

Chapter 7

100 Years of Groundwater Use and Subsidence in the Upper Texas Gulf Coast

Thomas A. Michel¹

Introduction

Imagine yourself more than a hundred years ago, living in southeastern Texas. You would have faced many challenges, among others: 100 degree temperatures and 80 percent humidity in the summers, ruthless mosquitoes, roaming alligators, and a whole host of other challenges of the early 20th century that we do not worry about today. One challenge that residents of Galveston, Houston, and the surrounding area did not have to face was water. Water was already distributed throughout the area, underground, in what is today referred to as the Gulf Coast Aquifer System. It was only necessary to drill a shallow well and clean groundwater would flow from the well, even without a pump to withdraw it. Water was abundant.

Today, in the early 21st century, we have air conditioners that counteract the heat and humidity of the summer months, government trucks that spray pesticides to greatly reduce the mosquito population, and for whatever reasons the alligators don't seem to roam the streets of downtown Houston as they once did. Oh, how the times have changed. As the population grew throughout the last century and industries blossomed, the demand for water increased greatly. Unlike 100 years ago, one of our greatest challenges today is our water supply. You can't just drill a shallow well today in your backyard anymore and expect clean, fresh water to come bubbling up.

In today's greater Houston area, groundwater still is utilized by many people, but surface water is the predominant supply. Years of increasing demand for groundwater caused irreversible harm to the area and measures were taken to combat the problems caused by the over-reliance of groundwater. So far, the efforts have been a great success story for the area and residents of yesterday should be appreciated for their foresight in developing surface water supplies such as Lakes Conroe, Houston, and Livingston. Residents of today's greater Houston area should be thanked for their continued efforts to provide for a reliable and sustainable water supply. Those residents yet to arrive to the area need to be reminded of the challenges faced and overcome, but also reminded that we will always need to protect our environment from our insatiable thirst for water.

¹ Harris-Galveston Subsidence District

The Rise and Fall of Groundwater Pumpage

At the beginning of the 20th Century, the rather small City of Houston was primarily an agricultural area with a population of only 45,000 people. The area gained national recognition due largely to the devastation of the Great Storm of 1900 and the many lives that were lost. The City of Galveston lost about one-sixth of its population in the storm, but the misfortunes of Galveston led to the beginnings of a boom in population that Houston has sustained even to today.

Water from underground in the Gulf Coast Aquifer System was utilized as the predominant water supply. The system is made up of layers of clays and sands with no stable rock within the primary pumping strata. Groundwater from the Chicot and Evangeline aquifers, within the aquifer system, provided the necessary water for developing industries and the population necessary to support those industries. The Chicot aquifer is the shallower aquifer within the Gulf Coast Aquifer System, with the Evangeline aquifer beneath the Chicot (Figure 7-1). Generally, the Chicot aquifer has served the water needs of the southeastern portion of Harris County and Galveston County while the deeper Evangeline served the needs of central, north, and west Harris County.

Municipal and industrial water needs began to rise with the oil boom in the early 1900s and the development of the Houston Ship Channel. The Port of Houston Authority was created in 1927 by the Texas Legislature, thus beginning the real boom in industry around the Houston Ship Channel. Post-World War II, Houston's economy had almost entirely switched from agriculture to the oil and gas industries and other emerging industries such as plastics. Historically, all of these industries and the surrounding municipal use were supplied with water from the Chicot and Evangeline aquifers.

