcrops along these segments.	High
Elm Fork of the Trinity River	0822, 0825, 0826, 0823, 0839, 0840, & 0824	Yes, gaining	Woodbine aquifer: outcrops along these segments.	High
Clear Fork of the Trinity River	0829, 0830,0831, 0832, & 0833	Yes, possible gaining during certain times of the year	Trinity Group: outcrops are along the river.	High
East Fork of the Trinity River	0819, 0820, & 0821	No, but possible interaction along alluvial deposits.	Over non-outcrop areas.	Low to medium
Chambers Creek and Richland Creek, from above Richland-Chambers Reservoir to headwaters	0814, 0815, 0816, 0837, & 0817	No, but possible along sands or alluvial deposits.	Nacatoch Formation: creeks are over thin-outcrop area.	Low to moderate
Chambers Creek and Richland Creek, from Trinity River through Richland-Chambers Reservoir	0835 & 0836	Yes, gaining	Carrizo-Wilcox aquifer: outcrop provides potential for interaction.	High
Misc. Reaches	0828, 0838, & 0827	No, but possible interaction along alluvial deposits.	Over non-outcrop areas	Low
9. Trinity-San Jacinto Coastal Basin				
Cedar Bayou	0901, 0902	Yes, gaining	Gulf Coast aquifer: the entire watershed is on the outcrop.	Low

Table 4.1 (Continued)
Occurrence of Aquifer Outcrops within a Major River Basin

Reach	Water Quality Segment	SW/GW Interaction	Aquifer(s) and Reasons for Interaction	Probability (H-M-L)
10. San Jacinto River Basin				
San Jacinto River above Lake Houston: East Fork, Peach Creek, Caney Creek	1003, 1011, 1010	Yes, gaining	Gulf Coast aquifer: the entire watershed is over the aquifer.	Medium
San Jacinto River above Lake Houston: West Fork, Spring Creek, Cypress Creek	1002, 1004, 1012, 1015, 1008, 1009	Yes, gaining or losing	Gulf Coast aquifer: the entire watershed is over the aquifer. Lake Conroe and Houston may recharge groundwater and then show up downstream as baseflow.	Medium
San Jacinto River below Lake Houston and above tide	1001	Yes, gaining or potentially losing	Gulf Coast aquifer: the entire watershed is over the aquifer. Lake Conroe and Houston may recharge groundwater and then show up downstream as baseflow.	Medium
Buffalo Bayou	1006, 1007	Yes, gaining	Gulf Coast aquifer: the entire watershed is over the aquifer. Lake Conroe and Houston may recharge groundwater and then show up downstream as baseflow.	Medium
11. San Jacinto-Brazos Coastal Basin				
Armand Bayou	1113	Yes, gaining or losing	Gulf Coast aquifer: underlies entire watershed.	Medium
Clear Creek	1101,1102	Yes, gaining or losing	Gulf Coast aquifer: underlies entire watershed.	Medium
Dickinson Bayou	1103,1104	Yes, gaining or losing	Gulf Coast aquifer: underlies entire watershed.	Medium
Chocolate Bayou	1105,1106	Yes, gaining or losing	Gulf Coast aquifer: underlies entire watershed.	Medium

