Galbryach

Land-surface Subsidence and Active Faulting in the Texas Coastal Zone

Presented to the
Special Interim Committee
on Water Supply and Waste Disposal
in Metropolitan Areas
Texas House of Representatives

by
Charles W. Kreitler, Research Scientist
Bureau of Economic Geology
The University of Texas at Austin
25 September 1974

LAND-SURFACE SUBSIDENCE AND ACTIVE FAULTING IN THE TEXAS COASTAL ZONE

Land-Surface Subsidence

Land-surface subsidence characterizes much of the Texas Coastal Zone, but is most common in the upper part of the Zone and especially in the greater Houston area. The degree of subsidence ranges from acute to that discernible only with precise instrument leveling. A number of factors can result in surface subsidence of land; however, the major cause in affected portions of the Texas Coastal Zone is the lowering of pressure heads due to the withdrawal of ground water. In local areas, subsidence has also been a function of the removal of oil and gas and the solution mining of sulfur and salt. Other causes, significant in other areas, are insignificant in the Texas Coastal Zone.

Land leveling surveys completed in 1973 indicate three areas of subsidence in the Texas Coastal plain: (1) an extensive area extending from the lattitude of Bay City north into Louisiana, (2) a local area in Jackson County, and (3) an area in the vicinity of Corpus Christi. The most acute area of subsidence includes a 230 square mile area centering on Pasadena and Baytown; throughout this area recorded subsidence exceeds five feet, but locally has been as much as 8.5 feet. Surrounding this area, and extending from approximately the Brazos to the Trinity rivers, is a 1,080 square mile zone where recorded subsidence up to 1973 ranges from one to five feet. The one foot subsidence contour line is moving away from Houston approximately one mile per year (figure 1). The rate of subsidence is increasing rapidly, both in area and in elevation; locally, the rate of subsidence is 0.5 foot per year.

2500

?

max 1964-73 = 0.39 ft/yr

In the Houston-Galveston area the long history of ground water production has led to a marked decline in piezometric levels, locally as much as 380 feet in the Pasadena area. Prior to 1954 all water supply was from ground water. In 1954, surface water from Lake Houston and the San Jacinto River became available, lessening the demand on ground water sources, but this has been offset by steadily increasing water demands. At present, ground water production in the Houston-Galveston area exceeds 500 million gallons per day and is drawn from two main aquifers: the Evangeline Aquifer and the Chicot Aquifer, which overlies the Evangeline.

Although the large production and withdrawal of ground water has resulted in marked decline of piezometric levels, ground water ? in the aquifers has not and is not being depleted. The high amount of rainfall (average of 45 inches per year) is more than sufficient to recharge the aquifers. A net ground water potential of 700 million gallons per day exists in the Houston area (Turner et al. 1966).

The Coastal Zone is underlain by a thick section of largely unconsolidated, lenticular deposits of sand and clay. The subsurface sands, charged with fresh water, constitute the underground aquifers. The interbedded sands and clays are saturated with water almost to the land surface, but the impermeable clays restrict the vertical movement of water, creating artesian conditions in the aquifers. Withdrawals of water from the artesian aquifers results in an immediate decrease in hydraulic pressure which partly supports the weight of overlying sediments. With this reduction in pressure, an additional load is transferred to the skeleton of the aquifers and a pressure difference between the sands and clays causes water to move from the clays to the sands. This dewatering of the interbedded clays results in their compaction and a reduction in their volume which in turn results in subsidence of the land surface. Because the clays are mostly inelastic and not easily recharged with water, compaction is permanent and resulting land surface subsidence is irreversible. The amount of clay beds in the section affected by pressure decline is thus a factor in determining the amount of clays that will undergo volume reduction and hence the amount of land-surface subsidence that will occur.

The relationship of piezometric decline or pressure reduction in the aquifers to land-surface subsidence in the Houston-Galveston area has been thoroughly documented. This is readily seen by comparing maps of piezometric decline contours (figure 2 and 3) and maps and profiles of land surface subsidence (figure 4 and 5); the affected areas are coextensive. Additionally the relationship is demonstrated by comparing piezometric levels in individual wells and the elevations of nearby bench marks (figure 6). The amount of piezometric decline and the amount of resulting land-surface subsidence is not directly a function of the total amount of water withdrawn, but rather of the concentration of wells, pumpage, and subsurface geology. For example, concentrated pumpage in the Pasadena area has resulted in a piezometric decline of about 300 feet (1942-1973) and a present land-surface subsidence of about 8 feet. By contrast, substantially more water is withdrawn in the Katy area but piezometric decline is on the order of 50 feet and land-surface subsidence is about one foot. In the Katy area, however, production comes from more widely spaced wells in an aquifer with appreciably less compressible clay. Land-surface subsidence is thus not directly related to the overall volume of withdrawal, but rather to the concentration of withdrawal and its effect on artesian conditions, as well as the subsurface geology.

While land-surface subsidence is the major problem associated with concentrated pumpage, salt water encroachment is another real or potential problem. In a downdip or coastward direction, aquifers become charged with brackish and salt water. Declines in piezometric levels in the fresh water portions of the aquifers cause an updip migration of the brackish and salt water, displacing fresh water ? and resulting in the coastward Chicot Aquifer; a few wells from this aquifer have already been affected. No immediate problem exists in the Evangeline Aquifer, as updip movement of salt water is slow. But, sustained declines in piezometric levels will ultimately cause updip wells to be affected. Although salt and brackish water is found at depths in the Houston area, generally at depths of about 3,000 feet excepting adjacent to salt domes, interbedded clays effectively preclude the vertical movement or encroachment of salt water. Unlike subsidence which is irreversible, salt water encroachment can be stopped or even reversed if an appropriate level of withdrawal and piezometric decline is maintained.

Land subsidence already experienced in the area is irreversible. Prediction of the amount of further subsidence depends on a number of assumptions but is related chiefly to projected declines in piezometric levels and to the thickness and compaction characteristics of subsurface clay beds. Projections made by Turner et al. (1966) indicate ultimate subsidence in the Pasadena area will be about

10.5 feet, assuming a total decline in the piezometric level of 425 feet; present decline is about 300 feet (1943-1973). Nearly all the subsidence predicted will occur as a result of declines already produced by present rates of withdrawal. Ninety percent of the ultimate subsidence of 10.5 feet will occur even if there is no increase in the current level of ground water withdrawal. Other projections indicate ultimate subsidence on the order of 6 feet in the City of Houston, 8 feet in the Ellington Field area, and 4.5 feet in the area adjacent to western Galveston Bay. Thus present declines will produce future subsidence equal to 0.5 to 1.5 times the present amount of subsidence.

