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December 2002
SFR-073

Effects of Leaking Petroleum Storage Tanks on the Trinity Group Aquifer

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Remediation Division

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

Effects of Leaking Petroleum Storage Tanks on the Trinity Group Aquifer

Prepared by
Remediation Division

SFR-073
December 2002

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EXECUTIVE SUMMARY

As required by Rider 39, Senate Bill 1, 77th Texas Legislature, the Texas Commission on Environmental Quality (TCEQ) has prepared this report on the problems caused by petroleum storage tanks (PSTs) located above aquifer recharge zones, with particular emphasis on the Trinity Group aquifer. The legislative rider specifies that the report should discuss the health and safety effects of inadequate PST spill containment systems as well as long- and short-term contamination remedies.

This study draws on information from several TCEQ program areas and highlights the following:

- PST releases rarely affect the quality of water delivered to customers by public drinking water (PDW) systems.
- Some private domestic water wells are vulnerable to PST releases, especially when those wells are completed in karst aquifers.
- Karst aquifer outcrops are particularly vulnerable to near-surface pollution releases.
- Benzene, a known carcinogen, can pose the greatest threat to public health when spilled.
- Regulations promulgated since the late 1980s have resolved much historical pollution and have put in place adequate protections for public health.

Much progress has been made in the cleanup and prevention of PST pollution in Texas since the U.S. Environmental Protection Agency first promulgated PST regulations in the mid-1980s and then delegated PST regulatory authority to the TCEQ (and predecessor agencies) in the early 1990s.

Pollution from PST sites is now largely preventable due to federal and state regulations requiring compliance of all PST systems with certain construction and monitoring standards. There are also state and local regulations that require additional leak prevention equipment for PST systems located in karst areas.

Petroleum Storage Tanks

Petroleum storage tank facilities are generally composed of tanks, fuel dispensers, connecting pipes, and ancillary equipment such as valves and

pumps. Most PST facilities are concentrated in population centers, along roadways.

Since the mid- to late 1980s when tank registration began, 66,763 petroleum storage tank (PST) facilities have been registered in Texas. Many of the original PST systems have now been removed from service because of outdated or leaking equipment, or because the site owner chose to use the property for another purpose. As of August 1, 2002, there were 28,734 active facilities.

Since the 1980s a significant number of leaks have been confirmed by the TCEQ at over 23,000 facilities. The most common source of leaks are corroded or broken underground piping associated with PST systems. More than 17,000 of the sites with leaks have reached closure under state regulations.

Information about Texas Aquifers

If a PST system located on an aquifer outcrop leaks, the released fuel can move down through the soil or permeable rock to the groundwater table. This fuel can pool on top of the water table where the more soluble constituents dissolve into the groundwater. This process creates a contaminant plume that spreads out from the source in the direction of the local groundwater flow. The behavior of this contaminant plume, and its potential effect on groundwater resources, depends in part on the physical characteristics of the aquifer.

An aquifer is a water-saturated layer of rock or sediment that can yield economically significant quantities of water to wells and springs. Where the rock is cracked or the grains do not fit together perfectly, and the resulting spaces are connected to each other, the water can flow through the layer. When water can flow this way, the layer is said to be permeable.

There are 9 major and 21 minor aquifers in Texas. An aquifer outcrop is the area where aquifer rock or sediment is exposed at the land surface. Water enters an aquifer as rainfall on outcrop areas and as seepage from streams and ponds. This is called aquifer recharge.

How open the aquifer materials are at the surface affects the recharge rate; i.e., the bigger and more numerous the openings, the more recharge can occur. The degree to which an aquifer is open to the recharge and movement of water depends on the physical characteristics of the materials comprising the aquifer.

There are three basic types of aquifers in Texas:

- Clastic aquifers are made up of gravel, sand, silt and clay. These granular materials are usually in discontinuous layers. Water occupies the spaces between the grains. The movement of water through clastic aquifers is relatively slow, steady and predictable. Because groundwater movement through clastic aquifers is relatively slow, and because fuel molecules can adhere to aquifer grains, PST contaminant plumes in clastic aquifers can naturally degrade without migrating more than a few hundred feet from the contaminant source.

- Fractured rock aquifers occur where water moves through cracks in the rocks. In most fractured rock aquifers, groundwater is stored in the rock itself—much like the water stored in a clastic aquifer— but it moves primarily through the cracks in the rock. Because the movement of water through these aquifers depends upon the permeability of the rock as well as fracture size and interconnectiveness, fractured rock aquifers have a broad range of water-bearing characteristics.

- Karst aquifers are made up limestone and other water-soluble rock. Cracks in the rock have been widened by water and provide paths for water movement through the formation. A distinctive feature of karst aquifers is a system of interconnected underground caves and conduits connected to the ground surface by openings such as sinkholes, cracks, and cave openings. The movement of water through karst aquifers is fast, turbulent, and unpredictable. PST contamination typically moves so fast through karst aquifers that the fuel constituents do not have time to degrade before they reach a water well.

The Trinity Group Aquifer

The outcrop of the Trinity Group aquifer extends in a wide band from north and west of San Antonio through Central and North Central Texas into Oklahoma, and then eastward along both sides of the Red River. The aquifer is a complex collection of sandstone, sand, limestone, and shale layers.

Seven water-bearing members of the Trinity Group aquifer are recognized. In general, each member is a different type of rock with differing abilities to take up, hold, and release water. The Trinity in the northern portion of its outcrop is composed mostly of sand; in contrast, the southern portion is characterized by thick layers of limestone. Karst aquifers present within

these limestone layers are a major focus of this study because of their vulnerability to contamination.

Vulnerability of Aquifers to Contamination

In studying the component layers of the Trinity Group aquifer, this report has found the following:

- Outcrops of karstic formations are vulnerable to contamination. In a karst aquifer, contamination can travel from the surface of the outcrop to nearby wells in a matter of hours to days.

- Outcrops of fractured rock aquifers can also be vulnerable to contamination. Contamination in these aquifers can follow a wide range of water movement characteristics including fast, turbulent flow similar to a karst aquifer, or slow, steady flow characteristic of a clastic aquifer.

- Outcrops of clastic formations are vulnerable to contamination, but travel of pollution within the formation is relatively slow, especially where a significant amount of fines (clay and silt) are present. Because flow through a clastic aquifer is relatively slow, nearby wells would not be affected by a release until months or years later.

Health and Safety Effects of PST Releases

Releases from PST sites can expose Texans to potentially toxic levels of petroleum hydrocarbon substances such as gasoline, diesel, or waste oil. Because of the greater volatility and mobility of gasoline when released into the environment, gasoline releases are usually more of a health concern than are releases of these other substances.

Fortunately, pollution from leaking PSTs has affected very few public water supply systems in Texas, according to records maintained by the TCEQ Public Drinking Water Program. However, leaking petroleum storage tank (LPST) impacts to private drinking water wells have been documented in a number of cases. When a private water well is affected by a PST release, it is shut down or the water is treated to remove contaminants.

Gasoline is a complex mixture of over 150 compounds. The BTEX compounds—benzene, toluene, ethylbenzene, and xylenes—pose a concern from a public health point of view because of their toxicity. Benzene is known to cause cancer. Ethylbenzene, toluene, and the xylenes cause liver and kidney damage.

Methyl tertiary butyl ether (MTBE) is a fuel additive that reduces engine emissions. Though not thought to be as toxic as the BTEX compounds, MTBE imparts a bad taste and odor to water at low concentrations and makes the water undesireable. Because it dissolves readily in water and moves through aquifers as fast as the water itself, MTBE often reaches a water well before other gasoline constituents.

Current Regulatory Protections

State and federal regulations require that all PST systems in Texas be equipped with corrosion protection, release detection, spill/overfill prevention and in some metropolitan areas, vapor recovery devices. There are also state and local regulations requiring additional leak prevention equipment for PST systems located in karst areas.

TCEQ rules require that new PST systems installed or replaced over the outcrop of the Trinity and Edwards aquifers in northern Bexar and Comal counties must have secondary containment pursuant to TCEQ regulations 30 Texas Administrative Code (TAC) §214. This secondary containment requirement also applies when existing PST systems in this area are upgraded.

The karstic Edwards Aquifer recharge zone is provided additional protection by TCEQ rules. Secondary containment in the form of continuously monitored double-walled tanks and lines is required for USTs installed in or near the recharge zone of the Edwards (30 TAC §213). In some particularly vulnerable portions of the Edwards recharge zone, triple-walled tanks and lines, or an additional impervious liner or vault outside a double-walled system, are required. As an extra protection, tankhold excavations are required to be inspected to determine if the third barrier is needed.

PST regulations and ordinances have also been promulgated by local government entities in Texas to offer additional protection to karst aquifers. These include:

- Rules promulgated by the Edwards Aquifer Authority in October 2002 which effectively bars the installation of most new PSTs on the Edwards Aquifer recharge zone. These regulations will ultimately require upgrade of existing PST systems to triple-wall containment.

- A 1995 City of San Antonio ordinance which restricts construction of new UST facilities on the Edwards recharge zone within the city limits unless the site was already platted for USTs.

- The City of Austin requires a permit for UST installation in the city's jurisdictional area, including portions of the Edwards Aquifer recharge zone. These permits are reviewed for renewal every three years and during annual audits.

- The City of San Marcos requires a pre-installation inspection of tank pits for new PST systems located over the Edwards Aquifer recharge zone.

INTRODUCTION

To fulfill the requirements of Rider 39 to Senate Bill 1 passed by the 77th Texas Legislature, the Texas Commission on Environmental Quality (TCEQ) has prepared this report on the problems posed by petroleum storage tanks (PSTs) located over aquifer recharge zones in general and the Trinity Group aquifer in particular. The legislative rider specifies that the report should discuss the health and safety effects of inadequate PST spill containment systems as well as long- and short-term contamination remedies. The text of the rider is provided in Appendix A of this report.

Since the 1980s, federal, state, and local regulations designed to prevent pollution from PST facilities have been promulgated. Regulations providing extra protection for sensitive karst aquifers began in 1977 for the Edwards Aquifer. Efforts to clean up PST pollution under TCEQ regulations have been successful at over 17,000 sites.

The Trinity Group aquifer provides a good example of how PST pollutants released near the ground surface within the recharge zone (i.e., outcrop) of an aquifer can potentially threaten human health. This is because the Trinity, unlike most aquifers, is comprised of a variety of rock types. Each of the three basic types of aquifers that occur in Texas—clastic, fractured rock, and karst—are represented in the Trinity Group aquifer.

Organization of Report

- This report begins with a discussion of the problems caused by releases of pollution by PST systems. This first section includes an overview of the physical layout and operation of petroleum storage tank systems, identification of common PST pollutants, and a discussion of spills and releases.

- The second and third sections describe how water moves into and through aquifers and provides a summary of Texas aquifers and specific information about the Trinity Group aquifer.

- The fourth section describes how PST contaminants behave in soil and groundwater and provides two case studies which illustrate the difference in the behavior of contaminants in sand and karst limestone aquifers.

- The fifth section identifies health and safety problems PST contamination can cause.

- The sixth section discusses protective measures currently applicable in Texas to prevent PST releases from affecting groundwater resources.

Limitations of the Study

This is a report on the effects of PST releases on Texas groundwater resources in general and on the Trinity Group aquifer in particular. There are limitations of the study that should be identified.

- Because of the large number of Texas PST facilities and the emphasis on the Trinity Group aquifer, only maps and data tables defining PST locations over the Trinity are included.

- Only PST contaminants are discussed. PST contaminants are generally fuel constituents that are lighter than water, float on the shallowest groundwater zone encountered in the subsurface, and naturally degrade to harmless compounds in a relatively short period of time.

- Public drinking water (PDW) wells identified in this report are only a fraction of the water wells in the state of Texas. Five percent of the population of Texas gets its drinking water from the many non-PDW wells in the state. Other non-PDW wells are used for irrigation, livestock, or industrial purposes. The exact number of these non-PDW wells is unknown and they are not included in electronic databases such as those used to annotate maps presented in this report (Figures 2, 10, and 11; see Appendix E for sources). Non-PDW wells were also not used to prepare the table in Appendix B.

