Brown, C.A., Militello, A., and Kraus, N.C. 1995. Hydrodynamic Assessment for Elevation of the JFK Causeway, Corpus Christi, Texas. *Proceedings Texas Water '95*, Texas Section of the American Society of Civil Engineers, 31-41.

HYDRODYNAMIC ASSESSMENT FOR ELEVATION OF THE JFK CAUSEWAY, CORPUS CHRISTI, TEXAS

Cheryl A. Brown[1], Adele Militello[2], Nicholas C. Kraus[3], M. ASCE

ABSTRACT: The John F. Kennedy Causeway was constructed across the Laguna Madre, Texas, in 1950 as a landfill and bridge causeway. Because it contains only three relatively small openings in its 4.5-km length, concerns have been raised that water exchange between Corpus Christi Bay and the hypersaline Laguna Madre has been impeded to the detriment of the ecology of the lagoon. This paper describes a hydraulic assessment performed as part of a multi-disciplinary study to evaluate environmental and safety issues related to the causeway. Monitoring and numerical modeling of the water level and current were conducted to evaluate the existing condition and to compare several alternative designs for elevating the causeway. Calculations with a calibrated hydrodynamic model showed that the total discharge through the lagoon was almost unaffected by causeway opening size. An optimal economic design involving elevation of the western-most 1.5 km of the causeway was identified that increased circulation over shallow flats while eliminating stagnation zones near the causeway.

INTRODUCTION

The John F. Kennedy (JFK) Causeway was constructed in Corpus Christi, Texas, in 1950. The fill and bridge causeway spans approximately 4.5 km across the Laguna Madre near its northern terminus that joins with Corpus Christi Bay (Figure 1). The causeway limits the water exchange between Corpus Christi Bay and the Upper Laguna Madre to three openings: a 150-m wide opening called Humble Channel located along the western shore; a 170-m wide opening through which the Gulf Intracoastal Waterway (GIWW) passes; and a 50-m wide relief channel along the eastern shore that is part of a residential development and marina complex. The U.S. Army Corps of Engineers completed the GIWW along the south Texas Coast in 1949. The GIWW, which is 4 m (12 ft) deep, 38 m (125 ft) wide at the bottom, and 91 m (300 ft) wide at the top (design dimensions), was dredged through the entire length of the Laguna Madre.

---

1) Research Scientist, Conrad Blucher Institute for Surveying and Science, Texas A&M University-Corpus Christi, 6300 Ocean Drive, Corpus Christi, Texas 78412-5503.
2) Research Scientist, Conrad Blucher Institute; and Ph.D. Candidate, Marine and Environmental Systems, Florida Institute of Technology, Melbourne, Florida.
3) Director, Conrad Blucher Institute for Surveying and Science.

