SHORELINE CHANGES DUE TO PROPOSED DEEPENING OF THE FREEPORT, TEXAS ENTRANCE CHANNEL

I. INTRODUCTION

The US Army Engineer District, Galveston, (SWG) is studying a series of options to deepen the Gulf of Mexico navigation channel leading to the port of Freeport, TX (site location shown in Figure 1) from its currently authorized depth of 45 ft (13.7 m). The Coastal and Hydraulics Laboratory (CHL) of the US Army Engineer Research and Development Center is assisting SWG in their analysis by examining how these longer, deeper, and wider channels will change the refraction patterns of waves passing over the channel, and how this refraction will change the longshore sediment transport rates on the adjacent shorelines. This Letter Report discusses these potential impacts.

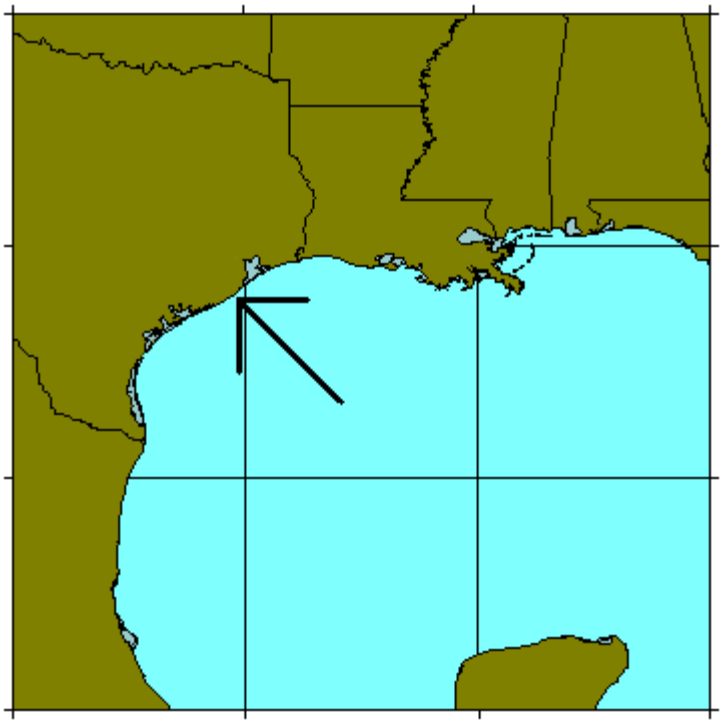

Figure 1. Freeport Harbor, Texas study area location map.

The bathymetry offshore of Freeport, TX, along with the proposed channels are shown in Figure 2. In this figure, the Freeport jetties are shown in red, the channel location in orange, the shoreline in white and bathymetry contours in green. The blue arrows along the channel show the offshore terminuses of the present 45 ft (13.7 m), 50 ft (15.2 m), 55 ft (16.8 m), 58 ft (17.7 m), and 60 ft (18.3 m) channels from landward to seaward, respectively. Table 1 lists the dimensions of the alternatives.

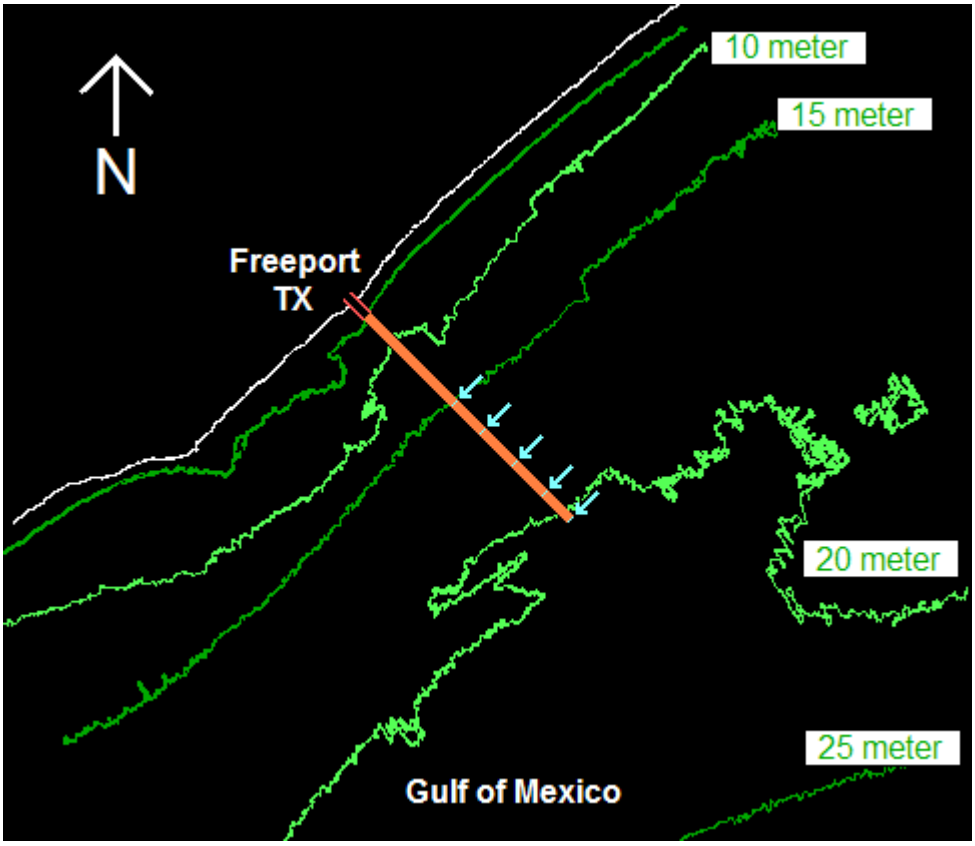

Figure 2: Extent of project alternatives.

Table 1 Channel Dimensions			
Name	Depth	Bottom width	Length from jetty tip
45 ft (as is)	51.27 ft (15.63 m)	400 ft (122 m)	21,200 ft (6,500 m)
50 ft (proposed)	56.27 ft (17.15 m)	600 ft (183 m)	27,800 ft (8,500 m)
55 ft (proposed)	61.27 ft (18.68 m)	600 ft (183 m)	35,900 ft (8,500 m)
58 ft (proposed)	64.27 ft (19.59 m)	540 ft (165 m)	43,000 ft (13,100 m)
60 ft (proposed)	66.27 ft (20.20 m)	540 ft (165 m)	49,200 ft (15,000 m)

The purpose of the study is to assess the wave-induced impacts of the proposed deepening of the Freeport Channel in the Gulf of Mexico on the open-coastal shorelines adjacent to the project area. This study's approach has been to use the numerical model, GENESIS, to compute sediment transport rates and shoreline change rates for each of the five channels. Comparing the GENESIS output for the "as is" condition with the proposed channels output revealed the effects of the bathymetry changes on the wave-induced longshore transport and the shoreline change rate. Breaker wave heights and angle inputs to GENESIS were obtained from the numerical wave propagation and refraction model, STWAVE. STWAVE modeled the refraction over five different bathymetry grids corresponding to the present and proposed channels.

II. STUDY AREA

Freeport Harbor, in Brazoria County is a major industrial port located on the Texas coast about 40 miles (65 km) southwest of Galveston and about 130 miles (200 km) northeast of Corpus Christi. Much of the Gulf shoreline in the study area is undeveloped or lightly developed. The major coastal community within the study area is Surfside, adjacent to the northeast side of the harbor. This community has had a history of long-term, moderate beach erosion as shown by the threatened houses in Figures 3 and 4. The bulk of the community is within about 2 miles (3 km) of the jetties, but a limited amount of beachfront development extends along Follet's Island (Highway 332, Bluewater Highway) all the way to Treasure Beach at San Luis Pass, about 13 miles (21 km) to the northeast (Figure 5). The community of Quintana and Quintana Beach County Park are immediately southwest of the jetties, but there is very limited beachfront development in this area (Figure 6). Further southwest is Bryan Beach State Park and the mouths of the Brazos River (about 6 miles, 11 km, southwest of the jetties) and the San Bernard River (about 10 miles, 16 km southwest of jetties). There is no road access to the beach between the inlets and no beach front development in this area.

Figure 3 – Collapsing seawall and threatened homes at Surfside (10 Oct 2006).

Figure 4 – Threatened homes and roadway at Surfside (10 Oct 2006).

Aerial photographs of the study area between San Luis Pass and the San Bernard River mouth are shown in Figures 5 and 6. These images were assembled from unrectified aerial photographs obtained from: http://www.texmaps.com/aerials/05brazosport-area/index.html, and are courtesy of Texmaps.com. The approximate scale, extending ten miles in both longshore directions from the Freeport jetties, covers the extent of shoreline in the study area.