CAUSES OF POLLUTION BY STORAGE TANKS

This chapter describes in general the environmental problems that can be caused by leaking PSTs. It begins with information on the layout and operation of PST systems and discusses contamination that can result from spills and releases at PST facilities.

Overview of PST Systems

PST systems are widely used in Texas to store motor vehicle fuels and other petroleum and nonpetroleum substances. PST systems may be buried underground (underground storage tanks or USTs) or placed above ground (aboveground storage tanks or ASTs).

Corrosion, faulty installation, site accidents, or inadequate operating and maintenance procedures have resulted in many PSTs leaking fuels and other substances into the environment. Such leaks can cause human health, safety, and financial problems. Even a gasoline leak of one-tenth of an ounce per minute will release more than 400 gallons of gasoline into subsurface soils and/or groundwater in one year.

A UST *system* is defined as a UST, all associated underground piping and underground ancillary equipment, spill and overfill prevention equipment, release detection equipment, corrosion protection system, secondary containment equipment (as applicable), and all other related systems and equipment. A generalized view of a typical underground storage tank system is shown in Figure 1, and additional information on the various components of UST systems is included in Appendix C.

Both state and federal regulations now require that all UST systems be equipped in a manner that provides corrosion protection, release detection, and spill/overfill prevention. In some metropolitan areas of Texas designated as ozone non-attainment areas, PST systems must also be fitted with vapor recovery devices to limit the release of volatile organic compounds (VOCs) to the atmosphere.

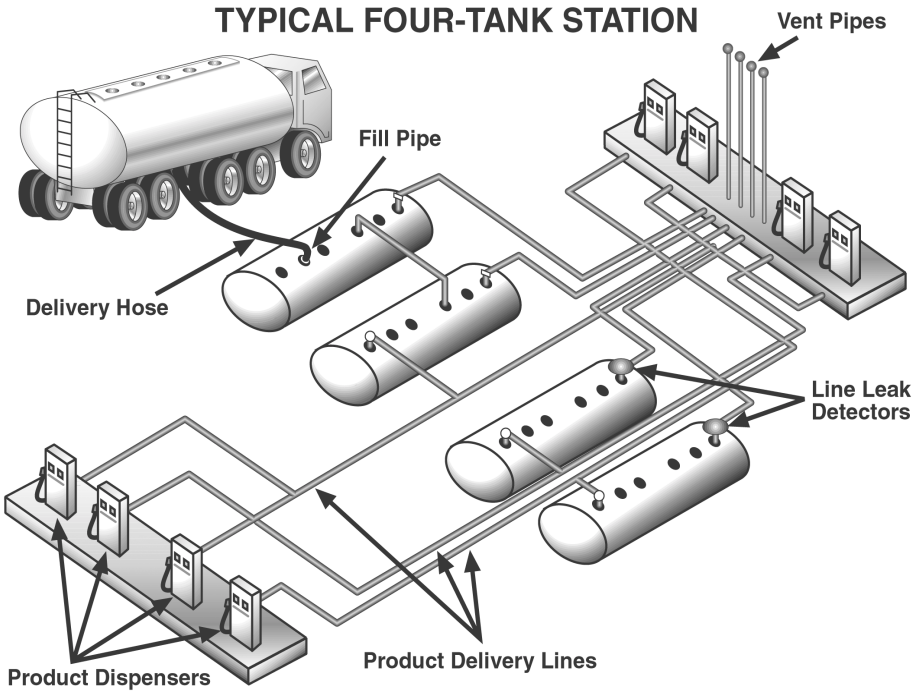


Figure 1. Typical underground storage tank system (generalized)

Occurrence of PSTs in Texas

From the time the state began regulating PSTs statewide in the late 1980s, up to August 1, 2002, a total of 66,763 PST facilities were registered. Also as of the latter date, there were 28,734 active PST facilities containing one or more tanks. The vast majority of these facilities are retail service stations and convenience stores.

Generally, the highest concentrations of PST facilities are in metropolitan areas and other population centers, along highways, at rural crossroads, and at remote interstate highway exits. Figure 2 shows the locations of PST facilities around and in the randomly-selected town of Weatherford, which overlies the Trinity Group aquifer outcrop. The figure shows that most of the PST and leaking PST (LPST) facilities are along major roads and highways and are more numerous within the city limits of Weatherford.

The greatest occurrences of PSTs over the Trinity aquifer outcrop are near the cities of Weatherford, Granbury, Stephenville, Burnet, Fredericksburg, Kerrville, Bandera, and Boerne; and along highways that cross the outcrop

area. Many of these PST facilities are located within one-half mile of a public or domestic water well (see Figure 2, page 7).

Leaking Petroleum Storage Tanks (LPSTs)

The owner/operator of a PST system is required to notify the TCEQ of any release that causes or could cause pollution to the waters of the state. The owner/operator is required to follow up on this initial notification by submitting a Release Determination Report (RDR) to the TCEQ within 30 days. The RDR includes sampling results and other information that helps the TCEQ determine whether or not the site should be designated as a leaking PST (LPST) site, and if so, what further assessment or remediation is required.

As of August 1, 2002, TCEQ had been notified of 23,082 (LPST) sites. Through more than a decade of progress, 17,072 cases have been closed from a regulatory standpoint. Assessment and cleanup is ongoing at the remaining LPST sites.

The U.S. Environmental Protection Agency (USEPA) has studied releases from PST systems in Region VI, which includes Texas. This study set out to determine the causes and sources of PST releases, and how releases are discovered. In order of most common to least common, the study showed that:

1. The causes of leaks are mechanical failure, unknown, physical damage, corrosion, spill or overfill, and other.

2. The primary sources of leaks from PST systems are piping (almost 40 percent), unknown, spill or overfill, dispenser, and tank vessels.

3. Leaks are discovered through leak detection systems, by visual or olfactory detection, during system removal, through investigations of groundwater contamination, during property transfer environmental assessment, unknown, and by the presence of water in a tank (USEPA, unpublished draft).

This study concludes that the most common sources of PST releases are leaking pipes. Nonetheless, the source of many releases is unknown or not indicated in reports submitted to the TCEQ. Many of the worst product releases at UST sites have been caused by corroded, improperly installed or damaged pressurized piping. Releases from pressurized systems can be especially severe because the leak causes a reduction in product pressure inside the pipe that triggers the UST system pump to turn on just like it would if the dispenser nozzle handle was depressed. Piping joints and connectors are especially susceptible to developing leaks. Like tanks, piping can be single-, double-, or triple-walled.

PST Contaminants

PST contaminants include benzene, ethylbenzene, toluene, xylenes (BTEX); methyl tertiary butyl ether (MTBE); polycyclic aromatic compounds (PAHs); total petroleum hydrocarbons (TPH); and metals such as lead. Because gasoline contains constituents and is generally the most mobile petroleum hydrocarbon substance when released to the environment, the discussion of PST contamination in this report will be limited to gasoline.

Gasoline is a complex mixture of at least 150 petroleum hydrocarbon compounds and various additives. BTEX and MTBE are the two constituents of concern from a contamination standpoint.

BTEX

The BTEX group of contaminants consists of benzene, toluene, ethylbenzene, and three xylenes. These volatile organic compounds make up 15 to 20 percent of gasoline. Because they are very soluble in water and toxic, these compounds are common groundwater contaminants and a major focus during assessment and cleanup of LPST sites. Of the BTEX contaminants, benzene causes the greatest concern because it is carcinogenic and—as the most soluble of the BTEX constituents—it is more mobile in groundwater than the others.

MTBE

Methyl tertiary butyl ether (MTBE) is a volatile organic compound that has two roles as a gasoline additive: to boost octane levels and to reduce emissions. When added to gasoline, MTBE generally comprises up to 15 percent of the gasoline by volume (Kinner, 2001). PST releases are a major source of MTBE groundwater contamination. This is because MTBE is much more soluble in water than any other component of gasoline. More information on MTBE can be found in subsequent sections and in Appendix D.

Releases of BTEX and MTBE from PST facilities have the potential to affect human health if there is a pathway for exposure. This report focuses on the groundwater pathway. Before proceeding to discuss the behavior of PST releases and their health and safety concerns, this report will present some background information on groundwater and the Trinity aquifer in the next chapter.

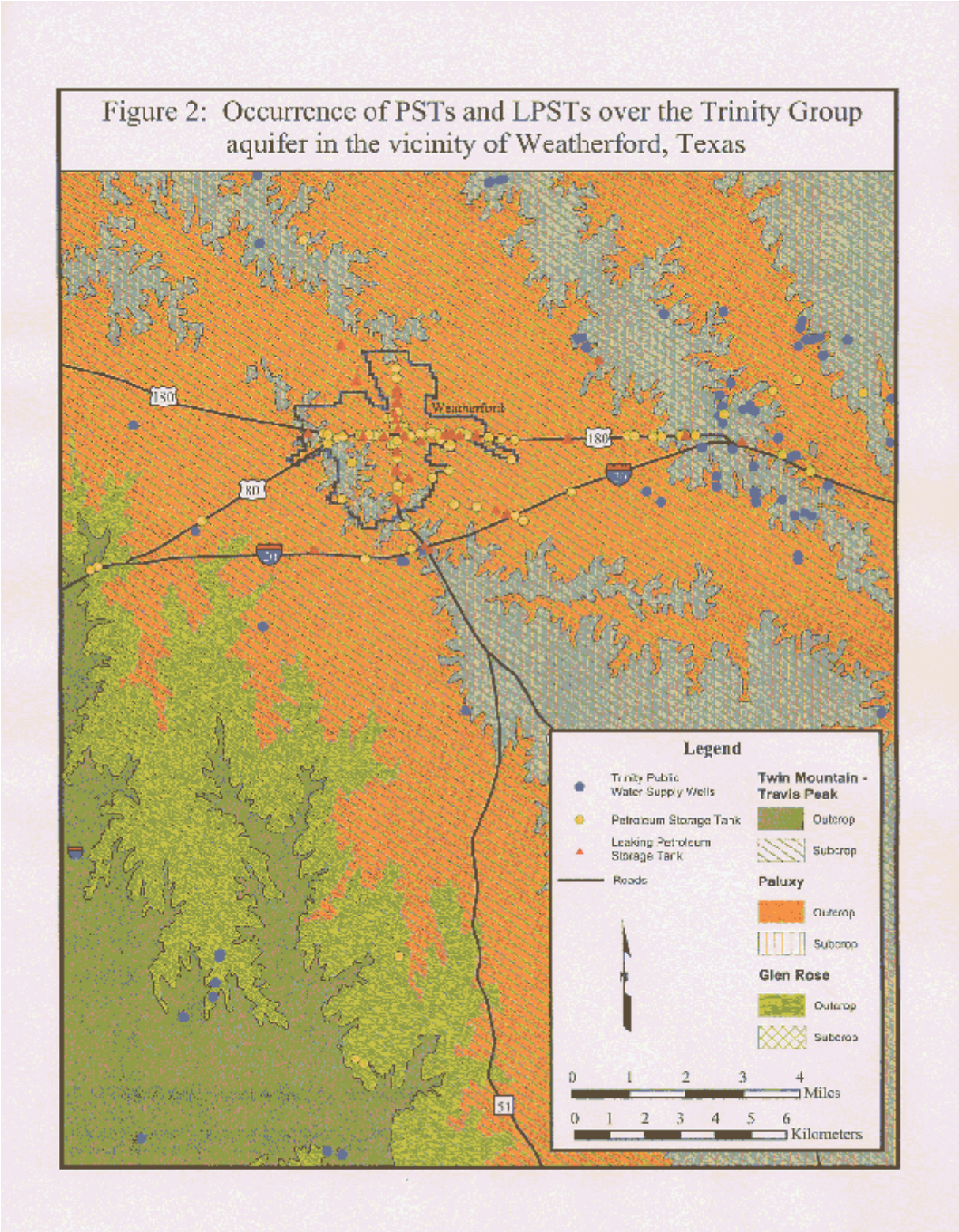


Figure 2. **Occurrence of PSTs and LPSTs over the Trinity Group aquifer in the vicinity of Weatherford, Texas**

THE GROUNDWATER PATHWAY

This section summarizes information on Texas aquifers and describes how water moves in, through and out of aquifers. It also provides information about the Trinity Group aquifer, a unique aquifer composed of a variety of rock formations.

