Wetland Subsidence, Fault Reactivation, and Hydrocarbon Production in the U.S. Gulf Coast Region

Wetland losses are so extensive in the Gulf of Mexico Coast region of the United States that they represent critical concerns to government environmental agencies and natural resource managers. Each year, millions of dollars are spent in coastal Louisiana alone to restore wetlands and to maintain the natural ecosystem that is vital to the Nation's economy.

Wetland subsidence and fault reactivation induced by oil and gas production generally have been disregarded in the Gulf Coast region because much of the wetland loss occurs in Louisiana, where many other factors contribute to coastal change (Williams and others, 1994). Understanding the influence of hydrocarbon production on wetland changes is important for predicting future wetland conditions and for planning wetland restoration projects.

Hydrocarbon production is interpreted to cause movement along faults and wetland subsidence (fig. 1) if the following situations co-occur:

1. Large areas of wetland are lost at the same time and in the same places as hydrocarbons are produced
2. The cumulative volumes of fluids produced are so large that they lead to rapid declines in subsurface pressures
3. Subsurface faults near the producing reservoirs and surface faults activated after initial production have the same orientation and direction of displacement
4. Subsidence rates measured near the oil and gas wells during production are substantially higher than geological rates of subsidence

Each condition by itself does not directly link wetland loss, subsidence, and hydrocarbon production, but together they are compelling indicators of causality.

Subsidence and Hydrocarbon Production

In the Gulf Coast region, subsidence was first linked to hydrocarbon production in the mid-1920's at the Goose Creek Field near Galveston, Tex. (Pratt and Johnson, 1926). Subsidence at Goose Creek of about 1 meter (m) was enough to change the setting from a vegetated upland to open water.

A similar pattern of production-induced subsidence, which led to wetland replacement by open water, occurred at the Port Neches Field, Tex., between 1956 and 1978 (figs. 2 and 3). The similarity in area of wetland loss in 1978 compared with present conditions suggests that the subsidence was rapid initially but then slowed or possibly stopped.