???
0.25 max

The most serious effect of land-surface subsidence is the loss of land elevation and, to an extent, an actual loss of land. Each incremental loss of elevation through subsidence subjects more land to flooding, especially flooding from hurricane surges in the low-lying coastal areas. Extensive areas of low-lying land within the area of subsidence include those bordering the Houston Ship Channel; the areas adjacent to Clear Lake, Dickinson Bay, Moses Lake, and Dollar Bay; and south of Texas City along the mainland part of Galveston County. Analysis of topographic conditions in the area of subsidence indicates that the projected ultimate subsidence of 10-12 feet will cause 20,000 acres to be inundated by the Galveston Bay and a hurricane with the same flood levels as Carla would inundate an additional 45,000 acres.

Depending upon the original topography, subsidence may also result in some regional changes in land slope, affecting drainage patterns by either increasing or decreasing slope and stream gradients.

Locally, as in Texas City, clogging of sewer and drainage lines, along with other types of misalignments, has occurred. Damage to both water and oil and gas well casings has been reported. Cutting of the top few feet of oil well casings to prevent breaks in the surface pipes and fittings has become a normal operating procedure in many oil fields. ?

Active Faulting

Faults are a statewide feature. Most of the surface faults have been mapped and defined. In most cases they are inactive, do not involve movement, and pose no real threat. In other cases movement is active, and if not appreciated in initial structural design, can cause major damage to structures.

The area of the State most impacted by surface faults is the greater Houston area where activation of faults and their movement is largely a by-product of groundwater withdrawal. The monitoring of active faults in western Houston clearly demonstrates this relationship (figure 7).

? Conflicting?

Active faults also appear to control the amount of subsidence occurring in any particular locality. They may be responsible for up to 50% of the subsidence in some areas. This control is evident in the subsidence profile for Texas City or the subsidence profile south of Baytown (figure 9). Generally, activation becomes most common where subsidence in excess of 1.5 feet has occurred (figure 10). About 1,200 square miles of such land exists centering on the greater Houston region. As the area of subsidence is increasing at a relatively rapid rate, the attendant problem of surface faulting assumes greater significance.

In the past the people of Houston-Galveston area have generally been unaware of the presence of active faults. The labyrinth of railroad tracks and interstate highways is continually being broken by active faults. Runways at both Hobby Airport and Ellington Air Force Base are laced with these active features. Houses in subdivisions from western Houston to Virginia Point are now worthless, because they straddled faults. Some contractors have not even been able to finish building before the foundation was damaged beyond repair. In Hitchcock, part of the high school is breaking up because it was built over an active fault.

Where active surface displacement has occurred, these faults can be mapped. A great number have already been so delineated. If known, such lines of displacement can simply be avoided in building and construction and no problem exists. A significant problem arises, however, in areas where surface faults have not yet become active but, under the pressure of subsidence, are potentially active. The Bureau of Economic Geology has developed a method of predicting zones where fault movement could occur. This is largely accomplished by mapping photographic linears at the surface. This is mostly completed for the Coastal Zone and when the predictive method is perfected, faulting or potential faulting need not constitute a hazard if it is avoided. The problem impacts all kinds of rigid structures placed on a fault or potential fault and is highly critical in the siting of nuclear reactors. Very little can be done to provide protection for structures presently in place across active faults, short of moving the structures. Reduction of future losses can be accomplished

Some linears have turned out to be at right angles to faults, section lines, etc.

best by careful selection of sites in respect to active or potentially active faults. Where structures such as pipelines, railroad tracks, and highways must be built across active, or potentially active faults, they should be designed to accomodate anticipated movement. In experience in areas outside of Texas, it has been shown that careful site evaluation results in resiting prior to construction of about 85 percent of structures that otherwise would have been built across faults. Accordingly, techniques are at hand to practically eliminate damage from fault hazards.

Faulting-Subsidence Interaction

Faulting and subsidence in the Houston-Galveston area can no longer be considered as separate geologic phenomena. The amount of subsidence will indicate the amount of faulting. Conversely the geographic extent of severe subsidence is controlled by the location of faults. In designing a program to limit the economic losses incurred by subsidence, the effects of active and potentially-active faulting must be considered.

SELECTED REFERENCES

Fisher, W. L., et al. (1972) Environmental geologic atlas of the Texas Coastal Zone: Galveston-Houston area: Univ. Texas, Bur. Econ. Geology, 91 pp., 9 maps.

Gabrysch, R. K., (1969) Land-surface subsidence in the Houston-Galveston region, Texas: Internat. Symposium on land subsidence Tokyo, Japan, Proc., 1969, p. 43-54.

________________ (1972) Development of ground water in the Houston district, Texas, 1966-1969: Texas Water Devel. Bd., Rept. 152, 24 pp.

________________, and McAdoo, G. D. (1972) Development of ground-water resources in the Orange County area, Texas and Louisiana, 1963-71: Texas Water Devel. Bd., Rept. 156, 47 pp.

________________, and Bonnet, C. W., 1974, Land-surface subsidence in the Houston-Galveston region, Texas: U.S. Geologic Survey Oper. File Report, 23 p.

National Geodetic Survey, 1974, Report: 1973 releveling of the Houston-Galveston area, Texas, U.S. Dept. Commerce, 49 p.

Pettit, B. M., Jr., and Winslow, A. G. (1957) Geology and ground-water resources of Galveston County, Texas: U.S. Geol. Survey Water-Supply Paper 1416, 157 pp.

Pratt, W. E., and Johnson, D. W., 1926, Local subsidence of the Goose Creek oil field: Jour. Geol., v. 34, p. 577-590.

Reid, W. M., 1973, Active faults in Houston, Texas, dis., Univ. of Texas at Austin, 122 p.

Sheets, M. N. (1971) Active surface faulting in the Houston area, Texas: Bull, Houston Geol. Soc., vol. 13, no. 7, pp. 24-33.

Turner, Collie, and Braden, Inc., Consulting Engineers (1966) Comprehensive study of Houston's municipal water system for the City of Houston, Phase I, Basic studies, 50 pp.