Groundwater is an essential resource in Texas. Of the water used in Texas in 1999, 58 percent was groundwater (TWDB, 2002). Though most major Texas cities have developed surface water supplies, groundwater remains the primary drinking water source for the city of San Antonio and many smaller cities, towns, and private homes. Groundwater is also used for agricultural irrigation in many parts of the state and is an important resource for some industrial facilities.

What's an Aquifer?

An aquifer is a layer of rock or sediment that can yield economically significant quantities of water to wells and springs. Where the rock is cracked or the grains of sediment do not fit together perfectly, the resulting spaces can hold water. If the spaces are connected to each other, forming tiny tunnels, the water can flow through the layer. When water can flow this way, the layer is said to be permeable.

The Texas Water Development Board (TWDB) has identified 9 major aquifers and 21 minor aquifers in Texas that supply usable water. A major aquifer is defined as a regional aquifer that yields large quantities of water. Minor aquifers either yield large quantities of water in small areas or yield small quantities of water to large areas. The locations of major and minor aquifers in Texas are shown in Figures 3 and 4 on pages 11 and 13.

Groundwater is obtained by pumping from a water well that is completed in a subsurface, water-saturated zone in the aquifer. Users usually obtain groundwater by pumping it from water wells, but some users get it from springs.

How Water Moves through Aquifers

Water enters an aquifer as rainfall on outcrop areas and as seepage from streams and ponds. This is called aquifer recharge. Gravity pulls the water down through the spaces between particles of soil or through cracks in the ground. Eventually the water reaches a depth where all the openings in soil or rock are filled with water.

How open the aquifer materials are at the surface affects the recharge rate—the bigger and more numerous the openings, the more recharge can occur. How open the aquifer materials are underground affects the amount

of water an aquifer can store, move, and yield to water wells. The degree to which an aquifer is open to the recharge and movement of water depends on the physical characteristics of the rock or sediment that comprises the aquifer.

Aquifer Components

Some aquifers have two distinct components: the outcrop and the subcrop. These components are shown in Figure 5. The outcrop is the area where the aquifer materials (rock or sediment) are present at the surface. Groundwater in the outcrop portion of the aquifer usually occurs under atmospheric pressure, or in geologic terms, is unconfined. The depth to water in an unconfined aquifer is always the same as the depth to groundwater in a well.

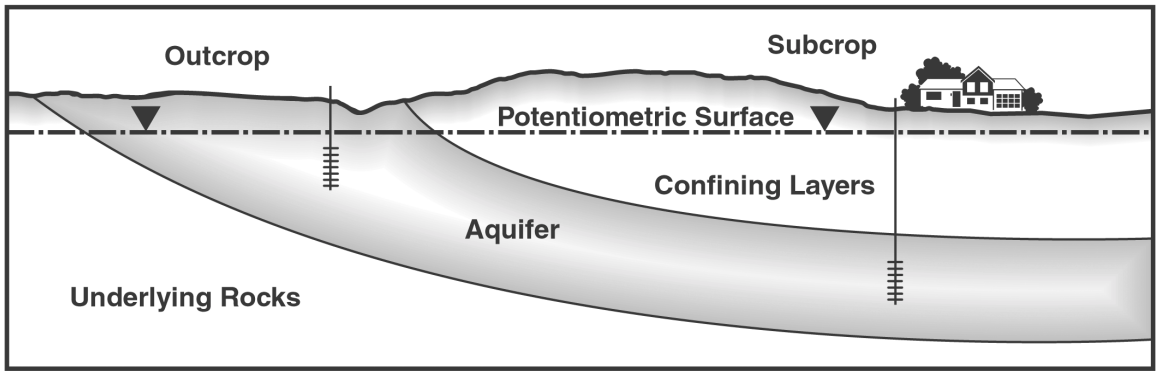
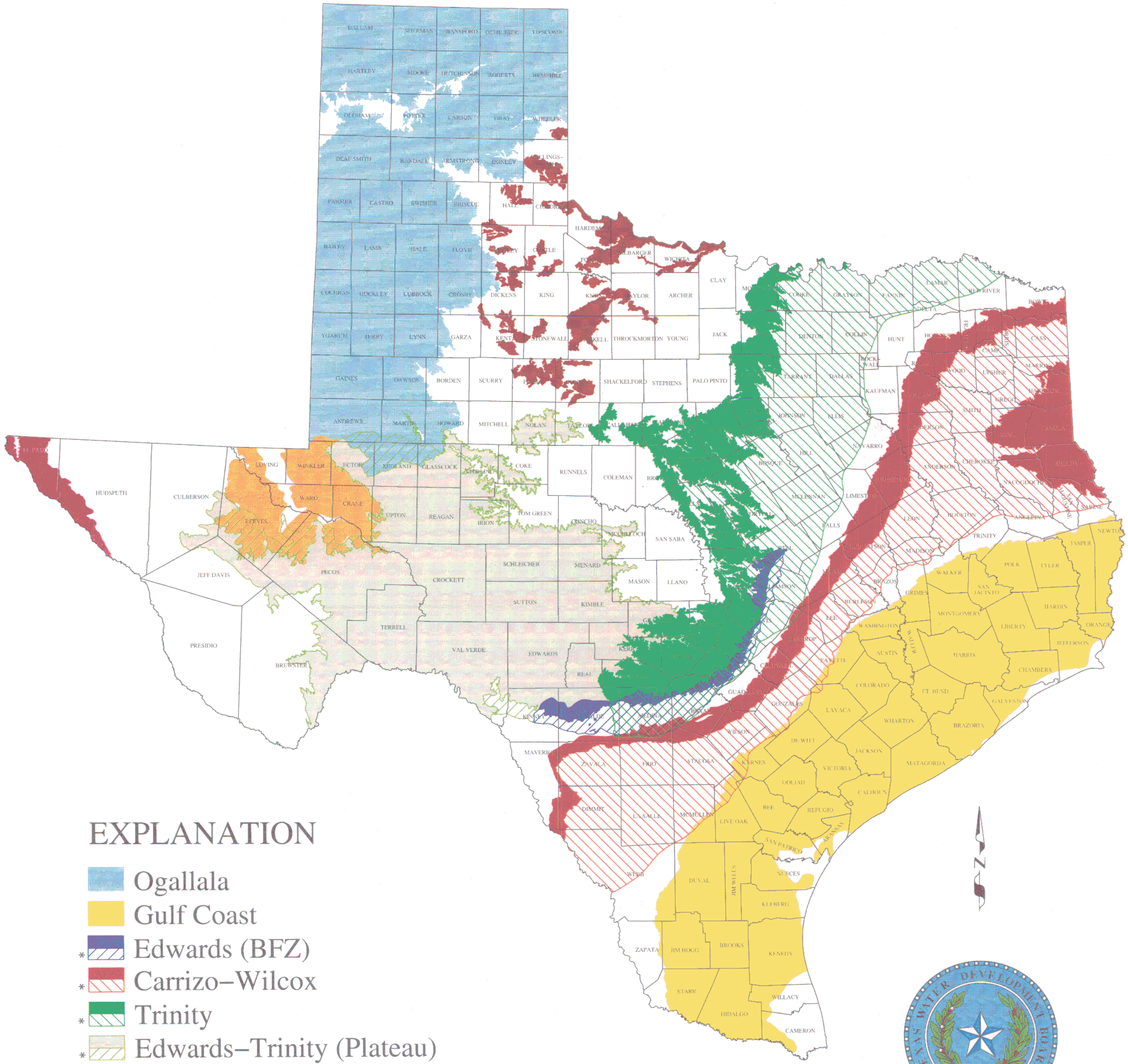


Figure 5. Aquifer outcrop and subcrop. Aquifers can receive recharge in areas where they outcrop. In subcrop areas, the water level is often under pressure and may rise above the top of the aquifer.

The subcrop is the aquifer component that is covered by an overlying sequence of rock or sediment. If the overlaying material makes an impermeable (watertight) cap on the aquifer materials, groundwater in the subcrop will be under pressure, or in geological terms, confined. In a confined aquifer, the pressure within the aquifer makes the water level in a well rise up higher than the top of the water-saturated aquifer material. In some cases the pressure is great enough to push the water above the ground surface, a condition some people call artesian.

The Trinity Group and the Carrizo-Wilcox are two major Texas aquifers that have subcrop areas of significant size. The map of major Texas aquifers (Figure 3) shows the locations of both the outcrop and subcrop of these aquifers.

MAJOR AQUIFERS OF TEXAS



EXPLANATION

- Ogallala
- Gulf Coast
- * Edwards (BFZ)
- * Carrizo–Wilcox
- * Trinity
- * Edwards–Trinity (Plateau)
- Seymour
- Hueco–Mesilla Bolson
- Cenozoic Pecos Alluvium

OUTCROP (That part of a water-bearing rock layer which appears at the land surface.)

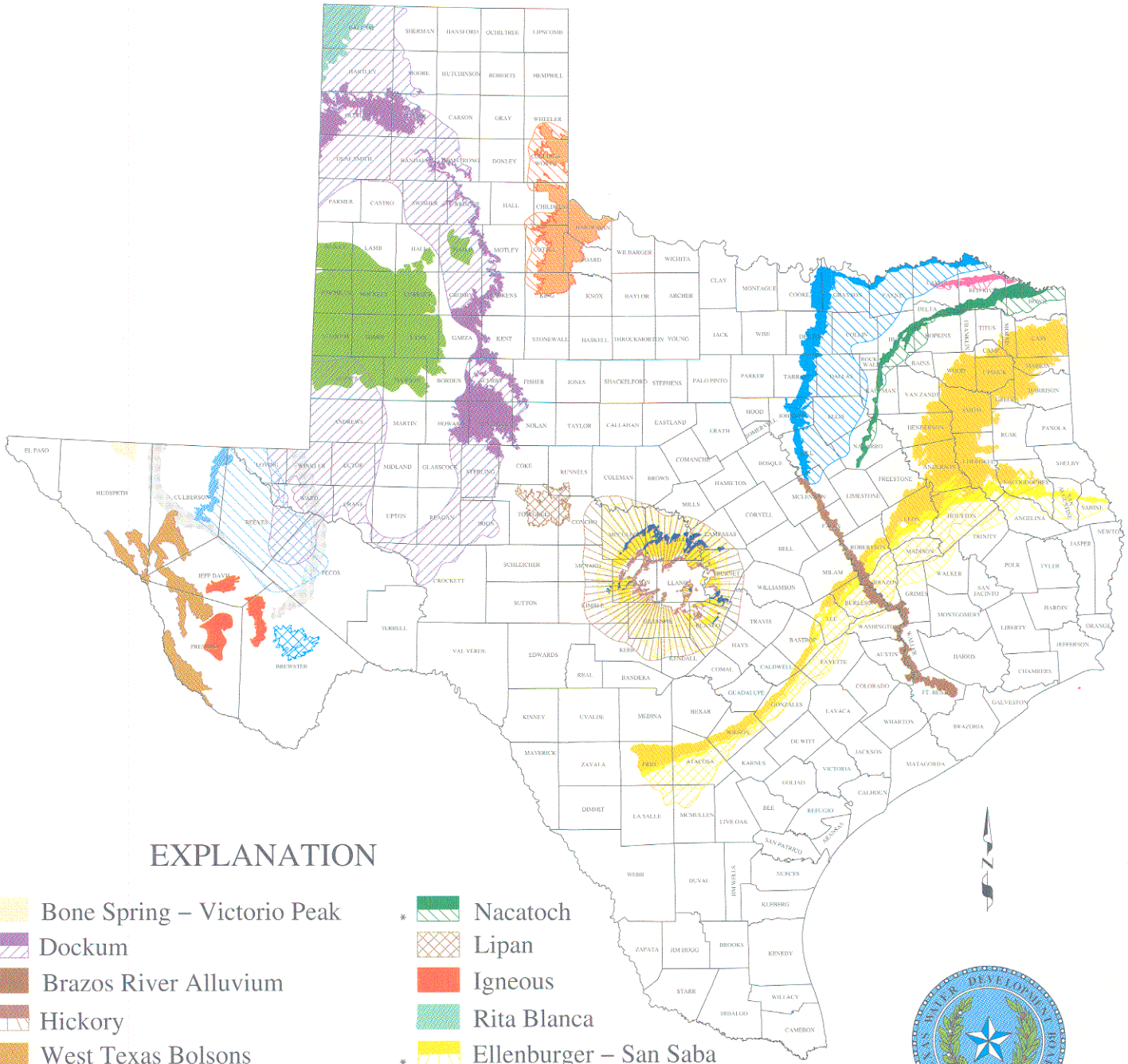
* DOWNDIP (That part of a water-bearing rock layer which dips below other rock layers.)

