Technical Report TAMU-CC-CBI-96-07

PACKERY CHANNEL FEASIBILITY STUDY: BAY CIRCULATION AND WATER LEVEL

REPORT 2 OF A TWO-PART SERIES

Final Report

by

Cheryl A. Brown and Adele Militello

Prepared for:
Naismith Engineering, Inc.
Mr. John Michael, Contract Manager
4501 Gollihar Road
Corpus Christi, Texas 78411

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Conrad Blucher Institute for Surveying and Science
Division of Coastal and Estuarine Processes
Texas A&M University-Corpus Christi
6300 Ocean Drive, Corpus Christi, Texas 78412-5503

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PREFACE

The present report is Report 2 of a two-part series investigating the feasibility of the proposed re-opening of Packery Channel. Report 1 (Kraus and Heilman 1997) covers inlet functional design and sand management, and Report 2 covers bay circulation and water level. These reports were prepared under contract with Naismith Engineering, Inc., as part of a cooperative effort involving several studies approved by Nueces County Commissioners Court, Texas. The work described in this report was authorized by Naismith Engineering, Inc., on February 12, 1996, and was conducted at the Conrad Blucher Institute for Surveying and Science, Texas A&M University-Corpus Christi by Cheryl A. Brown, Research Scientist, and Adele Militello, Visiting Research Scientist and Ph.D. Candidate at the Florida Institute of Technology, Melbourne, Florida. Mr. John Michael, Vice President, Naismith Engineering, Inc., was the contract technical monitor.

Numerous staff members of the Division of Coastal and Estuarine Processes of the Blucher Institute assisted in this study and preparation of the report. Ms. Deidre Williams, graduate student, and Ms. Margie Langley, undergraduate student, digitized aerial photographs and prepared site location maps for this study. Blucher Institute Environmental Instrumentation Laboratory personnel, Mr. Daryl Slocum, Ms. Charee Jackson, Mr. Darrell Reamer, Ms. Diana Reamer, Mr. Jamie McCormick, Mr. Robert Murry, Mr. Corey Miller, and Mr. Rob Kite, assisted in the deployment and maintenance of instrumentation, which was invaluable for calibration of the numerical model, and conducted a reconnaissance bathymetric survey in the vicinity of Packery Channel. Dr. Nicholas C. Kraus, former Director of the Blucher Institute, provided technical support and review of this report.

The authors would like to thank the U.S. Army Corps of Engineers, Galveston District, and the National Geophysical Data Center for providing digital bathymetric data of the upper Laguna Madre and Corpus Christi Bay, respectively.

EXECUTIVE SUMMARY

Packery Channel is a closed natural historic tidal inlet, located at the southeast corner of Corpus Christi Bay, which periodically re-opens during the passage of storms and north fronts. Nueces County, Texas, is considering re-opening and permanently maintaining Packery Channel to provide: 1) coastal recreational amenities to the public; 2) small-boat access to the Gulf of Mexico; 3) water exchange between the Gulf of Mexico and the Corpus Christi Bay-upper Laguna Madre system; and 4) a migration route for marine organisms. This study is the bay circulation and water-level component of a coastal processes assessment, which addresses the following concerns:

- Changes in circulation and water level.
- Changes in storm-related water level and velocities.
- Currents in the proposed opening.

The objectives of the circulation and water level component of the assessment were achieved using a two-dimensional numerical model of the hydrodynamics. Model simulations were performed for representative summer and storm conditions, as well as for various channel configurations.

Because of the small cross-section of Packery Channel relative to the Corpus Christi Ship Channel and the volume of the bay system, changes in circulation and water level associated with Packery Channel are expected to be minimal and restricted to Packery Channel and the portion of the Laguna Madre adjacent to Packery Channel. Simulations indicate that there would not be a substantial change in water-level variations at the J.F.K. Causeway; therefore, low-lying sections of the roadway are not expected to experience increased incidence of flooding if Packery Channel is re-opened. Changes in circulation would be limited to the region east of the Gulf Intracoastal Waterway and south of the "bulkhead." There would be increased tidal exchange on the shallow flats adjacent to Packery Channel and in other regions directly connected to inlet, such as in the canals of the Lake Padre subdivision, in the inner basin adjacent to the entrance channel, and at the SH361 bridge. During certain phases of the tidal cycle, there would be a small region of decreased velocities on the flats due to opposing currents flowing from the Gulf via Packery Channel and Corpus Christi Bay. Model simulations indicated that there would be no change in the currents at the intersection of Packery Channel and the Gulf Intracoastal Waterway if Packery Channel is re-opened.

At the Gulf entrance of Packery Channel, maximum velocities are expected to be approximately 3.3 ft/sec (1 m/sec). The inner basin would be relatively calm with flows of less than 1 ft/sec (30 cm/sec) and would serve as a settling basin for suspended sediment entrained in the currents. The present constriction in Packery Channel at the SH361 bridge will produce current velocities reaching approximately 3 ft/sec (1 m/sec) during non-storm conditions and approximately 5 ft/sec (1.5 m/sec) during storm conditions. Because of these relatively high velocities, the region under the bridge is expected to scour until equilibrium depth and width are achieved.

Based on model simulations and measurements from the former and neighboring Mustang Island Fish Pass, the Packery Channel inlet is expected to be predominantly flood-dominated, except during the passage of north fronts. During summer conditions, the net discharge into the Laguna Madre is estimated to be approximately 475 million gallons per day (1.8 x 10^6 m^3 per day). To put this discharge rate in perspective, the intake of the Barney Davis Power Plant in Flour Bluff withdraws 540 million gallons of water per day from the Laguna Madre for cooling purposes.

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1. INTRODUCTION

This chapter introduces the study problem and objectives, as well as provides an orientation to the study site, a description of the proposed pass, and a short description of physical processes in the study area. The technical approach for this hydrodynamic assessment is outlined, and a description of the contents and structure of this report is provided.

Problem Statement

Packery Channel is the historic southeast corner inlet for Corpus Christi Bay as discussed by Collier and Hedgpeth (1950) and Price (1952). This inlet connecting Corpus Christi Bay and the Gulf of Mexico closed sometime after the dredging of a 12-ft (4-m) deep channel from the Aransas Pass inlet into Corpus Christi Bay in 1912 (Price 1947). Packery Channel has remained closed since the stabilization of Aransas Pass and deepening of the Corpus Christi Ship Channel (except for temporary re-opening during storms). The present study was performed to consider the feasibility and impacts of re-opening and maintaining Packery Channel.

As one of two Quality of Life Projects, Nueces County, Texas, is considering re-opening and permanently maintaining Packery Channel, located between Mustang and Padre Islands, reconnecting upper Laguna Madre to the Gulf of Mexico. In the past and more recently, interest has been expressed in re-opening Packery Channel (1) to provide coastal recreational amenities to the public; (2) to provide small-boat access to the Gulf of Mexico; (3) to improve water exchange between the Gulf of Mexico and Corpus Christi Bay-upper Laguna Madre system; and (4) to provide a migration route for marine organisms.

Technical issues have been identified regarding the feasibility and impacts of the opening of the pass, including the stability of the inlet, required maintenance costs, erosion of the adjacent Gulf shoreline and channel banks, and environmental consequences.

This study is part of a coastal processes assessment conducted by the Conrad Blucher Institute for Surveying and Science to provide scientific data to aid Nueces County in determining if it should proceed with the re-opening of Packery Channel. This study addresses changes in bay circulation, water level, and current velocities associated with the re-opening of Packery Channel. A companion report (Kraus and Heilman 1997) addresses inlet stability, shoreline processes, and sand-management issues.

Background and Overview of the Site

Packery Channel is a natural tidal inlet which, together with nearby Newport Pass and Corpus Christi Pass, serves as part of a complex of storm-washover channels (Figure 1) which intermittently re-open during the passage of storms and strong north fronts. There have been several failed attempts at creating a permanent pass through the barrier island in the study area. In 1972, approximately 5 miles north of Packery Channel, Texas Parks and Wildlife Department opened Mustang Island Fish Pass to increase water exchange and provide a fish migration route between Corpus Christi Bay and the Gulf of Mexico. This narrow, 1.5-mile long channel (with bottom width of 60 ft, top width of 120 ft, and depth of 8 ft MSL) shoaled to about 4 ft MSL within 3 months of opening the pass (Behrens and Watson 1973, Watson and Behrens 1976, and Behrens, *et al.* 1977). This section will discuss the background of the present study site, including a description of the proposed design for Packery Channel and environmental setting.

