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Salt Water Contamination of the Chicot Aquifer from Historic Oil Field Operations, Tomball Field, Harris County, Texas

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Introduction

At the request of the Texas Department of Licensing and Regulation (TDLR), Water Well Driller Division, the TNRCC Surface Casing Team, Waste Permitting Division, investigated a large plume of saltwater in the Pleistocene-aged Chicot Aquifer (Lissie/Willis Formations) in the Tomball/Houston metroplex of north Harris County. This presentation focus is primarily on the Boudreaux Estates Subdivision (Fig. 1), which is off Boudreaux Road and immediately west of Hwy. 249/Tomball Freeway. The plume, however, extends southward to a nearby subdivision, Hoffman Estates.

Both subdivisions are on the southwest flank of Tomball Field, which is largely abandoned. The geological investigation finds a Chicot Aquifer recharge zone in Boudreaux Estates Subdivision, which compromises geological isolation of the lower Chicot from surface contamination sources. In addition, examination of historical oilfield activity in the subdivision suggests that old tank battery and pit sites, on present-day Boudreaux Estates Subdivision Lots 9 and 11 (Fig. 1), are a probable point-source for the contamination.

Tobin International supplied TNRCC with digital ortho maps, oil and gas well locations, and historical aerial photographs of the area, which were essential in confirming the placement of production facilities, pipelines, and wells. Today, little evidence is present on the ground indicating that the area was an active oilfield. The principal geological data sources are geophysical logs of oilfield wells and public-supply/private water wells and drillers' logs of private water wells.

Graphic representation of the Tobin and geological data is presented through ESRI software, rather than in the standard slide format. Using the ESRI software is particularly helpful in showing the layering of historical oilfield activity with present-day culture. Also, geological data can be quickly manipulated in active three-dimension to show depositional environments, map horizons, and plume geometry.

Background

Much of Boudreaux Estates is subdivided into large, estate-sized lots. The subdivision has been under development since the 1980's. Many land owners have equestrian facilities on their property besides their private homes. The subdivision covers approximately 265 acres and has 210 lots. To date, 110 private water wells have been drilled. Fifty private water wells encountered elevated chlorides, above 300 parts per million (ppm) Total Dissolved Solids (TDS). Out of that number, five wells had very high chlorides, greater than 1000 ppm TDS, with a minimum detection of benzene. No public water supply exists for the subdivision and surrounding area.

Initially, most water wells were completed at around 200 feet in the upper Chicot Aquifer and encountered no saltwater. In the late 1990's, as local and regional water use increased in concurrence with a drought period, the shallow water wells experienced reduced yields. Water wells were drilled to the deeper, lower Chicot, where several wells found elevated chlorides. Saltwater contamination complaints were filed with the Railroad Commission of Texas (RRCT), which regulates the exploration and production of oil and gas. The RRCT and a former operator are conducting their own investigation. The same operator is providing bottled drinking water to all residents, has installed water filtration systems for contaminated wells, and is planning a public supply system for the area.

In view of the many complaints and apparent liability to the water well drillers, the TDLR asked the TNRCC Surface Casing Team to investigate and to assist in making recommendations for area water well construction and completion. The purpose of the investigation was to determine the extent of the contamination plume in satisfying the TDLR request.

TNRCC has no jurisdictional authority in this matter. Unquestionably, the saltwater source is from oil and gas operations, which is totally within the jurisdiction of the RRCT. TNRCC has statutory responsibility to act as geological advisor on ground water protection to the TDLR at their request. RRCT rules require TNRCC geological recommendations on ground water protection for specific oil and gas operations, such as drilling and waste disposal, but none apply to contamination site-assessment and remediation matters.

Probable Contamination Source and Pathway

Tomball Field, discovered in 1930, is a deep-seated salt dome with most of its cumulative oil production (125 million barrels) from the Eocene-aged Yegua and Wilcox Formations. Typical of most Gulf Coast reservoirs, the Yegua and Wilcox are water drives. Boudreaux Estates is on the southwest flank of the producing structure. Three Quiltar leases covered the subdivision and have produced around six million barrels of oil and an unknown quantity of saltwater. A reasonable guess of produced-saltwater near the original oil-water contact could be as much as 10-15 million barrels with the six million barrels of oil.

In the subdivision, the Lissie/Willis Formations range from fluvial at the outcrop to delta plain with depth. The lower Chicot Aquifer distributary-channel sands are preferred for their yield and water quality. For example, the lower Chicot section supplies the City of Tomball with drinking water. In Boudreaux Estates, the same sands host the saltwater contamination. As saltwater is heavier than fresh water, the plume sought the best porosity/permeability pathway at the base of coalesced distributary channels. In Fig. 2, electric/gamma ray logs exhibit the characteristic fining-upwards, channel-sand profile, with reduced resistivity and increased spontaneous potential development across the saltwater plume.

Conceivably, produced saltwater leaked over several years from pits associated with the production and saltwater separation facilities on present-day Lots 9 and 11. This speculation is based solely on documented plume geometry and the coincidental location of the suspected pits and tank batteries on a Chicot Aquifer direct-recharge zone.