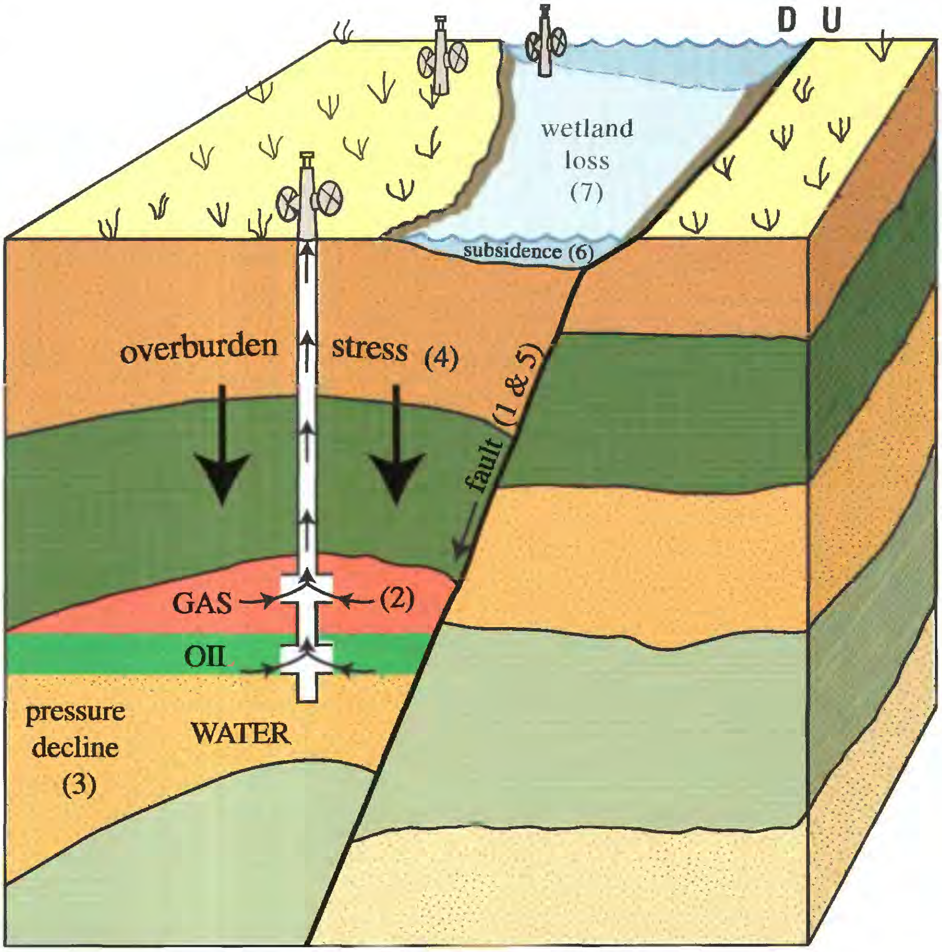

Figure 1. Possible effects of petroleum production. Prolonged or rapid production of oil, gas, and formation water (2) causes subsurface formation pressures to decline (3). The lowered pressures (3) increase the effective stress of the overburden (4), which causes compaction of the reservoir rocks and may cause formerly active faults (1) to be reactivated (5). Either compaction of the strata or downward displacement along faults can cause land-surface subsidence (6). Where subsidence and fault reactivation occur in wetland areas, the wetlands typically are submerged and changed to open water (7). Figure is not to scale. D, down; U, up.