Miles

0 25 50 75 100

January 1994

MINOR AQUIFERS OF TEXAS



EXPLANATION

- Bone Spring – Victorio Peak
- * Dockum
- Brazos River Alluvium
- * Hickory
- West Texas Bolsons
- * Queen City
- * Woodbine
- Edwards – Trinity (High Plains)
- * Blaine
- * Sparta
- * Nacatoch
- Lipan
- Igneous
- Rita Blanca
- * Ellenburger – San Saba
- * Blossom
- Marble Falls
- * Rustler
- Capitan Reef Complex
- Marathon

Miles
0 25 50 75 100

OUTCROP (That part of a water-bearing rock layer which appears at the land surface.)
* DOWNDIP (That part of a water-bearing rock layer which dips below other rock layers.)

January 1994

Basic Types of Aquifers

There are in general three types of aquifers in Texas: clastic, fractured rock, and karst. Each type behaves differently with regard to the movement of water into, through, and out of the aquifer.

Clastic Aquifers

"Clastic" is a term geologists use to describe granular materials such as gravel, sand, silt and clay. In clastic aquifers these grains are arranged in discontinuous layers. Water occupies the spaces between the grains as shown in Figure 6. The amount of water a clastic aquifer can yield, and the speed with which the water can move through the aquifer toward a well or spring, both depend upon the size of the aquifer's grains and how well the spaces between the grains are interconnected. Water generally moves faster through a gravel layer than it does through a sandy layer. There is little or no movement through clay.

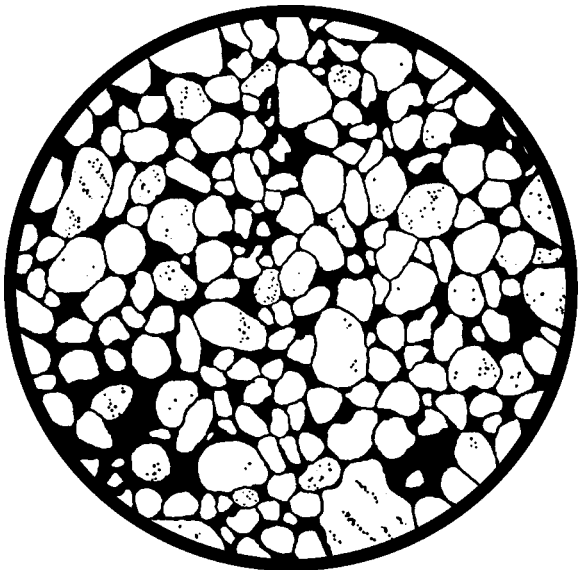


Figure 6. Magnified view of sand grains found in clastic aquifers. Grains may consist of clay, silt, sand, gravel, or a mixture thereof. In a clastic aquifer, groundwater is present in the spaces in and around the individual grains *(after Williams et al. 1954)*.

As rain falls on the outcrop of a clastic aquifer, some of the water filters into the ground through the soil and becomes part of the soil water. Soil water flows from high points to lower points in the same way that surface water flows downhill. Soil water that is not taken up by plants, does not evaporate and does not seep out of the soil, can reach the water table and become part of the groundwater system.

An exception is where a clay layer forms an impermeable barrier that prevents the movement of the soil water to the underlying clastic aquifer.

In this case, a local zone of saturation is created above the regional water table; this zone is called a 'perched' aquifer.

Water moves through a clastic aquifer in the spaces between grains of gravel, sand, silt, and clay. This flow is slow, steady, and predictable. The Ogallala Aquifer of the High Plain, the Gulf Coast Aquifer, and the Paluxy Formation of the Trinity Group aquifer are examples of clastic aquifers.

Fractured Rock Aquifers

In most fractured rock aquifers, groundwater is stored in the rock itself—much like the water stored in a clastic aquifer— but it moves primarily through the cracks in the rock. These fractures and faults are paths of least resistance (see Figure 7) and therefore direct the flow of water.

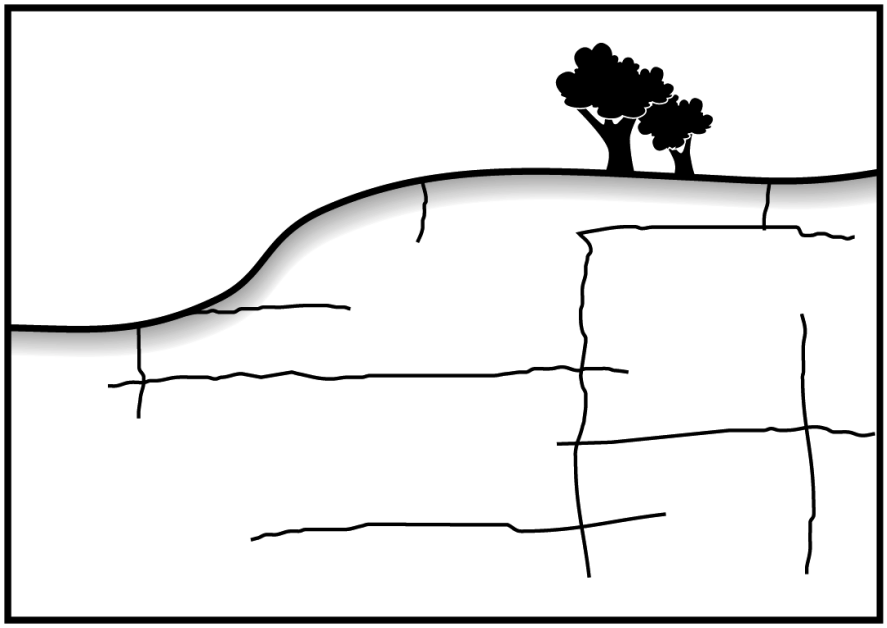


Figure 7. Fractures and cracks in a fractured rock aquifer. Water can enter the groundwater system through fractures at the ground surface *(after Fetter, 1988)*.

The size and degree of interconnectiveness of these fractures are major factors affecting the flow of water through these aquifers. Another key factor is the permeability of the rock. Because the fracture characteristics and permeability vary widely, there is a broad range of water-yielding characteristics in fractured rock aquifers (ASTM, 1995). This range can be illustrated by discussing the two opposite extremes.

If a fractured rock aquifer is made up of very permeable rock, like sandstone, and fractures are small, numerous, and well-connected, groundwater can move through fractured rock slowly and in a relatively

predictable downhill direction, similar to a clastic aquifer. Recharge of these aquifers occurs much like it does in a clastic aquifer. As rain falls on the outcrop, some of the water enters the rock and slowly seeps down to the water table. Additional recharge occurs where water enters fractures near the ground surface and moves relatively fast down to the water table.

At the other extreme, is an aquifer made up of relatively impermeable rock, like granite or shale, and a limited number of large fractures. Groundwater moves very quickly in such an aquifer, because the large fractures are like pipes, but the direction of groundwater flow is difficult to predict unless fracture locations are known. As rain falls on the outcrop of impermeable rock, a small fraction of the water enters the aquifer through fractures that are open to the ground surface. These fractures also provide direct access for contaminants to enter the groundwater system.

Examples of fractured rock aquifers are found in the granite and metamorphic rock surrounding the Llano Uplift in central Texas. Other aquifers in Texas are also affected by fractures and faulting, especially those situated within the Balcones Fault Zone.

Karst Aquifers

Karst aquifers are made up of limestone and other soluble rock that has been altered by water. Fractures, faults, and bedding planes within the rock provide paths for water to move through the formation. (A bedding plane is a separation between two adjacent layers of rock.) Figure 8 illustrates the system of caves, conduits, and openings that is a distinctive feature of a karst aquifer. This system develops over time, the water dissolves the rock

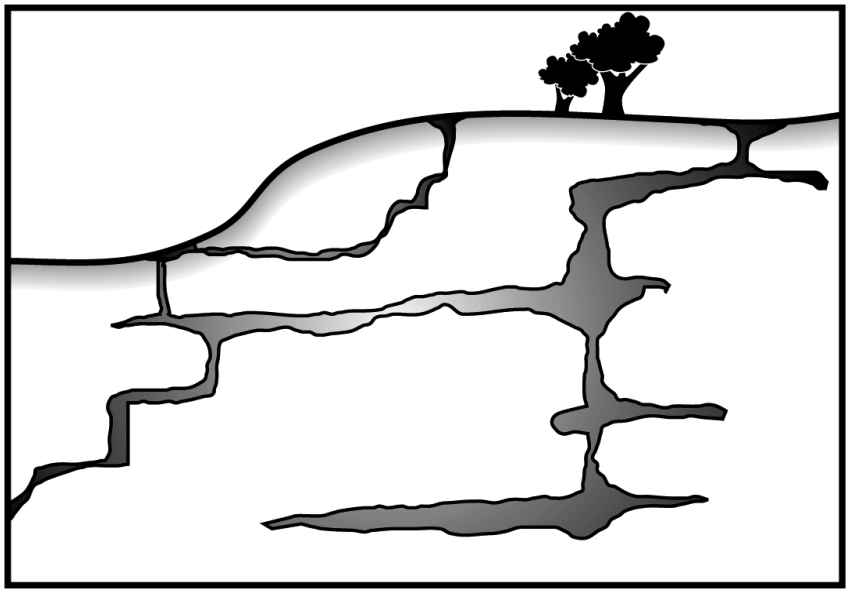


Figure 8. Underground system of interconnected underground caves and conduits typical of a karst aquifer *(after Fetter, 1988)*.

from each side of the bedding plane. Eventually, this dissolution process produces a system of interconnected underground caves and conduits connected to the ground surface by openings such as sinkholes, cracks, and cave entrances.

The amount of water that is stored in a karst aquifer depends on the size and number of interconnected caves and conduits and, to a lesser extent, on the permeability of the surrounding rock.

As rain falls on the outcrop of a karst aquifer, some of the water goes underground through the exposed openings or recharge features illustrated in Figure 9. These recharge features range from fairly small cracks and depressions to the larger depressions and sinkholes. (A sinkhole forms when the rock above a cave or subsurface conduit collapses.)