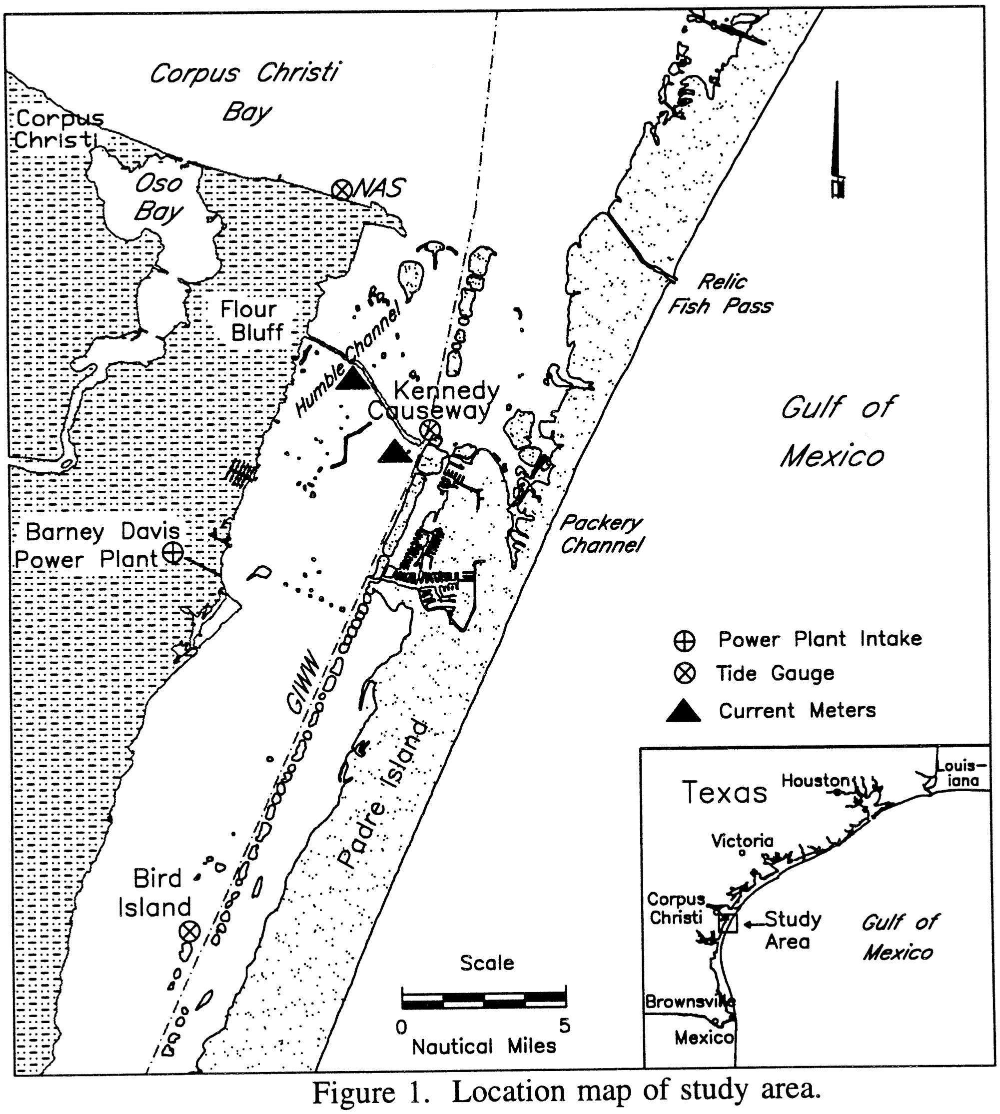

Figure 1. Location map of study area.

Prior to and subsequent to the construction of the causeway, the local community and the State of Texas expressed environmental concern of the perceived degradation of water circulation and water quality in the vicinity of the causeway (Collier and Hedgepeth 1950, Simmons 1957). However, only three reconnaissance-level, unpublished studies have been performed to evaluate the impact of the causeway on circulation and water quality (Duke 1990, Matsumoto 1991, Solis 1991), and the need for a more definitive study based on more comprehensive field measurements was identified.

As part of a recent comprehensive study of environmental and safety issues related to the JFK Causeway sponsored by the Texas Department of Transportation (TXDOT), the Conrad Blucher Institute for Surveying and Science, Texas A&M University-Corpus Christi, conducted the required hydrodynamic assessment to evaluate water movement for the existing condition and for possible alternatives involving elevation of portions of the causeway to promote circulation and enhance water quality. The assessment employed numerical simulation models of the circulation and water elevation, ground-truthed by extensive data, and it was performed as part of a multi-organizational team effort involving biologists, bridge design specialists, and civil engineers.

The main objective of the hydrodynamic assessment was to quantify the change in circulation for possible alternative designs (formulated to elevate portions of the causeway) by comparison of calculation results for the alternatives and those for the existing condition. A two-stage modeling approach was taken. The first stage involved use of a one-dimensional (1D) model (Amein and Kraus 1992) to obtain an overall understanding of the forces moving the water in the Laguna Madre and its response. The 1D model simulated the water elevation and circulation along the major (north-south) axis of the lagoon, but omitted circulation across the lagoon. Detailed analysis was then conducted at the second stage by using a numerical simulation model of the two-dimensional (2D) horizontal circulation (Militello 1993), which represents changes in water elevation and the along- and across-axis circulation. The numerical model was calibrated and tested by comparison of calculations to measurements both of the water level at an internal location of the calculation domain (Packery Channel) and of the current at the openings in the causeway for the existing condition. After calibration of the model, various alternatives as determined by the team and by citizen evaluation groups were then tested. The 1D and 2D models included forcing by the tide and wind; bottom topography and bottom friction; locations of islands and channels; and specific configuration of the causeway depending upon the alternative.

This paper describes the field measurements and hydrodynamic modeling conducted to evaluate alternative plans for elevation of the causeway.