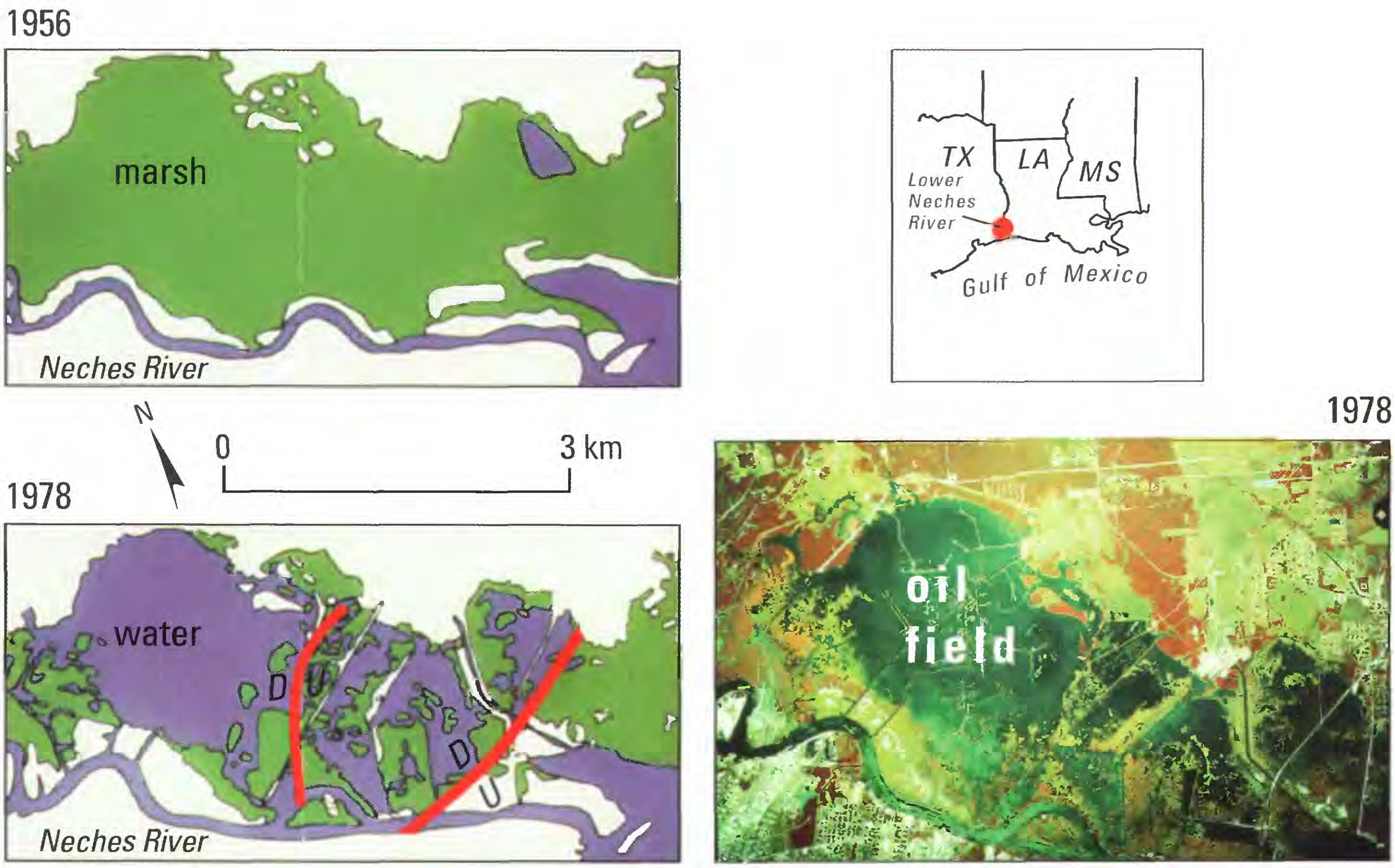

Figure 2. Air photograph of the Port Neches oil and gas field in Texas in 1978 and maps showing that wetlands above the field were healthy and continuous in 1956 but deteriorated and were converted to open water by 1978. The change was caused by induced subsidence and fault reactivation resulting from hydrocarbon production. From White and Morton (1997). Relative motion along faults: D, down; U, up.

Induced subsidence cannot be sustained indefinitely. Instead, the duration of surface adjustment is related to the history of production. As shown in figure 3, there was a time gap between the onset of production and the first visible evidence of surface disturbance and wetland loss. Whatever losses are occurring today, they are occurring at a much slower rate than when the wetlands deteriorated between 1956 and 1978. This reduction in rates of subsidence corresponds to the rapid decline in hydrocarbon production.

Regional Depressurization

When large volumes of oil, gas, and associated formation water are extracted from the subsurface, the natural pressures in the reservoirs are reduced (fig. 4) and stresses around the reservoir increase (fig. 1). The increased stresses cause reservoir compaction, which, in places, leads to surface subsidence. Nearly 20 billion barrels of oil and more than 150 trillion cubic feet (4.2 trillion cubic meters) of gas have been produced from coastal Texas and Louisiana since the 1920's. Although the fluid production is concentrated within the field areas, the effect of the pressure decline extends far beyond the individual fields. Where multiple fields are producing from the same strata, regional depressurization can cause subsidence and wetland losses in the areas between the fields (Kreitler and others, 1988). Consequently, induced subsidence can be either near the fields (fig. 2) or away from the fields.

Coincidence of Subsurface and Surface Faults

Throughout the Gulf Coast region there are many deep faults that serve as structural traps for the hydrocarbons. Some of the primary faults that trap hydrocarbons also extend upward to shallow depths near the surface (fig. 1). If the pressure drop in the producing formation is large, faults that are near the threshold of failure may be reactivated, and rocks along them may move. When the fault is active, the land area subsides on the downthrown side of the fault near the fault plane. Depending on the depth and angle of the fault, the induced subsidence may occur several kilometers away from the producing wells (fig. 1) rather than directly above the producing reservoirs (fig. 2).