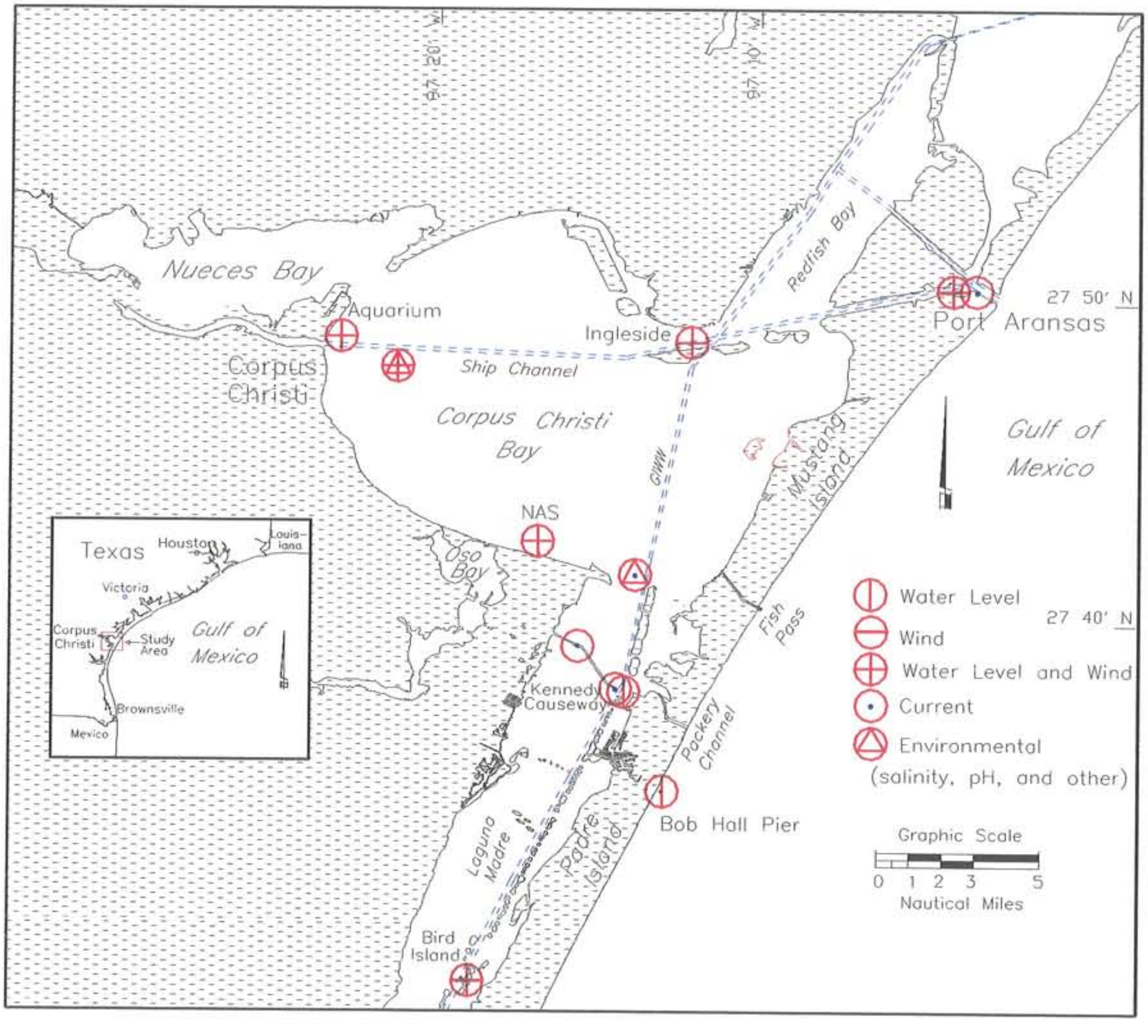

Figure 1. Location map of study area.

Description of the Proposed Pass

Figure 2 is a recent photograph of the study area overlaid with the proposed design for Packery Channel. The design consists of 1,400-ft impermeable jetties, which extend to the 11-ft mean sea level (MSL) depth contour in the Gulf and are aligned at a 12-deg orientation north from shore normal to provide shelter from southeast waves. The design for the re-opening of Packery Channel specifies an entrance channel with a depth of 11 ft MSL, 140-ft bottom width, and 1 on 3 channel slopes (Kraus and Heilman 1997), providing a cross-sectional area of 1,800 ft^2. The entrance channel opens into a relatively wide and deep inner basin with approximate dimensions of 600 ft by 500 ft and a depth of about 12 ft. Packery Channel constricts at the State Highway 361 (SH361) bridge, which presently has a cross-sectional area of about 1,200 ft^2 and a centerline depth of 11 ft MSL (from bathymetric survey performed on August 17, 1996, for this study). Landward of the SH361 bridge the bottom width of the channel ranges from 30 ft to 50 ft with a depth of 5 to 6 ft (MSL). Canals in the Lake Padre subdivision are connected to the inner basin by a 50-ft wide and 8-ft deep seagate, which is aligned approximately perpendicular to the landward end of the entrance channel.

Data Available for the Study

Figure 1 shows the location of physical processes monitoring sites operated by the Blucher Institute. Data from these sites were used for calibration and verification of the numerical models applied in this study. As part of the Texas Coastal Ocean Observation Network (TCOON), the Blucher Institute collects water level data at 6-min intervals to National Ocean Service standards as well as wind speed and direction data at 1-hr intervals. For this study, TCOON water-level gauges located at Port Aransas, Naval Air Station-Corpus Christi (NAS-CC), Bob Hall Pier, and Bird Island were used as forcing conditions, and gauges at Ingleside, Aquarium, and Packery Channel were used as interior verification points. In addition to the TCOON data-collection stations, the Blucher Institute also collect current, water level, and environmental data at several other locations in the study area, including adjacent to the Corpus Christi Ship Channel in Corpus Christi Bay (Slocum, *et al.* 1996), at the southern terminus of Corpus Christi Bay (Militello, *et al.* 1997), and at the John F. Kennedy Causeway. Wind data from the platform located in Corpus Christi Bay were used as wind forcing for the storm conditions, because wind data from this station are not influenced by land effects and the sampling interval is longer and more frequent (once every half hour for 9 min). In addition to the existing data-collection platforms, as part of this study, a temporary data-collection platform was deployed at two locations in the vicinity of Packery Channel (near SH361 Bridge and in Packery Channel approximately ¾ of mile east of the Packery Gauge). The data-collection platform provided additional water level and current data at 6-min intervals.

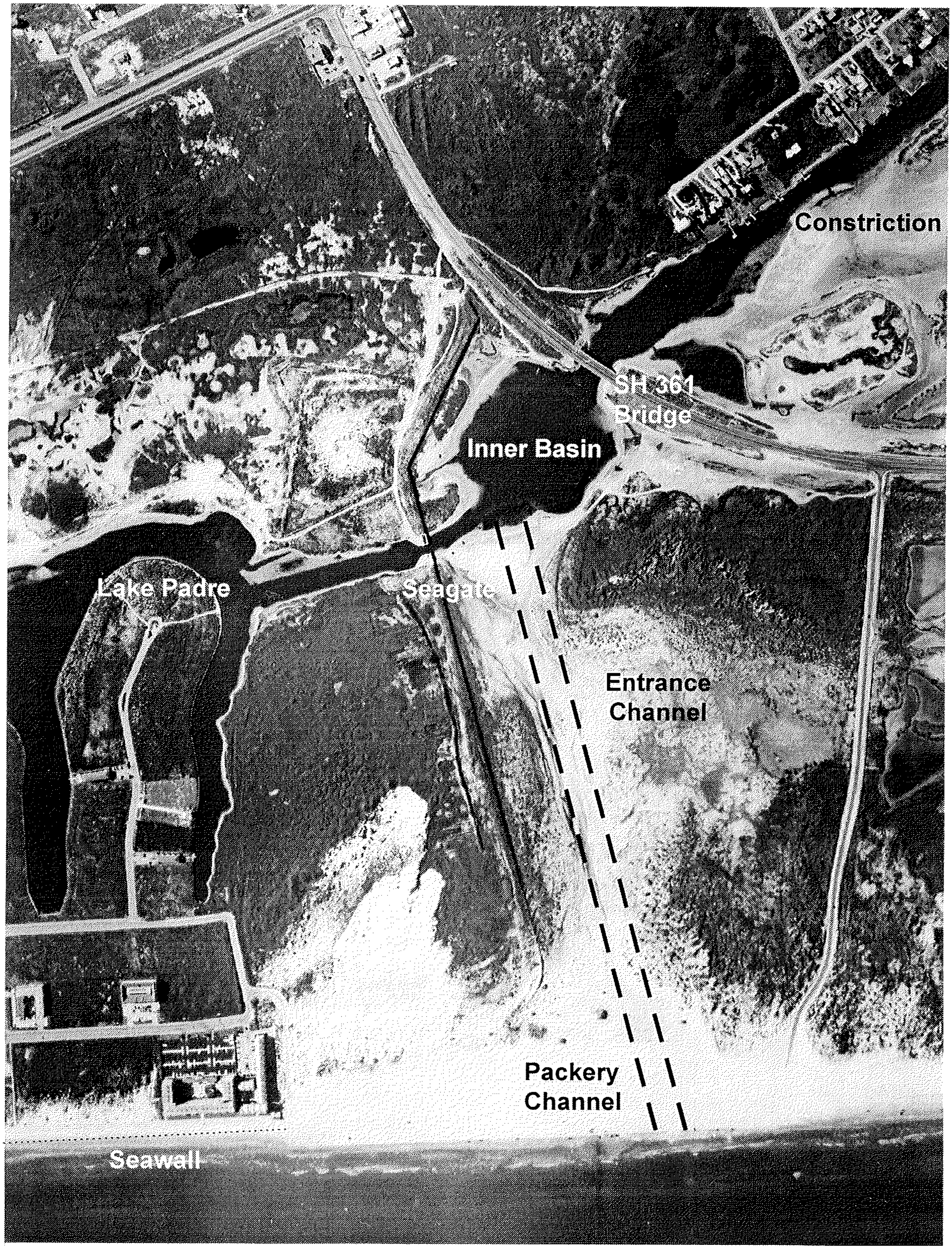

Figure 2. Aerial photograph of Packery Channel, January 12, 1996 (Lanmon Aerial Photography, Inc.).

Physical Processes in the Study Area

The study area is characterized by strong bi-modal winds originating primarily from the southeast and north quadrants. Presented in Figure 3 is the annual wind rose for 1995 at Naval Air Station-Corpus Christi (see Figure 1 for location). During the months of March or April through August or September, the study area is characterized by strong southeast winds. From September or October through February or March the region experiences strong north winds associated with the passage of cold fronts (Behrens, *et al.* 1977; Militello, *et al.* 1997).