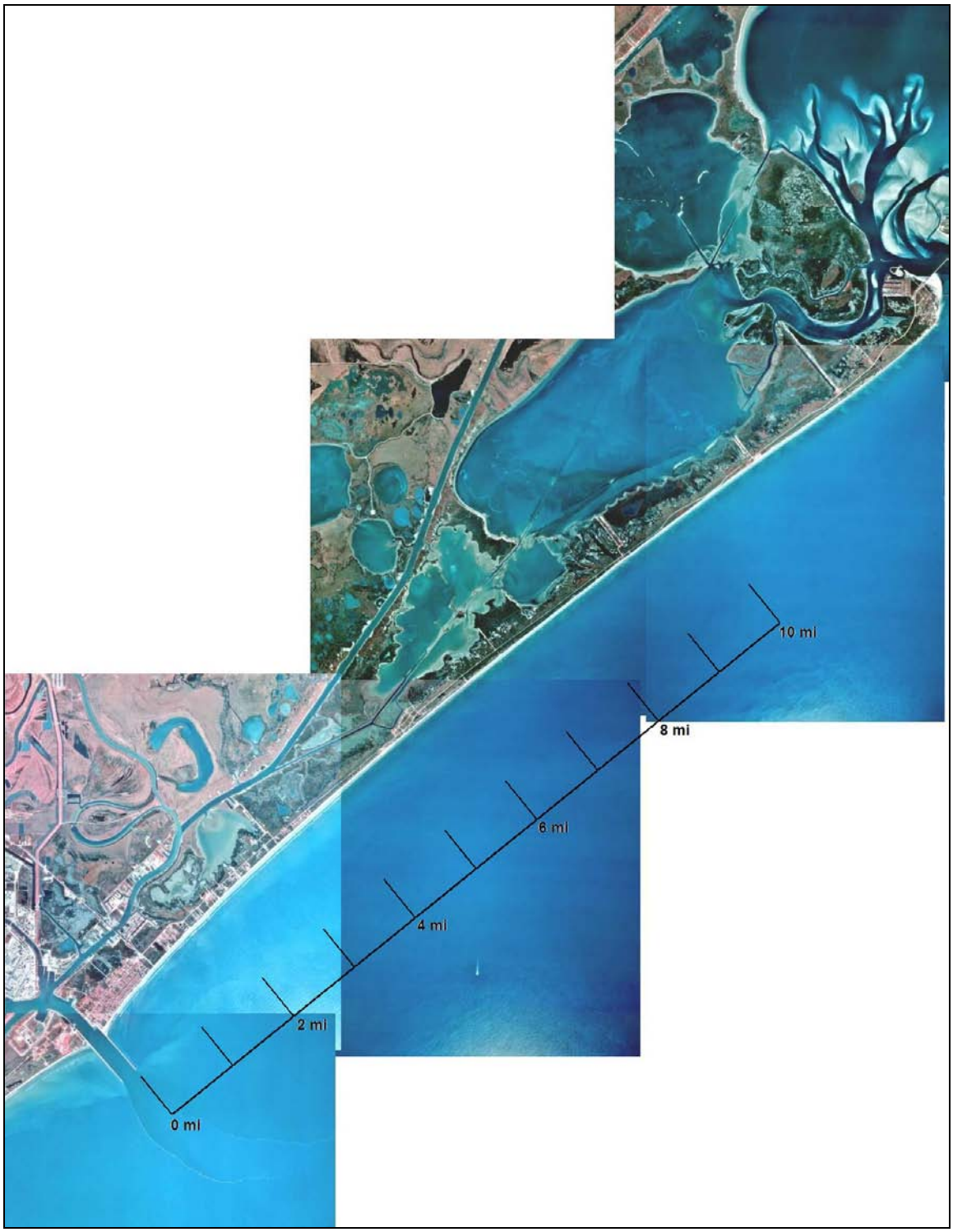

Figure 5. Composite aerial photo; San Luis Pass (upper right) to Freeport Harbor (lower left).

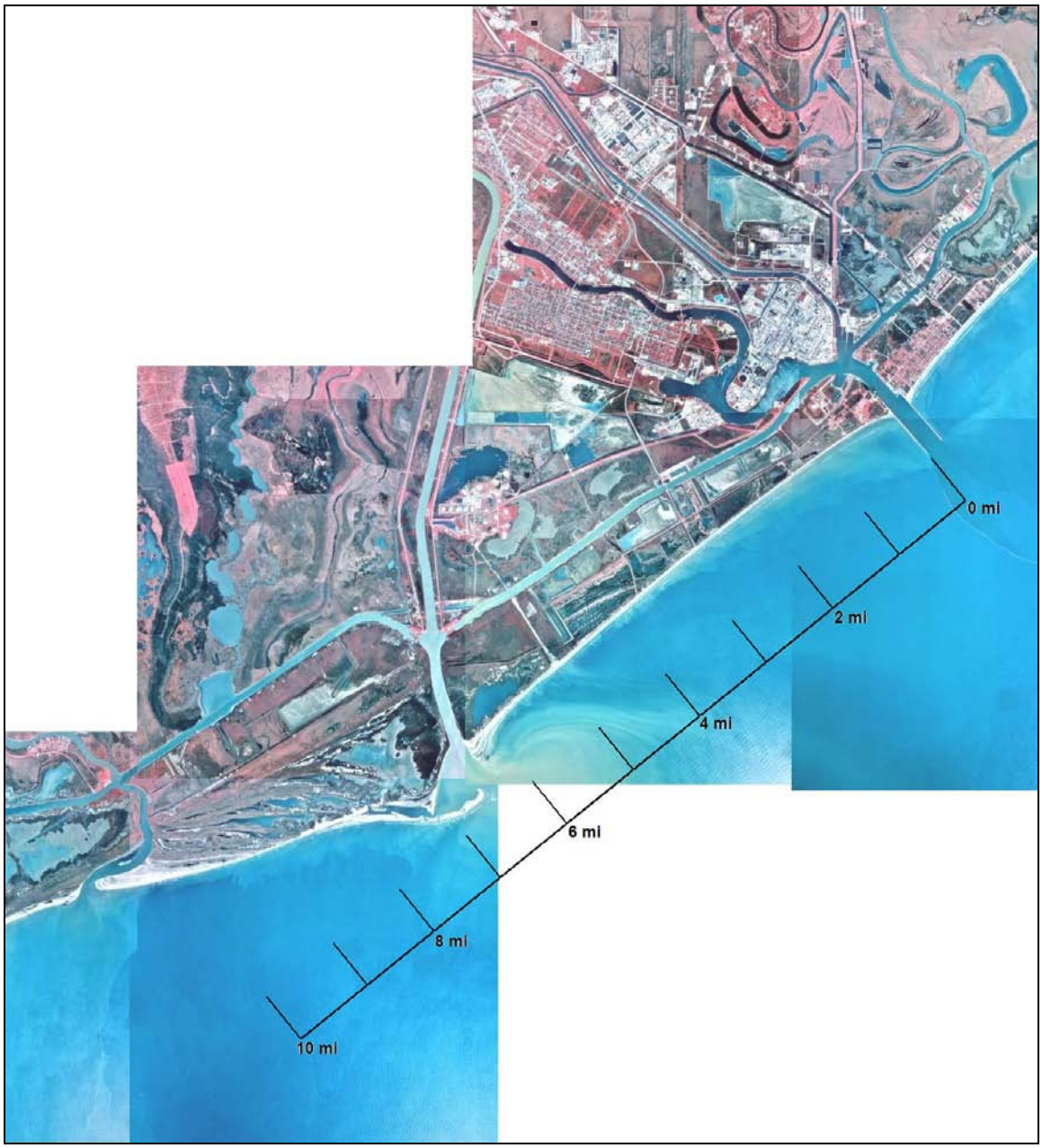

Figure 6. Composite aerial photo; Freeport Harbor (upper right) to San Bernard River (lower left).

Texas shoreline change rates have been calculated by the Bureau of Economic Geology (BEG), University of Texas, Austin, as part of their *Texas Shoreline Change Project*. Figure 7 shows a blowup of a portion of their Region II final report map (available on the web at: http://www.glo.state.tx.us/coastal/erosion/erosionrates.html.) Their change rates were obtained using a regression analysis of the available shorelines. Their map shows that in the vicinity of Freeport Harbor the shoreline is eroding at a rate of 9 to 10 feet/year. Five to six miles northeast of the Freeport, the shoreline is shown to be stable and further northeast it again becomes erosional. Between the Brazos and the San Bernardo River mouths, the shoreline is very dynamic, with strong erosional and accretional regions.