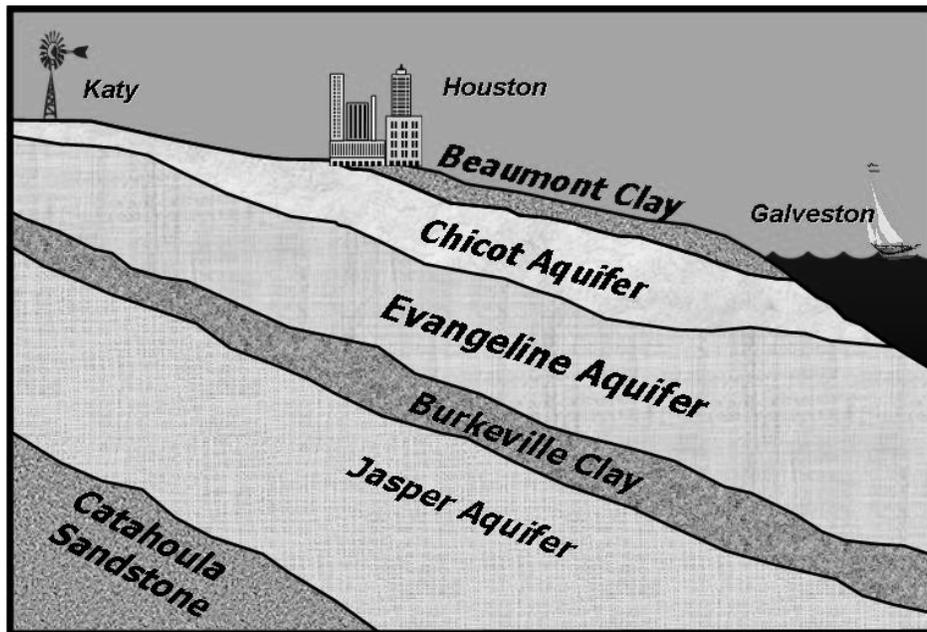


Figure 7-1. Illustrated cross-section of the Gulf Coast Aquifer System.

In Harris County and the surrounding counties (Figure 7-2), generally referred to as the Greater Houston Area, groundwater was withdrawn from the Chicot and Evangeline aquifers as the demands rose rapidly. The results of the groundwater withdrawals led to declines in the water levels of both aquifers. From 1943 to 1977, the Chicot aquifer experienced water-level declines of as much as 200 feet, while the Evangeline aquifer had declines on as much as 300 feet (Figure 7-3). Declines within both aquifers were generally recorded in central and southeastern Harris County and throughout Galveston County.

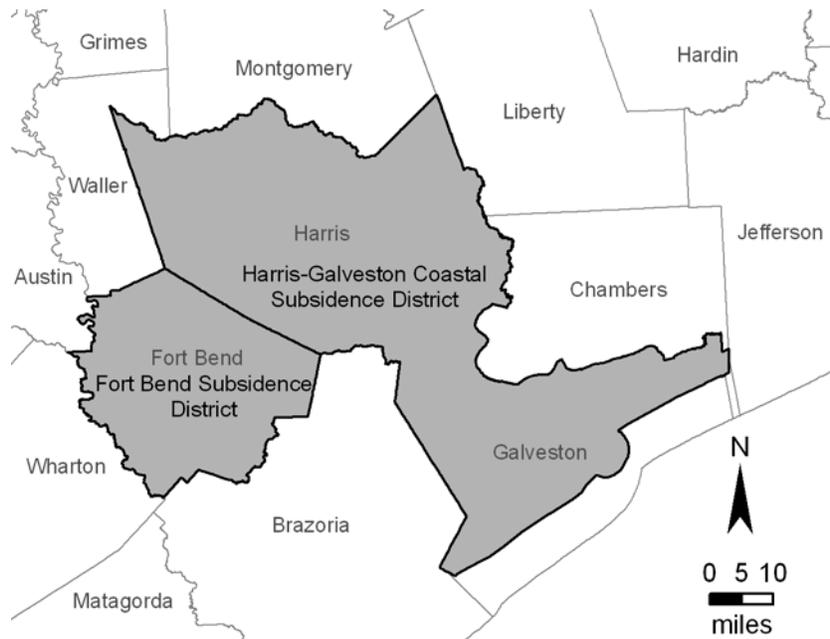


Figure 7-2. Map of Harris and surrounding counties, showing the boundaries of the subsidence districts.