Water-level variations in the study area occur in response to various forcing, including astronomical tides, local wind forcing, and other meteorological effects. The daily tidal ranges in the Gulf of Mexico along the Texas coast are relatively small, with diurnal and semidiurnal tidal ranges of 1.6 ft and 0.3 ft (0.5 m and 0.1 m), respectively, at the Bob Hall Pier (Figure 1). The only connection between the study area and the Gulf of Mexico is the 45-ft deep Corpus Christi Ship Channel at Aransas Pass. As the Gulf tidal signal propagates through the Ship Channel, Corpus Christi Bay, and the Laguna Madre, the signal is exponentially attenuated by the shallow water and narrow channels of the region (Smith 1977, 1988) resulting in relatively small tidal range in the vicinity of Packery Channel (approximately 0.4 ft or 12 cm).

The primary hydrodynamic connection between the relatively deep (14 ft or 4 m) Corpus Christi Bay and the shallow Laguna Madre (average depth of about 3 ft or 1 m) is via the Gulf Intracoastal Waterway (GIWW), a 12-ft (4-m) deep and 125-ft (38-m) wide channel (bottom width) dredged through the entire length of the Laguna Madre. At the junction of Corpus Christi Bay and the upper Laguna Madre, exchange is limited to the east of the GIWW by a shallow (~1 ft), sill-like feature, referred to as the "bulkhead," and to the west by a series of islands. The bathymetry of the upper Laguna Madre is complex, composed of shallow flats (less than 3 ft) interrupted by numerous small channels and small islands.

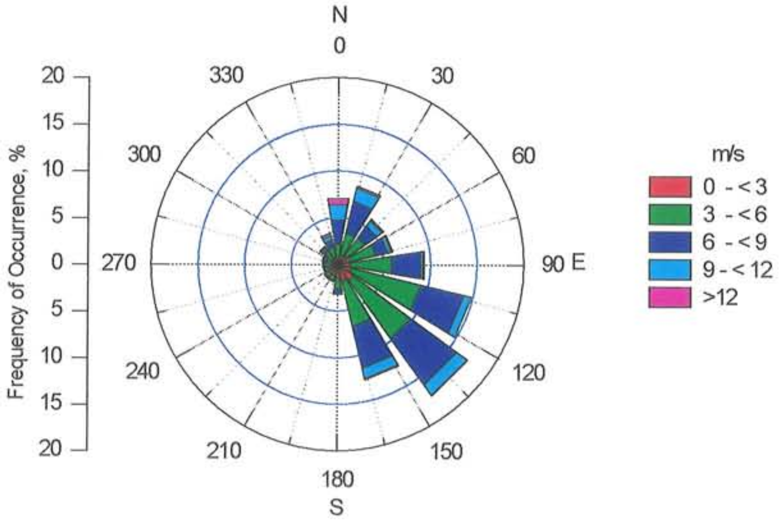

Figure 3. Wind rose for 1995 at NAS-CC.

Objectives of the Study

The objectives of the circulation and water level component of the coastal processes assessment were to estimate changes in circulation and water level with the project, Packery Channel, in place. In particular, the following were specific objectives:

- To quantify changes in circulation and water level.
- To quantify storm-related water level and velocities.
- To quantify long-term changes in water level.
- To quantify currents in the proposed opening.

Modeling Efforts

At the start of the study, an effort was made to apply a 1-dimensional (1D) numerical simulation model of the hydrodynamics (Amein and Kraus 1992) to calculate the flow and water-level change at the project site. The focus of the 1D modeling was to provide estimates, early in the study, of the expected flow along Packery Channel and at its entrance to the Gulf of Mexico. These estimates were needed for analysis of inlet stability, navigability (wave-current interaction), and inner bank erosion that were being conducted for Report 1 (Kraus and Heilman 1997). The 1D modeling was considered necessary because of other commitments of personnel and the time required to prepare the bathymetry grid and boundary conditions for the more comprehensive two-dimensional (2D) hydrodynamic numerical simulation model that was planned to be employed.

For the 1D model, it was assumed that an adequate estimate could be made of the hydrodynamics at Packery Channel if the simulated area was terminated on its northern boundary at the entrance of the Laguna Madre to Corpus Christi Bay. The TCOON water-level gauge and wind gauge at the Naval Air Station could conveniently provide water-level forcing at that boundary. The southern terminus of the simulated area was at South Bird Island, where TCOON water-level and wind gauges are also located. The TCOON water-level gauge at Packery Channel could, therefore, provide measurements at an internal point on the calculation grid for calibration of the model. Tidal fluctuations at Bird Island are very weak, and that terminus of the model was considered acceptable. There was concern that some of the water storage in Corpus Christi Bay and current flowing down the GIWW, as well as across the entire northern boundary, might contribute to increase the flow or a head (upward tilt in the water surface) at Packery Channel. The head would be caused by impedance to the southward flow caused by the Kennedy Causeway. The head and greater current would drive a stronger current through the opened Packery Channel, but would be neglected in the 1D model. Nevertheless, the judgment was made to proceed, and the model was calibrated well at the Packery Channel water-level gauge for summer, winter and storm conditions (20 days of summer conditions, 28 days during storm conditions, and 60 days of winter conditions).

A second cause of error was determined to stem from the grid configuration applied in the 1D modeling effort. The 1D grid consisted of a main channel reach extending from

South Bird Island to just north of the intersection of the Upper Laguna Madre and Corpus Christi Bay. A second reach represented Packery Channel and a portion of the shallow region of the Upper Laguna Madre between the GIWW and the SH361 bridge (existing condition) or the Gulf (with entrance). The Packery Channel reach included part of the Upper Laguna Madre north of Packery Channel so that exchange between Packery Channel and the ULM would be calculated. At the intersection of the two reaches, water could be exchanged, but this exchange was limited to the interface of the reaches. Water north of the Packery Channel reach could not move into this reach unless it came through the intersection of the two reaches. The source of error with this grid configuration was the lack of exchange between the Packery Channel reach and the region immediately to the north of it. This region was shown in the 2D modeling to be an area where the circulation patterns were altered by inclusion of the Packery Channel entrance.

As discussed in this report, the 2D model was forced at the Corpus Christi Ship Channel and, therefore, included all the storage in Corpus Christi Bay, as well as the current that would cross the north boundary of the 1D model. Upon examination, the current at the north boundary calculated with the 2D model was typically 2 to 3 times greater than that given by the 1D model. Therefore, weaker currents in the entrance of Packery Channel to the Gulf of Mexico calculated with the 1D model, as compared to those calculated with the 2D model, were considered incorrect. The analysis of the current at the north boundary of the 1D model was made subsequent to release of a draft version of this report that contained the results of both the 1D and the 2D models. Comparison of the 1D and 2D model results and investigation of the cause of the difference between calculations had to await relocation of some personnel involved in the work. Because the 1D model results are considered erroneous owing to lack of representation of Corpus Christi Bay and incorrect representation of the system by the grid configuration, the material related to the 1D model has been removed in the final (present) report. Report 2 was revised to incorporate only flows calculated with the 2D model.

Organization of Report

The two-dimensional model was applied to quantify changes in circulation and water level in the adjacent bay region as well as currents and discharge through Packery Channel. The modeling approach is presented in Chapter 2, including descriptions of the model applied in this study, boundary conditions and forcing data, and model calibration and verification results. The simulation results are presented in Chapter 3, and concluding discussion is presented in Chapter 4.

2. NUMERICAL SIMULATION OF HYDRODYNAMICS

Details of the 2D modeling effort are provided in this chapter including descriptions of the governing equations, bathymetric grids, boundary conditions, calibration, and verification.

Description of the 2D Model

The two-dimensional numerical model (M2D) applied in this study calculates water surface fluctuations and two horizontal components of the depth-averaged current at cells defined by a variably-spaced rectilinear computational grid. This numerical model has been applied in several inland waters of Texas, including the lower and upper Laguna Madre, and East Matagorda Bay (Kraus and Militello 1996; Brown, *et al.* 1995a, 1995b; Militello and Kraus 1995). The water surface fluctuations over the grid are referenced to a common datum, which was specified as mean sea level. The model calculates depth-integrated currents, which are the mean currents through the water column, for each cell in the grid. Vertical currents are not considered.

Model features implemented in this study include: water-level forcing at specified locations, open-flow boundary conditions, wind forcing with the wind stress coefficient varying with wind speed, and spatially-variable bottom friction coefficient (Manning's *n*).

The model is a finite-difference approximation of the mass continuity and momentum equations given by

$$\frac{\partial \eta}{\partial t} = h\left(-\frac{\partial u}{\partial x} - \frac{\partial v}{\partial y}\right) \qquad (1)$$

$$\frac{\partial u}{\partial t} = -g\frac{\partial \eta}{\partial x} - u\frac{\partial u}{\partial x} - v\frac{\partial u}{\partial y} + 2a_h\frac{\partial^2 u}{\partial x^2} + fv - C_b\frac{u|u|}{(h+\eta)} + C_d\frac{\rho_a}{\rho_w}\frac{W^2\cos(\theta)}{(h+\eta)} \qquad (2)$$

$$\frac{\partial v}{\partial t} = -g\frac{\partial \eta}{\partial y} - u\frac{\partial v}{\partial x} - v\frac{\partial v}{\partial y} + 2a_h\frac{\partial^2 v}{\partial y^2} - fu - C_b\frac{v|v|}{(h+\eta)} + C_d\frac{\rho_a}{\rho_w}\frac{W^2\sin(\theta)}{(h+\eta)} \qquad (3)$$

where h is the still-water level referenced to a specified datum, η is the deviation in water level from h, u is the current speed parallel to the x axis, v is the current speed parallel to the y axis, g is the acceleration due to gravity, a_h is a horizontal coefficient of eddy viscosity, f is the Coriolis parameter, C_b is an empirical bottom friction coefficient, C_d is a wind stress (drag) coefficient, ρ_a is the density of air, ρ_w is the density of water, W is the wind speed, and θ is the wind direction. The value of the eddy viscosity was not assigned for this project because the mixing term was not included in the computations. The Coriolis parameter is given by

$$f = 2\Omega\cos(\varphi) \tag{4}$$

where Ω is the angular frequency of the earth's rotation, and φ is latitude. The friction coefficient is calculated by the equation

$$C_b = \frac{g}{C^2} \tag{5}$$

where C is the Chezy coefficient given by

$$C = \frac{R^{\frac{1}{6}}}{n} \tag{6}$$

where R is the hydraulic radius, and n is the Manning coefficient. The hydraulic radius is the cross-sectional area divided by the wetted perimeter. The wind stress is variable and depends on the wind speed. The formulation for the wind stress coefficient applied in the model is given by (Hsu 1988)

$$C_d = \left(\frac{0.4}{14.56 - 2\ln U_{10}}\right)^2 \tag{7}$$

where U_{10} is the wind speed at 10 m. The value of U_{10} from measurements collected at other anemometer heights is approximated by (USACE 1984)

$$U_{10} = W\left(\frac{10}{H_w}\right)^{\frac{1}{7}} \tag{8}$$

where W is the wind speed at the anemometer height H_W.