The Boudreaux Estates area has been exposed to erosion since the early Holocene. As a result, the Montgomery Clay, which outcrops in the area, is not present across the western half of the subdivision and allows local recharge of the upper Chicot sands. Most of the Chicot recharge, especially the lower Chicot, is about 5 miles northwest in Montgomery County. In Harris County, inter-distributary clays usually prevent direct-recharge into the lower Chicot from the surface; however, that is not true in Boudreaux Estates.

From evaluation of geophysical logs and drillers' logs of Boudreaux Estates water wells, two distinct inter-distributary clays are present within the upper 150 feet of section. Clay 1, at 100-130 feet, is present in the western half of the subdivision and Clay 2, at 60-90 feet, is present in the eastern half of the subdivision. Unfortunately, they are separate depositional events, neither time-equivalent nor coalescent, that give way to a stacked channel sequence, which extends to the base of the Chicot Aquifer and along the north-south line of Fountaine Bleau Drive in the subdivision. Moreover, well control establishes sand at or near the surface westward from this line. Any production/saltwater separation facility on or near this direct-recharge zone is considered a likely contamination point-source. Consequently, the old tank batteries, once on present-day Lots 9 and 11, are suspected sources. Near the eastern edge of the subdivision, an old tank battery on Lot 101 is not believed to be a source because the Montgomery Clay is present at the surface and the area is underlain by Clay 2.

Several pipelines cross the recharge zone; however, no records of large saltwater spills exist. Records of oil and gas wells drilled and plugged in the subdivision document adequate protection of ground water. Furthermore, surface casing for all wells was set below known contamination levels.

Plume Migration and Geometry

The greatest influence on plume migration is depositional environment (channel geometry), saltwater head, the dynamics of the recharge zone itself, and pump gradient

from water wells. Regional structural gradient is about 35 feet in one mile; therefore, the local gradient is flat and has little if any influence on plume migration. As the plume migrated along channel permeability fairways, the drive mechanism is the conjunctive force of the original saltwater head and the recharge zone's fresh water head. Subsequent water well completions have also complicated plume geometry by induced pump gradient.

Water wells were constructed with pressure cemented casing and with 10-foot slotted screen completions. Water analyses of contaminated zones suggest considerable dilution of the original field saltwater. A reasonable guess of Yegua field saltwater TDS is 50,000 ppm. While having facilitated Chicot contamination, the recharge zone is also an effective agent in diluting the contamination. Not surprisingly, the greater the reservoir dynamics the greater the mixing. Before-and-after logs of disposal-well injection zones of similar depositional environments display little mixing of injectate plumes with native formation waters when the only reservoir dynamics is injection. Studies of fresh water injection into saltwater reservoirs for aquifer storage and retrieval show little mixing of the two contrasting water salinities in stable, low-dynamics reservoirs.

Other evidence for a local, active recharge-zone is the fact that upper Chicot water wells in Boudreaux Estates experienced water table fluctuation, which in turn led to the saltwater discovery by deeper drilling. Limited temperature data register a gradient of around five degrees above normal, which would support direct recharge from the surface. Another interesting point is that unlike much of Harris County, which has a shallow water table within ten feet, the Boudreaux Estates water table is much deeper. It is perched immediately above Clay 1, at about 80 feet, and above Clay 2, at about 40 feet. A landowner adjoining the subdivision on the west side dug a 20-foot deep lake in continuous sand. Despite several inches of rain during four months, the unlined lake remained dry until 30 inches of rainfall from Tropical Storm Allison filled it. When the lake was clay-lined, three months after Allison, the water depth had dropped to five feet. The rapid drop in lake level was due to the local water-table recharge into the lower Chicot. The rate of plume migration is difficult to assess. Although limited to within the last 20 years, water well history does give some idea of plume migration. Calculations of plume migration in the Hoffman Estates Subdivision suggest that the plume could move about 1 mile in 100 years. Hoffman Estates is not in the direct-recharge area; therefore, the effect of the recharge zone would be reduced and pump gradient may be the principal factor in migration. This glacial-rate movement of the plume would tend to lessen the probability of any off-site point source for the contamination.

Dense water well control defines a complex plume geometry, as expected from the effects of the depositional environment, the dynamics of the recharge zone, and the pump gradient. The plume is not a solid front, but a diluting, fingering tongue that is moving at varying rates and directions along the distributary-channel, high-porosity fairways. The lower Chicot has several sets of distributary channels and the plume has entered the base of at least two channel sets. As can be seen from the Fig. 2 cross section of electric logs, a very thin permeability barrier can "perch" the saltwater above a fresh water sand.