FIELD MONITORING

Water Level and Wind

The Texas General Land Office (TGLO) and the Texas Water Development Board (TWDB) have sponsored a network of water-level gauges located along the Texas coast that includes the study site. The southern end of this Texas Coastal Ocean Observation Network (TCOON) is operated by the Blucher Institute and contains several water-level and tide gauges in Corpus Christi Bay and in the Laguna Madre. Because of the shallow water of the Laguna Madre and limited connections with the Gulf of Mexico, the mean tidal range varies from 0.51 m (1.7 ft) in the Gulf at Aransas Pass; 0.18 m (0.6 ft) at Naval Air Station-Corpus Christi (NAS) on northern end of the Laguna Madre; 0.12 m (0.4 ft) at Packery Channel adjacent to the Causeway; to less than 0.06 m (0.2 ft) at Bird Island. TCOON gauges are operated to national standards and provide mean water-level measurements at 6-min intervals.

For the purpose of the hydrodynamic assessment, the study area comprised a section of the Upper Laguna Madre (ULM) extending from its joining area at NAS in Corpus Christi Bay on the north end southward to Bird Island (Figure 1). This section was convenient because it encompassed the causeway and the cooling water intake of the Barney Davis Power Plant. The power plant typically removes approximately 24 m^3/sec (540 million gal/day) from the Laguna Madre and discharges it from a cooling pond into Oso Bay.

Hydrodynamic boundary and forcing conditions are well defined at the northern and southern ends of this area by the TCOON water-level gauges located at the NAS and at Bird Island, respectively. In addition, a TCOON station at Packery Channel, just to the north of the eastern end of the causeway, is located inside the study area and provides measurements with which to compare numerical model predictions. The ends of the defined study area are far enough from the vicinity of the causeway to allow examination of the full circulation pattern in its vicinity, yet not so far away as to introduce ambiguities in the boundary conditions. Along the south Texas coast, wind-generated currents often dominate the tidal forcing from the Gulf. For this project, hourly values of wind velocity (6-min average) were available at both Bird Island and NAS, and the data from NAS were used.

Bathymetry

The bathymetry in the study area is marked by numerous along-axis and across-axis channels in addition to the GIWW. Natural islands, islands made of dredged material, and islands constructed for hydrocarbon extraction are also located in the study area. Toward the north, as the entrance of ULM opens into Corpus Christi Bay, a shallow ridge popularly called "The Bulkhead" runs approximately east-west on the east side of the opening. On the west side, flow is also restricted by connection of Demit Island to the mainland occupied by the Naval Air Station. A map produced in 1846 shows that in the study area the ULM was deepest along the eastern shore, near which a broad channel ran through otherwise very shallow water (Duke 1990). Along-channel (along-lagoon) flow was favored on the western bank of the lagoon because of forcing by the predominant southeast sea breezes of summer (persisting some 9 months of the year) and the strong northeast winds accompanying fronts moving from the north in winter.

Current

Through cooperative sponsorship agreement involving the Coastal Bend Bays Foundation, the Port of Corpus Christi Authority, TXDOT, the TGLO (Oil Spill Prevention and Response), and other organizations, in June, 1994, the Blucher Institute began monitoring the currents at the openings in the causeway. Current meters were installed at mid depth under the causeway at Humble Channel, the GIWW, and the Relief Channel. The current is measured with an accurate acoustic meter (Kraus et al. 1994). Three components of the current are measured at 1-sec intervals, and 6-min averages of these readings are stored. These current meters provided data for verifying the hydrodynamic model and for quantifying the exchange between Corpus Christi Bay and Upper Laguna Madre. The value of the present flow measurements is that they are being made over time periods simultaneously with measurement of the water level and wind.

NUMERICAL SIMULATIONS

1D Model

The fully implicit 1D model DYNLET (Amein and Kraus 1992) was first established to examine rapidly and economically the time intervals for which complete data were available. In this reconnaissance, the responses of the lagoonal circulation to various wind and tide forcing were examined. The model was calibrated for a Manning's coefficient value of 0.033. In addition to revealing properties of the data sets, two general results were obtained: (1) It was essential to account for transition losses at the openings in the causeway to reproduce measurement of currents at the openings; and (2) Removal of sections of the causeway did not notably increase total discharge along the lagoon. Interpretation of the latter result is that the channels at the GIWW and Humble Channel have now scoured to equilibrium depth to allow complete water flow. Depth under the causeway at Humble Channel has increased from an estimated 2 m in 1950 to 7.5 m at present; similarly, scour at the GIWW has taken the depth from 4 m to 8 m.