The water level declines within the two aquifers would prove to be related closely to the phenomenon that some were beginning to see in the land-surface elevations. With the large amount of groundwater that was being pumped from underground throughout most of the 20th century, water levels were declining, but groundwater was also literally being “sucked” from the layers of clays within the aquifers. The clays compacted due to the reduced internal pressure in the clays and the overburden, resulting in land-surface subsidence.

Beginning to a large extent in the mid-1970s, surface water started to be utilized as a replacement of groundwater. Galveston County began converting from groundwater to surface water from the Brazos River through a series of over-land canals that brought water to the Texas City population and industries. The cities of Baytown, Houston, Pasadena, and others, along with major industries along the coast, converted most of their groundwater use to surface water from the San Jacinto and Trinity rivers. Groundwater withdrawals within Harris and Galveston counties were reduced considerably and quickly from a high in 1976 of 456 million gallons per day (Figure 7-4). In 2004, the last year for which groundwater withdrawals have been quantified, groundwater withdrawals within the two counties had been reduced to 245 million gallons per day (Figure 7-4).

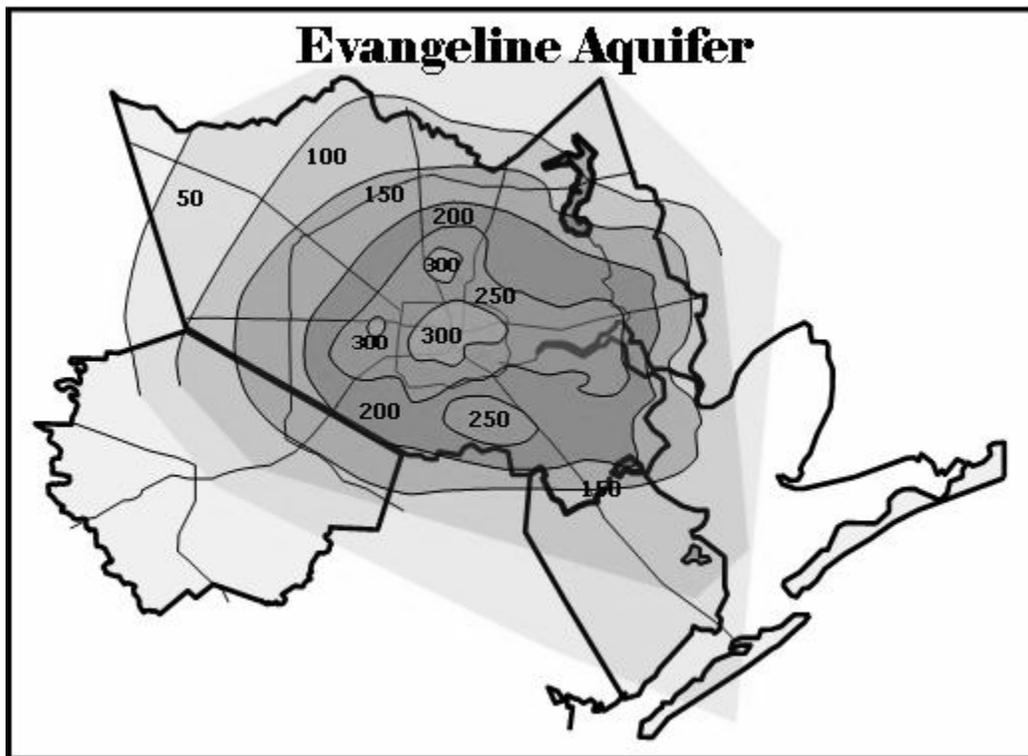


Figure 7-3. Evangeline aquifer, water-level declines 1943–1977 (Kasmarek, 2005).

As the population in the greater Houston area exploded and overtook historically agricultural lands, agricultural use diminished to only five percent of the total groundwater usage (light grey bars—Figure 7-4). Industrial groundwater usage (dark grey bars—Figure 7-4) decreased rapidly with the introduction of surface water in the mid-1970s and makes up only six percent of the 2004 total groundwater produced. While municipal groundwater use in Galveston County and the central and southeastern portions of Harris County decreased dramatically from the mid-1970s, the northern and western portions of Harris County continued to grow on groundwater. In 2004 municipal groundwater use (black bars—Figure 7-4) made up nearly 90 percent of the total groundwater production in Harris and Galveston counties, with about 220 million gallons per day being pumped from the unconverted northern and western Harris County.