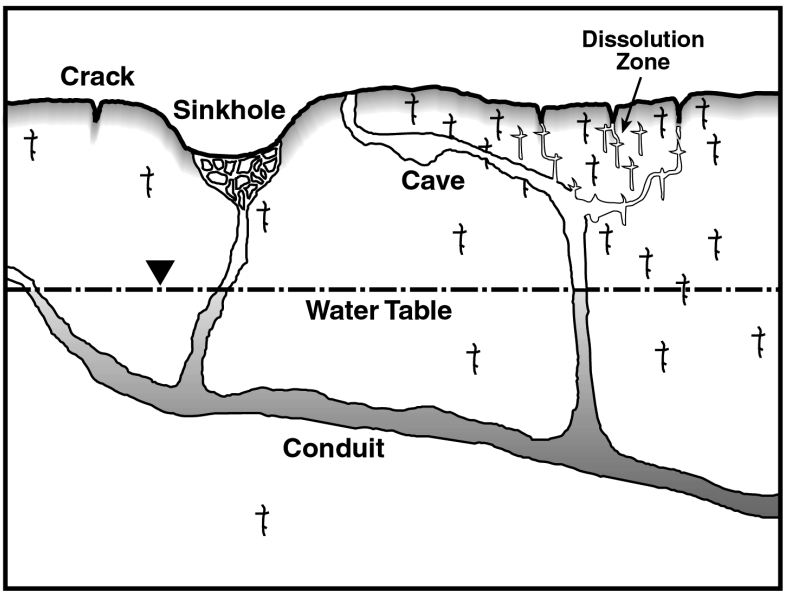


Figure 9. Sinkholes and caves in the outcrop (recharge zone) of a well-developed karst aquifer.

Because sinkholes located in streambeds or floodplains deliver large amounts of water to the aquifer when the streams are running, they are important recharge features. Unfortunately, sinkholes and other recharge features also provide direct access for contaminants to enter the groundwater system.

The uppermost 30 to 50 feet of karst bedrock is generally highly fractured and marked by dissolution features. When the aquifer is recharged by a rainfall event, some of the recharge passes right through this uppermost zone down to the water table, but some of it becomes trapped in dissolution features that are isolated from the saturated zone except during high-flow recharge events.

The movement of water through a karst aquifer depends on the size and number of interconnected caves and conduits and how these features are oriented. The direction of groundwater movement beneath a given location can be extremely difficult to predict unless the subsurface locations of caves and conduits are already known, which is rarely the case. At sites where hazardous materials have been released to the outcrop of a karst aquifer, the direction of groundwater movement from the site is usually only known after a water well or spring has been affected.

Flow through a karst aquifer is fast, turbulent, and unpredictable. The abundantly productive Edwards Aquifer and the less productive lower Glen Rose Formation of the Middle Trinity Group aquifer are examples of karst aquifers.

Additional Information

For more specific information about each of Texas' major and minor aquifers, see the TWDB publication, Aquifers of Texas (Report 345, November 1995). Additional information is also available through the "References" section of this report. This report focuses specifically on the Trinity aquifer, which is described in the next section.

THE TRINITY GROUP AQUIFER

The Trinity Group aquifer is an important water supply source for much of north-central, central, and southwest-central Texas. From Uvalde County in the southwest to Red River County in the northeast, 55 Texas counties lie completely or partially above this aquifer (see the green band in Figure 10, opposite). Parts of four major populations centers—the San Antonio, Austin, Forth Worth and Dallas metropolitan areas—lie directly over the subcrop of the Trinity aquifer. In all, over 7 million people live over the outcrop and subcrop areas of this aquifer.

This complex aquifer is composed of layers of limestone, dolomite, sandstone, sand, and shale that formed during approximately the same time period.

Physical Characteristics of the Trinity

The Trinity Group aquifer is comprised of a variety of rock types, each with its own unique properties. Because of this variety, seven major members are recognized (Nordstrom and Quincy, 1999). The Trinity aquifer divided into its seven members is shown on Figure 11 on page 23.

In the north, members of the Trinity are the Twin Mountains, the Glen Rose, the Paluxy and the Antlers formations. With the exception of the Glen Rose limestone, the northern portion of the Trinity is mostly sand.

In the south, the Trinity aquifer has even more formations. Based on their water-yielding characteristics, these formations are grouped into three members: the Lower Trinity, the Middle Trinity, and the Upper Trinity. The Lower Trinity includes the Hosston Sand and the Sligo Limestone and is confined by the Hammett Shale. The Middle Trinity includes the Cow Creek Limestone, the Bexar Shale, the Hensell Sand, and the lower member of the Glen Rose Formation. The Upper Trinity is comprised of the upper member of the Glen Rose Formation.

The fact that there are many types of rock in the Trinity aquifer is a direct result of the depositional environment that existed in Texas within the time period that the rock and sediment originated. These materials were formed between 145 and 65 million years ago in a shallow inland sea.

Use of Trinity Groundwater

Many of the people living over the aquifer rely on it as a water supply. In general, the most productive part of the Trinity aquifer is in the outcrop areas and adjacent subcrop from Brown County northeastward into northeastern Texas. Within this area, wells located in the Antlers and Twin Mountains formations yield larger quantities of water than wells in the Paluxy and Glen Rose formations.

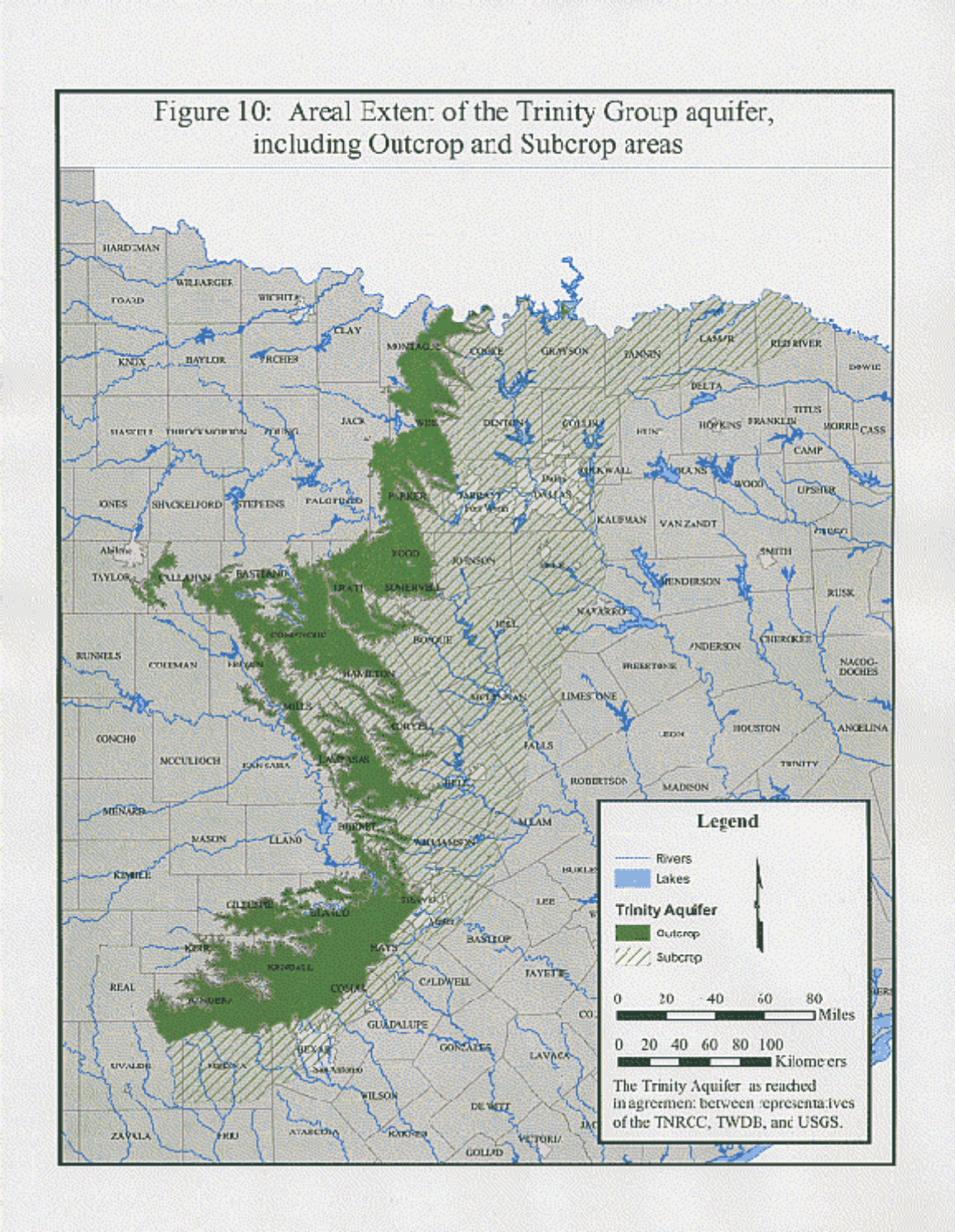


Figure 10. Areal extent of the Trinity Group aquifer, including outcrop and subcrop areas.

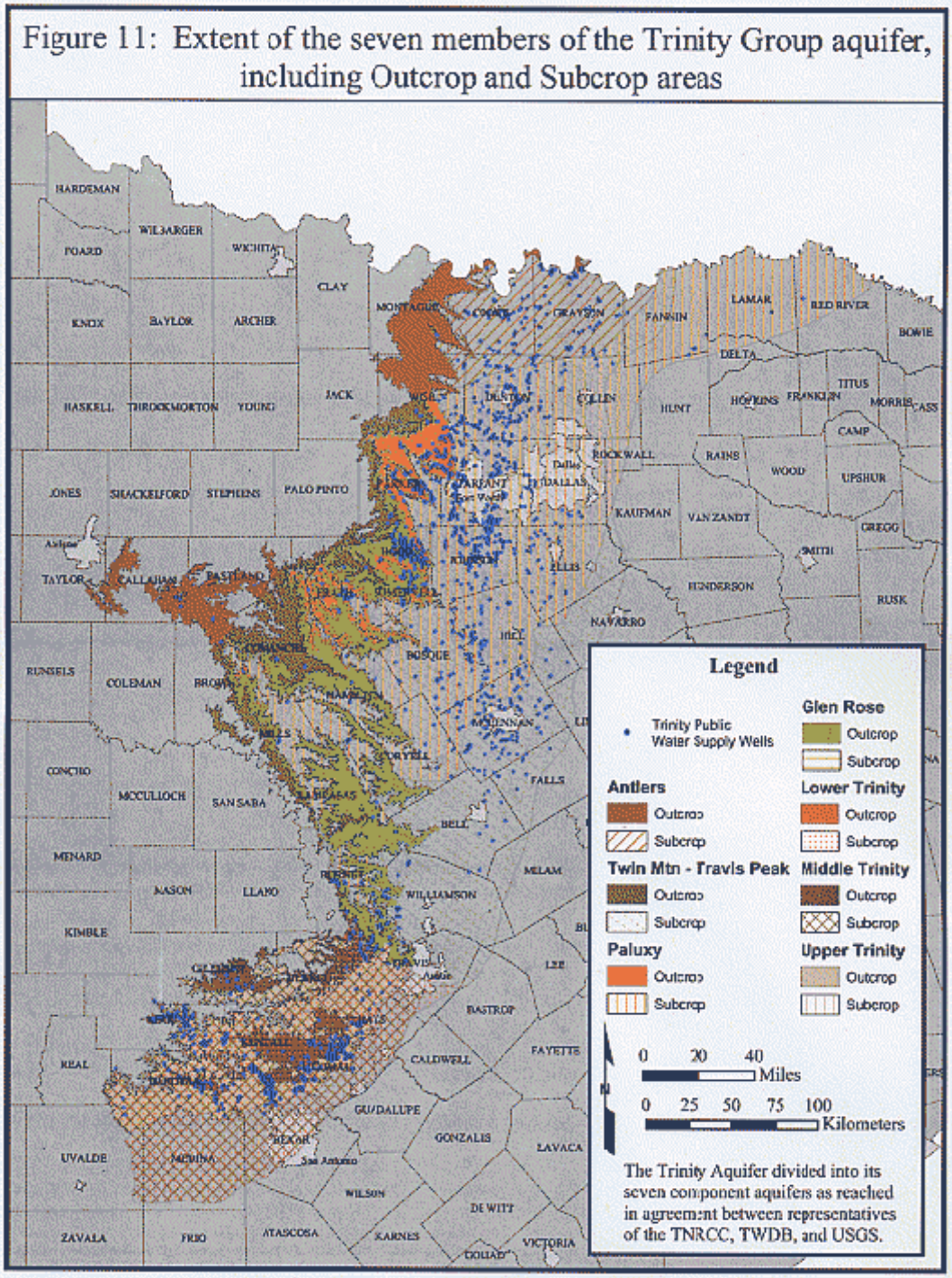


Figure 11. Areal extent of the seven members of the Trinity Group aquifer.