A finite-difference approximation was implemented expressing the governing equations in numerical form. The finite-difference scheme is central in space, explicit in time for the momentum equations (with the exception of the advective terms), and partially explicit in time for the continuity equation. The approximation for the continuity equation incorporates updated values of velocity from momentum equation calculations and applies those values to the calculation of the water surface elevation. The advective terms (second and third terms in Eqs. 2 and 3) are spatially and temporally averaged to reduce numerical instabilities.

The time step Δt for the model is limited by the stability criterion

$$\Delta t \leq \frac{\Delta s}{\sqrt{gh}} \tag{9}$$

where Δs is the size dimension of a cell, and s is representative of either the x or y coordinate. Practical application of this criterion for the M2D model requires the time step to be approximately 0.6 to 0.7 times the theoretical maximum time step given by Eq. 9. For simulations performed in this study, a time step of 1 sec was specified.

Three types of boundary conditions applied for this study were:

1. Water surface elevation forcing boundary.
2. Open boundary with no forcing.
3. Closed, reflective boundary.

The water surface elevation forcing boundaries were applied at the Corpus Christi Ship Channel boundary for the existing condition. For simulations performed with Packery Channel open, water surface elevation forcing boundaries were applied at the Corpus Christi Ship Channel and the Gulf of Mexico. These boundary conditions apply water-level data to specific grid boundary cells so that the water surface in these cells vary exactly as the input data. Open boundary conditions were applied at grid cells that reside on water conduits extending beyond the grid domain. Water can flow in and out of the domain at these boundaries. The locations where this type of boundary are applied at the northern and southern boundaries, Redfish Bay and Bird Island, respectively. An open boundary condition represents a flow for which there is no gradient (no change) in slope between the cells adjacent to the grid boundary.

Closed reflective boundaries do not allow water to flow through them and can be considered as walls. Velocities in cells with this type of boundary condition must be aligned parallel to the boundary so that the velocity perpendicular to the boundary is zero. Closed reflective boundaries were specified at the perimeter of the bay and adjacent to islands.

Representation of Study Area

A computational grid is a discretized representation of the model domain and contains information specific to each cell included in the grid. M2D requires a rectilinear grid, but the grid can be variably spaced. Spacing of the grid can be fine or coarse depending on the resolution required of a particular region of the grid. The grid contains the following information for each cell:

1. Cell number.
2. Cell numbers of neighboring cells.
3. Boundary conditions for each side of the cell.
4. Cell type.
5. Cell dimensions.
6. Cell depth referenced to a specific datum.
7. Manning friction coefficient.
8. Row and column numbers.
9. Latitude.
10. *x*- and *y*-coordinates of the cell center.

Grid-generation software was used to develop the various grid layers and to incorporate the detailed bathymetric data available for this study. Highly-detailed rectilinear, irregularly-spaced grids extending from Port Aransas to Bird Island were generated, including Corpus Christi, Redfish, and Nueces bays, and the northern portion of the Laguna Madre (from Corpus Christi Bay south to Bird Island). Oso Bay and the intake of the Barney Davis Power Plant were not included in this modeling effort. Brown, *et al.* (1995a, 1995b) found that the zone of influence of the intake of the power plant was limited to the immediate vicinity of the intake. Freshwater inflows into Nueces Bay were not included in this modeling effort. The northern limit of the grid was located in Redfish Bay, where SH361 crosses Redfish Bay. Grids were created for the existing condition and for the proposed re-opening of Packery Channel. Each grid consisted of approximately 25,000 active computational cells with cell dimensions ranging from 46 ft (14 m) to 1040 ft (317 m). Figures 4 and 5 show the bottom topography and grid domain for each of the grids generated for this study. Figure 6 is a detailed view of the bathymetric grid in the vicinity of Packery Channel. In these figures, the black regions indicate inactive cells or land, and the colored regions represent active cells with the color indicating approximate depth in meters.

Digital bathymetric data required for the generation of the grids were provided by the U.S. Army Corps of Engineers and the National Geophysical Data Center. All bathymetric data were referenced to Mean Lower Low Water (MLLW) with positions in NAD83 State Plane Coordinates. The geographic coordinates were rotated 24.5 deg clockwise (east of north) to align the *y*-axis of the grid with the longitudinal axis of the Laguna Madre. Depths for Nueces Bay were approximated from bathymetric contours published in Mannino and Montagna (1996). Location of land boundaries in the study area were determined from nautical charts and aerial photographs (taken on February 11, 1995 and January 12, 1996). Utilizing water level datums computed for Texas Coastal Ocean Observation Network (TCOON) gauges in the study area (for location of gauges see Figure 1), all bathymetric data were adjusted to MSL.

Table 1. Datums for TCOON gauges in study area.

Gauge	Difference between MLLW and MSL, ft (cm)	Tidal Range, ft (cm)
Bob Hall Pier	0.9 (27)	1.3 (40)
Port Aransas	0.5 (15)	0.8 (24)
Ingleside	0.3 (9)	0.8 (24)
Aquarium	0.3 (9)	0.6 (18)
NAS-CC	0.3 (9)	0.6 (18)
Packery Channel	0.2 (6)	0.4 (12)
Bird Island	less than 0.2 ft	less than 0.2 ft

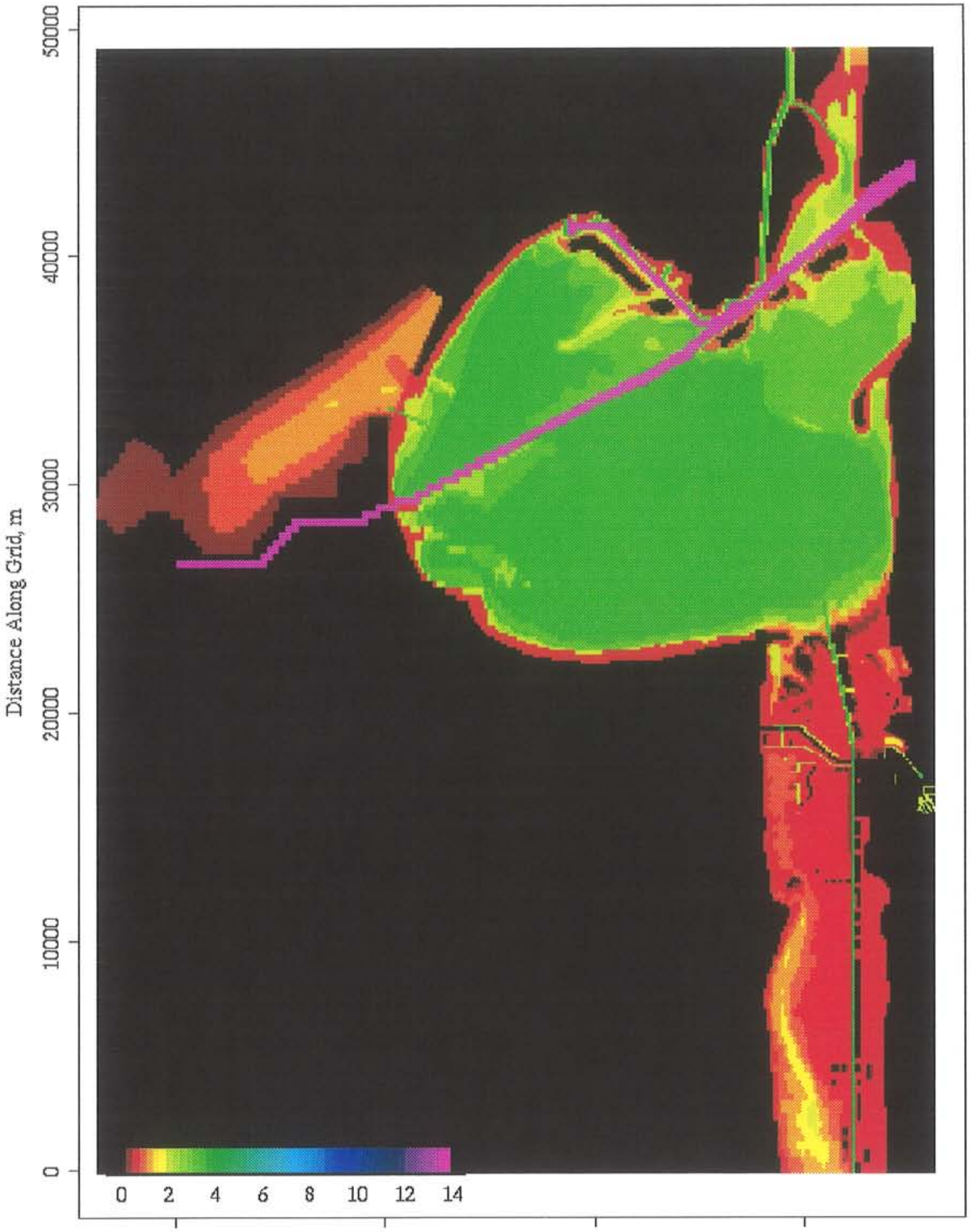

Figure 4. Bathymetric grid for existing condition with depth indicated in meters (MSL).