2D Model

The depth-averaged horizontal circulation was simulated with an explicit-solution, finite-difference model (Militello 1993) established on an irregularly spaced rectangular grid. Grid cell dimensions ranged from 40 m to 600 m. Flexibility in setting cell size allowed fine resolution of channels and islands, and the model consisted of 13,000 active cells. Three types of boundary conditions were specified: 1) open tidal-forcing, 2) constant flow rate forcing, and 3) closed, reflective boundaries. In addition to the tidal and constant flow forcing conditions, wind forcing (wind speed and direction) was included. The tidal-forcing data were Fast Fourier Transform smoothed to eliminate spikes associated with vessel traffic, and water levels were adjusted to mean lower low water (MLLW) at each gauge. The levels of the MLLW datums were not changed relative to one another. In the calibration, which involved summer conditions of July, 1994, and southeast winds (which blow approximately 9 months of the year), a Manning's friction coefficient value of 0.035 was used except in the cells in the vicinity of approximately ± 100 m from the channels under the causeway, for which the larger coefficient value of 0.2 was applied to account for the transition (flow expansion and contraction) loss. The calibrated model was tested for representative winter (northeast) winds that occurred in April, 1995.

Calibration and verification results for water level and current are shown in Figures 2 and 3 and in Figures 4 and 5, respectively. The structure and magnitude of the measured water level are well reproduced by the model, including the hourly water-level change as well as the longer trend. A slight phase shift is observed in calculated water level for the July, 1994, period of low water. The shift is believed to be caused by inaccuracies in the inferred bathymetry, which would become more apparent as the water level decreases, making uncertainties in depth more notable for smaller mean depth.

The structure of the along-channel current at Humble Channel is well reproduced, but the magnitude is typically over-estimated. Two possible reasons for the over-estimation are: (1) the current meters, mounted on bride pilings or fenders, might be located in the boundary layer or otherwise sheltered, thereby tending to give a reduced flow speed; and (2) the wind drag coefficient given by the WAMDI Group (1988), although developed for shallower water, may not apply to the very shallow water of the Laguna Madre. Overall, the results of the model were judged to be highly satisfactory for conducting an assessment of the alternative designs for elevating the causeway.

HYDRODYNAMIC ASSESSMENT

The 2D hydrodynamic model reproduced the two general results found with the 1D model, namely that: (1) It was essential to account for transition losses at the openings in the causeway to reproduce measured currents; and (2) Removal of sections of the causeway did not notably increase total discharge along the lagoon.

The circulation was simulated with the calibrated model for five design alternatives, defined by the length of causeway elevated, under summer and winter wind conditions. Of particular interest was the areal extent of improved flow over the shallow flats of the Laguna Madre. Figure 6 is an example of a flow difference plot obtained by subtracting the current velocity with the existing condition from the velocities calculated, for this case, with Alternative 4a, which elevated the westernmost 1.5 km (5000 ft) of the causeway. Difference vectors were plotted for cells having an increased circulation greater than 0.01 m/sec. It was found that this alternative gave almost the same improved circulation and reduction of stagnation areas as for the alternative of removing the entire causeway. In addition, Alternative 4a tended to re-establish the flow pattern that was inferred from consideration of the 1846 map.

Figure 7 compares calculated total areal increase in circulation for the alternatives during an ebb tide with southeast winds. Alternative 5 is elevation of the entire causeway.