Depths of wells completed in the Trinity aquifer commonly range between 50 and 800 feet, but some of the deeper wells that tap into the subcrop exceed 3,000 feet. Water commonly flows from wells at 50 to 500 gallons per minute, but may flow as much as 2,000 gallons per minute. In the southern portion of the Trinity, well yields fall to levels of less than 100 gallons/minute in the Middle and Upper Trinity members south of Blanco and Hays counties; yields as low as 5 gallons/minute and declining water levels are not uncommon in this area.

In 1999, groundwater supplied more than 55 percent of the total water use in 17 of the counties over the aquifer, while another 6 counties received at least 45 percent of their water supply from groundwater (TWDB, 2002). Current potential groundwater supplies from the Trinity aquifer were estimated to be 156,000 acre-feet per year under drought conditions (TWDB, 2002). This estimate excludes any groundwater contributions from the Trinity to the Edwards-Balcones Fault Zone, which is an even more significant groundwater source.

Recorded use of Trinity groundwater in past decades exceeds recent estimates of the amount of water available in the aquifer during a drought. In 1994, the Trinity supplied 192,961 acre-feet of water (TWDB, 1997). Most of this water (55 percent) was used as municipal supply while almost a third (29 percent) was used for irrigation. The one exception to this pattern occurs in the area overlying the Antlers formation outcrop in North and Central Texas. In this region, groundwater is used primarily for irrigation (TWDB, 1997).

PST POLLUTANTS IN GROUNDWATER

This section describes the behavior of fuels released from PST systems when they come in contact with groundwater. Case studies illustrate how the type of aquifer can affect the severity of environmental problems resulting from a release.

Behavior of PST Pollutants

When a release from a PST system encounters soil or permeable rock in the subsurface, the fuel percolates downward through force of gravity. If enough liquid fuel was released, it will migrate to and pool on top of the groundwater table. The fuel in contact with the water table slowly dissolves into the water and a plume of contaminated water is formed. This plume moves away from the source in the direction of the local groundwater flow.

In a clastic aquifer, the direction and rate of movement of PST plumes are easy to predict and monitor. The plume moves in the direction of the local groundwater flow, which usually mimics the slope of the land surface. Some of the dissolved fuel adheres to aquifer materials, so the plume moves more slowly than the groundwater.

Benzene can move faster through fine-grained clastic aquifers than the other BTEX compounds because of the small size of its molecules. Mace and others (1997) compiled data on 605 benzene plumes at LPST sites throughout Texas and found that 75 percent of them were less than 250 feet long and impacted an area of less than 49,000 square feet. They found this to be true for all kinds of aquifers except for those in karst terrain.

The movement of contaminant plumes in karst and fractured rock aquifers is very difficult to predict. Investigators rarely have detailed information about local subsurface fractures or karst features. Lack of such information makes it difficult to know which pathways a release could take to reach the water table. Often, the location of karst conduits or fractures is only known after a water well is impacted and the release is traced back to the source.

Another challenge encountered when investigating releases to karst aquifers is that groundwater movement is very fast, and contaminants released can reach a well or spring within days or even hours. Also, contaminants trapped in dry caves and conduits can mobilize when it rains, resulting in a slug of contamination affecting the aquifer. Once a fuel release reaches the water table, the contamination can then move long distances in a matter of days (or hours). Plume lengths of over 7,600 feet have been documented in karst aquifers by Mace and others (1997).

The petroleum constituents that make up an LPST contaminant plume are largely determined by the solubilities of the fuel constituents. The higher

the solubility of a compound, the more that compound can dissolve into a given volume of water. MTBE is by far the most soluble PST contaminant. MTBE moves faster through groundwater than BTEX and MTBE plumes are generally larger than their associated BTEX plumes.

BTEX constituents will naturally degrade in an aquifer. This degradation takes place because naturally occurring bacteria use the organic molecules as a food source and transform the BTEX constituents into carbon dioxide and water. Oxygen is necessary for this natural degradation process to be effective as a remedy. This process is referred to in the environmental literature as natural attenuation or intrinsic remediation.

Recent studies suggest that MTBE in aquifers will naturally degrade to other compounds, but the process is not yet fully understood and could be too slow to be a practical remedial alternative in some settings. Field studies indicate that BTEX degradation occurs first, followed by MTBE (Kinner, 2001).

PST Pollutants and Drinking Water Supplies

People in Texas obtain drinking water from two sources: public drinking water (PDW) systems with surface water or groundwater sources, and domestic (private) drinking water wells.

Public water supply systems provide drinking water for approximately 95 percent of Texas' population. The TCEQ Water Supply Division oversees all public drinking systems to ensure the quality of water. The water produced by these systems is sampled at regular intervals to ensure that it is safe to drink.

PDW wells are, in general, constructed to produce high volumes of water and sealed to allow only water from the desired aquifer zone to enter the well. In contrast, many private domestic wells are shallow, low-volume wells that, because of advanced age or poor construction, may not be adequately sealed to prevent inflow of near-surface contaminants.

The TCEQ has sampled PDW systems annually or triannually since 1992, collecting over 45,000 samples at 6,500 systems. These samples are analyzed for petroleum constituents including BTEX and MTBE and other substances such as pesticides, metals, and nitrate. This monitoring program has detected MTBE and BTEX contamination from PST sources at levels of concern for human health in fewer than 10 PDW systems. **As such, PST sources are not a health concern for a majority of Texans drinking from PDW systems.**

This result may seem surprising considering the number of LPST sites in Texas, but there are good reasons why this is true. PDW wells are

protected from shallow contamination by excellent construction and regular maintenance. Some PDW systems are composed of many wells, so any contamination that affects a few wells in the system would be diluted. In addition, it is likely that routine pumping and treatment of water removes volatile contaminants such as BTEX and MTBE. If contamination is detected above health-based levels, the PDW system operators usually take care of the problem quickly by shutting down the affected well(s) or treating the water.

Private domestic wells, given their relatively shallow depth and construction quality, are in general more vulnerable to LPST releases than PDW wells. Private wells supply water to 5% of Texas' population.

Aquifer Pollution Case Studies

The two case studies presented below highlight some of the concepts discussed in this report and show how a PST release on the outcrop of a sandy portion of the Trinity Group aquifer behaves very differently than a release to the outcrop of a karst portion of the same aquifer. These examples also help illustrate how water well features—such as depth, integrity of well seals, and location in relation to the local groundwater flow direction or karst features—can dictate how vulnerable a well is to impact by a contaminant source.

The first case study concerns a PST release to the sandy Paluxy member of the Trinity Group aquifer, which has resulted in no known impact to nearby drinking water wells. The second case study describes a release to a karst outcrop of the Trinity Group aquifer, which affected numerous private drinking water wells in a nearby subdivision.

Case Study 1: Spill in a Sandy Aquifer

The fuel-dispensing convenience store in this case study was built and its USTs installed in the early 1950s. In 1998, a surface spill was reported to have occurred when a late-night customer accidently drove off with the dispenser nozzle still inserted in the vehicle's gas tank. The damaged dispenser nozzle released approximately 400 gallons of gasoline on to the pavement before the spill was discovered. The spill was cleaned up (at least at the surface) by the following morning.

Subsequent sampling of monitoring wells located at the site indicated the presence of elevated BTEX and total petroleum hydrocarbons (TPH) in the shallow, possibly perched groundwater. The contamination found in the groundwater may be related to the 1998 spill incident, to the cumulative effects of spills and overfills in the nearly 50 years of operation at the site, or to a combination of these factors.

The site is located over the outcrop of the Paluxy Formation, which forms the upper unit of the Trinity Group aquifer in this area. Well logs of monitoring wells drilled at the site indicate a shallow subsurface of clay, sandy clay, and clayey sand; a depth to water of approximately 12 feet below ground surface; and a groundwater flow direction to the west-northwest. This shallow groundwater is likely under perched conditions, and may or may not be hydraulically connected to the Trinity aquifer.

The current source of drinking water in the area is a PDW system that obtains water from a nearby reservoir. Several former public supply wells and some domestic wells are located within 0.5 mile of the site. Most of the former public supply wells in this area are about 420 to 500 feet deep and are screened (open to the aquifer) in the depth interval of about 330 to 480 feet below ground surface. Screened intervals for the domestic wells are not known, but most of these wells are approximately 100 to 200 feet deep, and it is presumed that they are screened near the bottom.

The highest concentrations of benzene, toluene, and MTBE found thus far in the groundwater at the site are 23.8, 30, and 30.8 parts per million (ppm), respectively. Recently, 0.22 feet of free-phase fuel was detected in one of the monitoring wells. Six more monitoring wells are planned to define the size of the plume and allow for future monitoring of plume stability/eventual dissolution. Most benzene plumes in Texas (except those that occur in karst hydrogeologic environments) are less than 250 feet in length and 49,000 square feet in total area, as defined by the 0.01 ppm contour of benzene (Mace and others, 1997).

Once the plume is further defined in size and concentration, the next step is to select the remediation method most suitable for the conditions at the site. Typical options include soil vapor extraction, pump and treat, skimmer pumps, hand bailing, or a combination of these methods. (Hand bailing and skimmer pumps are used primarily to remove free-phase product.)

Case Study 2: Spill in a Karst Aquifer

The fuel-dispensing food store in this case study is located in an area where the karstic Middle Trinity aquifer (part of the Trinity Group aquifer) is the primary drinking water supply. The PST system was installed in the mid-1990s and, by all appearances, was fully compliant with all TCEQ regulations, including leak detection. Once in 1999, a customer backed into one of the fuel dispensers, knocking it off its base. At the time, no one realized that the accident resulted in a broken fuel line about two feet below the surface and that fuel was releasing to the subsurface. Inventory records later indicated that approximately 930 gallons of gasoline were missing.

Several days later, a landowner from a nearby subdivision reported that his well water tasted and smelled like gasoline. Each residence in this subdivision has its own private domestic well that draws water from the

middle Trinity aquifer. Store personnel notified the TCEQ (then TNRCC) of the landowner complaint, and the agency ordered additional testing. Ultimately 21 sole-source domestic water supply wells in the subdivision were found to be affected.

As mentioned previously, this store directly overlies the karstic Middle Trinity portion of the Trinity Group aquifer. The store is also near the Balcones Fault Zone, and several faults and fractures, which serve to enhance both horizontal and vertical movement of water, have been mapped in the area. The local direction of groundwater flow is to the east-northeast.

The store is located on a hilltop. This hill slopes down north-northeast toward a major creek that borders the subdivision, located on the opposite side of the road. The gasoline released beneath the pavement of the gas station likely encountered a solution-enlarged fault or faults in the limestone and quickly moved into the groundwater system. The groundwater and contamination then spread eastward, and afterwards followed a general northeastward course.

Within a few days, the gasoline plume impacted eight residential wells and had extended a distance of approximately 3,000 feet. The highest benzene and MTBE levels detected in well water were 2.28 and 4.21 ppm, respectively. No free-phase product was detected in the water wells.

Water levels in the Middle Trinity are reported to be approximately 240 feet below ground surface, but fluctuations of 100 feet or more may occur with rain and heavy pumping withdrawals. The local direction of groundwater flow may also change. The nearby creek is a significant recharge feature for the Trinity Group aquifer in this area.

Water production from the area's domestic wells is about 10 to 50+ gallons per minute or more. Two public wells west of the site reportedly yield >200 gallons per minute. Wells typically are cased from surface to 200 feet below ground level, then are open hole to as much as 400 feet below ground level. The upper 10 feet and lower 10 to 20 feet of casing is usually cemented. Pumps are typically installed 100 feet below the water table.

Activated carbon filters were installed on the private wells, which removed the MTBE and other gasoline components to nondetectable levels, and remediation activities (soil vapor extraction, pump and treat) were initiated at the site. Cleanup of the release took more than two years and cost the store owner over $3 million.