Hopefully, groundwater usage in Harris and Galveston counties has seen its high point. With the groundwater regulations that face the area, more conversions from groundwater to surface water are just around the corner. By the year 2010, north and west Harris County will join the others within the greater area with a 30 percent reduction in groundwater use. By the year 2030, total groundwater usage within Harris and Galveston County should be far less than 20 percent of total water demand.

Tale of the Subsidence District

Around 1920, in the Goose Creek Oil Field in Baytown, Texas, on the Gaillard Peninsula, oil and gas was beginning to be rapidly withdrawn from relatively shallow wells. In 1926, Wallace Pratt

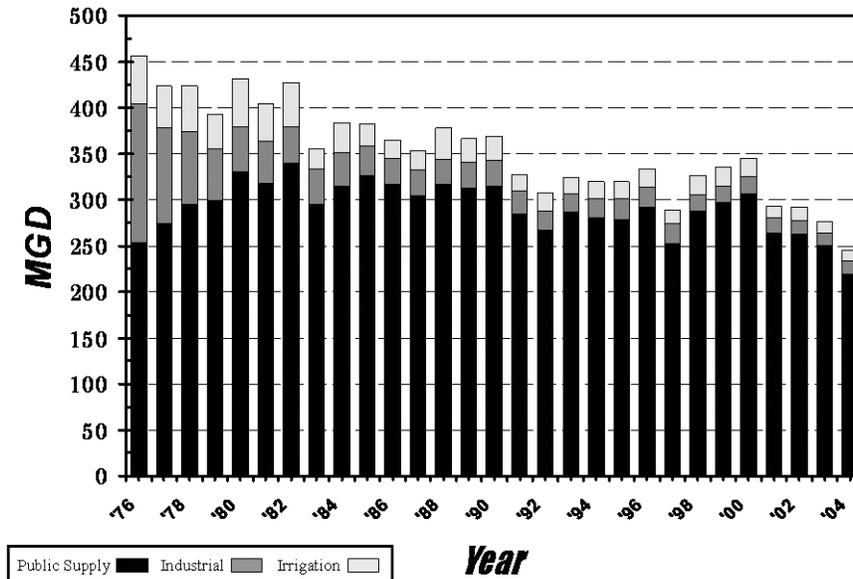


Figure 7-4. Groundwater pumpage 1976 to 2004, Harris and Galveston counties.

and Douglas Johnson published the first known documentation of subsidence (Pratt and Johnson, 1926). Pratt and Johnson documented roughly three feet of subsidence in a very localized area over an eight year period from 1917 to 1925. The oil and gas was being withdrawn from a depth about twice that from which water would eventually be pumped.

Pratt and Johnson were the first authors of a subject that would unfortunately lie dormant in the area for roughly 50 years. Again, the Baytown area took center-stage. The Brownwood Subdivision is a very nice subdivision on a peninsula along the San Jacinto River within about five miles of the Goose Creek Oil Field. In the late 1950s and early 1960s, residents of Brownwood had a sinking feeling. They noticed that the water was rising. In reality the water wasn't rising—the land was sinking. It would take Hurricane Carla in 1961 to bring serious attention to the problem of subsidence in Baytown and other areas around Houston. Texas City, which was just a little higher than sea level in some areas in the 1960s, began noticing that elevations were changing. Industries along the Houston Ship Channel were finding that the ships they were servicing in the Ship Channel were increasingly higher than the docks and loading facilities.