Releveling Surveys

Subsidence and fault displacement also can be inferred from benchmark releveling surveys. The elevations of benchmarks in the Gulf Coast region are periodically resurveyed by the National Geodetic Survey. Comparing leveling surveys provides a basis for measuring rates of subsidence for the period between the dates of the surveys. For example, releveling surveys in 1965 and 1982 along Louisiana Highway 1 between Valentine and Leeville, La., showed that subsidence was greater near hydrocarbon-producing fields than between the fields (fig. 5).

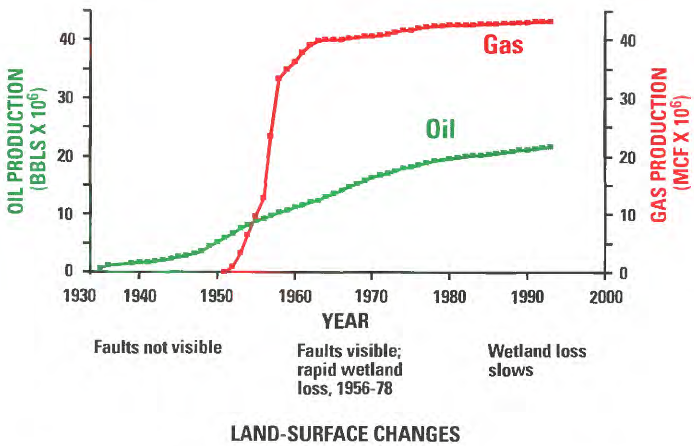

Figure 3. Cumulative hydrocarbon production in the Port Neches Field, Tex., from 1930 to 1994, compared with changes in faults and wetlands observed in air photographs. From White and Morton (1997). Wetlands began rapidly disappearing when the field began rapidly producing large volumes of gas in the early 1950's. Wetland loss slowed after 1978, when hydrocarbon production rates declined rapidly. Oil production is in millions of barrels; gas production is in billions of cubic feet (to convert to cubic meters, multiply cubic feet by 0.02832).

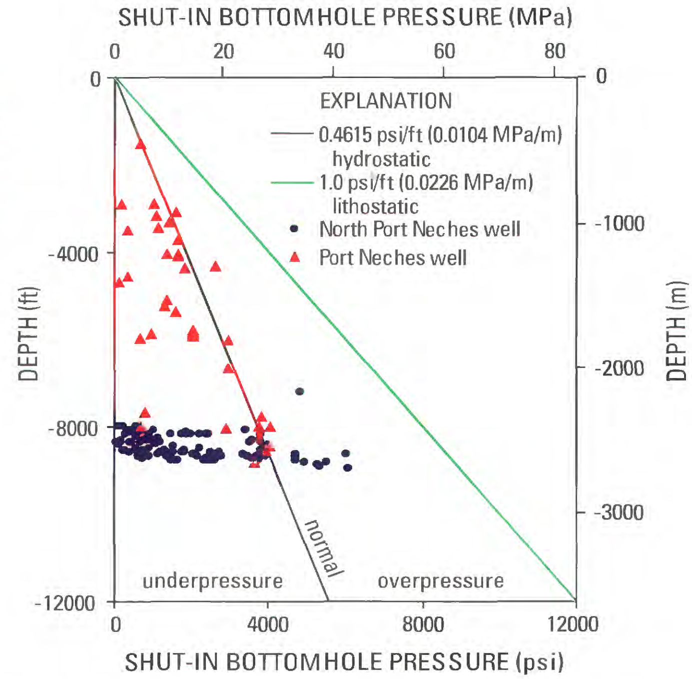

Figure 4. Subsurface pressures measured in gas wells in the Port Neches Field and North Port Neches Field, Tex. (unpub. data from Fred Wang, University of Texas at Austin, Bureau of Economic Geology, 2001). Low subsurface pressures like those graphed can lead to increased overburden stress, compaction of the strata, reactivation of faults, and land-surface subsidence. Depths are in feet and meters; pressures are in pounds per square inch and megapascals.