HEALTH AND SAFETY EFFECTS OF PST RELEASES

If a PST release occurs, part of the fuel remains in the subsurface soil or rock in a free phase. If the fuel comes in contact with groundwater, part of the fuel will dissolve into groundwater (dissolved phase) and part of it will float undiluted on the top of the groundwater as free-phase product. These two different phases of fuel result in two different types of health concerns—short-term concerns and long-term concerns. Generally speaking, the free-phase fuel is responsible for the short-term health concerns and the dissolved-phase fuel is responsible for the long-term health concerns. While fuel contamination of soil can present health risks, this report will just address fuel contamination of groundwater.

Short-Term Health Concerns

The most immediate short-term health concern with free-phase fuel is its explosion potential. Vapors from fuel spills can move through soil and cracks and plumbing openings in foundations to collect in buildings. These vapors can reach explosive levels if they build up to certain levels. Fortunately, while explosions can occur at PST facilities, they are extremely rare.

Also, exposure to very high levels of gasoline vapors can cause acute health effects. Short-term exposure (up to several hours) to gasoline can cause eye, skin and lung irritation, dizziness, headaches, giddiness, euphoria, vertigo, blurred vision, nausea, numbness, and drowsiness. These symptoms normally resolve themselves soon after removal from the exposure.

Long-Term Health Concerns

Fuels such as gasoline and diesel are complex mixtures, typically containing more than 150 chemicals. Longer-term exposure (months to years) to gasoline constituents can cause behavioral and intellectual changes, including tremors, an abnormal walk, affected speech, fatigue, headaches, memory loss, and sleep problems. However, these effects are primarily seen in people with concentrated individual exposure (e.g. sniffing gasoline, such as teens who sniff gasoline. Gasoline, and diesel to a smaller extent, also contain benzene, which can cause the effects described above. Benzene is also a human carcinogen, known to cause specific types of leukemia in some people after long-term exposure. Fuels also contain toluene, ethylbenzene, and xylene, which can cause liver and kidney damage.

Three animal cancer studies have been conducted on MTBE. This amount of study is highly extraordinary since most chemicals have had only one animal cancer study conducted on them, if any. The results of these studies indicate that MTBE can induce cancer (and other effects such as liver and

kidney damage) in animals at high exposure concentrations. Using these and other toxicity studies, the TCEQ has developed a health-based acceptable exposure level of 240 (parts per billion) ppb in drinking water.

MTBE imparts a taste and odor to water at very low concentrations, giving it good warning properties. The TCEQ has adopted a taste and odor threshold of 15 ppb for MTBE. Because of MTBE's very low taste and odor threshold, the majority of people would typically not use MTBE-contaminated water for long enough periods of time that could lead to health problems. Therein lies an important issue with MTBE—because of its very low taste and odor threshold, low concentrations of MTBE can render water undesirable.

Pathways of Exposure

An important point to consider when discussing the health effects of fuels is the pathway through which people are exposed to the fuel. In the case of an aquifer contaminated with dissolved-phase fuel from an LPST, one important pathway people are exposed through is drinking contaminated groundwater. Allowable, or safe, levels of fuel constituents in drinking water are typically very low. For example, the drinking water standard for benzene is 5 ppb. Consequently, even a small leak from a PST could make groundwater unhealthy for drinking.

Another important exposure pathway is inhalation of fuel vapors. The inhalation of fuel vapors can occur where there is vapor intrusion into a building due to the presence of contaminated soil or groundwater, or by household use of contaminated groundwater. If a shallow aquifer contaminated with dissolved-phase fuel lies beneath a house, the fuel components can migrate through the soil and accumulate in the building. This is referred to as vapor intrusion. While the levels typically would not accumulate to the same extent that they would if free product were under the house, they can accumulate to the point that long-term health effects would be a concern. Further, levels that are of a long-term health concern may not necessarily be discernable by the sense of smell, so the residents may not realize that fuel components are in the air in their house.

Also, household use of contaminated groundwater can introduce vapors into residences that can cause a long-term health concern. Most of the components of fuels are volatile, meaning they readily evaporate from water into air. For instance, when a person takes a shower, volatile contaminants in the water will enter the air and will be inhaled. Showering, bathing, washing hands, washing clothes, washing dishes, and flushing toilets have also been demonstrated to be sources of personal exposure to volatile organic compounds.

PROTECTIVE MEASURES

State and federal regulations require that all PST systems in Texas be equipped with corrosion protection, release detection, and spill/overfill prevention. These requirements are described in "Overview of PST Systems" (see page 3 of this report) and in Appendix C. **In addition, TCEQ rules require that PST facilities located in certain populated karst areas be equipped with extra protection.**

State regulations (30 TAC, Chapter 213) require that secondary containment in the form of continuously monitored double-walled tanks and lines be provided for USTs installed in or near the recharge zone of Edwards Aquifer. Tertiary containment, in the form of triple- walled tanks and lines or an additional impervious liner or vault outside a double-walled system, is currently required on the Edwards transition and/or recharge zones for any new UST system situated within 150 feet of a sensitive feature such as a water well or cave.

Under the requirements of Texas Water Code Chapter 26, Section 26.3476, and Title 30 TAC, Chapter 214 of TCEQ rules, secondary containment is also required when new USTs are installed or existing USTs are replaced over the outcrop of the Trinity and Edwards aquifers in Bexar and Comal counties. This requirement is to provide extra protection to guard against contamination of public and private water supplies. Chapter 214 defines secondary containment as a method by which a secondary wall or barrier is installed around a UST system in a manner designed to prevent a release of a regulated substance from migrating beyond the secondary wall or barrier before the release can be detected. That definition also states that a secondary containment system may include an impervious liner, jacket, containment boot, sump, or vault surrounding a primary tank or piping system, or a double-wall tank or piping system.

Local regulations or ordinances have also been promulgated in Texas to provide additional protection to karst aquifers. These include rules promulgated by the Edwards Aquifer Authority (EAA) in October 2002 which bar the installation of most new PSTs on the Edwards Aquifer recharge zone. The EAA rules will ultimately require upgrade of existing PST systems to triple-wall containment. A 1995 City of San Antonio ordinance bars the development of a new UST facilities on the Edwards recharge zone within the city limits unless the land was already platted for that purpose. In addition, the City of Austin requires a permit for UST installation. The permit is reviewed for renewal every three years and during annual audits. Finally, the City of San Marcos has an ordinance that requires inspection of tank pits located on the Edwards Aquifer recharge zone prior to installation of PST systems.

The ability of local governments to adopt regulations or ordinances to protect karst aquifers, or other resources, from the affects of UST releases is limited by Texas statute. The Texas Water Code, § 26.359, states that local regulations or ordinances concerning the design, construction, installation, or operation of USTs that were not in effect on January 1, 2001 are not valid. The statute is unclear on two points: the validity of the rule adopted by the EAA and the ability of local governments to amend their UST existing, valid UST regulations or ordinances. The statute is provided as Appendix F.

CONCLUSIONS

This report to the 78th Texas Legislature makes five key points, as follows:

- Releases from PST systems to Texas aquifers do occur. These releases rarely affect the water delivered by PDW systems to their customers. However, some private water wells are vulnerable to PST releases, especially when those wells are completed in karst aquifers.

- Contamination from leaking PSTs can pose health risks. The two most common ways for a person to be exposed to unhealthful levels of PST contaminants is through the inhalation of vapors and the drinking of contaminated groundwater.

- Karst aquifers are more vulnerable to contamination than other types of aquifers. This is because karst outcrops are more open at the surface. Once contamination enters a karst aquifer, it moves very quickly.

- State and Federal regulations require that all UST systems be equipped in a manner that provides corrosion protection, release detection, and spill/overfill prevention. Additional protection is required for UST systems constructed or upgraded over certain karst outcrop areas. These areas are the Edwards aquifer (30 TAC 213) and the Trinity aquifer in Bexar and Comal counties (30 TAC 214).

- When problems arise from the operation of PST systems, the long-term and short-term consequences can be adequately addressed by current statutes and TCEQ regulations.

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APPENDIX A: LEGISLATIVE MANDATE FOR THIS REPORT

Senate Bill 1, Article VI, Rider 39, of the 77th Legislature reads in part:

> **"POLLUTION OF AQUIFERS STUDY. It is the intent of the legislature that the Texas Natural Resource Conservation Commission, pursuant to its authority under Chapter 26 of the Water Code, study the problems caused by petroleum storage tanks located above aquifer recharge zones, with particular emphasis on the spillage of benzene, toluene, and MTBE into the Trinity aquifer. It is the intent of the legislature that the study include the causes of pollution by petroleum storage tank systems, the health and safety effects of inadequate containment systems, and long-term and short-term solutions and remedies."**

APPENDIX B: PSTS AND PDW WELLS ON THE TRINITY AQUIFER OUTCROP

County Name	Aquifer Name	Area (sq. miles)	Public Supply Wells	PST Sites	LPST Sites*
BANDERA	Middle Trinity	57.8	16	8	0
	Upper Trinity	528.3	1	5	5
BELL	Glen Rose	66.9	0	2	0
BEXAR	Middle Trinity	14.4	13	0	0
	Upper Trinity	163.0	9	23	3
BLANCO	Lower Trinity	1.7	0	0	0
	Middle Trinity	181.6	3	0	4
	Upper Trinity	343.2	0	7	5
BOSQUE	Glen Rose	23.5	0	0	0
	Paluxy	58.0	0	0	0
BROWN	Antlers	52.1	4		
	Glen Rose	56.1	0	0	1
	Paluxy	32.9	0	2	0
	Twin Mountain–Travis Peak	112.1	0	7	0
BURNET	Glen Rose	328.4	0	5	0
	Lower Trinity	6.2	4	0	0
	Middle Trinity	16.6	0	0	0
	Paluxy	27.9	0	0	0
	Twin Mountain–Travis Peak	46.8	6	8	6
	Upper Trinity	3.8	0	0	0
CALLAHAN	Antlers	256.4	10	10	7
COMAL	Middle Trinity	166.2	25	16	1
	Upper Trinity	154.6	16	17	5
COMANCHE	Antlers	15.4	0	0	0
	Glen Rose	208.0	0	2	1
	Paluxy	55.3	0	0	0
	Twin Mountain–Travis Peak	475.5	5	45	13
COOKE	Antlers	121.7	0	0	0
CORYELL	Glen Rose	227.6	0	0	0
	Paluxy	57.0	0	1	0
DENTON	Antlers	2.5	0	0	0
EASTLAND	Antlers	305.7	5	8	1
	Glen Rose	2.4	0	0	0
	Paluxy	4.9	0	0	0
	Twin Mountain–Travis Peak	38.4	0	0	2

County Name	Aquifer Name	Area (sq. miles)	Public Supply Wells	PST Sites	LPST Sites*
ERATH	Glen Rose	321.8	0	28	19
	Paluxy	320.7	0	37	8
	Twin Mountain–Travis Peak	177.7	1	1	0
GILLESPIE	Middle Trinity	190.0	14	42	30
	Upper Trinity	172.6	0	1	0
GRAYSON	Antlers	15.4	1	0	0
HAMILTON	Glen Rose	220.3	0	4	1
	Paluxy	93.7	0	13	2
	Twin Mountain–Travis Peak	6.5	0	0	0
HAYS	Lower Trinity	0.3	0	0	0
	Middle Trinity	55.3	8	1	0
	Upper Trinity	295.2	7	13	5
HOOD	Glen Rose	214.7	0	51	21
	Paluxy	104.6	0	14	1
	Twin Mountain–Travis Peak	58.3	3	1	0
JACK	Antlers	4.1	0	0	0
	Glen Rose	6.2	0	0	0
	Paluxy	7.9	0	0	0
	Twin Mountain–Travis Peak	36.2	0	0	0
JOHNSON	Glen Rose	0.8	0	0	0
	Paluxy	3.3	0	0	0
KENDALL	Middle Trinity	199.8	21	4	2
	Upper Trinity	332.5	6	34	16
KERR	Middle Trinity	1.8	0	0	0
	Upper Trinity	255.6	3	65	51
LAMPASAS	Glen Rose	337.8	0	3	3
	Paluxy	43.7	0	1	0
	Twin Mountain–Travis Peak	71.7	0	33	10
MEDINA	Upper Trinity	121.0	0	0	0
MILLS	Glen Rose	95.6	0	0	1
	Paluxy	38.3	0	0	0
	Twin Mountain–Travis Peak	150.8	0	2	0
MONTAGUE	Antlers	415.9	0	39	19
PALO PINTO	Twin Mountain–Travis Peak	14.2	0	0	0