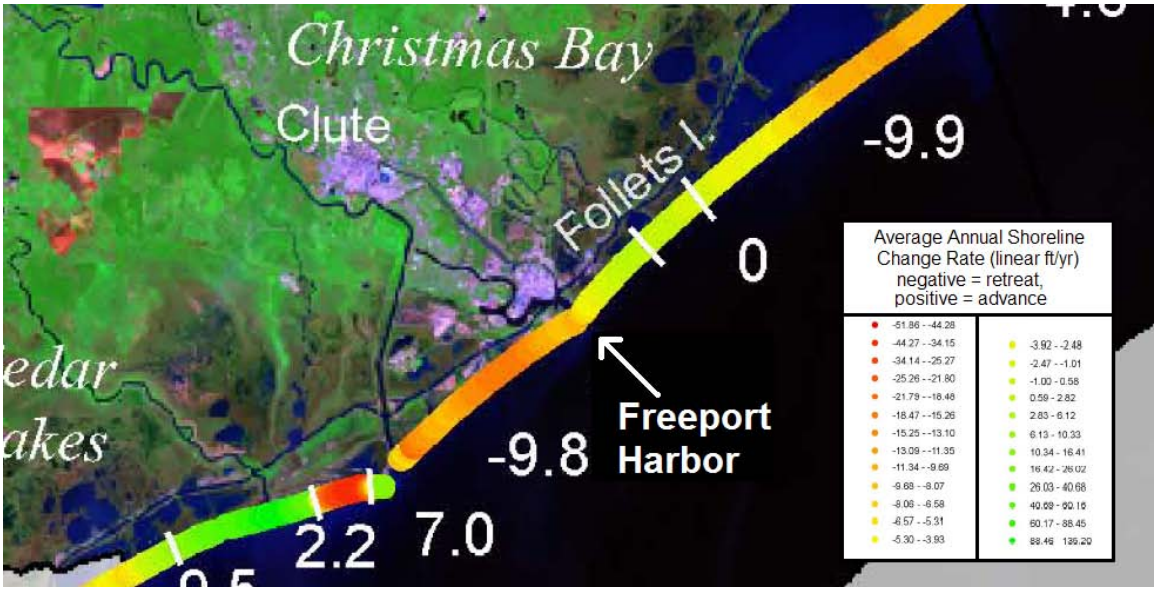

Figure 7. Blowup of Bureau of Economic Geology shoreline change rate map showing study area.

Several shorelines, collected between June 1974 and May 2006, (largely the same set as used by BEG) were examined in detail for this study. Figure 8 shows these shorelines for distances of ten miles on either side of the Freeport jetties, and Figures 9 and 10 show blowups of small portions of these shorelines. These figures are oriented looking offshore, so that the negative numbers on the left side of Figure 8 correspond to the shoreline running northeast from the Freeport jetties (toward Galveston), which is the shoreline shown in Figure 5. The right side of Figure 8 corresponds to the shoreline in Figure 6. Figures 9 and 10 show blowup examples of the Figure 5 shoreline. Note that Figures 8, 9, and 10 are distorted. In all three figures, one unit in the cross-shore (vertical) direction roughly equals five units in the along-shore (horizontal) direction.

These shorelines showed a general erosion trend along much of the study area; however, the pattern is not straight forward. Individual shorelines do not maintain a fixed relationship to each other, and most of the shorelines are, at one location or another, the most landward and the most seaward of the group. Figure 8 shows that the shoreline between the unjettied Brazos and San Bernard River mouths (+6 to +10 miles) is extremely variable. In this region shoreline dynamics are governed by inlet processes. GENESIS does not model inlet processes, so the model should not be applied in this region. Figure 8 shows that, at these scales, the shoreline running northeast from Freeport Harbor is much more stable. Figures 9 and 10 show examples of the degree of variability in the relationships of these shorelines to each other. They also show that the inter-annual variability (the year-to-year changes) of the shoreline position is of the order of a few feet to a few tens of feet per year.

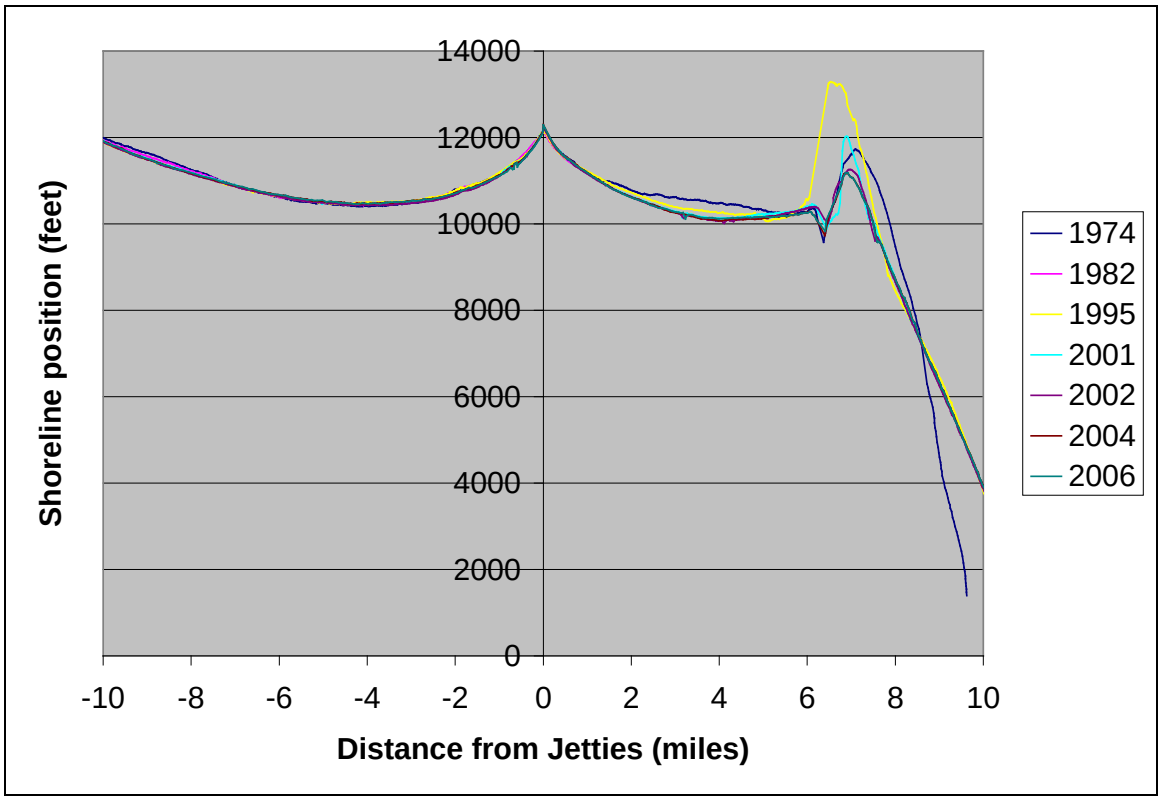

Figure 8. Shorelines in the vicinity of Freeport Harbor.

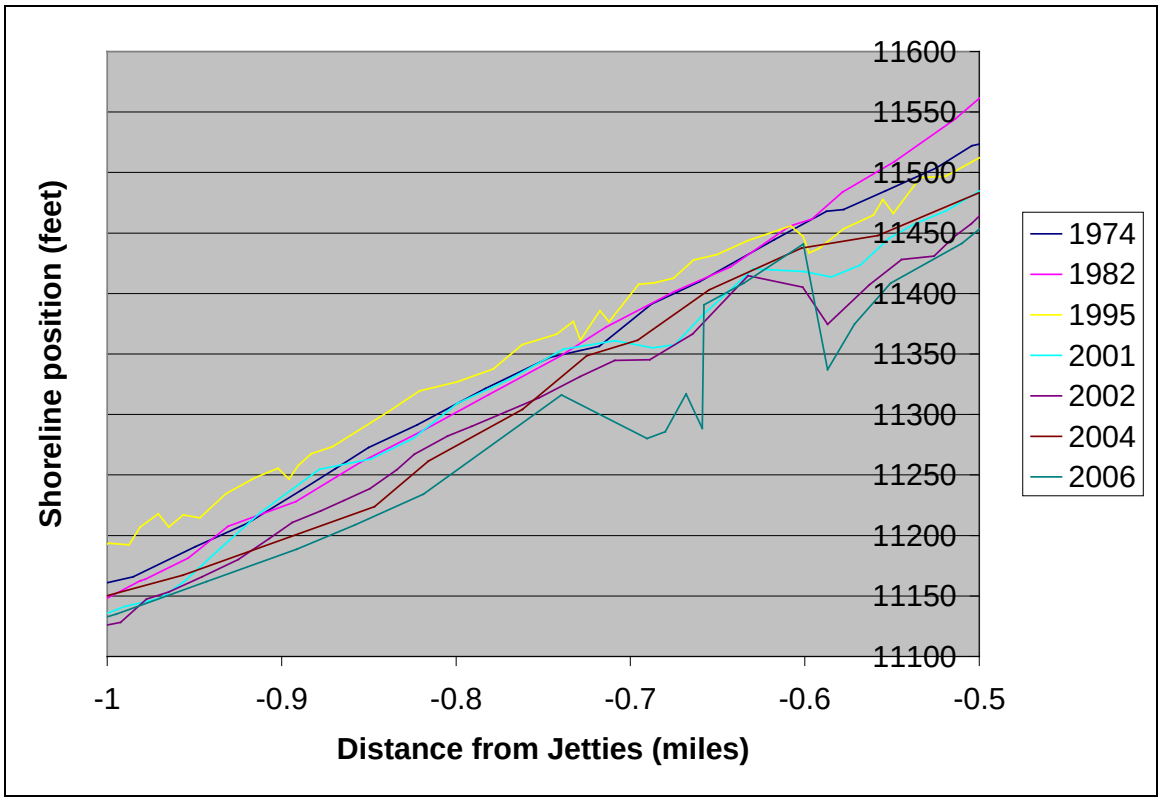

Figure 9.Blowup of Figure 8 shorelines, vicinity of Surfside.