Van Siclen, D. C. (1967) The Houston fault problem, <u>in</u> Proc., 3rd Annual Mtg., Texas Sec., Amer. Inst. Professional Geologists, pp. 9-29.

Wesselman, J. B. (1972) Ground-water resources of Fort Bend County, Texas: Texas Water Devel. Bd., Rept. 155, 176 pp.

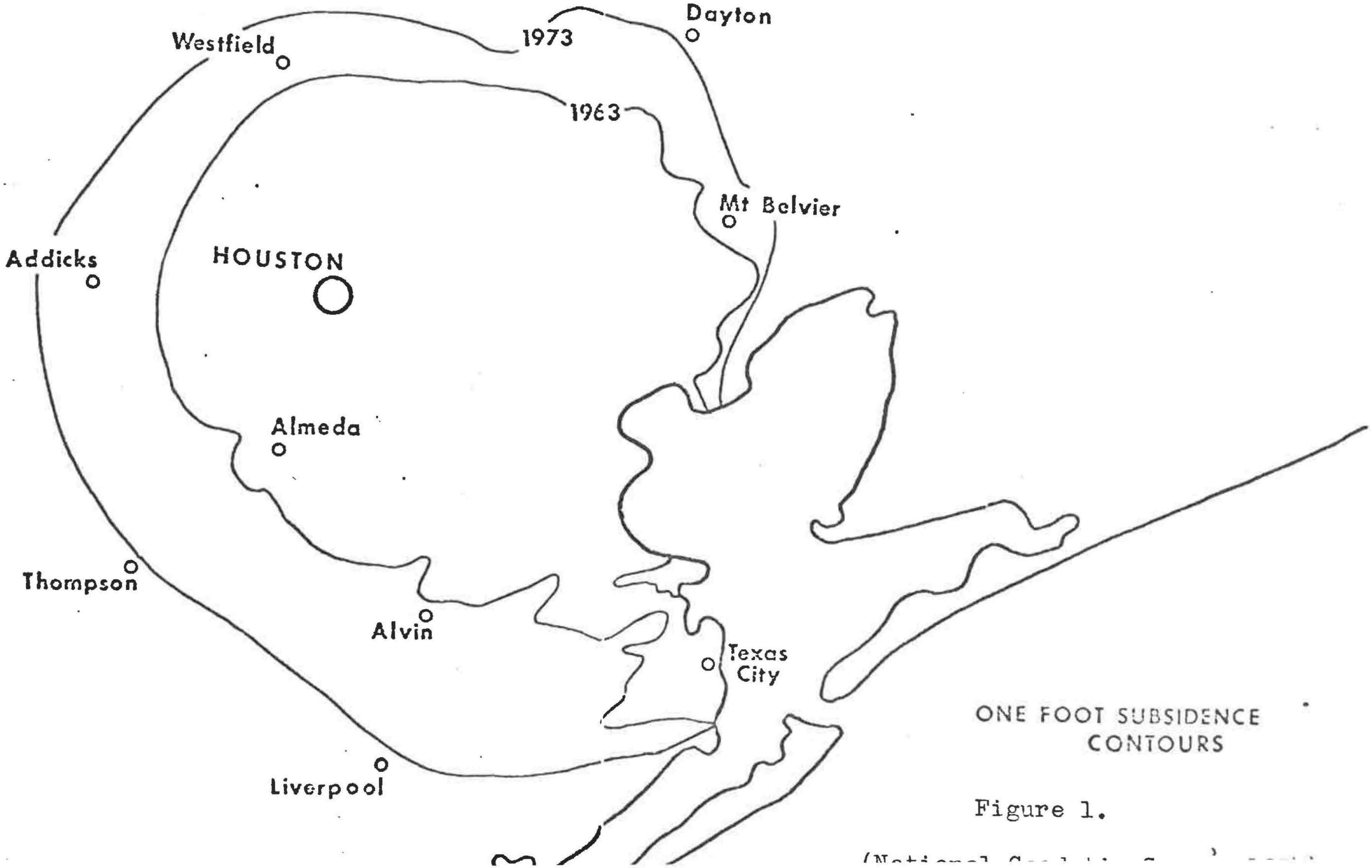
Winslow, A. G., and Doyel, W. W. (1954) Land-surface subsidence and its relation to the withdrawal of ground water in the Houston-Galveston region, Texas: Econ. Geology, vol. 49, no. 4, pp. 413-422.

______________, and Wood, L. A. (1959) Relation of land subsidence to ground-water withdrawals in the Upper Gulf Coast region, Texas: Trans., AIME, vol. 214, pp. 1030-1034.

Wood, L. A., and Gabrysch, R. K. (1965) Analog model study of ground water in the Houston district, Texas: Texas Water Comm. Bull. 6508.