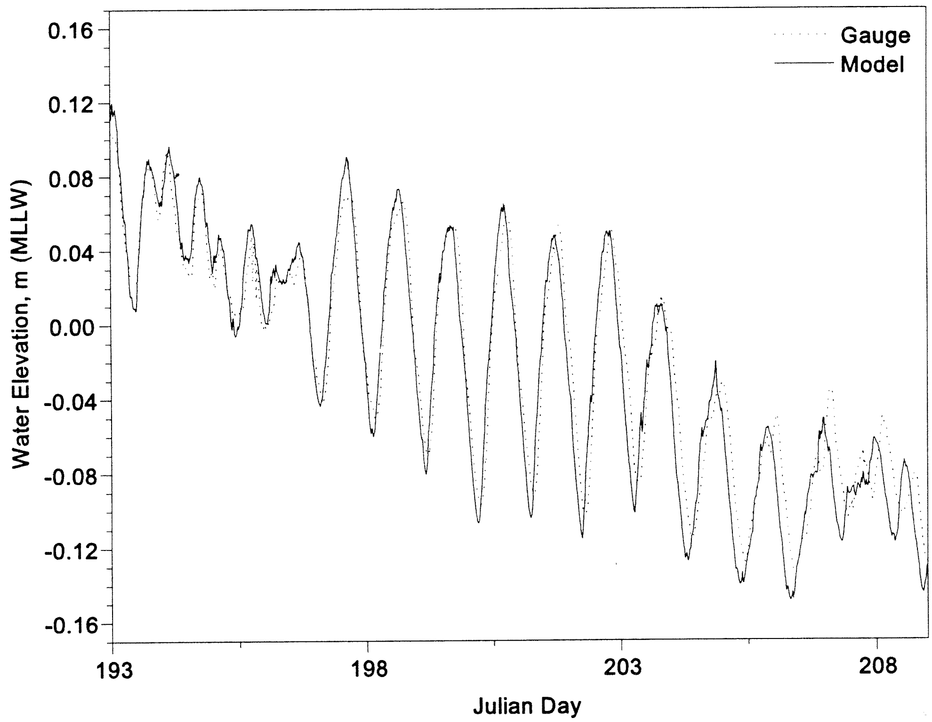

Figure 2. Comparison of measured and modeled water elevation at Packery Channel for July 12-28, 1994.

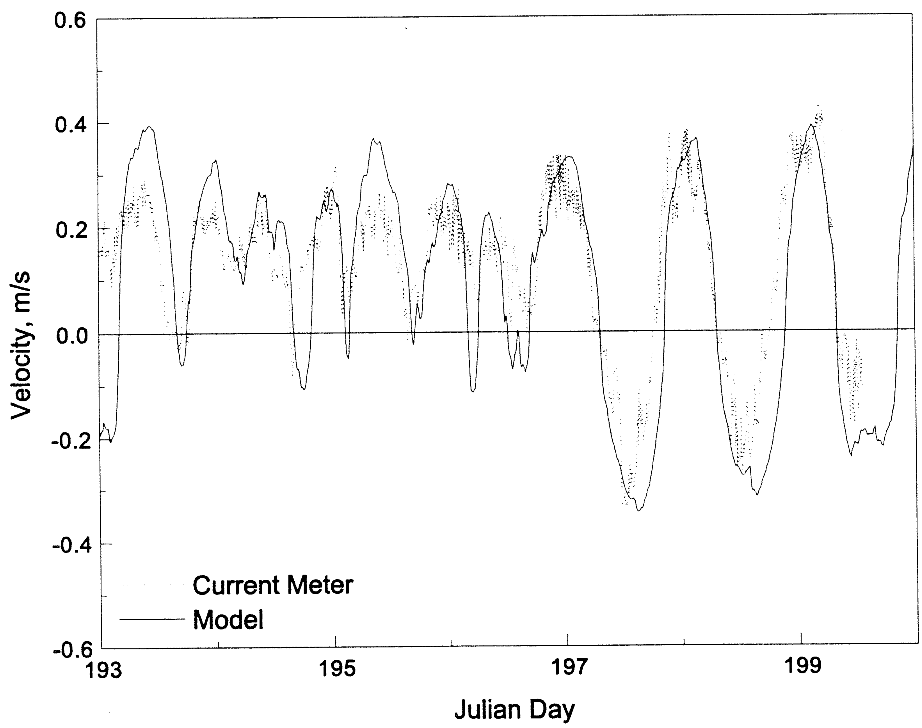

Figure 3. Comparison of measured and modeled current at Humble Channel for July 12-19, 1994.