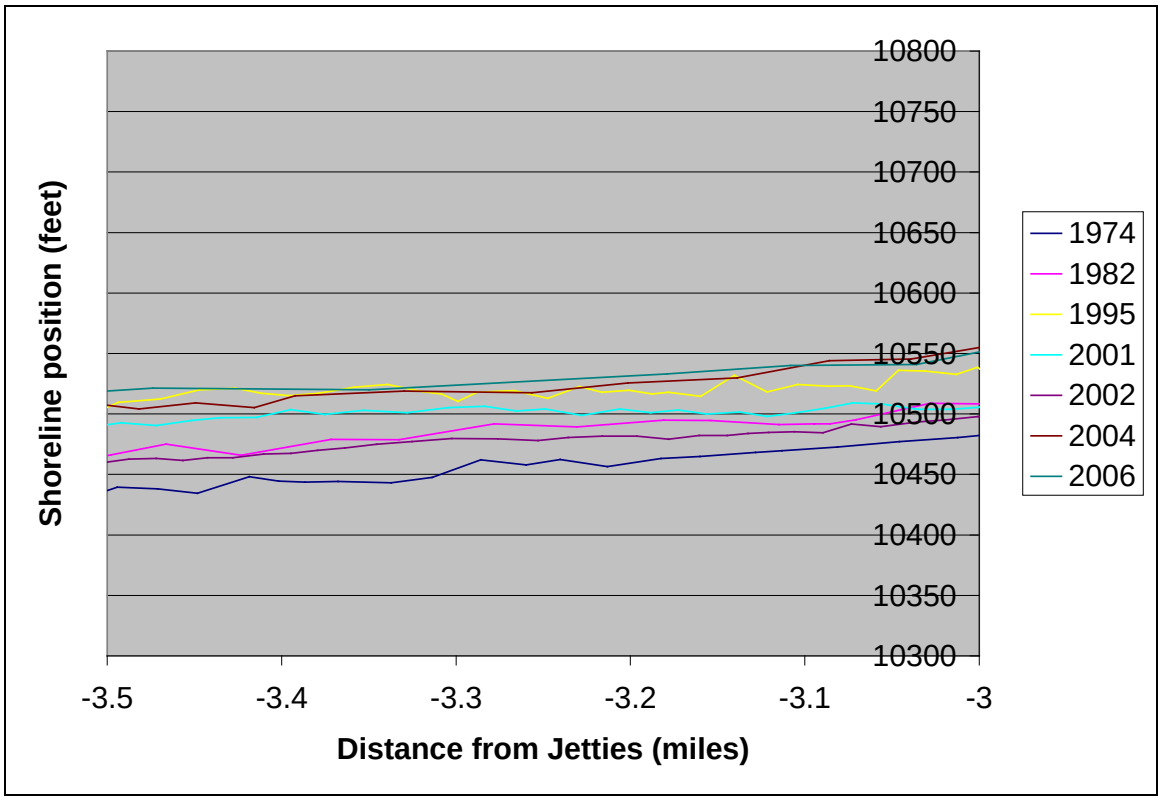

Figure 10. Blowup of Figure 8 shorelines, northeast of Surfside.

III. MODEL OVERVIEW

The GENESIS (Hanson and Kraus 1989) model has been applied to numerous engineering projects and has demonstrated favorable capability to predict long-term shoreline change. GENESIS was designed to simulate long-term shoreline change produced by temporal and spatial differences in the longshore sand transport at coastal engineering projects. The beach profile is assumed to remain in a state of quasi-equilibrium over the long-term. The advance or recession of the beach is realized as a seaward or landward translation of the entire profile so that only one point of the profile, taken as the shoreline, is required to model the evolution of a sandy coast. Cross-shore processes are assumed to average out over a sufficiently long simulation interval, and shoreline change produced by cross-shore sand transport is represented as sediment sources or sinks.

The accuracy of shoreline change modeling calculations is improved with better estimates of breaking wave height and direction. The breaking wave pattern is determined by the offshore wave parameters (wave height, period, and direction) and the bathymetry over which the waves propagate. A nearshore wave transformation simulation was performed with the steady-state spectral wave model STWAVE (STeady-state spectral WAVE model) (Resio 1988; Smith, Sherlock, and Resio 2001).

IV. STWAVE CONFIGURATION

Waves are the dominant forcing for longshore sediment transport. A 20-year hindcast (1980-1999) of hourly interval wave heights, periods, and directions was obtained at WIS station 65 (blue circle in Figure 11) located at Latitude 28° 45' N, Longitude 95° 10' W in 20 meters of water depth from the website: http://frf.usace.army.mil/cgi-bin/wis/atl/atl_main.html. Wave direction data from this WIS station were referenced to the local shore normal. The zero degree direction of wave propagation is 315.7^o clockwise from North. Positive wave angles are those approaching the coast from the east or northeast (from the left of shore normal for a person standing on the beach looking offshore).

The 20-year wave climatology from WIS station 65 was characterized by binning the significant wave heights, peak spectral wave periods, and vector mean wave directions at the peak spectral frequencies, as shown in Figures 12 and 13. Figure 12 is a histogram of wave heights, periods, and directions shown as percent occurrence. Bright yellow bins indicate those occurring most frequently and bright blue, least frequently. Figure 13 is the corresponding block diagram of wave period versus wave direction. These figures show that average wave heights are around a meter, average wave periods are a little above five seconds and that there is a broad spread in wave direction, with a small majority of the waves coming from the South.

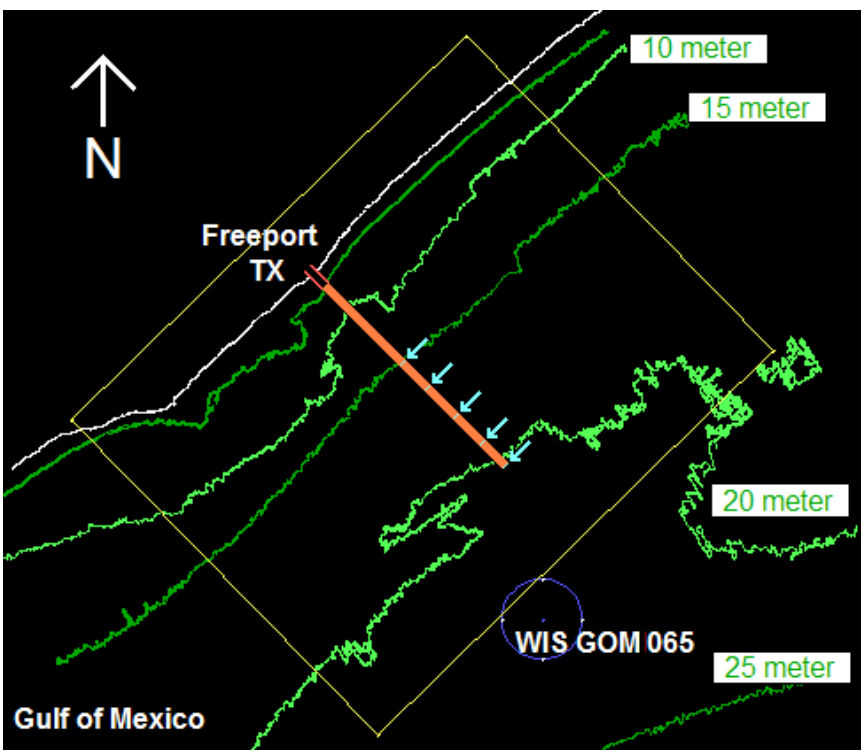

Figure 11. Location of WIS station and STWAVE grid.