Weaver + Sheets 1958

Van Siclen



ONE FOOT SUBSIDENCE CONTOURS

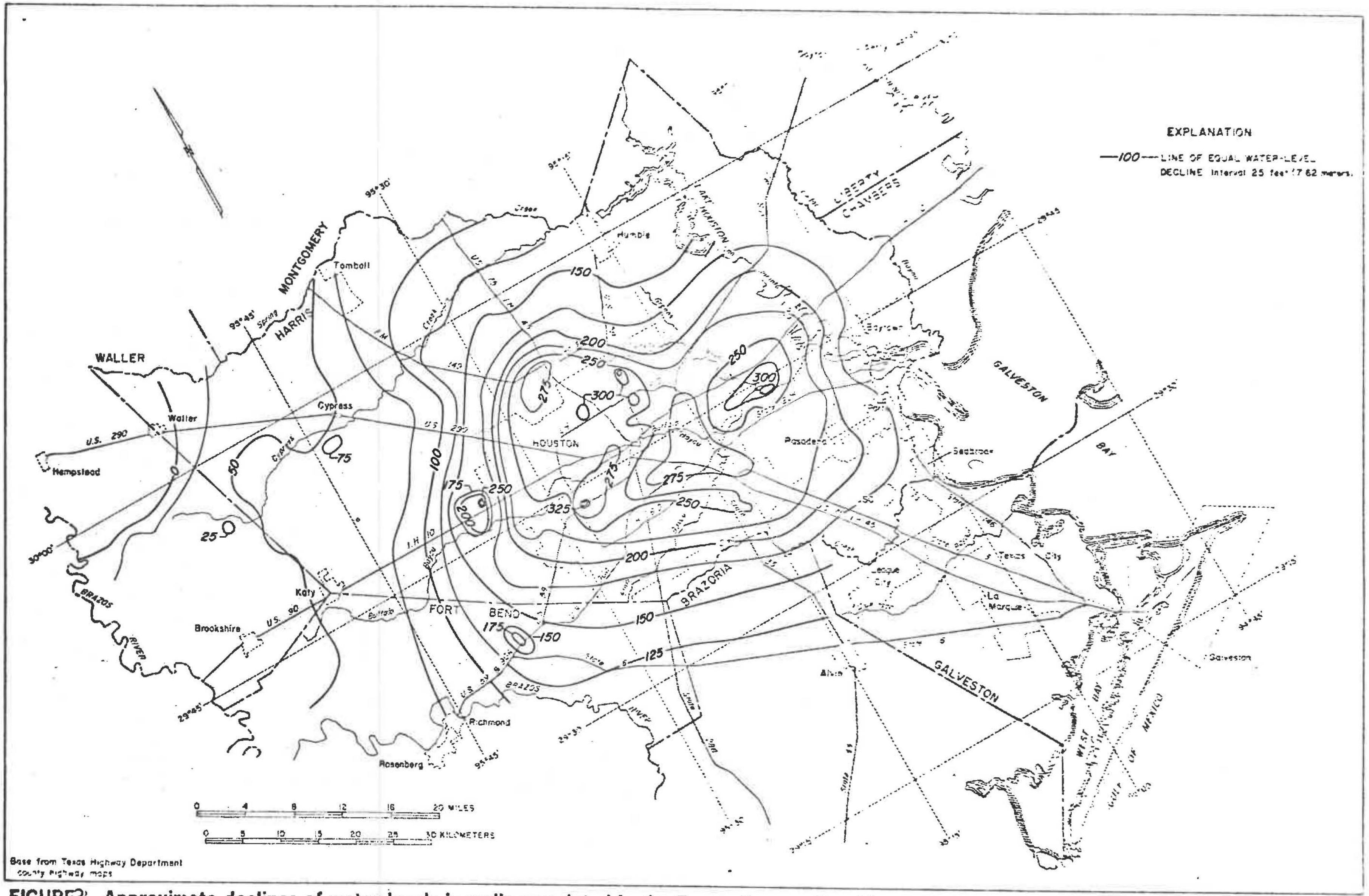
Figure 1.

(National Geodetic [illegible]

Base from Texas Highway Department county highway maps

FIGURE 2-Approximate declines of water levels in wells completed in the Chicot aquifer, 1943-73

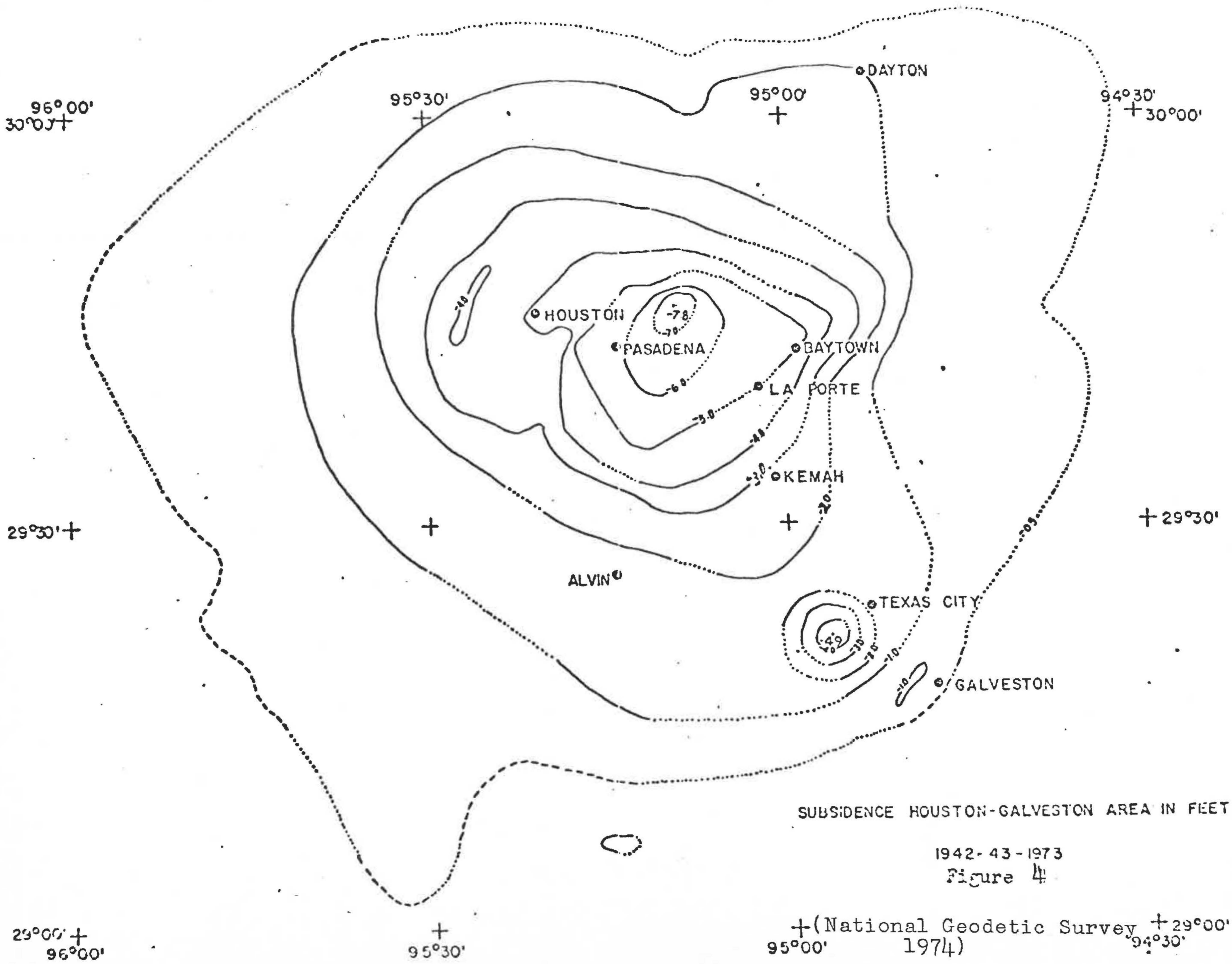
(Gabrysch and Bonnet, 1974)