County Name	Aquifer Name	Area (sq. miles)	Public Supply Wells	PST Sites	LPST Sites*
PARKER	Glen Rose	58.0	0	0	0
	Paluxy	355.9	27	98	48
	Twin Mountain–Travis Peak	149.6	3	4	3
REAL	Upper Trinity	12.7	0	0	0
SHACKELFORD	Antlers	0.1	0	0	0
SOMERVELL	Glen Rose	94.4	0	21	4
	Paluxy	46.9	1	0	0
	Twin Mountain–Travis Peak	0.8	0	0	0
TARRANT	Paluxy	58.1	14	37	14
TAYLOR	Antlers	27.2	0	0	0
TRAVIS	Glen Rose	145.8	0	22	13
	Lower Trinity	0.4	0	0	0
	Middle Trinity	43.6	1	3	3
	Twin Mountain–Travis Peak	10.9	0	0	0
	Upper Trinity	163.1	2	64	23
UVALDE	Upper Trinity	84.4	2	0	3
WILLIAMSON	Glen Rose	68.2	0	5	1
WISE	Antlers	291.9	0	18	13
	Glen Rose	33.6	0	0	3
	Paluxy	139.3	5	14	8
	Twin Mountain–Travis Peak	127.7	3	3	4

*** Please note that these Leaking Petroleum Storage Tank (LPST) numbers represent both active and closed sites. For the counties listed above, approximately 80 percent of the LPST sites have already been closed.**

APPENDIX C: COMPONENTS OF A UST SYSTEM

The following is a brief description some of the different components of underground storage tank (UST) systems.

! The **tank** or tanks form the storage receptacle for the petroleum substance. The majority of tanks are made of steel. In the 1920s when tanks were first buried to prevent fires and explosions, they were made of plain carbon steel with little or no corrosion protection. Corrosion was one factor that led to the eventual leaking of tens of thousands of USTs across the country.

  Today, steel tanks must be protected from corrosion by either cathodically protecting them and/or by coating them with a noncorrodible material such as fiberglass or polyurethane. Tanks may also be constructed entirely of noncorrodible materials such as fiberglass-reinforced plastic (FRP). Tanks may be single-walled, double-walled, or triple-walled. Sizes of fuel tanks used at service stations will typically range from about 4,000 to 20,000 gallons in size. Tanks used for oil and waste oil storage are smaller, generally less than 1,000 gallons.

! Tank UST system **piping** is typically constructed of noncorrodible FRP or of cathodically protected steel. Piping systems may be suction or pressurized If a suction system is used, a suction pump will be located inside each dispenser. If a pressure piping system is used, a submersible pump will be located inside each tank.

  Many of the worst product releases at UST sites have been caused by corroded, improperly installed or damaged pressurized piping. Releases from pressurized systems are especially severe because the leak causes a reduction in product pressure inside the pipe that triggers the UST system pump to turn on just like it would if the dispenser nozzle handle was depressed. Piping joints and connectors are especially susceptible to developing leaks. Like tanks, piping can be single-, double- or triple-walled.

! **Ancillary equipment** is defined as any devices used to distribute, meter, or control the flow of petroleum substances or hazardous substances into or out of a UST, including, but not limited to piping, fittings, flanges, valves and pumps. As mentioned above, UST systems have either suction or pressure pumps to move the product out of the tanks, through the piping and dispensers, and into motor vehicle fuel tanks.

- **Release detection** is defined as the process of determining whether a release of regulated substance is occurring or has occurred from an UST system. TCEQ rules require owners/operators to provide an ongoing method or methods of release detection capable of detecting a release from any portion of the UST system which contains regulated substances, including the tanks, piping, and other underground ancillary equipment.

  The rules allow eight separate methods of release detection which range in required monitoring frequency from annual line testing to continuous interstitial monitoring of double- or triple-walled systems. Most of the methodologies require a monthly monitoring frequency.

  Typically these methods will detect a releases of 0.1 to 0.2 gallons per hour. In addition, all UST systems that use pressurized piping must be equipped with an automatic line leak detector on each separate pressurized line that will detect large leaks of 3 gallons per hour or greater and shut down the pump for that line within 1 hour of detecting the release.

- **Spill and overfill prevention** is required by TCEQ rules and is provided by equipping each tank fill tube with a device that forms a liquid-tight seal during filling operations; a catchment basin for the tank fill tube that will catch any fuel spilled when the filler hose is disconnected; and a shutoff or restriction device that will prevent the tank from being filled to a level greater than 90 to 98 percent full, depending on the type of device.

- **Corrosion protection** is required by TCEQ rules and is provided by either isolating underground metal components of the UST system from surrounding backfill or by coating and cathodically protecting those components. Cathodic protection is provided by equipping the UST system with sacrificial anodes (either a more active metal than the part being protected or an electrode that emits a low voltage). The purpose is to ensure that electrons flow from the anode to the protected part, thereby preventing corrosion.

APPENDIX D: MTBE INFORMATION

Methyl tertiary-butyl ether (MTBE) is a gasoline additive that has garnered widespread attention over the past several years.

Purpose of MTBE

! *Octane Booster.* In 1973, the USEPA instituted the lead phase-down program to minimize the lead content of gasoline because it had found that lead particle emissions from motor vehicles presented a significant health threat to urban populations, especially children. Since the removal of lead lowered the octane rating, substitute octane-enhancing compounds came into use. MTBE began to be used as an octane-enhancer in 1979 and is still widely in use in Texas as the primary octane-enhancer. Conventional gasoline refiners manufacture regular gasoline and add MTBE to boost the octane to mid-grade and premium gasolines.

! *Emissions Reduction.* Also, provisions of the 1990 Clean Air Act Amendments require the use of oxygenates such as MTBE in fuel to help reduce emissions from cars. Oxygenates are oxygen-containing compounds which make gasoline burn cleaner. The reformulated gasoline (RFG) and oxygenated fuel programs were established to help improve the combustion of gasoline and to reduce toxic emissions from tailpipes. The Clean Air Act does not expressly require the use of MTBE, only that oxygenates be used.

The oxygenated fuel program is a wintertime control for carbon monoxide. It began in 1992. In Texas, only El Paso County is subject to the program. Through the early part of the program, ethanol was the oxygenate of choice, but tertiary-amyl methyl ether (TAME) and MTBE are in use now. The approximate market share for each oxygenate during the 1998-1999 winter control period was 40 percent ethanol, 34 percent TAME, and 26 percent MTBE.

The RFG program is a year-round ozone-control program to reduce volatile organic compound (VOC), nitrogen oxide (NO_x), and toxics emissions. Since 1995, RFG has been sold in the Houston-Galveston and Dallas-Fort Worth ozone non-attainment areas. MTBE is the primary oxygenate used, though there is a small percentage of TAME in use.

APPENDIX E: SOURCE OF GIS MAPS

Three (3) maps in this report were generated by the Information Resources Division of the TCEQ utilizing GIS software and the data sources listed below. None of these maps are survey products, and no claims are made as to the accuracy or completeness of the data or to their suitability for a particular use. For more information concerning these maps, contact the TCEQ Information Resources Division at (512) 239-0800.

- Figure 2: Occurrence of PSTs and LPSTs over the Trinity Group aquifer in the vicinity of Weatherford, Texas
- Figure 10: Areal extent of the Trinity Group aquifer, including outcrop and subcrop areas
- Figure 11: Areal extent of the seven members of the Trinity Group aquifer

Figure 2: Occurrence of PSTs and LPSTs over the Trinity Group aquifer in the vicinity of Weatherford, Texas

This map represents the Trinity aquifer (*Twin Mountain–Travis Peak*, *Paluxy*, and *Glen Rose* outcrops and subcrops) in the vicinity of Weatherford, Texas, located in Parker County west of Fort Worth. The map also represents *Trinity Public Water Supply Wells* and *Petroleum Storage Tanks* (leaking and non-leaking).

The map utilized the following data layers:

- Trinity Public Water Supply Wells—created by the U.S. Geological Survey, based on data provided by TCEQ Source Water Assessment and Protection (SWAP) Program
- Petroleum Storage Tanks (leaking and non-leaking)—created by the U.S. Geological Survey, based on data provided by TCEQ Source Water Assessment and Protection (SWAP) Program
- Trinity Divided (outcrop and subcrop)—provided by the U.S. Geological Survey. Used to represent the *Twin Mountain–Travis Peak*, *Paluxy*, and *Glen Rose* outcrops and subcrops.
- Texas Roads—provided by the U.S. Geological Survey
- Texas Cities—provided by the U.S. Geological Survey
- Texas Counties—provided by the U.S. Geological Survey

Figure 10: Areal extent of the Trinity Group aquifer, including outcrop and subcrop areas

This map represents the entire Trinity aquifer, which extends from Medina and Bexar County north to the Red River along the Texas-Oklahoma border.

The map utilized the following data layers:

- Trinity Divided (outcrop and subcrop)—provided by the U.S. Geological Survey
- Rivers—certified TCEQ Major Streams layer, derived from U.S. Census Bureau 1992 TIGER/Line data
- Lakes—certified TCEQ Major Streams layer, derived from U.S. Census Bureau 1992 TIGER/Line data
- Texas Cities—provided by the U.S. Geological Survey
- Texas Counties—provided by the U.S. Geological Survey

Figure 11: Areal extent of the seven members of the Trinity Group aquifer

This map represents the entire Trinity aquifer, divided into seven (7) smaller aquifers, each of which has an outcrop and a subcrop. The map also represents *Public Water Supply Wells* that lie within the Trinity aquifer.

The map utilized the following data layers:

- Trinity Public Water Supply Wells—created by the U.S. Geological Survey, based on data provided by TCEQ Source Water Assessment and Protection (SWAP) Program
- Trinity Divided (outcrop and subcrop)—provided by the U.S. Geological Survey. Used to represent the *Antlers*, *Twin Mountain–Travis Peak*, *Paluxy*, *Glen Rose*, *Lower Trinity*, *Middle Trinity*, and *Upper Trinity* outcrops and subcrops.
- Texas Cities—provided by the U.S. Geological Survey
- Texas Counties—provided by the U.S. Geological Survey

APPENDIX F: TEXAS LAW ON LOCAL UST REQUIREMENTS

Texas Water Code § 26.359. Local Regulation or Ordinance

(a) In this section, "local government" means a school district, county, municipality, junior college district, river authority, water district or other special district, or other political subdivision created under the constitution or a statute of this state.

(b) A regulation or ordinance adopted by a local government that imposes standards for the design, construction, installation, or operation of underground storage tanks is not valid.

Text of subsec. (c) as amended by Acts 2001, 77th Leg., ch. 965, § 14.10 (HB 2912)

(c) This section does not apply to a regulation or ordinance in effect as of January 1, 2001.

Text of subsec. (c) as amended by Acts 2001, 77th Leg., ch. 966, § 11.02 (SB 2)

(c) This section does not apply to a rule adopted by the Edwards Aquifer Authority, or to a regulation or ordinance in effect as of January 1, 2001, or thereafter amended.

Added by Acts 1987, 70th Leg., ch. 277, § 1, eff. Sept. 1, 1987.

Amended by Acts 2001, 77th Leg., ch. 965, § 14.10, eff. Sept. 1, 2001; Acts 2001, 77th Leg., ch. 966, § 11.02, eff. Sept. 1, 2001.