Table 4.1 (Continued)
Occurrence of Aquifer Outcrops within a Major River Basin

Reach	Water Quality Segment	SW/GW Interaction	Aquifer(s) and Reasons for Interaction	Probability (H-M-L)
Oyster Bayou	1109,1110, 1112	Yes, gaining or losing	Gulf Coast aquifer: underlies entire watershed.	Medium
12. Brazos River Basin				
From Lake Whitney Dam to Navasota River	1242	Yes, gaining	Carrizo Sand and Quaternary Alluvium aquifers.	Medium
Brazos River below Navasota River	1201, 1202	Yes, gaining	Outcrops of Quaternary Alluvium, Gulf Coast, and Tertiary Group aquifers.	High
13. Brazos-Colorado Coastal Basin				
San Bernard River from Headwaters to the Gulf	1301,1302	Yes, gaining	Gulf Coast aquifer: underlies entire basin.	Medium
Caney Creek from Headwaters to East Matagorda Bay	1304,1305	Yes, gaining	Gulf Coast aquifer: underlies entire basin.	Medium
14. Colorado River Basin				
Colorado River above Lake J.B. Thomas	1413	Yes, losing	Ogallala and Edwards-Trinity Plateau aquifers: depth to aquifers are below streambeds; ephemeral streams in semi-arid area indicate losing flow conditions; USGS gaging station data above lake indicates streamflow only in August and September.	High

Table 4.1 (Continued)
Occurrence of Aquifer Outcrops within a Major River Basin

Reach	Water Quality Segment	SW/GW Interaction	Aquifer(s) and Reasons for Interaction	Probability (H-M-L)
Below Lake J. B. Thomas and above E. V. Spence Reservoir	1412	Yes, gaining or losing.	Ogallala, Edwards-Trinity Plateau, and Santa Rosa aquifers: seepage from lakes; flow is regulated by Lake JB Thomas. Three USGS gaging station data indicated there were no flows, i.e., losing conditions; Coke County (Wilson 1973) groundwater report indicates gaining conditions. Mount et al. (1967) stated that south of Colorado City, Santa Rosa aquifer outcrop contributes baseflow.	Medium
Between E. V. Spence Reservoir and the confluence with Concho River (O. H. Ivie Reservoir)	1411, 1426 & 1433	Yes, gaining or losing.	Ogallala, Edwards-Trinity Plateau, and Santa Rosa aquifers: prior to Spence Reservoir, the river had more flow than below. Flow increased downstream; also had no flow days.	Medium
Concho River	1424, 1423, 1422, 1425 & 1421	Yes, gaining at springs and losing to the mouths.	Edward-Trinity (Plateau) aquifer: Concho River is gaining along the main stem probably due to springs from the base of aquifer. Dove Creek Spring between the South and Middle Concho flows at 16.4 cfs.	Medium
Below O. H. Ivie Reservoir and above Pecan Bayou	1410	Yes, gaining or losing	Edward-Trinity (Plateau) aquifer on the west side of the river only: annual streamflow increased below O. H. Ivie Reservoir from 215 cfs to 272 cfs west of US Highway 377. Below San Saba river, discharge was 1,340 cfs. Pecan Bayou and San Saba River flowed at 134 cfs and 222 cfs, respectively, at mouths with the Colorado River	Medium
Pecan Bayou	1420, 1418, 1417, 1419	Yes, gaining and losing	Trinity aquifer partial outcrop: outcrops at east-half of Brown County. The bayou cuts though the Strawn Group below Lake Brownwood to its mouth with the River. Groundwater may contribute to streamflow below the lake. Above the lake, the stream may be losing.	Medium

Table 4.1 (Continued)
Occurrence of Aquifer Outcrops within a Major River Basin

Reach	Water Quality Segment	SW/GW Interaction	Aquifer(s) and Reasons for Interaction	Probability (H-M-L)
San Saba River	1416	Yes, gaining	Trinity-Edwards (Plateau) aquifer: discharge from springs and seeps and outcrop of the aquifer. However, faults created by the Llano Uplift might cause river losing to the Ordovician limestones.	High
Llano River	1415	Yes, gaining	Edwards-Trinity (Plateau) aquifer water-bearing outcrops sustained the river from springs above Junction in Kimble County (Holland and Mendieta, 1965).	High
Pedernales River	1414	Yes, gaining	Edwards-Trinity (Plateau) aquifer water-bearing outcrops sustained the river from springs above Junction in Kimble County (Holland and Mendieta, 1965) (Holland and Hughes, 1964).	High
Colorado River between San Saba River and Onion Creek	1409, 1408, 1407, 1406, 1405, 1404, 1403	Yes, gaining	Ordovician limestone aquifers, Glen Rose aquifer, and the Edwards aquifer: These water-bearing units discharge to the river.	High
Onion Creek	1427	Yes, gaining	Edwards aquifer: discharge conditions.	High
Colorado River below Onion Creek to its mouth	1402, 1401	Yes, gaining	Gulf Coast and Carrizo-Wilcox Sand aquifers: discharge conditions.	High
15. Colorado-Lavaca Coastal Basin				
Tres Palacios Creek	1501,1502	Yes, gaining	Gulf Coast aquifer: underlies creek area.	Low
West and East Carancahua Creek	NA	Yes, gaining	Gulf Coast aquifer: underlies creek area.	Low
Cox Creek	NA	Yes, gaining	Gulf Coast aquifer: underlies creek area.	Low