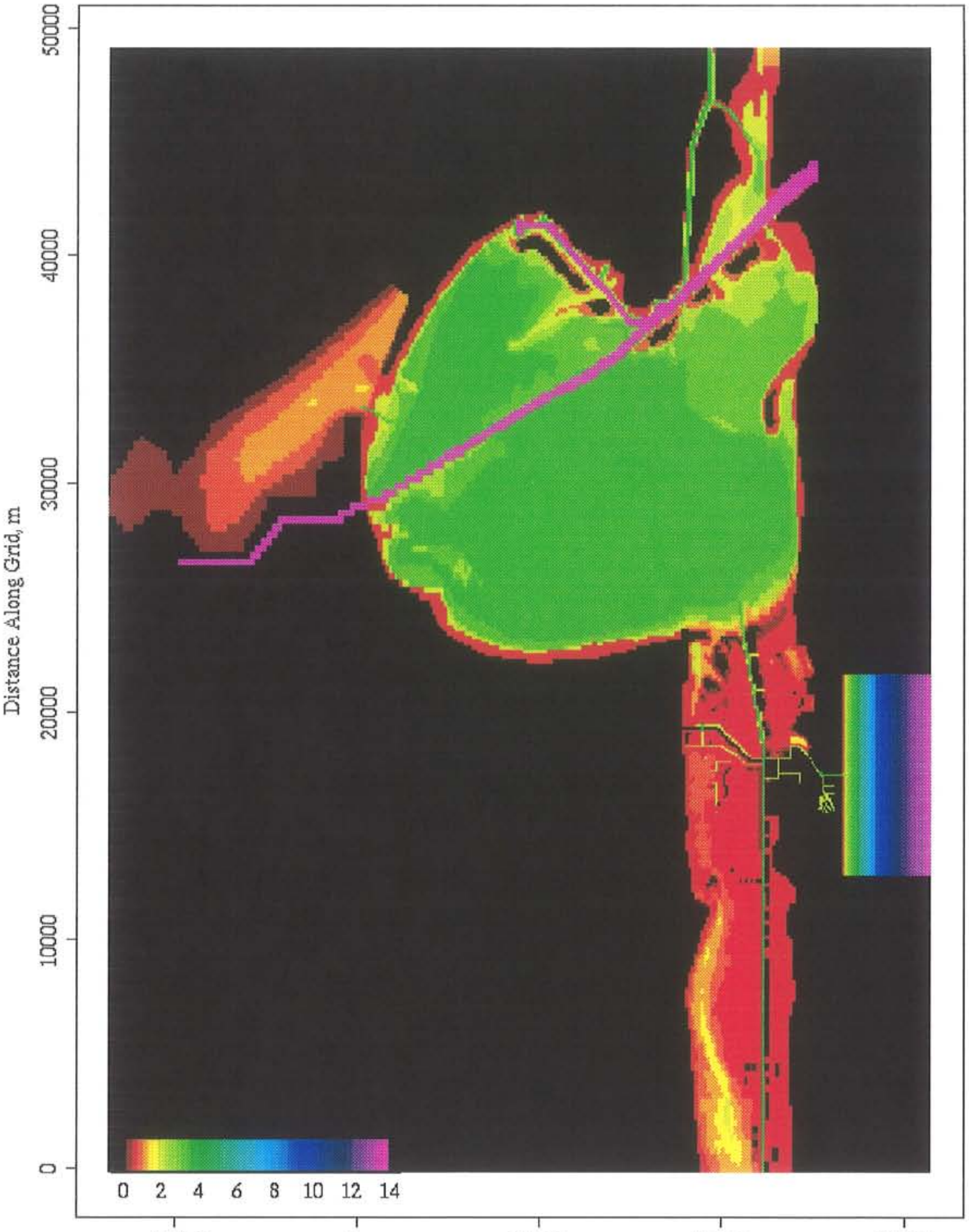

Figure 5. Bathymetric grid for proposed re-opening of Packery Channel with depth indicated in meters (MSL).

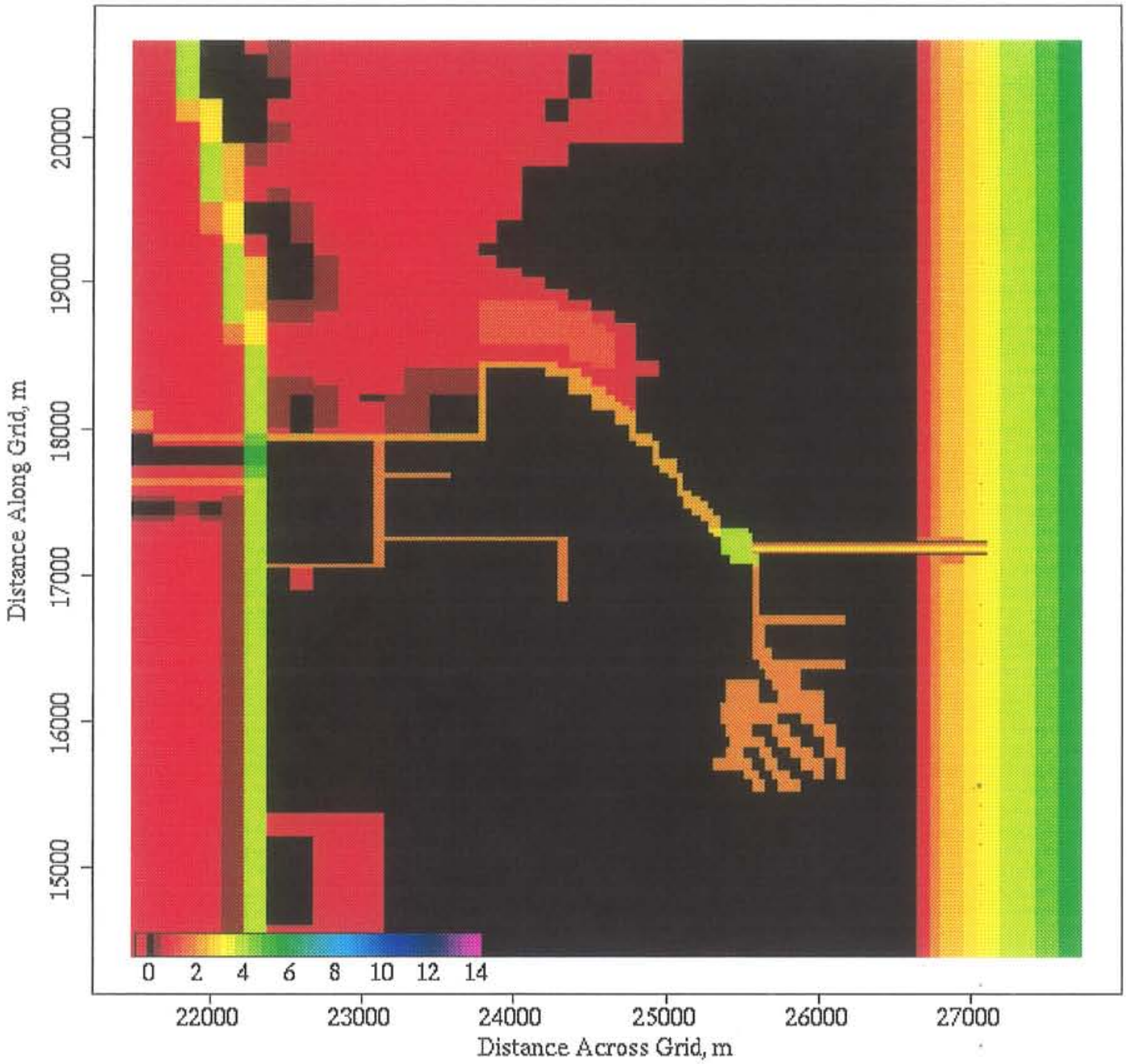

Figure 6. Detailed bathymetric grid in vicinity of Packery Channel.

Forcing Data and Initial Conditions

Water surface elevation data from Port Aransas Gauge (located in the Corpus Christi Ship Channel - see Figure 1) provided the open water surface elevation forcing for model simulations performed for the existing condition. Water surface elevation data from both Port Aransas and Bob Hall Pier (located in the Gulf of Mexico - see Figure 1) provided the water surface elevation forcing for simulations performed with Packery Channel open. Wind forcing (wind speed and direction) was included using data from Naval Air Station-Corpus Christi for summer conditions, and Corpus Christi Bay for storm conditions. Water surface elevation data were low-passed filtered to eliminate variations in the water level with periods less than 5 hours, such as those associated with the passage of ships. All water surface elevations were referenced to the local MSL determined for each of the gauges. Small breaks in the forcing data (water level and wind) were filled using linear interpolation of the data points adjacent to the gap.

Model simulations were performed for two representative conditions, summer and storm conditions. Summer conditions were simulated for the two-week interval of Julian Day 182 to 196, which correspond to June 29 - July 14, 1996 (Figure 7). The period of Julian Day 275 to 285 (October 1-10, 1996) was selected as a representative storm condition (Figure 8), which included the presence of the recent Tropical Depression/Storm Josephine in the Gulf of Mexico. Although this tropical depression did not pass through the study area (Figure 9), it caused flooding along the Texas Gulf coast and a dramatic rise in water level in inland waters of the study area. High waters from this storm flooded the J.F.K. Causeway and the Gulf beaches resulting in their closing. In this study, the wind direction is expressed as the direction the wind is coming from, with 0 deg representing wind from the north and the direction increasing with clockwise rotation.

Table 2. 2D Model calibration and verification cases.