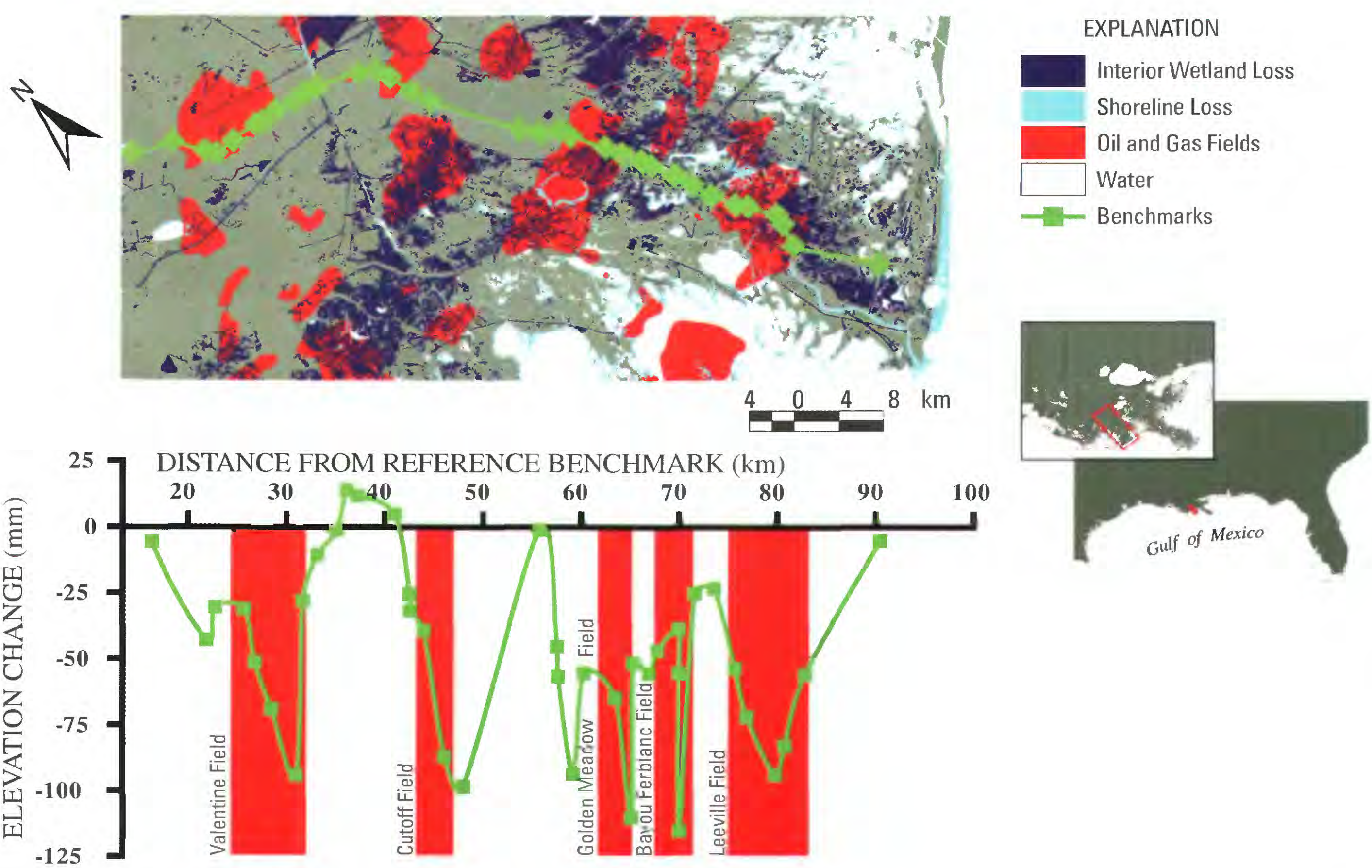

Figure 5. Map along Louisiana Highway 1 between Valentine and Leeville, La., showing locations of benchmarks, oil and gas fields, and shoreline and wetland losses and graph showing changes in surface elevation (in millimeters) at the benchmarks between 1965 and 1982. Subsidence was greatest near the oil and gas fields. Wetland losses from Britsch and Dunbar (1993). Elevation changes from National Geodetic Survey data.