Table 4.1 (Continued)
Occurrence of Aquifer Outcrops within a Major River Basin

Reach	Water Quality Segment	SW/GW Interaction	Aquifer(s) and Reasons for Interaction	Probability (H-M-L)
16. Lavaca River Basin				
West Mustang Creek and Sandy Creek above Lake Texana	NA	Yes, gaining	Gulf Coast aquifer: underlies basin. Expected that shallow groundwater would discharge to surface water.	Medium
Navidad River from Lake Texana to headwaters	1063, 1604	Yes, gaining	Gulf Coast aquifer: underlies basin. Expected that shallow groundwater would discharge to surface water.	Medium
Lavaca River from bay to headwaters	1601, 1602	Yes, gaining	Gulf Coast aquifer: underlies basin. Expected that shallow groundwater would discharge to surface water.	High
17. Lavaca-Guadalupe Coastal Basin				
Gracitas and Placedo Creek above bay	NA	Yes, gaining	Gulf Coast aquifer: outcrop.	Medium
18. Guadalupe River Basin				
Guadalupe River above New Braunfels	1811, 1812, 1805, 1806, 1816, 1817, 1818	Yes, gaining	Edwards-Trinity (Plateau) and Edwards aquifers: discharge from springs and seeps and discharge from the Comal Springs.	High
Guadalupe River below New Braunfels and above the mouth with the San Marcos River	1804	Yes, gaining or losing	Carrizo-Wilcox aquifer: no interaction where the river traverses over the Midway Clay outcrop. May lose or gain outcrop.	Medium
Guadalupe River below the San Marcos River and the San Antonio Bay	1803, 1802, 1801, and 1807	Yes, gaining	Gulf Coast aquifer: springs and seeps.	High
San Marcos River above San Marcos	1814	Yes, gaining	Edwards aquifer: sustained by flow from San Marcos Springs.	High

Table 4.1 (Continued)
Occurrence of Aquifer Outcrops within a Major River Basin

Reach	Water Quality Segment	SW/GW Interaction	Aquifer(s) and Reasons for Interaction	Probability (H-M-L)
Blanco River above San Marcos	1809, 1813, 1815	Yes, gaining and losing	Edwards aquifer: gaining from springs In Segment 1813 and 1815 but losing in segment 1809.	High
San Marcos River above Guadalupe River	1808, 1810	Yes, gaining and losing	Carrizo-Wilcox aquifer: the river flows over the outcrop, which may contribute to baseflow.	Medium
19. San Antonio River Basin				
Medina River above Medina Lake	1905	Yes, gaining and losing	Edwards aquifer: gaining between Medina and Bandera but losing from Bandera to Medina lake.	High
Medina Lake and Diversion Lake	1904, 1909	Yes, losing	Edwards aquifer: Major BFZ faults located below Medina Lake that induce leakage to Edwards aquifer.	High
Medina River above San Antonio River	1903, 1912	Yes, gaining	Edwards and Carrizo-Wilcox aquifers: upward leakage from the Edwards aquifer and discharge from the Carrizo-Wilcox Sand aquifer to the river.	Medium
Leon Creek	1907,1906	Yes, losing	Edwards, Upper Trinity and Middle Trinity aquifers: not a perennial stream above San Antonio due to geology.	High
Salado Creek	1910	Yes, losing and gaining	Edwards, Upper Trinity and Middle Trinity aquifers: not a perennial stream above San Antonio due to geology.	High
Cibolo Creek from headwaters to I-35	1908	Yes, losing	Edwards and Middle Trinity aquifers: area of the BFZ.	High
Cibolo Creek from I-35 to mouth with San Antonio River	1913, 1902	Yes, losing and gaining	Carrizo-Wilcox aquifer: may lose streamflow when first enters the sand but gains downstream where the sand discharges to creek as springs and seeps.	Medium