Pratt and Johnson had touched on a cause and effect. When fluids were withdrawn from the compactable subsurface, compaction would result and the land surface would subside. The trouble with their work in the late 1920s was that it was focused on oil and gas production and not water. Excessive groundwater withdrawals would be found to be the culprit of the vast majority subsidence throughout the greater Houston area. By the late 1970s, subsidence had surpassed nine feet along the Houston Ship Channel and as much as five feet in the Texas City area, with a large part of Harris County experiencing at least one foot of subsidence (Figure 7-5).

In 1975, the 64th Texas Legislature created the Harris-Galveston Coastal Subsidence District (the District). In 2005, the Legislature modified the District's enabling act, removing the word

“coastal” from the name and placing the District within Chapter 8801 of the Special Districts Code. The purpose of the District has always remained as the need to regulate groundwater withdrawals as they relate to land-surface subsidence in Harris and Galveston counties. In 1990,

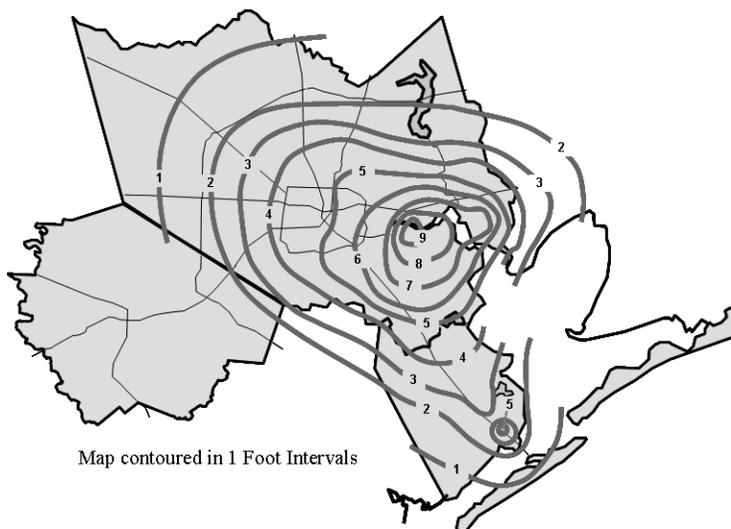


Figure 7-5. Subsidence, 1906 to 1978.

the Legislature created the Fort Bend Subsidence District, and the two Districts cooperate on an annual basis to halt subsidence within Fort Bend, Galveston, and Harris counties. The District immediately began a permitting effort to require permits for non-private household water wells and called for the installation of meters on virtually all permitted wells.

The District then set out on the task of understanding all of the technical factors associated with groundwater withdrawal. They began studies to determine the relationships between withdrawals, water-level declines, compaction of the subsurface clay layers, and the land-surface elevations. The District started a wide area water-level monitoring network with the U.S. Geological Survey in 1977 for the Chicot and Evangeline aquifers. The District also established a strong relationship with the National Geodetic Survey to conduct accurate first-order benchmark re-levelings throughout the area.

The District’s first major regulatory effort was the adoption of the 1976 Regulatory Plan. Due to the infancy of the District, the 1976 Plan was not a “mandate” but rather a suggestion or plea to the major permittees along the coast. The 1976 Plan mapped out an area that a storm surge of 15 feet would inundate and labeled it the Area of Concentrated Emphasis (ACE). Within the ACE, the District called upon permittees to voluntarily do whatever they could to reduce groundwater withdrawals. Cities and industries had already begun to realize the effects of their groundwater withdrawals and started to convert to alternative water supplies.

In 1985, after a number of years of collecting data and studying the relationship between groundwater and subsidence, the District adopted the first mandated groundwater reductions. The 1985 Regulatory Plan borrowed upon the ACE and mapped out what is still referred to as Regulatory Areas 1 and 2. There were eight regulatory areas in total, all with groundwater

reduction requirements scheduled for the future. Areas 1 and 2 were required to convert 90 percent and 80 percent, respectively, of their total water demand from groundwater to surface water. Due to the cooperation experienced with the 1976 Plan from the District's permittees, a large amount of the required conversions had already occurred. The 1986 Plan worked well in the more coastal areas of the District. Subsidence rates slowed dramatically in southeastern Harris County and were halted throughout most of Galveston County (Figure 7-6).