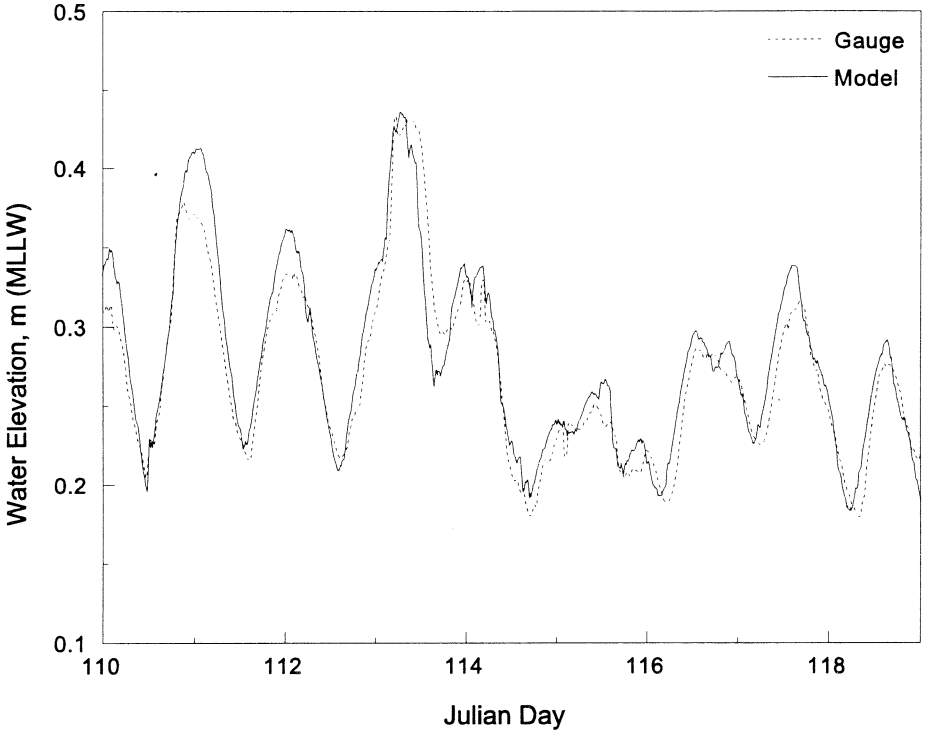

Figure 4. Comparison of measured and modeled water elevation at Packery Channel for April 20-29, 1995.

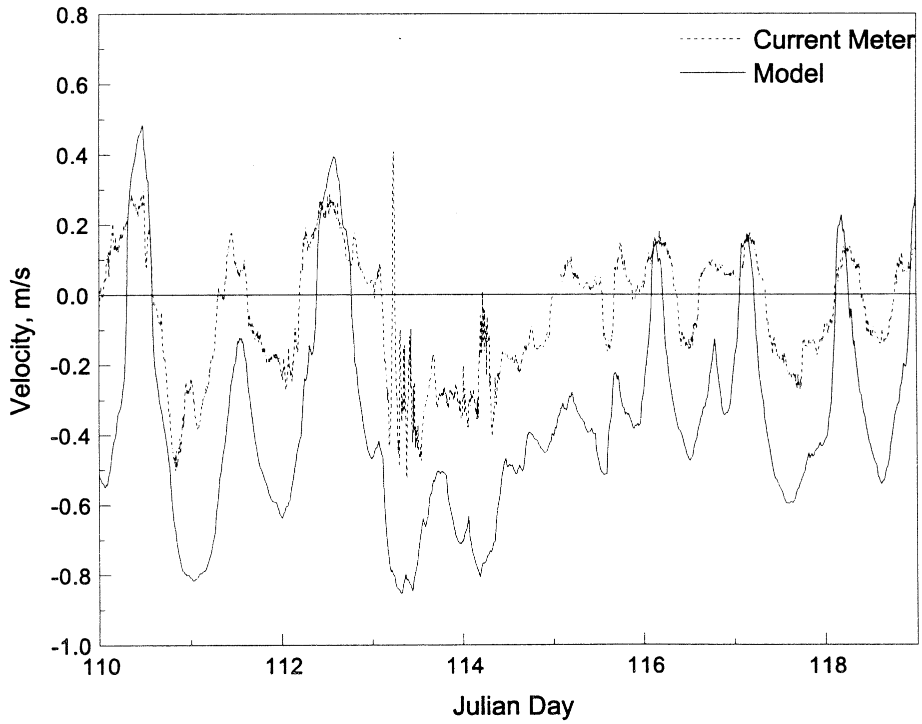

Figure 5. Comparison of measured and modeled current at Humble Channel for April 20-29, 1995.