Base from Texas Highway Department county highway maps

FIGURE3 .-Approximate declines of water levels in wells completed in the Evangeline aquifer, 1943-73

(Gabrysch and Bonnet, 1974)



SUBSIDENCE HOUSTON-GALVESTON AREA IN FEET

1942-43-1973

Figure 4

(National Geodetic Survey 1974)

GRAPH OF LAND SUBSIDENCE
PROFILE - CONROE VIA HOUSTON AND ALGOA TO ANGLETON, TEXAS

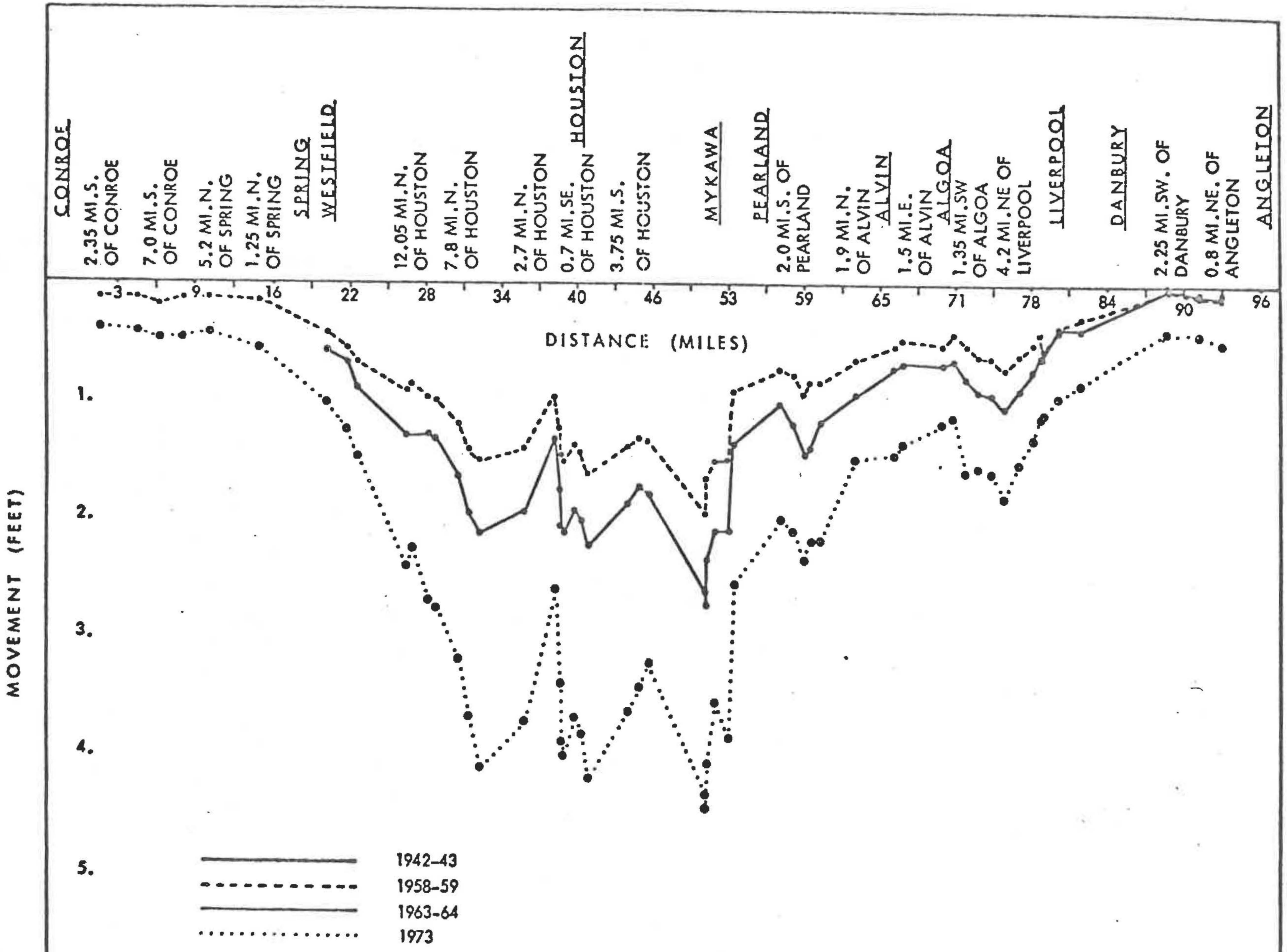
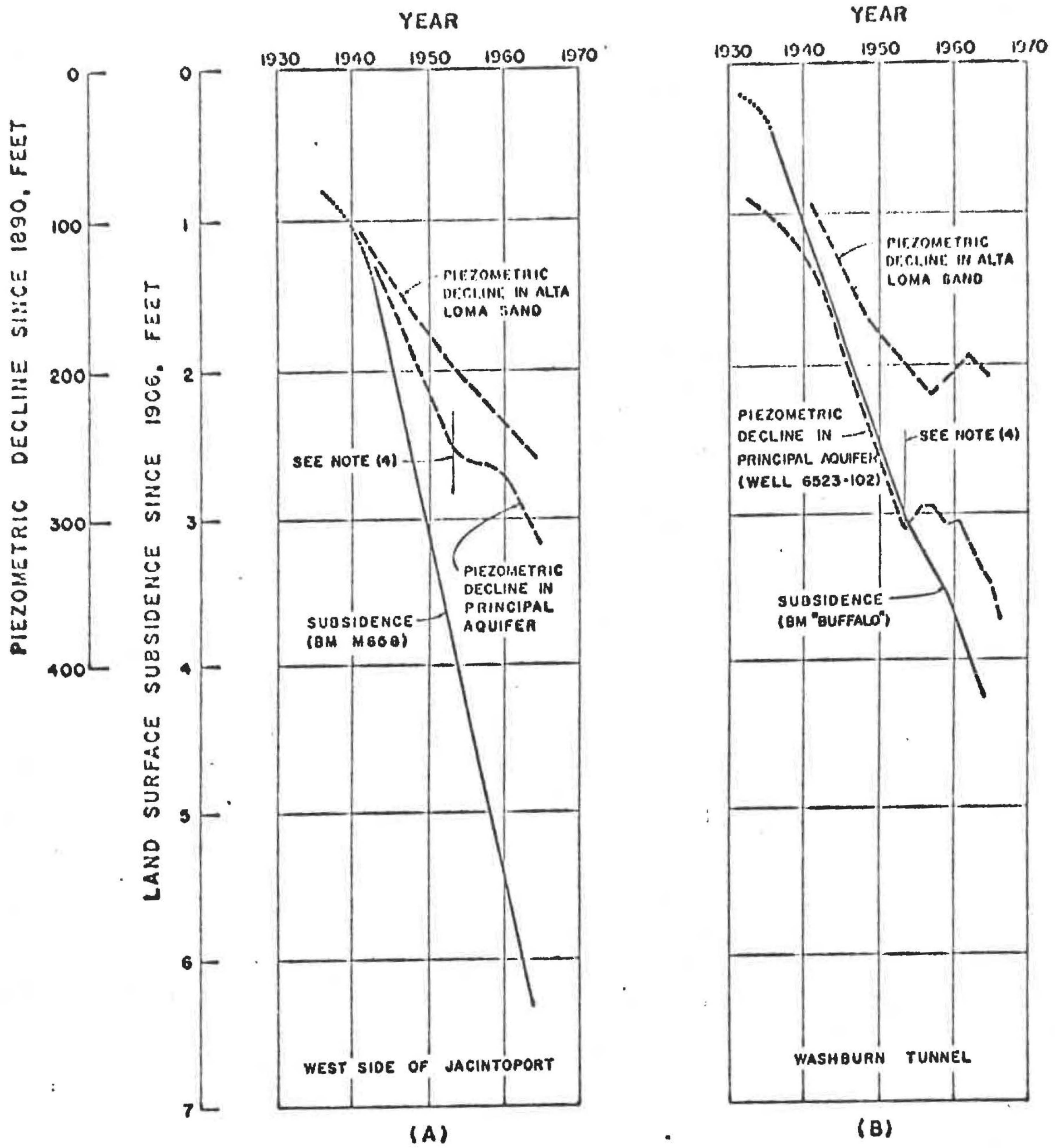