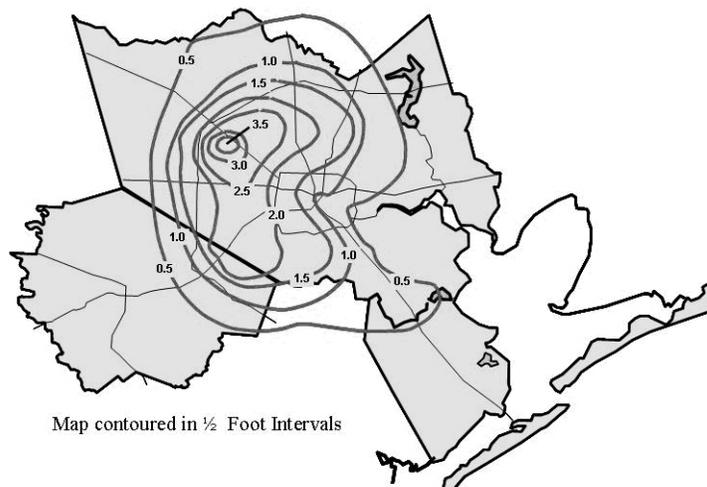


Figure 7-6. Subsidence, 1978 to 1995.

With the successes of the 1976 and 1985 Plans, the District's efforts continued to move farther inland. Water demands were increasing with the growing population in the remaining parts of Harris County. In 1992, with more than fifteen years worth of groundwater pumpage history and water-level measurements in the aquifers and two large area land-surface benchmark elevation re-levelings (1978 and 1987), the District adopted an update to the 1985 Plan. Again, due to the successful implementation of the existing regulations for the 1976 ACE and 1985 Areas 1 and 2, those areas were not the focus of the 1992 Plan (Figure 7-7). The total number of regulatory areas was reduced to seven. Areas 3 through 7 were redrawn based on predicted water demands and new conversion schedules were determined based on the effects of the predicted groundwater withdrawals. The 1992 Plan did not endure for long, however.

Some additional factors became evident by 1994: the 1990 census data was indicating different population growth patterns and the regulation strategy that had been so successful along the coast would be almost impossible to implement in the more inland areas. The District took five years and reworked every technical piece of the subsidence puzzle. Population projections were developed using the 1990 Census as the base-line. Estimated growth was divided into small grid cells about seven square miles. A new groundwater model was created for the area and calibrated using the pumpage history and water-level measurements taken over the 20-year life of the District. More than 20 site specific, highly detailed and researched areas were developed for use as subsidence models. Last, but not least, the District studied the political subdivision makeup of the area to the north and west.

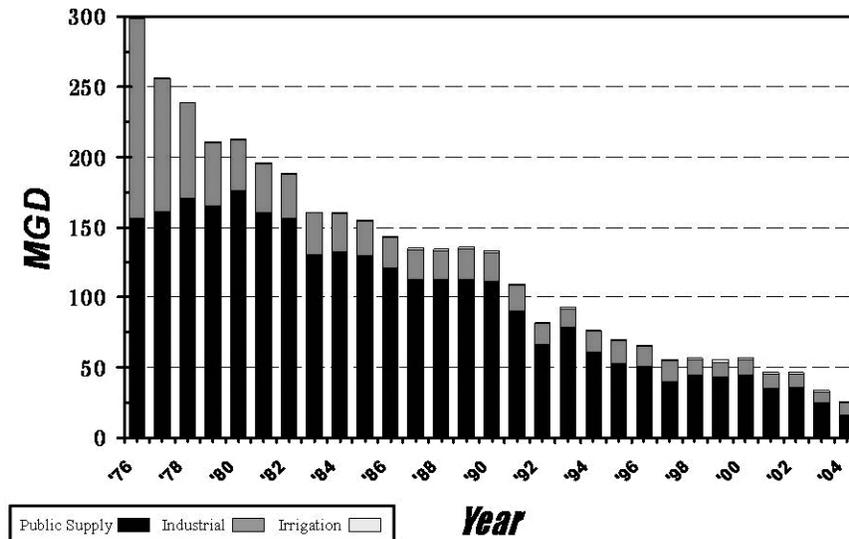


Figure 7-7. Groundwater pumpage from 1976 to 2004 for Regulatory Areas 1 and 2.