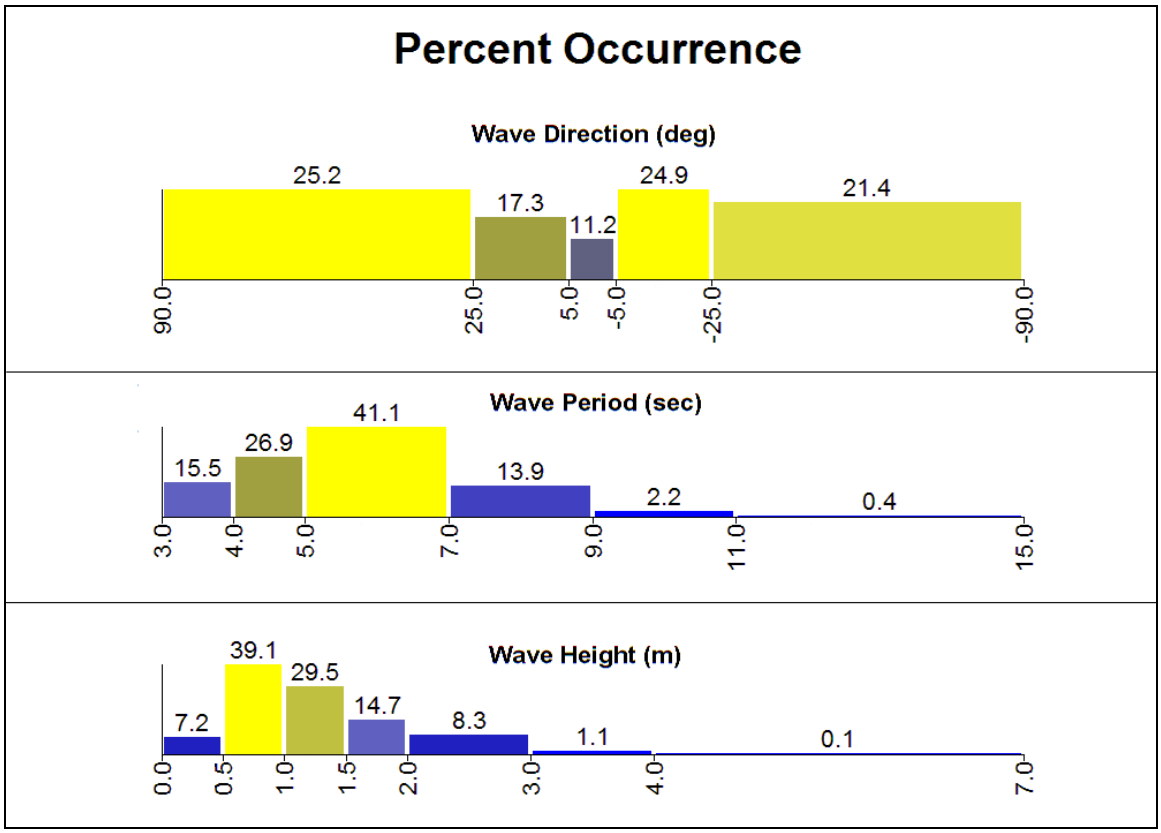

Figure 12. Histogram of Wave Directions, Periods, and Heights with percentages of occurrence.

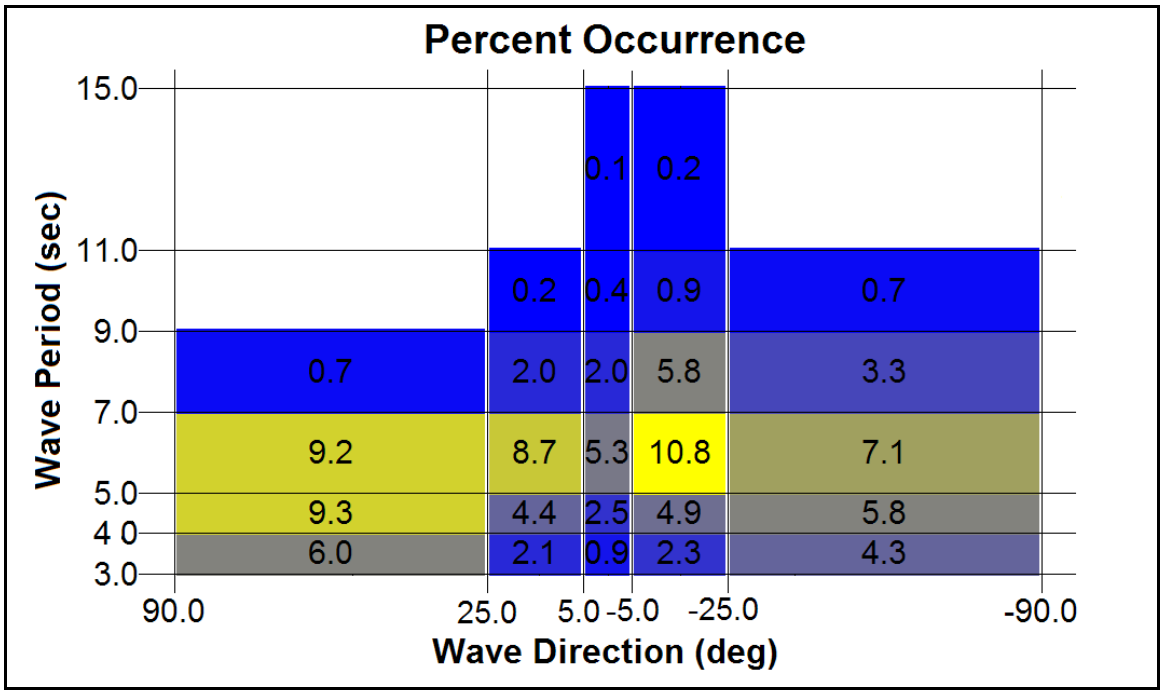

Figure 13. Block Diagram of Wave Period vs. Direction. Numbers in each block are the percent of time that waves having those periods and directions (excluding calm conditions) occur in the wave record.

STWAVE grids were generated for the existing condition and four alternative configurations with the same grid boundary for each, which is shown in yellow in Figure 11. This grid extendeds 20 miles (32 km) along shore, centered at the Freeport Channel or from about the middle of Christmas Bay in the Northeast (or from about 3 miles SW of San Luis Pass) to near the mouth of the San Bernard River in the Southwest (see Figures 5 and 6). The grid extended 16 miles (26 km) offshore to approximately the 66 ft (20 m) depth contour.

STWAVE grid cell spacing in both the along-shore and offshore directions for all the grids was set at 80 ft (24.4 m) to properly resolve the channel bottom with a minimum of 5 cells in the along-shore direction. Thus, the grids extended 1320 cells in the along-shore direction by 1056 cells in the offshore direction. The orientation of the grids was the same as for the channel (offshore azimuth of 135.7 degrees measured clockwise from north). The nearshore output save stations were set at a depth of 16 ft (5 m), which was near the surf zone but seaward of essentially all the depth limited wave breaking.

Bathymetry for the Freeport area were obtained from NOS hydrographic surveys that were available in electronic format from the Geophysical Data System (GEODAS, ver. 4.0) developed by the National Geophysical Data Center. Horizontal survey datums were converted from the North American Datum of 1927 (NAD27) to the North American Datum of 1983 (NAD83), Texas State Plane Coordinate System, South Central Zone 4204, meters. Vertical survey datums were converted from mean low water (MLW) to the North American Vertical Datum of 1988 (NAVD88) by adding 0.19 feet (0.058 m) of depth to each sounding, the relationship established at NOAA Tide Station 8771510, located on the Galveston Pleasure Pier at Latitude 29° 17.1' N, Longitude 94° 47.3' W. The vertical datum relationships were obtained from the NOAA webpage: http:// tidesandcurrents.noaa.gov/benchmarks/benchmarks_old/ 8771510.html#DatumsPage.

Recent surveys of the channel area were supplied by SWG. For these data, horizontal datums were converted from NAD83, State Plane, feet to NAD83, State Plane, meters. Vertical datums were converted from a local datum, MLT, to NAVD88 by adding 1.43 feet of depth (conversion supplied by SWG). These surveys showed the average channel depth to be 51.27 ft, NAVD88 (15.63 m) along the length of the channel seaward of the jetties. This represents the present authorized depth of 45 ft., plus 2 ft. of advanced maintenance, 2 ft. allowance for wave action, and 2 ft. of allowable over-depth.

Bathymetries for the five grids were identical except for the area of the entrance channel (Table 1). All the channels had side slopes of 1 on 3 from the bottom of the channel up to the natural bathymetry elevation and a channel alignment of N44^{o} 15' 12"W. The channel lengths are measured from the seaward tips of the Freeport jetties.

V. GENESIS CONFIGURATION AND CALIBRATION

Two GENESIS grids were set up. Grid A covered 10 miles of shoreline northeast of the Freeport jetties, as shown in Figure 5. Gird B was originally intended to cover the same distance to the southwest of the jetties. However, its extent was reduced to the first

6 miles southwest of the Freeport jetties to aviod the two inlets where the model results would not be applicable (Figure 6). The cell spacing for these grids was 80 ft (24.4m), the same resolution as the STWAVE grid. The only structures incorporated in the grids were the Freeport jetties.

Using field measurements, Mason (1981) estimated the net longshore sediment transport rate at Freeport to be 67,000 m^3/yr to the southwest. Other researchers agree that the net direction of sediment transport is to the southwest along most of the upper Texas coast. However, preliminary *CERC* formula and GENESIS estimates made at the beginning of this study indicated that the direction of net sediment transport is to the northeast. This contradiction was not unexpected, as several modelers have found this result when applying standard modeling techniques to this area of the Texas coastline. King (*in prep*) found that by accurately including both the effects of local winds on wave propagation from deep to shallow water and the direct effect of local winds on longshore currents, that GENESIS predicted net sediment transport to the southwest along Galveston Island.

A similar approach was used for this study. Local winds were used as an additional longshore current driving term in GENESIS using the method described in King (*in prep*, Appendix B). In addition, the five-meter offshore contour was applied as a regional contour input in the model. With these additions to the model, GENESIS predicted net transport to the southwest for most of the study area for most of the years in the study.

For Grid A, the 1982 and 2002 shorelines were selected for calibration, with the 1974 and 1982 shorelines being used for verification. The 1982 shoreline did not cover all of Grid B so the 1995 and 2002 shorelines were used for calibration and the 1974 and 1995 shorelines were used for verification. Figure 14 shows the average annual rate of shoreline change for Grid A for the 1982-2002 time period (pink line), for the 1974-1982 time period (blue line) and the GENESIS prediction (green line). Positive values indicate accretion. Figure 15 shows the same calibration results for Grid B. With the removal of the Brazos and San Bernardo inlets from the model reach, the calibration and verification showed reasonable to quite good agreement with the shorelines and the BEG results.