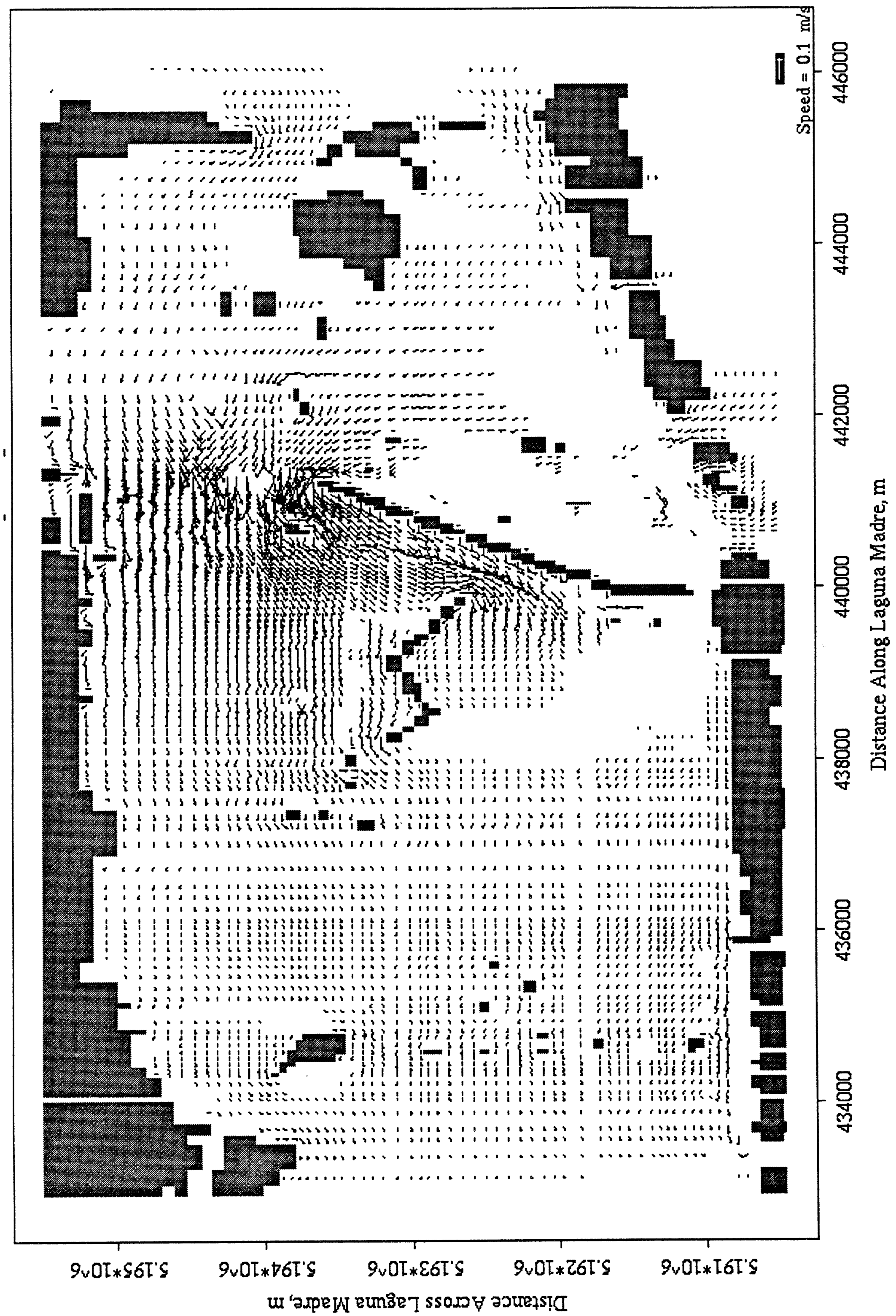

Figure 6. Vector plot of differences in circulation between existing configuration and Alternative 4a.