The Evangeline Aquifer should not be affected by the contamination. It is geologically separated by a regional marine clay, which is a paleo-Trinity Bay flooding sequence. Unfortunately, the upper Evangeline sands are not present on the west side of Boudreaux Estates. A deep water well, in Lot 3, encountered fine, red silts that are not suitable for water well completions. Good quality, upper Evangeline sands are found within a 2-mile radius of the subdivision. This area of non-deposition is possibly a delta plain fresh/brackish lake, perhaps similar to present-day Lake Anahuac on the Trinity River Delta. The upper and lower Evangeline Aquifers are two distinct depositional events and should not be expected to mirror each other in depositional environments. Regionally, the upper Evangeline is the preferred aquifer for water quality and yield. Lower Evangeline sands are suitable, but with diminished water quality in a thinning sand section, which reflects a lower delta plain to prodelta depositional environment with depth. If the upper Evangeline is present in the eastern half of Boudreaux Estates, drilling to the lower Evangeline will not be necessary for future public water supply needs.

Conclusions and Recommendations

Saltwater contamination of the Chicot Aquifer has resulted from historic oilfield operations. Most probably, the contamination pathway was a direct, local recharge-zone. Given the complex plume geometry, remediation by removal of the saltwater contamination would be difficult with frustrating and possibly negative results. The recharge zone complicates the reservoir dynamics such that the mass balance would be easily upset by saltwater withdrawal, which could adversely mobilize the plume. If remediation is attempted, it should be after a public water supply is in place and all residents have an alternate water supply.

The TNRCC Surface Casing Team has recommended drilling all new water wells to the top of the marine clay, below the Chicot. Moreover, the wells are to be evaluated by open-hole electric/gamma ray logs. By restricting well bores to the Chicot, the possibility of Evangeline contamination through well bores is reduced. The Surface Casing Team is working with the TDLR Water Well Driller Program and local water well drillers in determining water well completion zones that will avoid saltwater zones and will not adversely affect the plume. As water well demand continues with development in the subdivision, the aim is to drill and complete Chicot Aquifer private supply wells that are reliable water sources until a public supply system is in place.

Figure 1.
Boudreau Estates Subdivision
Tomball, Harris County, Texas
Location of Water Well Cross Section

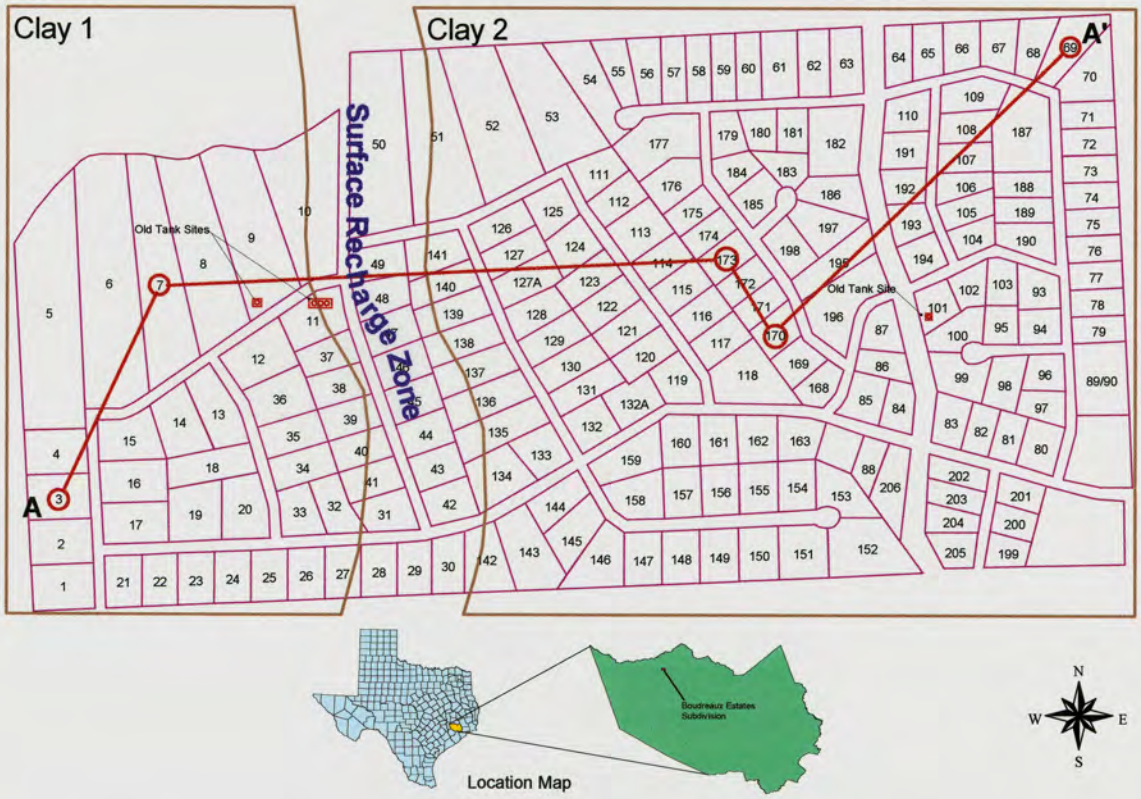

Figure 2.
Boudreaux Estates Subdivision
Tomball, Harris County
Water Well Electric Log
Cross Section