Case	Dates (Julian Days)	Duration days	Condition
2A	June 30-July 14, 1996 (182-196)	15	Typical southeast wind, no extreme events
2B	October 1 - 10, 1996 (274-285)	10	Storm condition, includes the passage of Tropical Depression/ Storm Josephine

In addition to forcing conditions, the model requires specification of initial conditions for the water elevation and current velocities. Quiescent water was specified as the initial conditions for all computational cells. To minimize possibility of transient error associated with the specification of initial conditions while reducing the time required for the model to reach equilibrium, the water elevation, wind, and current measurements were examined. Simulations were begun when the local water surface elevation at all gauges in the study area were at a common elevation relative to the local MSL and wind forcing was minimal. The wind forcing was incrementally increased to eliminate impulses while the model was in the start-up transition. Typically, approximately 24 hours were required for the transients to disappear from the system.

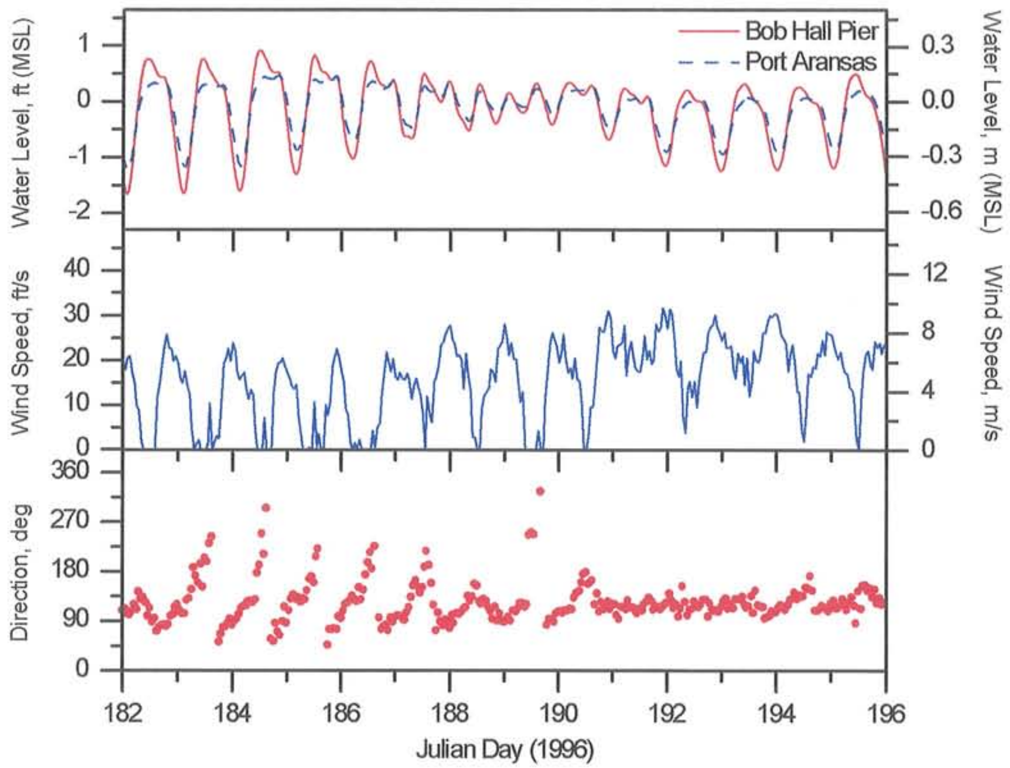

Figure 7. Forcing data for summer condition simulations (Case 2A).

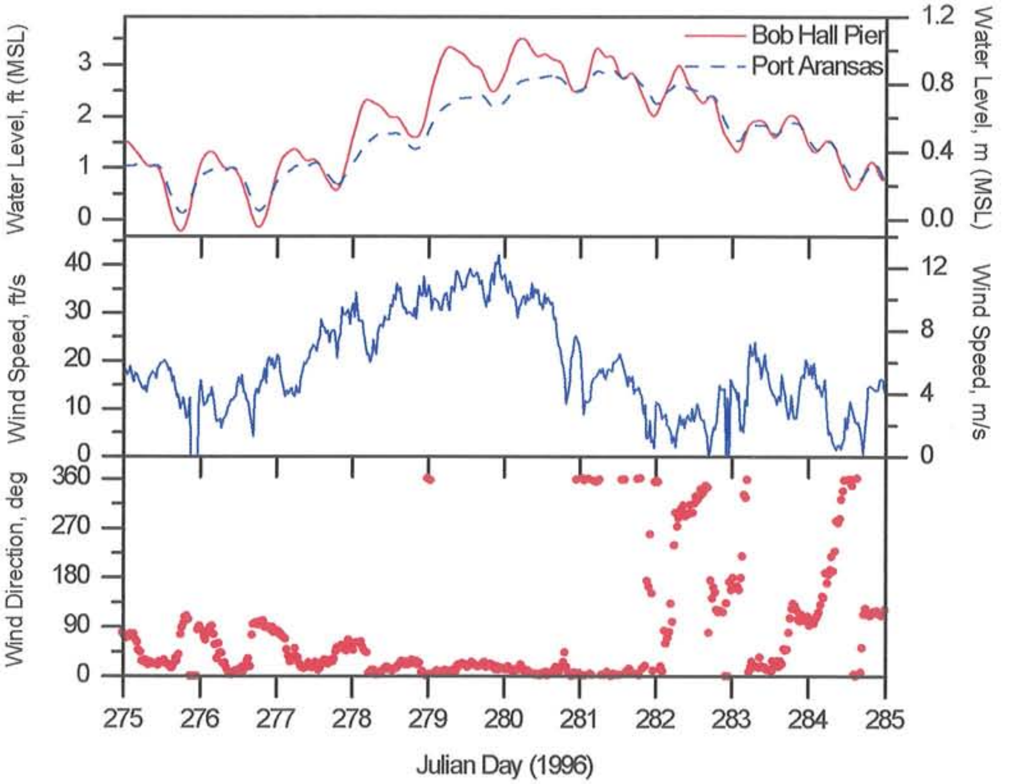

Figure 8. Forcing data for storm condition simulations (Case 2B).

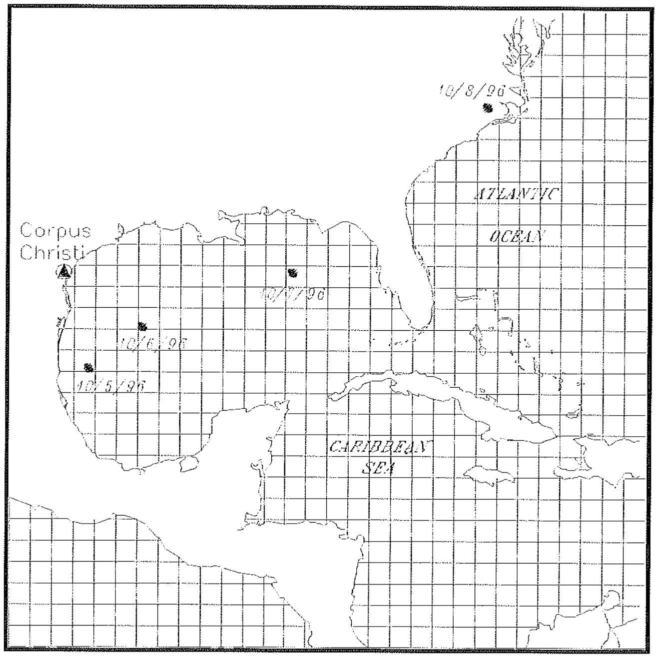

Figure 9. Track of Tropical Depression Josephine.

Model Calibration

Calibration is an iterative process in which the model is run and the output compared to measurements; then the model parameters are adjusted to bring the calculations closer to agreement with the measurements. The model is considered calibrated if the output compares well to the measurements for a range of conditions expected to be modeled. In this study, the only parameter adjusted for the calibration was the bottom friction coefficient, which took on values in the typical range for a fine sand-silt bottom (Chow 1959), $n = 0.010$ to 0.035 sec/ft$^{1/3}$. Manning coefficients applied in this modeling effort are presented in Table 6. In the Laguna Madre, friction coefficients were assigned different values depending upon the depth and the presence of vegetation. On the shallow flats and the shallow bulkhead, Manning coefficients of 0.0350 and 0.040 sec/ft$^{1/3}$ were specified, respectively. In the openings of the J.F.K. Causeway, the Manning coefficients were increased to $n = 0.30$ sec/ft$^{1/3}$ to account for transition losses associated with contraction and expansion of the flow and bridge structures which impede flow. Bottom friction coefficients are consistent with those used in previous modeling investigations of this region (Smith, *et al.* 1987; Brown, *et al.* 1995a, 1995b). For the proposed Packery Channel, the Manning coefficient was assumed to be 0.025 sec/ft$^{1/3}$, which is within the range ($n = 0.019$ to 0.030 sec/ft$^{1/3}$) of the mean value measured at Fish Pass (Behrens, *et al.* 1977, Behrens and Watson 1977). Sensitivity tests were performed by varying the Manning coefficient in Packery Channel from 0.020 to 0.030 sec/ft$^{1/3}$.

Table 3. Mannings coefficients for 2D model.	
Location	**Manning's Coefficient sec/ft$^{1/3}$**
Corpus Christi Ship Channel	0.010
GIWW	0.028
Corpus Christi Bay	0.015
Nueces Bay	0.035
Laguna Madre	0.025-0.040
Packery Channel	0.025
JFK Causeway Openings	0.300
Gulf of Mexico	0.025

Model calibration and verification were performed with the existing condition for two representative conditions or cases presented in Table 5. The model was calibrated for representative summer conditions (Case 2A) which did not include extreme events, and the model was verified for a storm event. Output at the cell corresponding to the location of the Packery Channel water-level gauge was compared to measurements taken from the gauge. Figure 7 shows the water level and wind forcing for the calibration period (Case 2A). Comparisons of water level at other gauges including Ingleside, Aquarium, and Naval Air Station-Corpus Christi are presented in Appendix A. The simulated and measured water level at the Packery Channel gauge for the calibration period are presented in Figure 10. The model accurately reproduces water-level variations with a maximum error of approximately 2 inches (5 cm). The model achieved equilibrium from an initial still surface in about one simulation day. During the last four days of the simulation (Julian Day 192 to 196), which coincide with a period of strong southeast winds, the error in the simulated water level decreased to less than approximately 1 inch (2.5 cm).