The effects undertaken from 1994 to 1999 led to the adoption of the 1999 Regulatory Plan. Again, the areas that had already converted were not tinkered with much. What were four areas in the 1992 Plan became just one large area in the 1999 Plan and labeled Area 3. The determination was made that the average size and sheer number of permittees, typically municipal utility districts, were not individually sufficient to convert from groundwater to surface water in an economical manner. In Areas 1 and 2, the District had dealt mainly with large entities, such as the City of Houston, Pasadena, Baytown, and Texas City, along with the large industries along the Houston Ship Channel. Those permittees were closer to surface-water sources and large enough to fund the necessary project to build the needed conversion infrastructure. In Area 3, with over 400 municipal utility districts and other smaller permittees, cooperation amongst the permittees was paramount.

The 1999 Plan allowed permittees in Area 3 to work together to collectively meet the District's mandated conversions from groundwater to alternative supplies. The 1999 Plan revised the conversion schedule with the first mandated reduction in Area 3 set to occur in 2010 at 30 percent of the total water demand. Two more conversions would be necessary, in 2020 and 2030, to get to the ultimate goal of groundwater constituting only 20 percent of total water demand in Area 3. With the projected implementation of the 1999 Regulatory Plan, subsidence rates would slow dramatically from 2010 to 2020 and then halt from 2020 to 2030 (Figure 7-8). Water levels within the aquifer are predicted to rebound by as much as 125 feet with successful groundwater withdrawal reductions.

The driving force behind the requirements in the 1999 Plan was the adoption of a Disincentive Fee. The Disincentive Fee is a permit fee for those permittees that refuse to comply with the District's regulations. When it was adopted in 1999, the Fee was set at \$3.00 per thousand gallons. It has since been increased to \$3.50 per thousand gallons. It is charged against groundwater withdrawn in excess of the 20 percent of the permittee's total water demand **IF** the

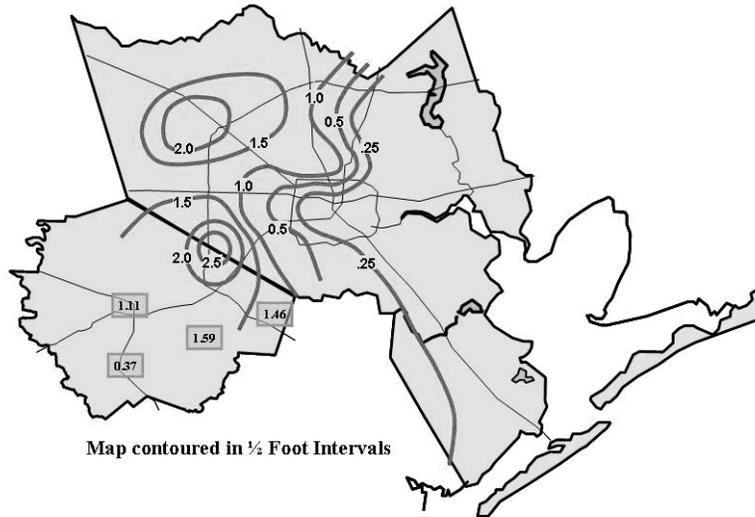


Figure 7-8. Predicted subsidence assuming implementation of the 1999 Regulatory Plan.

permittee has not complied with the District’s regulations. The Disincentive Fee went into effect for Areas 1 and 2 in 2001 and for Area 3 in 2003. To avoid the Disincentive Fee, a permittee could remain at or below the allowable limit of groundwater: 10 percent for Area 1, 20 percent for Area 2, and 20 percent for Area 3. In Area 3, permittees could also avoid the Disincentive Fee between 2003 and 2010 by developing and implementing a Groundwater Reduction Plan that outlined how the permittee would meet the 2010, 2002, and 2030 reduction requirements.