Brown, Militello & Kraus

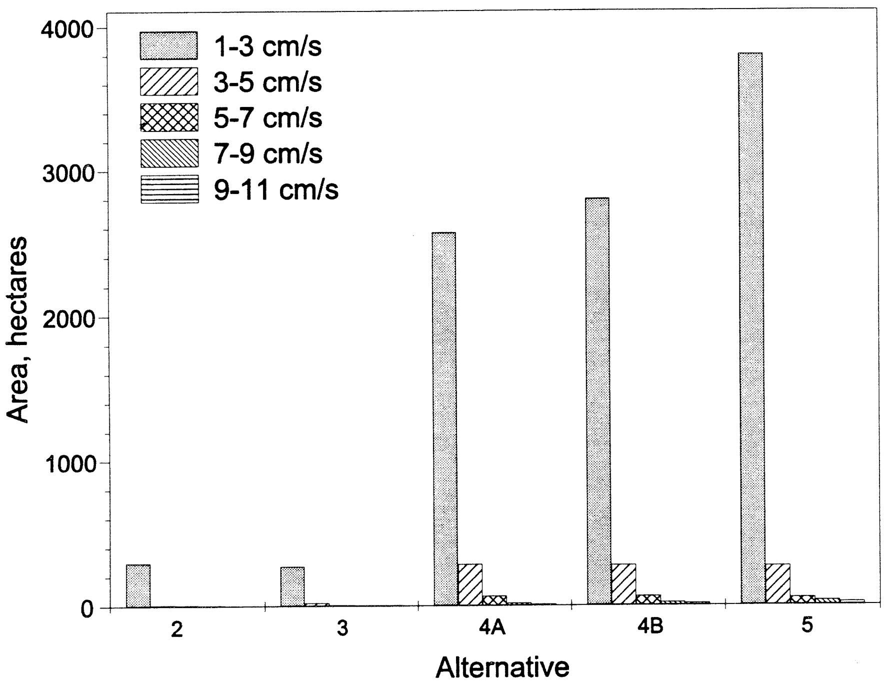

Figure 7. Comparison of total areal increase in circulation for alternatives during ebb tide with southeast winds.

Alternatives 2 and 3 consist of 1000-ft and 2000-ft openings, respectively. Alternative 4b is the same as Alternative 4a with an additional 500-ft opening in the center of the causeway and Alternative 5 is elevation of the entire causeway. The results are typical in showing that the increases in circulation obtained with Alternatives 2 and 3 are limited, and Alternatives 4a, 4b, and 5 produce increased ciculation over approximately 10 times the area as Alternatives 2 and 3. The predominant increase in velocities for all alternatives is in the range of 1-3 cm/s. Alternative 5 only produces minimal increases in benefits as compared to the more economical Alternative 4b of raising only the westerly section.

CONCLUDING DISCUSSION

A hydrodynamic assessment of water circulation was conducted for evaluating alternative designs for elevating the JFK Causeway. The study could proceed in an unambiguous manner by availability of TCOON data on water elevation and wind and by availability of current measurements sponsored by environmental and oil-spill response interests. Two levels of numerical simulation model were used to conduct the assessment in the relatively short time of six months, which included collection of supplementary bathymetry data.

A calibrated model of the 2-dimensional circulation showed that a relatively inexpensive alternative of elevating only the westernmost 1.5 km (5000 ft) of the causeway provided almost the same benefit as that resulting from the much more costly alternative of elevating the entire causeway. Considerations of biological processes must be added to the hydrodynamic assessment to reach a final design.

ACKNOWLEDGEMENTS

This study was sponsored by the Texas Department of Transportation, which provided an unconstrained and encouraging environment in which to conduct this study.

REFERENCES

Amein, M. and Kraus, N. C. 1992. DYNLET: Network Model for Tidal Inlet Dynamics. *Proc.2nd Intern. Conf. on Estuarine and Coastal Modeling*, ASCE, 644-656.

Collier, A., and Hedgpeth, J. W. 1950. "An introduction to the hydrography of tidal waters of Texas." *Contributions of Marine Science,* 1(2): 121-194.

Duke, J. H. 1990. "Upper Laguna Madre modeling study in the vicinity of the John F. Kennedy Causeway, Corpus Christi, Texas." Report for Texas General Land Office, Austin, Texas.

Kraus, N. C., Lohrmann, A., and Cabrera, R. 1994. "New acoustic meter for measuring 3D laboratory flows," *J. Hydraulic Engineering*, 120(3): 406-412.

Matsumoto, J. 1991. "Simulation analysis of changes in flow exchange in the upper laguna Madre with removal of portions of the John F. Kennedy Causeway. Part II. Study of the opening of the John F. Kennedy Causeway." Report for Texas General Land Office, Asset Management Program, Austin, Texas.

Militello, A. 1993. "Documentation for the three-dimensional hydrodynamic model M3D and its companion program GRID. Unpublished report, Division of Marine and Environmental Systems, Florida Institute of Technology, Melbourne, Florida.

Simmons, A. 1957. "An ecological survey of the Upper Laguna Madre of Texas." *Publ. Marine Institute of Science*, University of Texas, IV(2), 156-200

Solis, R. S. 1991. "Simulation analysis of changes in flow exchange in the upper Laguna Madre with removal of portions of the John F. Kennedy Causeway. Part I. Identification and analysis of problems with model runs for the Texas General Land Office. Report for Texas General Land Office, Asset Management Program, Austin, Texas.

WAMDI Group. 1988 (Dec.). "The WAM model – a third generation ocean wave prediction model." *J. of Physical Oceanography,* 1775-1810.