Table 4.1 (Continued)
Occurrence of Aquifer Outcrops within a Major River Basin

Reach	Water Quality Segment	SW/GW Interaction	Aquifer(s) and Reasons for Interaction	Probability (H-M-L)
San Antonio River above Median River	1911	Yes, gaining	Edwards aquifer: springs and artesian wells discharge from the aquifer.	High
San Antonio River below Medina River to mouth with Guadalupe River	1911, 1901	Yes, losing and gaining	Carrizo-Wilcox aquifer: same reason as Cibolo Creek segments 1913 and 1902	Medium
20. San Antonio-Nueces River Basin				
Mission River above Copano Bay	2001, 2002	Yes, gaining and losing	Gulf Coast aquifer: outcrop area.	Medium
Aransas River above Copano Bay	2003, 2004	Yes, gaining and losing	Gulf Coast aquifer: outcrop area.	Medium
21. Nueces River Basin				
Nueces River above La Pryor	2112	Yes, gaining and losing	Edwards-Trinity (Plateau) aquifer: gaining from the Edwards and Glen Rose limestone above Laguna but losing below Laguna to La Pryor.	High
Nueces River from La Pryor to Corpus Christi Bay	2105, 2104, 2106, 2103, 2102, 2101	Yes, gaining and losing	Carrizo-Wilcox and the Gulf Coast aquifer: flow is over the outcrop areas. May lose at the upgradient portion of the aquifer outcrop and gaining at the downgradient portion.	Medium
Frio River above US Highway 90	2113	Yes, gaining and losing	Edwards-Trinity (Plateau) aquifer: same as Nueces River above La Pryor. Stream loses water between Concan and US Highway 90.	High
Frio River below US Highway 90	2117,	Yes, gaining and losing	Over the West Gulf Coast Plain	Medium

Table 4.1 (Continued)
Occurrence of Aquifer Outcrops within a Major River Basin

Reach	Water Quality Segment	SW/GW Interaction	Aquifer(s) and Reasons for Interaction	Probability (H-M-L)
Sabinal River above Hondo Creek	2111, 2110	Yes, gaining and losing	Edwards-Trinity (Plateau), Trinity, and Edwards aquifers: gaining from the aquifers but losing when entering into the BFZ.	High
Hondo Creek above Frio River	2114	Yes, gaining and losing	Edwards-Trinity (Plateau), Trinity, and Edwards aquifers: gaining from the aquifers but losing when entering into the BFZ.	High
Atascosa River above Frio River	2107	Yes, losing and gaining	Carrizo-Wilcox aquifer: may lose streamflow when first enters the sand but gains downstream where the sand discharges to the river as springs and seeps.	Medium
22. Nueces-Rio Grande Coastal Basin				
Oso Creek in Corpus Christi	NA	Yes, but insignificant	Chicot aquifer: discharge from oil fields contributes perennial flow.	Low
San Fernado and Los Olmos Creeks above Baffin Bay	NA	Yes, but insignificant	Chicot aquifer: intermittent creeks indicates gaining and losing conditions.	Low
Arroyo Colorado from Laguna Madre to headwater	2201, 2202	Yes, gaining	Chicot aquifer: potentially gaining from irrigation induced high water table, and tail water	Low