Figure 16 shows the average annual gross and net longshore transport rates in the Freeport area for the combined GENESIS A and B grids. Net transport to the southwest is positive. These results compare favorably with the measurements of Mason (1981) as discussed above. The results shown in the rightmost quarter of this figure should not be relied upon without independent verification.

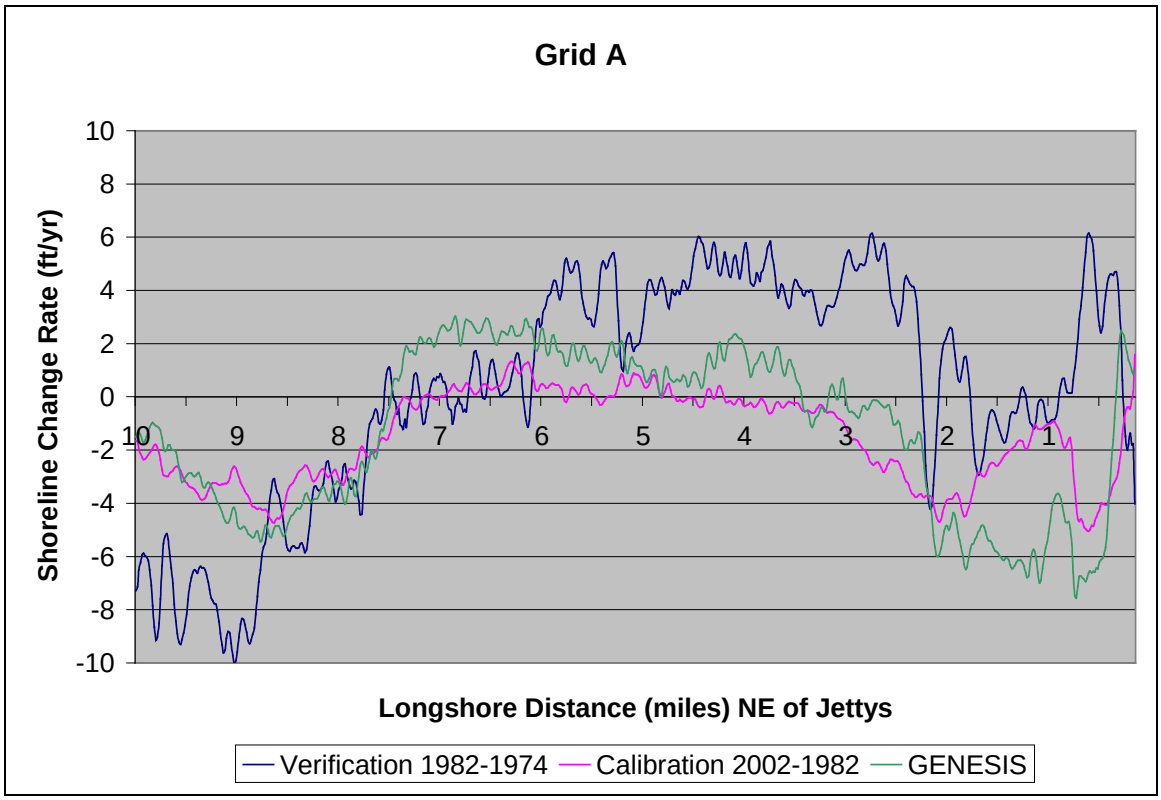

Figure 14: GENESIS calibration for Grid A.

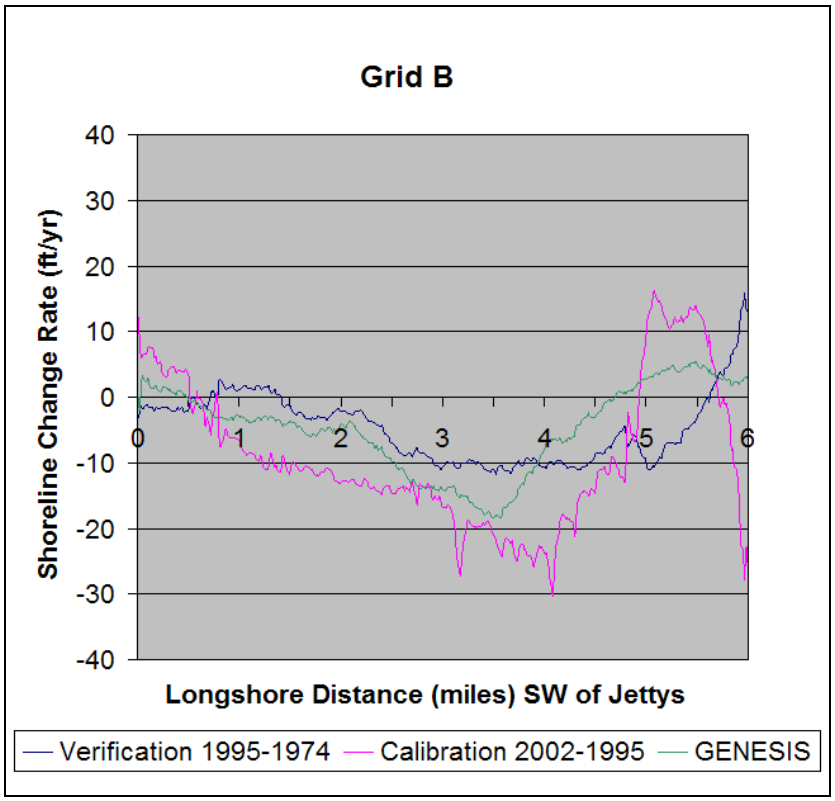

Figure 15. GENESIS calibration for Grid B.

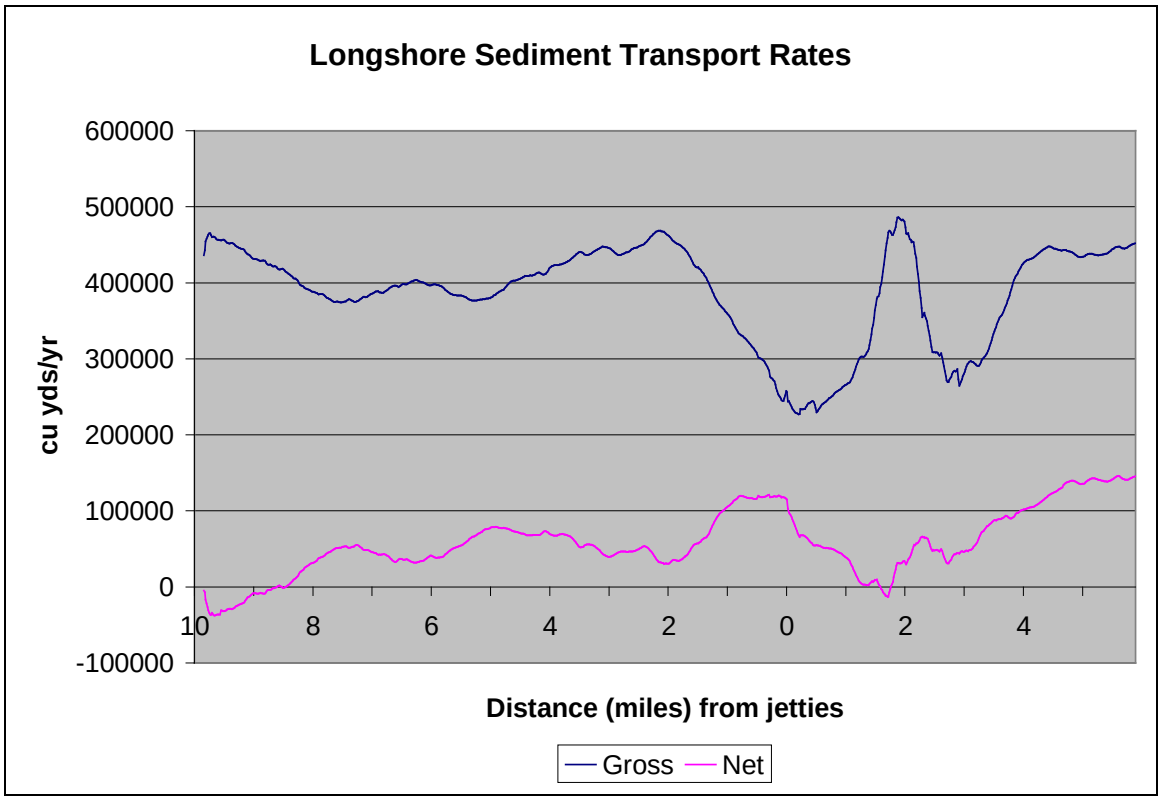

Figure 16. Longshore Sediment Transport Rate for "as is" conditions.