Figure 5

(National Geodetic Survey, 1974)



RELATIONSHIP OF PIEZOMETRIC DECLINE AND LAND-SURFACE SUBSIDENCE

(4) Reduction in rate of decline coincides with introduction of surface water into Houston

Figure 6.

(Turner etal, 1966)

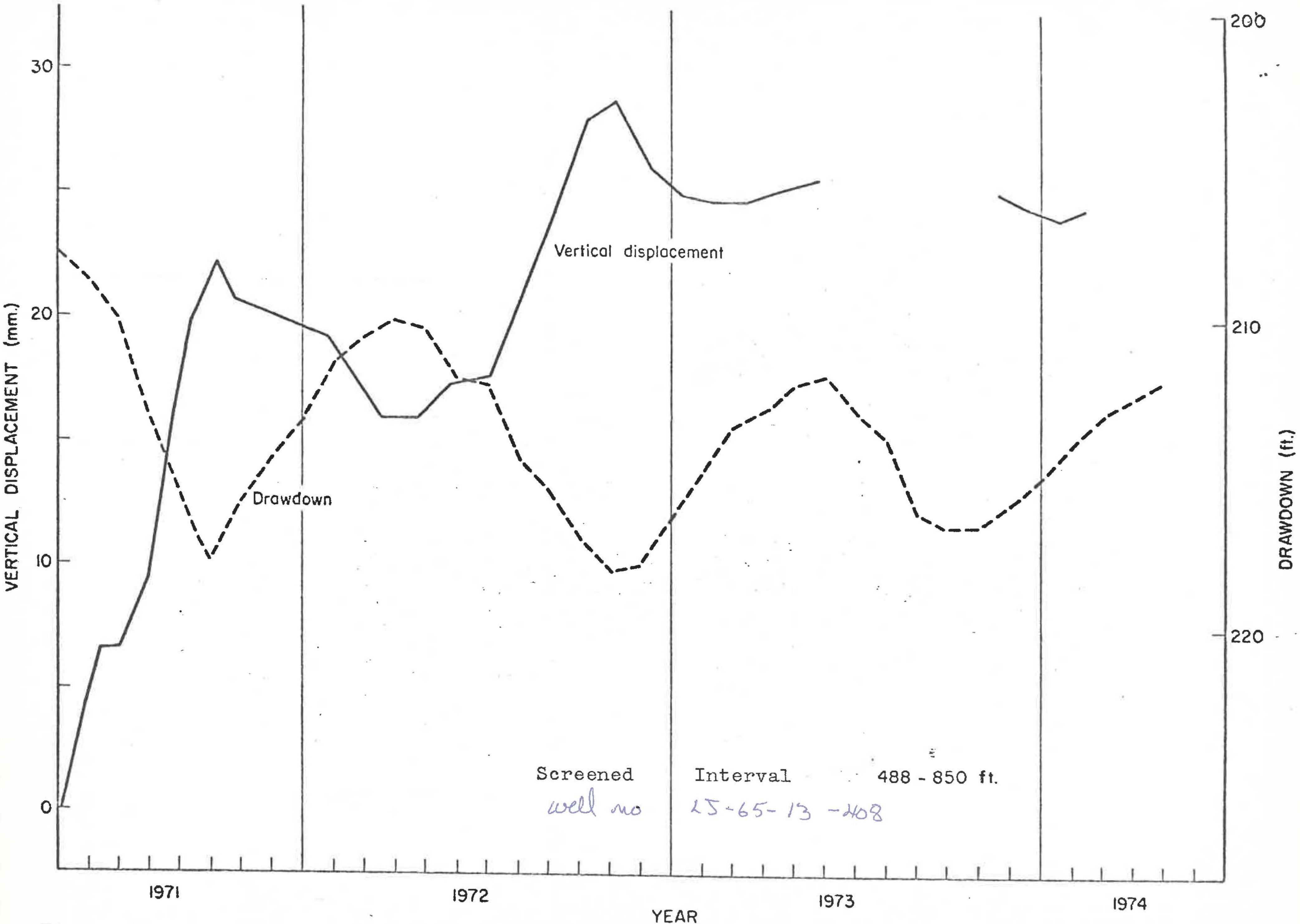


Figure 7. Correlation of vertical fault displacement on the Eureka Heights Fault(western Houston) and change in peizometric surface in the Chicot Aquifer.