Figure 11 shows the modeled and measured north-south component of current velocity at Humble Channel (the westernmost opening in the J.F.K. Causeway - see Figure 1), where positive values indicate flow directed towards the north. The current measurements (6-min averages) are obtained from an acoustic-doppler velocimeter deployed at mid-depth in the Humble Channel opening. Unfortunately, the current meter was damaged on Julian Day 187.8 and data are not available for the remainder of the calibration interval. The model accurately reproduces the magnitude of the current flow through the J.F.K. Causeway as well as the direction of the flow. The model also reproduces the observed dominance in both magnitude and duration of flow into the Laguna Madre (southward-directed flow) present during this interval. There is a lag between the simulated and observed current velocities of approximately 3.5 hours. At times, the model overpredicts the peak current velocity by as much as 0.25 ft/sec. This discrepancy between the modeled and measured current velocities may be due to the proximity of the current meter (approximately 18 inches) to the bridge pilings. In addition, due to the relatively small dimensions of the Humble Channel the opening is represented by one cell in the two-dimension model and differences would be expected between depth-averaged modeled values and point measurements.

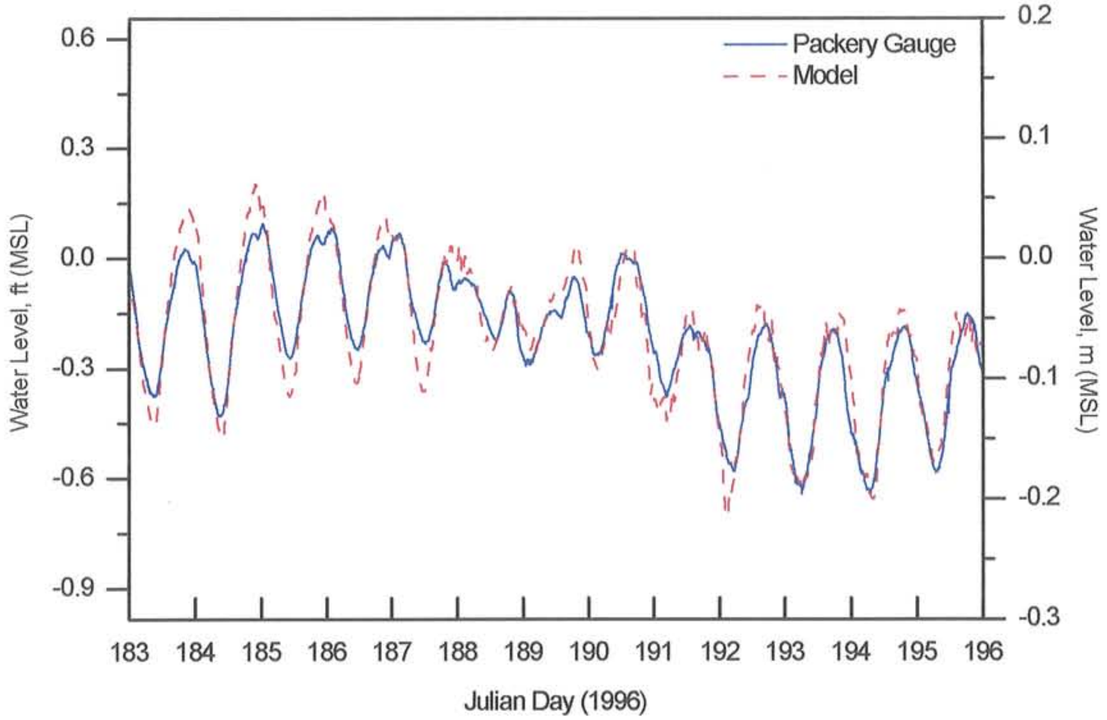

Figure 10. Measured and modeled water elevation at Packery Channel gauge for summer conditions (Case 2A).

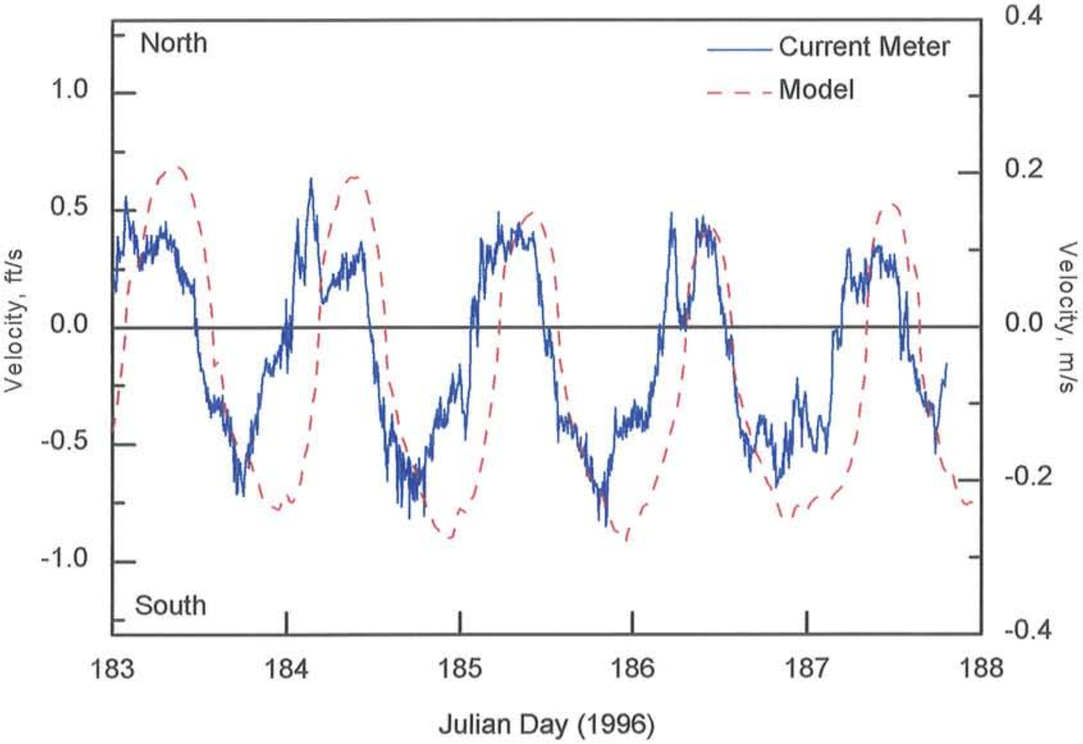

Figure 11. Measured and modeled water velocity at Humble Channel (JFK Causeway) for summer conditions (Case 2A).

Figure 12 shows the modeled and measured water elevation at Packery Channel for storm conditions. The model under-predicted the rise in the water level associated with the tropical storm by approximately 4 inches (0.1 m); however, the diurnal variations in the water level were of the proper magnitude, and the rate of draining of the bay after the passage of the storm was similar. Potential sources of error in the simulated water levels during storm conditions could be associated with the numerical model not including water level variations produced by local changes in atmospheric pressure and flow from the Gulf of Mexico into Corpus Christi Bay and the Laguna Madre associated with breaching and overwashing of the barrier island. During the passage of Tropical Storm Josephine, Packery Channel, Fish Pass, and Newport Pass opened due to high water in the Gulf of Mexico, thus providing routes for exchange of water between the Gulf of Mexico and the bay system.

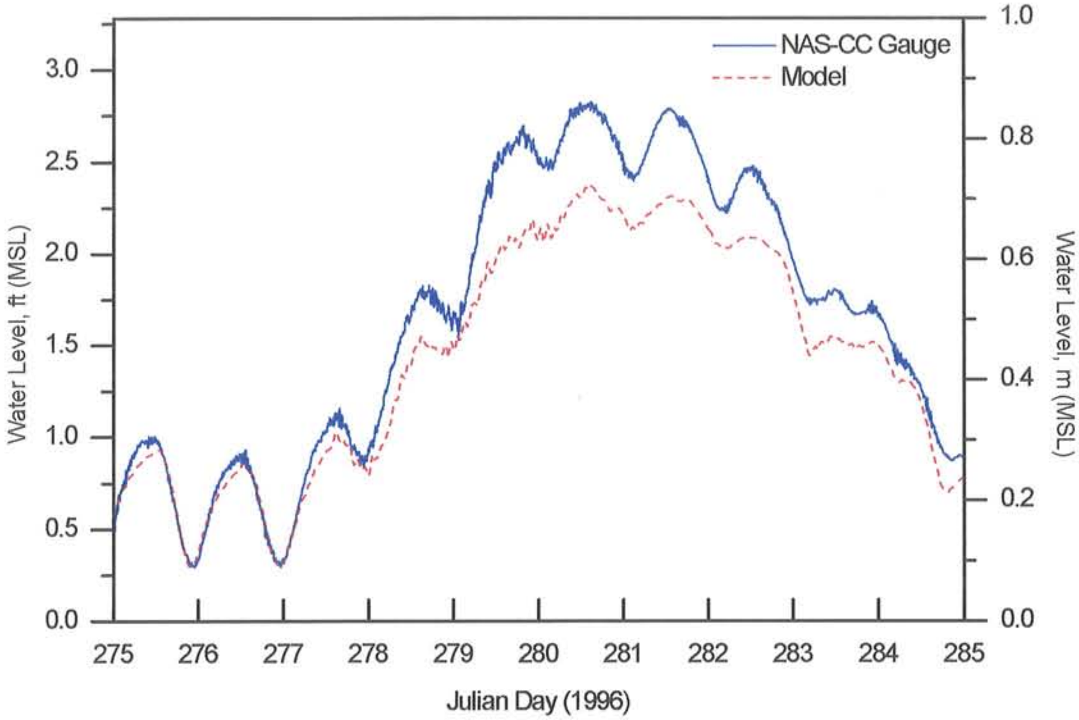

Figure 12. Measured and modeled water elevation at Packery Channel gauge for storm conditions (Case 2B).