VI. MODEL RESULTS

VI-A. STWAVE

An examination of the STWAVE results shows the effects that channel bathymetry changes have on nearby wave patterns. Figure 17 shows the expected near channel wave height changes for a particular offshore wave condition if the 58 ft channel were to be built. In this figure, the shore is at the bottom shown in gray and the channel is shown in brown. Wave bin 10601 has very oblique wave angles of 25 to 90° (relative to shore normal, that is, they will be coming from the east or upper left corner or left edge in Figure 17) and have wave periods of 11 to 15 seconds. Increased wave heights, shown in yellow, mostly occur to the left of the channel in this figure (to the northeast, offshore of Surfside), with maximum increases up to 13%. Decreased heights, in blue, mostly occur within the channel and to the right (southwest or offshore of Quintana). The maximum height decrease is 25%. This occurs within the channel and is obscured in the figure by the brown color delineating the channel.

Figure 18 shows the wave height changes near the breaker line for this condition (wave bin 10601, proposed 58 ft channel). This figure shows that breaker wave height changes essentially do not exceed approximately 10% anywhere and become negligible within four miles of the harbor entrance.

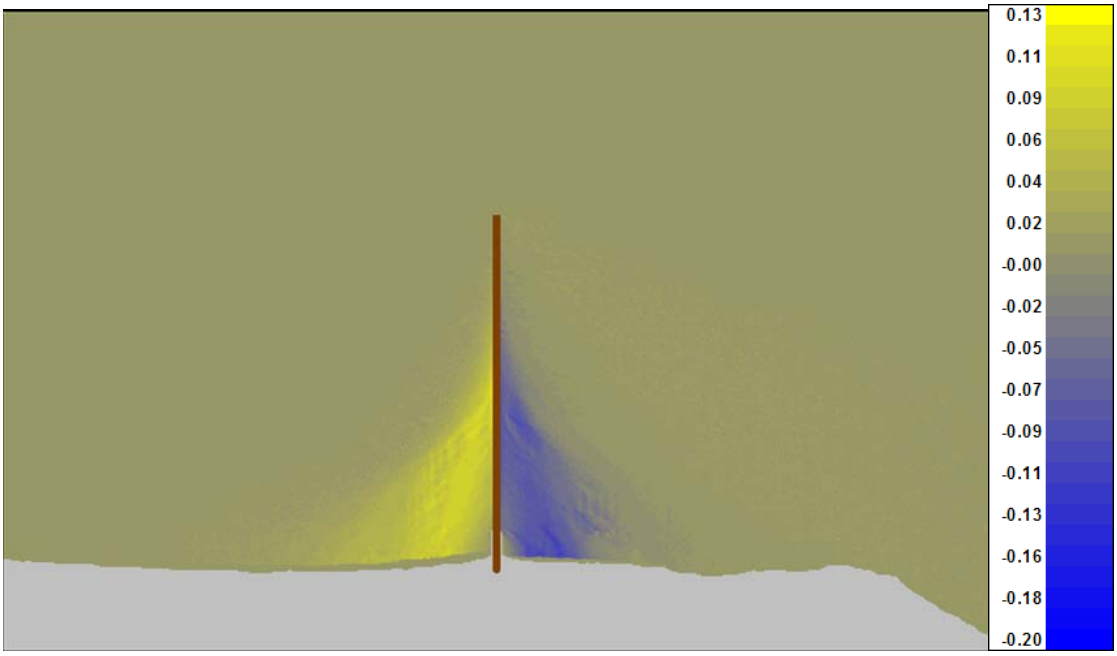

Figure 17. 58 ft channel wave height changes in the vicinity of the channel for the case of for bin 10601. The right hand scale shows the percent change.

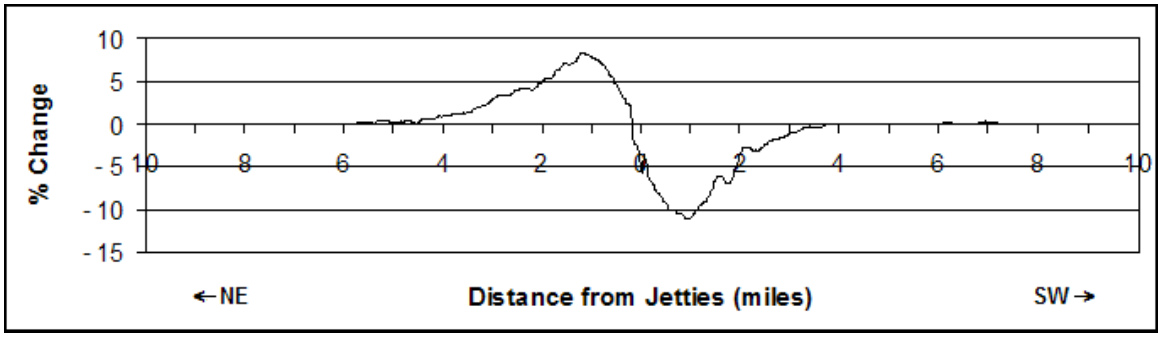

Figure 18. 58 ft channel along shore wave height changes for bin 10601.

There is a sister condition (50601) of very long period waves approaching the beach very obliquely from the right (or south), that produces near-mirror image results. These two conditions produce the most extreme changes in wave refraction from the present condition, and thus produce the greatest changes in nearshore wave height, nearshore wave angle and in longshore sediment transport. Both of these conditions are quite rare, occurring less than 0.1% of the time in the wave record, as shown in Figure 13. Thus, no offshore wave conditions should be expected to change near breaking wave heights by more than about 10% or have any impact on the beaches more than about four miles from the jetties.

Figures 19 and 20 show height changes for wave bin 40301, the most commonly occurring condition in the dataset (10.8% of the non-calm data records, Figure 13). These waves are coming from -5 to -25° (right side of the top edge of the figure) and have periods of five to seven seconds. For this condition, height increases are mostly to the left of the channel and decreases are to the right. Maximum wave height increases are

only 3% and maximum height decreases are 9% anywhere in the study area. Along the shoreline, the height changes are less than 2% and confined to distances of less than three miles from the jetties.

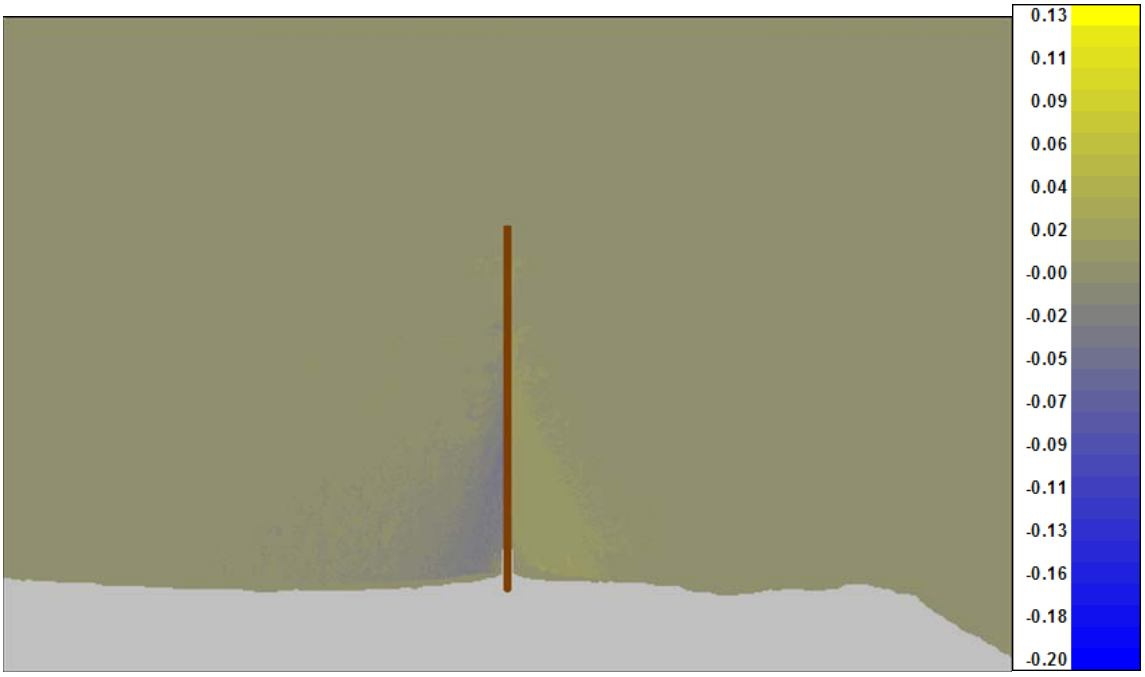

Figure 19. 58 ft channel near channel wave height changes for bin 40301.

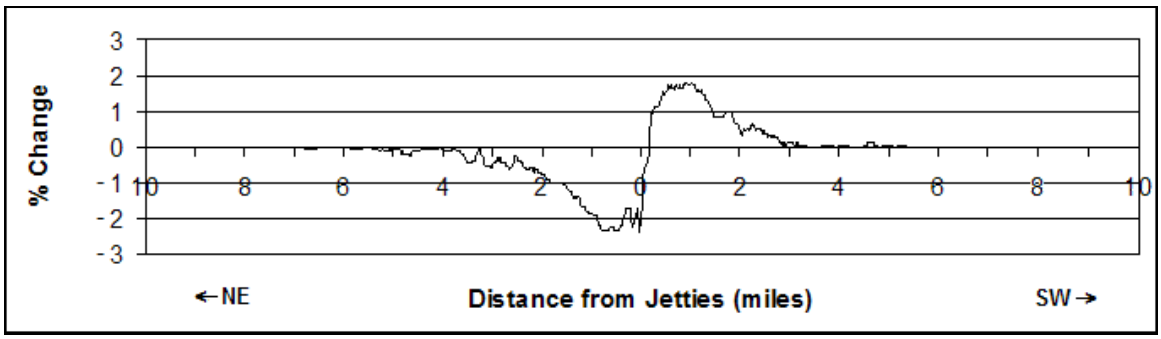

Figure 20. 58 ft channel along shore wave height changes for bin 40301.