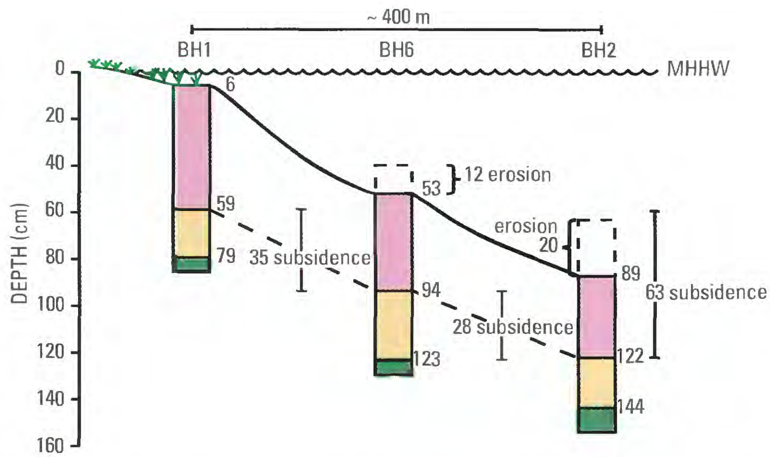

Figure 6. Stratigraphic correlations of shallow sediment cores illustrate the magnitude of wetland subsidence and erosion (in centimeters) at the Port Neches Field, Tex. The top unit consists of marsh sediments. MHHW, mean higher high water.

Stratigraphic Correlations

Subsidence and fault displacement around producing fields also can be measured directly by using basic coring techniques. Correlation of shallow stratigraphic markers in sediment cores provides a basis for determining the magnitude of displacement relative to some datum such as mean higher high water. Figure 6 shows that the correlated beds have been displaced progressively downward 35–63 centimeters (cm) compared to the adjacent marsh surface. Preservation of the marsh sediments beneath a meter of water is clear evidence that the marsh surface subsided first to form the open water area. Subsequent erosion of the marsh sediments was minor compared to subsidence.

Subsidence Rates

One way of detecting artificially induced subsidence around a producing field is by comparing the measured rate of subsidence there with natural subsidence rates in the same region. The wetland surface at Port Neches subsided about 63 cm in 22 years (figs. 2 and 6). These values yield a historical rate of wetland subsidence of about 3 cm/yr.

Some of the highest natural rates of subsidence in the Mississippi Delta of southern Louisiana are on the order of 1 cm/yr (Roberts and others, 1994). Thus, the short-term historical subsidence rate at Port Neches (3 cm/yr) is three times higher than the highest subsidence rates in a region that is known for rapid subsidence. It is 75 times higher than the subsidence rate of 0.04 cm/yr in southwestern Louisiana, which is the closest area having both a similar geologic setting and estimated subsidence rates.

Environmental Implications

Subsidence of a meter or less induced by oil and gas production is not great, especially when compared to the extreme examples of subsidence such as 9 m at Wilmington, Calif., or 4.5 m at the Ekofisk Field in the North Sea. Nevertheless, the relatively small observed reductions in elevation in the Gulf Coast region are sufficient to cause dramatic changes in the affected wetland ecosystems. This study demonstrates that even minor lowering of the marsh surface can translate to large wetland losses through a combination of coastal plain subsidence and marsh sediment erosion.

—ROBERT A. MORTON
NOREEN A. PURCELL

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For more information, please contact:

Robert A. Morton
U.S. Geological Survey
600 4th Street South
St. Petersburg, FL 33701
Telephone: 727–803–8747 x3080
Fax: 727–803–2032
E-mail: rmorton@usgs.gov