The District’s 1999 Regulatory Plan has been very successful. Groundwater withdrawals have already begun to decline in Area 3, more than five years ahead of schedule. Permittees have worked together to form collective Groundwater Reduction Plans, most notably the North Harris County Regional Water Authority, the West Harris County Regional Water Authority, the City of Houston and the permittees that have joined with Houston, and other smaller individual and combinations of permittees. To the District’s delight, very few Disincentive Fees have had to be issued. Since 2001, only about \$500,000 in Disincentive Fees have had to be billed and collected in total out of a potential for \$60 million annually.

Conclusion

The Harris-Galveston Subsidence District is celebrating its 30th Anniversary in 2005. In thirty years, the District has permitted over 10,000 water wells within its two counties, aided in the creation and operation of the Fort Bend Subsidence District, assisted in the monitoring of more than 500 water wells annually, conducted three major first-order benchmark re-levelings from stable inland elevations, led in the development of new technologies such as GPS to measure subsidence, been involved with six generations of groundwater models, and worked and reworked four major regulatory plans. The District has been responsible for the development of the regulations which required the conversion of millions of gallons daily from groundwater sources to surface water sources. The historical cost of the District’s regulations in today’s dollars would surely be in the billions. The cost of the District’s regulations to the residents of

today and tomorrow will be even greater. The District has never taken its mission lightly and certainly understands the magnitude of the impacts of its regulations. The real successes are the motivating factors.

Due to the successes of the past, some would believe subsidence is something to read about in history books. One only needs to look at places such as Baytown, Texas City, and the Houston Ship Channel to see the effects of subsidence. While subsidence has been halted in those areas, new generations must be reminded of the problems of over-relying on groundwater as a source of water. The residents of the greater Houston area have accepted the challenge of combating subsidence and are moving forward. Nothing can be done about the subsidence that has already occurred. The mission of the Subsidence District is to prevent future subsidence. The risks of failing are too great to sit back and admire previous accomplishments. More data is being collected today than ever before. A greater understanding of the relationships between groundwater pumpage and subsidence has never existed before. The tools of today, necessary to predict future water-level changes and subsidence, have never been more accurate. The District's policy makers of tomorrow will have the best data and tools available to them to make the difficult decisions about groundwater management in the greater Houston area. They will have to always be looking to the past to understand how the future will unfold, but looking to the future to see how they can understand the past better.

Cited References and References of Interest

- Pratt, W. E., and Johnson, D. W., 1926, Local subsidence of the Goose Creek oil field: *Journal of Geology*, v. 34, no. 7, p. 577–590.
- Kasmarek, M. C., 2005, U.S. Geological Survey, Open File Report 2005-1128.
- Harris-Galveston Coastal Subsidence District, 2005, Annual Groundwater Report, 2005.
- Harris-Galveston Coastal Subsidence District, 2003, District Regulatory Plan—1999, revised.
- Harris-Galveston Coastal Subsidence District, 1998, Groundwater Management Plan.
- Texas Special Districts Code Ann. Ch. 8801.
- Prince, K. R., and Galloway, D. L., editors, 2003, U.S. Geological Survey subsidence interest group conference: Galveston, Texas, November 27–29, 2001.
- Kasmarek, M. C., and Robinson, J. L., 2004, Hydrology and simulation of ground-water flow and land-surface subsidence in the northern part of the Gulf Coast Aquifer System, Texas: U.S. Geological Survey Scientific Investigations Report 2004–5102, 111 p.
- Gabrysch, R. K., and Coplin, L. S., 1990, Land-surface subsidence resulting from ground-water withdrawals in the Houston-Galveston region, Texas, through 1987: Harris–Galveston Coastal Subsidence District and U.S. Geological Survey.