Figure 21 shows the average near breaking wave height change if the 58 ft channel is constructed. It is a composite of the wave height changes in all the bins weighted by their frequency of occurrence. Thus, on average, the waves southwest of the jetties (Quintana) will be up to 0.4% higher than at present and up to 0.7% lower than at present a mile or so northeast of the jetties (Surfside). The 1.4% height decrease occurs within the jetties.

These examples are presented to help explain the patterns of change seen in the longshore sediment transport and changes in the shoreline change rate. The main take home message is that the expected shoreline impacts due to deepening the entrance channel are expected to be slight and limited to within a few miles of the jetties.

Figure 21. Average wave height changes, 58 ft option.

VI-B. Sediment Transport Results

Figures 22 shows the changes to the average annual net sediment transport rate that are expected to occur for the four proposed channel depths. As expected, the deeper the proposed alternative the greater the impact. However, all these changes are minor. Figure 23 compares these average annual net sediment transport rate changes to the current average annual net transport rate. That is, Figure 23 compares the four curves in Figure 22 with the red curve in Figure 16. It is seen that the expected changes to the net transport rates will be minor perturbations, typically of the order of a few percent, at most, of the present net rate.

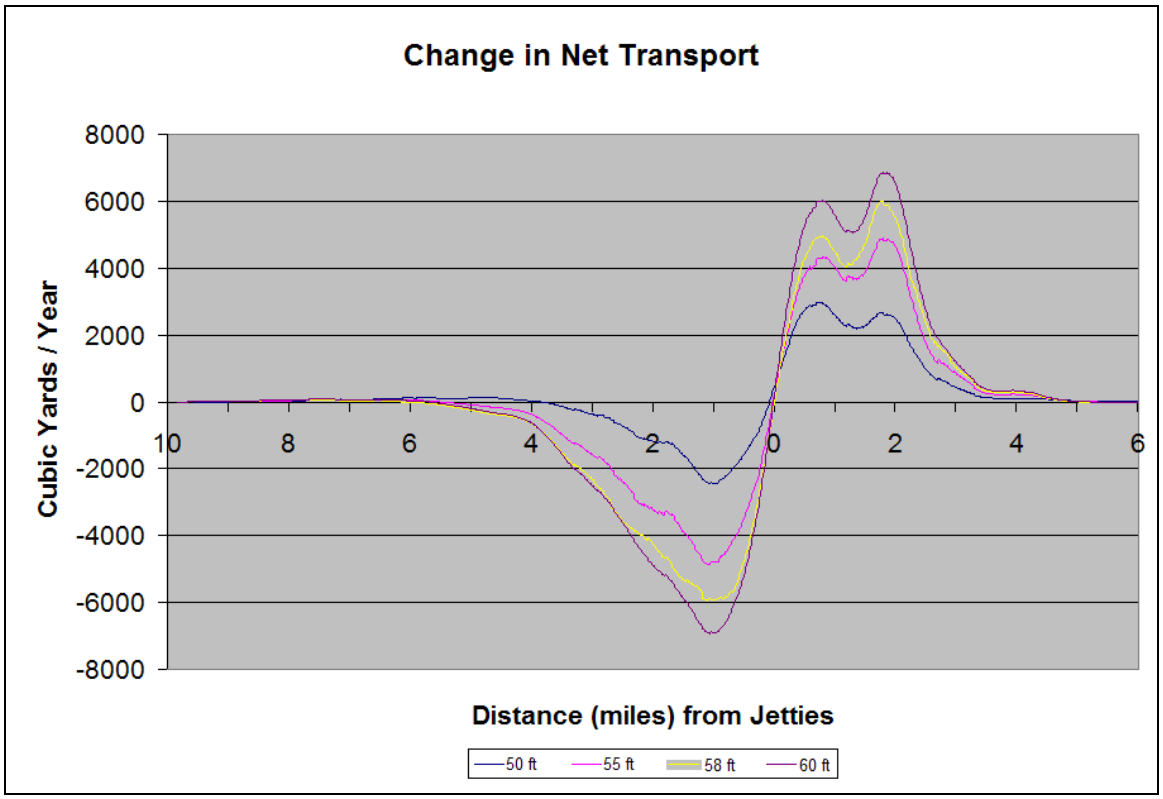

Figure 22. Expected changes to the net transport rate for the four proposed channels.

Figure 23. Comparison of current net sediment transport rate with potential changes.

VI-C. Shoreline Change Results

Figure 24 shows the changes in the estimated rate of shoreline change for each of the four alternatives. The analysis predicts that the shoreline immediately adjacent to both sides of the jetties will very slightly benefit and further from the jetties there will be a very slight negative impact. However, all these impacts are so slight that they will not be noticeable. To put this in perspective, this analysis predicts that the impacts particularly any negative impacts on the shoreline from any of the proposed deepening alternatives will be much less than the present shoreline change rate (Figures 14 and 15) and will be lost in the annual variation in shoreline position (Figures 9 and 10).

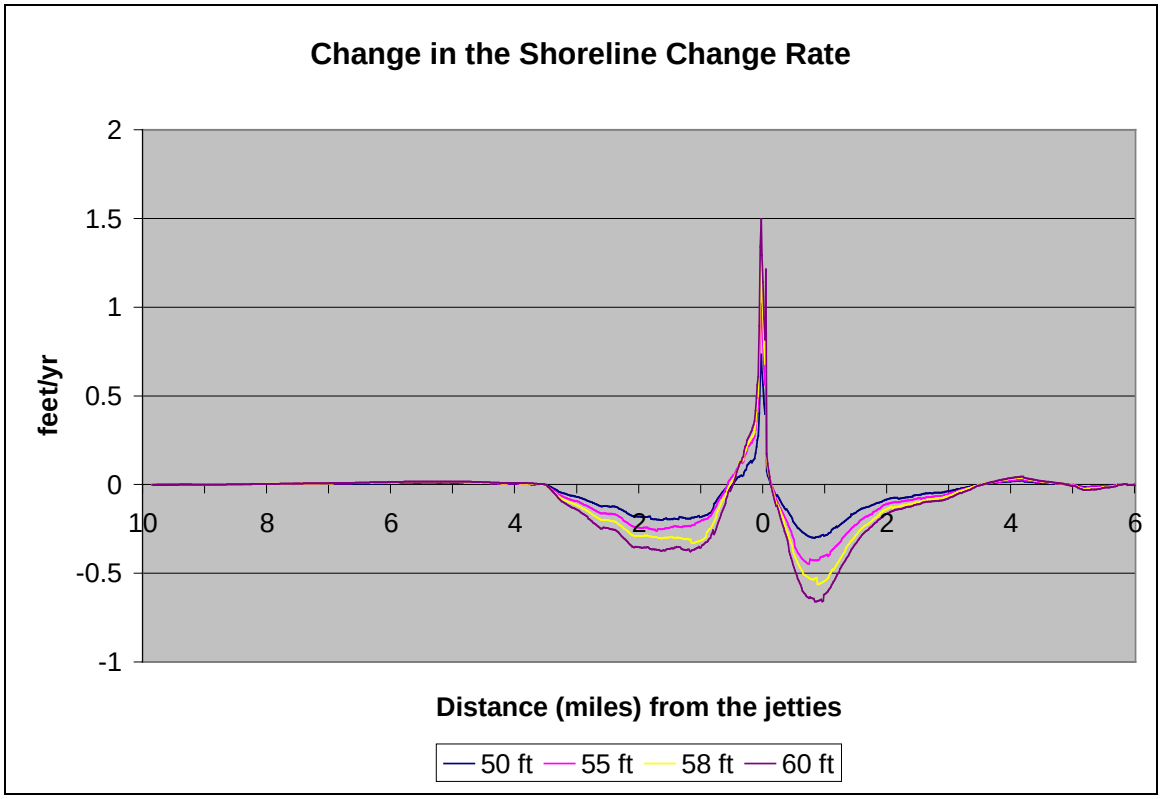

Figure 24. Changes in the shoreline change rate for each of the alternatives.

VII. CONCLUSIONS

- The primary conclusion from this analysis is that if any of the proposed deepening alternatives for the Freeport entrance channel are constructed, the wave-induced sediment transport impacts on the adjacent shorelines will be so slight as to not be noticeable and will be dwarfed by the inter-annual variability in shoreline position.
- The model predicts that the greater the proposed depth alternative, the greater the shoreline change, but for any alternative, these impacts will be minor and will not

extend further than three to four miles (five to six km) to either side of the Freeport jetties.

- The impacts of these alternatives are very comparable to the impacts predicted for the Sabine offshore channel deepening study (King and Gravens, 2003).

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