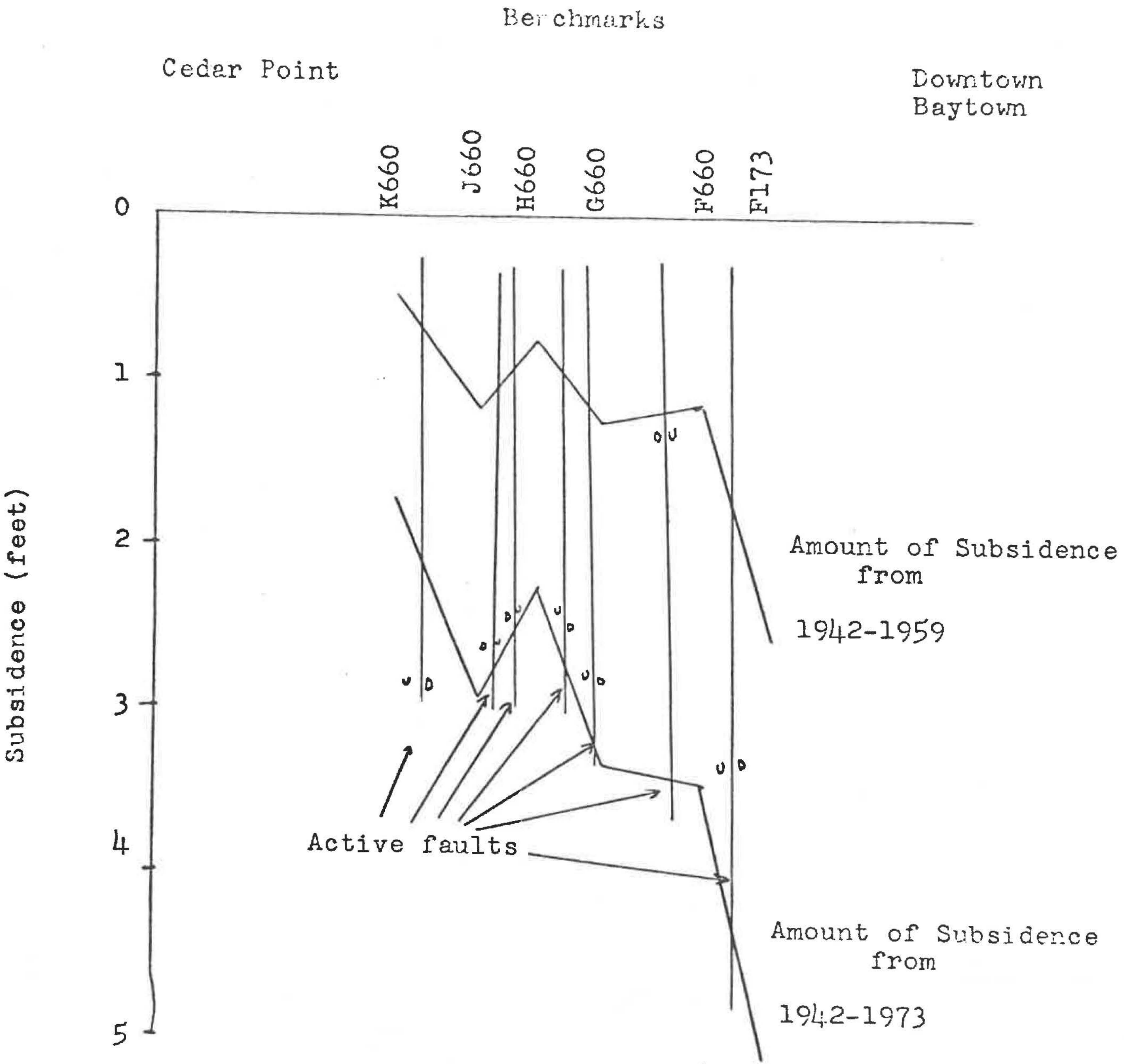


Figure 8.

Coincidence of active faults with sudden breaks in the amount of subsidence from south of Baytown to downtown Baytown shows that the amount of subsidence is, in part, controlled by the location of active faults.

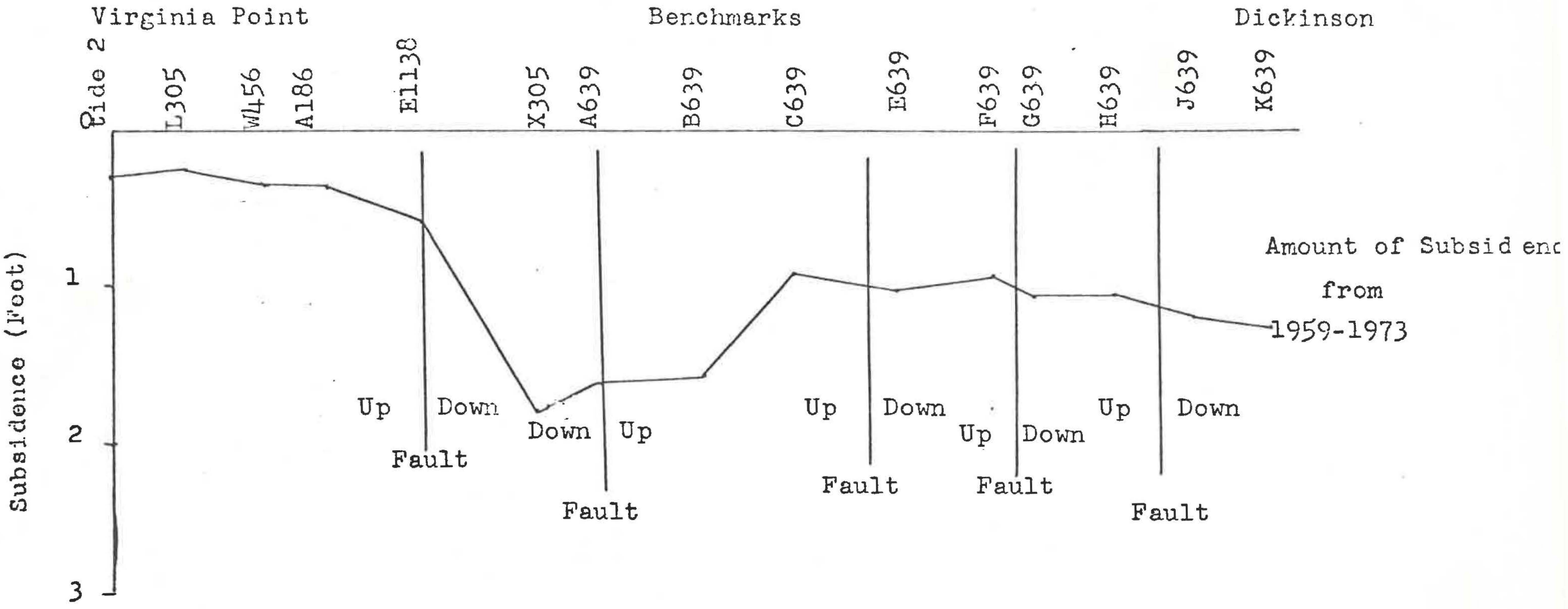
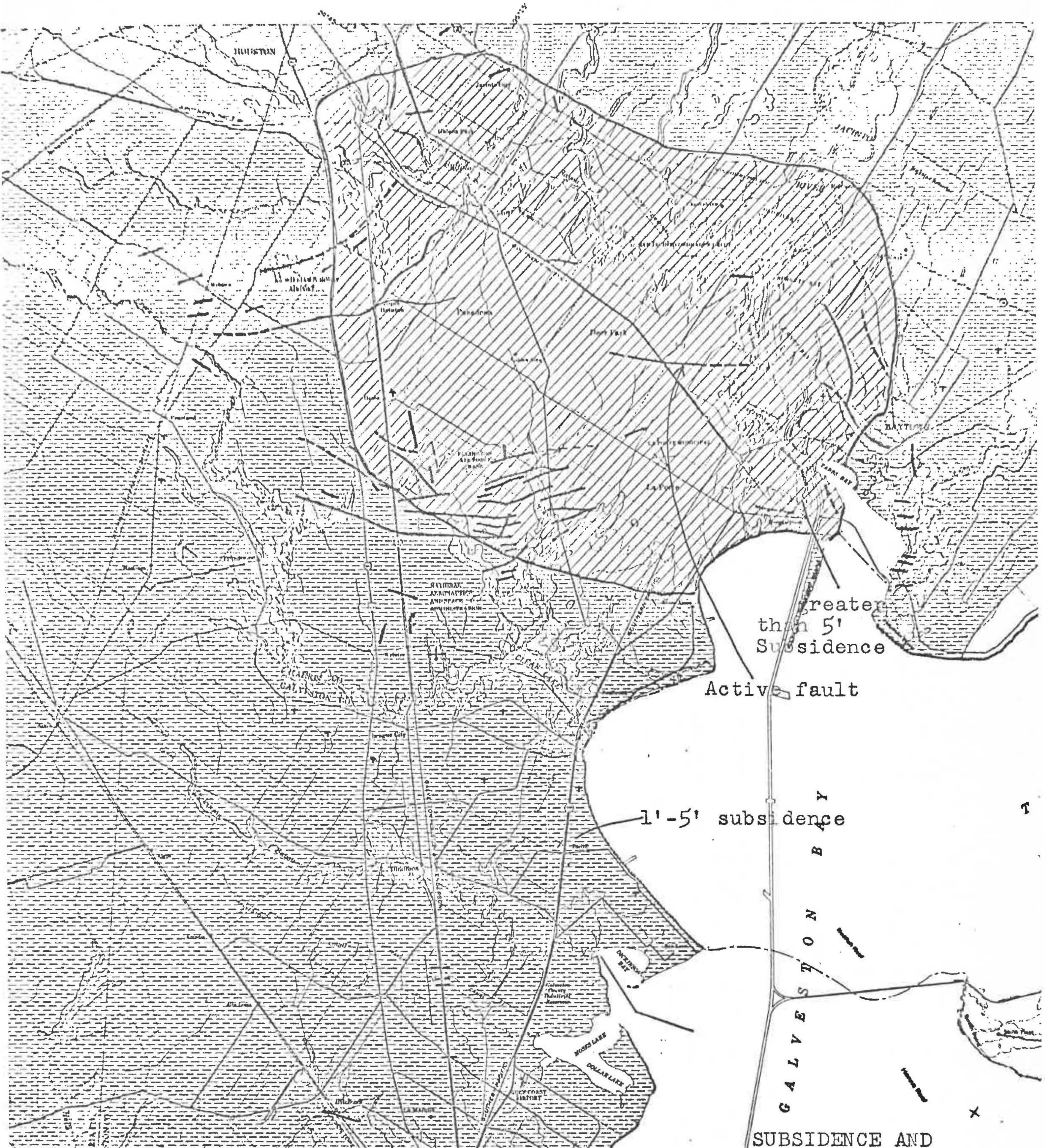


Figure 9.

Coincidence of active faults with sudden breaks in the amount of subsidence from Virginia Point to Dickinson along Rt. 3 shows that the amount of subsidence is, in part controlled by the location of active faults.



SUBSIDENCE AND
ACTIVE FAULTING
HOUSTON-GALVESTON
AREA

Figure 10

Fault Statistics in Houston-Galveston Area

Miles of active faults: greater than 150 miles

Rates of movement:

Maximum total movement: greater than 10 feet (Addicks Fault, north of Houston)

Average Rate : 1.3 in/yr

Range of rates: -0.8 in/yr to 4.7 in/yr

Is there catastrophic, episodic movement ? There is no evidence for this type of movement. Earthquakes are not expected with movement on these faults.

Damage to structures:

Airports

Hobby; faults in runways

Ellington Air Force Base : faults in runways, faults through operation buildings on the base

Interstate Highways crossing active faults

- I-10
  - Britmore Exit
  - Intersection of I-610 and I-10
- I-45
  - 2 active faults intersect I-45 in South Houston area
  - 2 active faults intersect I-45 in Ellington Air Force Base area
  - 2 active faults intersect I-45 in Texas City area

Railroad tracks crossing active faults: 28 intersections

Active faults in residential neighborhoods: at least 11 faults (estimated damage to individual dwellings has not been determined)

Monuments: active fault through the Reflection Pool at San Jacinto Monument] 784

Fault Statistics (cont.)

Indutrial buildings on active faults

1. Maryland Club House Coffee building (western Houston)
2. Exxon refinery in Baytown