3. SIMULATION RESULTS

Results of the modeling effort and discussion of issues pertinent to the project are presented in this chapter. Discussion and results include current speed through the Packery Channel entrance, currents along Packery Channel, circulation changes in relation to construction of the entrance, changes in water level, and sensitivity analysis to model parameters. Prediction of the current speed through the Packery Channel entrance under various conditions is necessary to assess inlet stability and navigation safety (see Report 1). The periods of most concern are when the current velocity is at its peak, which can cause modification of surface waves as they enter the entrance from the Gulf of Mexico. Strong currents may also scour the entrance and channel banks, and transport sediment. Because of the mild topographic slope and low elevation of the study area, a small increase in water elevation has the potential to cause large areas of land to be inundated and may result in increased flooding of the J.F.K. Causeway.

Results of the 2D model simulations are discussed in this section, including velocities at the Gulf of Mexico Entrance and along Packery Channel, changes in water elevation, and changes in bay circulation associated with the re-opening of Packery Channel. Simulated discharge rates through Packery Channel are compared to those measured previously at Fish Pass.

Velocities at Gulf Entrance

Figure 13 shows the along-channel velocities in the centerline of Packery Channel at the Gulf entrance during summer conditions (Case 2A) with positive and negative signs indicating ebb and flood flow, respectively. Maximum velocities occur landward of the tip of the jetties, attaining velocities as high as 3 ft/s (0.9 m/sec) during spring tides and 1.6 ft/sec (0.5 m/sec) during neap tides. At the tip of the jetties, the along-channel flow decelerates due to divergence of the flow, and peak velocities of approximately 2.5 ft/sec (0.75 m/sec) are attained. Seaward of the tip of the jetties the velocities decrease sharply with increasing distance from the jetties to less than 1 ft/sec (0.3 m/sec) within less than 400 ft (122 m) seaward of the tip of the jetties. The duration of the flood tide is longer than the ebb and during periods of strong southeast winds (Julian Day 191-196) the flood tide becomes stronger than the ebb (approximately 0.2 - 0.25 ft/sec greater). This flood enhancement is probably a result of the onshore-component of the southeast wind, which raises the Gulf water levels along the coast and lower the bay water levels on the seaward side of the bay producing a hydraulic head which enhances the flood tides (Behrens 1979). The onshore component of the wind will oppose the ebb tidal current and may shorten its duration and magnitude. Figure 14 shows the along-channel velocities at the Gulf entrance during storm conditions (Case 2B). During storm conditions, velocities as great as 3.3 ft/sec (1 m/sec) are reached at the Gulf entrance. During Julian Days 279 to 282, all of the flow is directed into Packery Channel from the Gulf of Mexico.

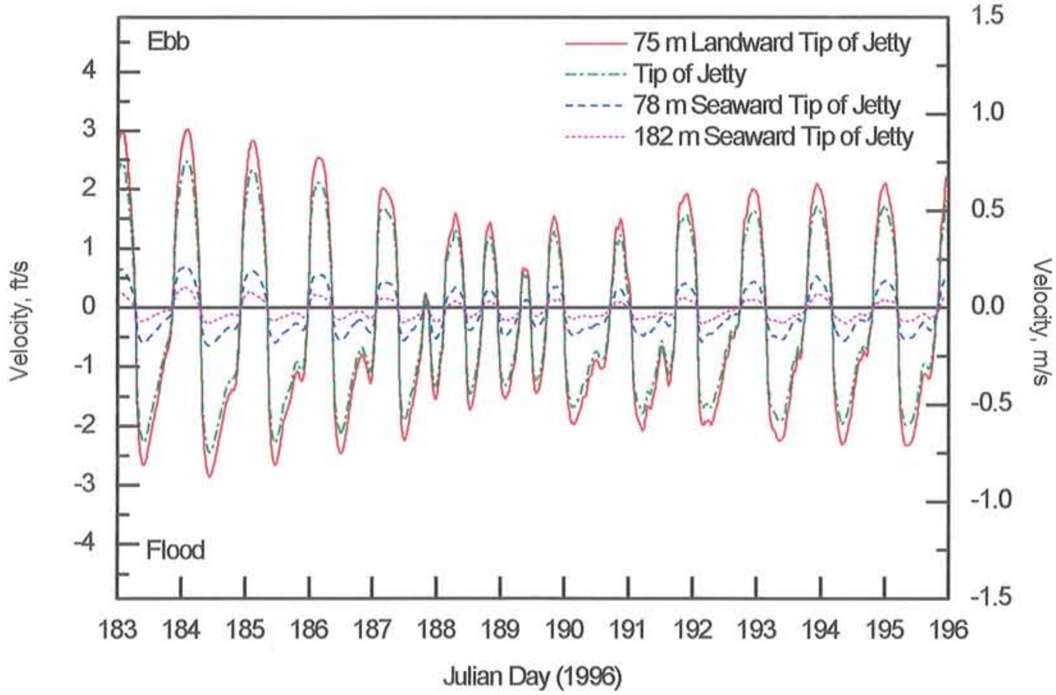

Figure 13. Along-channel velocities at Gulf entrance for summer conditions (Case 2A).

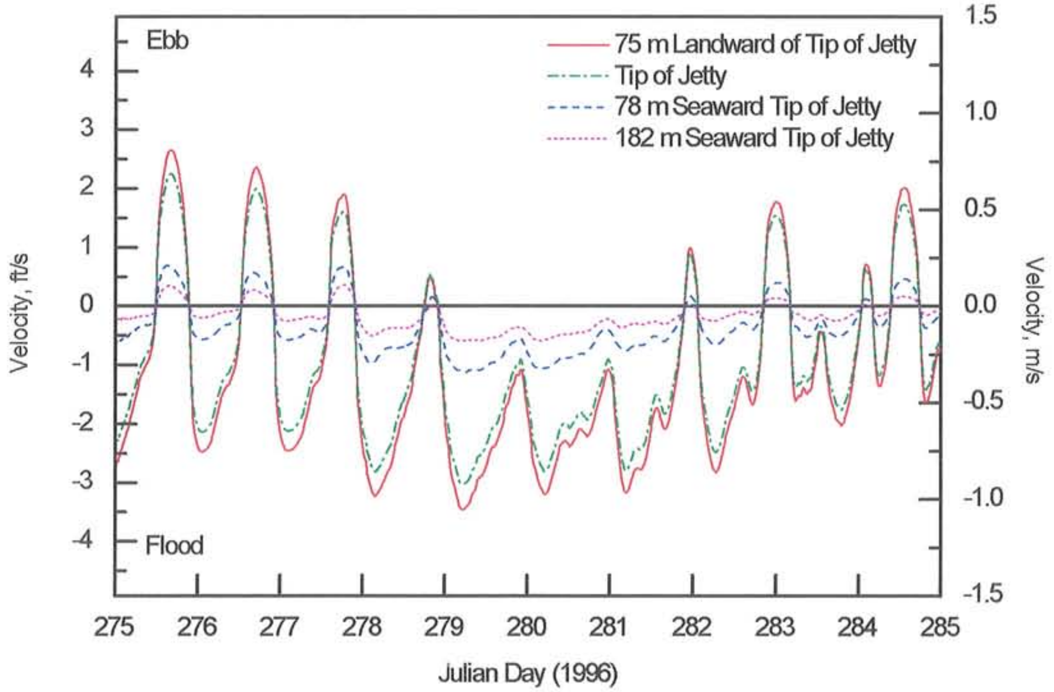

Figure 14. Along-channel velocities at Gulf entrance for storm conditions (Case 2B).

Velocities in Entrance Channel and Inner Basin

Figure 15 shows the total velocity (resultant magnitude of both velocity components, with the sign indicating whether the flow is ebbing or flooding) along the entrance channel and in the inner basin for summer conditions (Case 2A). Along the most seaward half of the entrance channel, the current remains fairly uniform with peak velocities of 2.95 ft/sec (0.9 m/sec) during summer conditions. From the middle of the channel to the landward end of the entrance channel (where the entrance channel meets the inner basin), the velocities decrease by approximately 20% due to frictional losses. In the relatively wide inner basin, the velocities decrease by about 75% to less than 1 ft/sec (30 cm/sec) in the expansion. This calm region with weaker currents will act as a settling basin for sediments entrained in both the ebb and flood currents. Figure 16 shows the total velocity along the entrance channel and inner basin during storm conditions, exhibiting a similar change in velocities with location.

Velocities at SH361 Bridge

Velocities at the SH361 bridge are a concern for navigation safety and scour. Figures 17 and 18 show the total velocity (resultant magnitude of both velocity components) at the SH361 bridge during summer and storm conditions for the existing condition and the proposed opening of Packery Channel. For the existing condition, the flow under the bridge is typically less than 0.16 ft/sec (5 cm/sec). With Packery Channel open, the peak velocity under the bridge increases to approximately 2.8 ft/sec (0.85 m/sec) during spring tide and 1.6 ft/sec (0.5 m/sec) during neap tide. The ebb and flood velocities have approximately the same magnitude; however, during the period of strong southeast winds (Julian Day 192-196) the magnitude of the flood velocities becomes stronger than the ebb. During simulated storm conditions (Figure 18), peak velocities of 3.3 ft/sec (1 m/sec) are reached at the SH361 bridge. Scour is expected to occur at the SH361 bridge if Packery Channel is permanently re-opened. The opening under bridge would scour until the cross-sectional areas under the bridge and the entrance channel were approximately equivalent. Based on the dimensions of the SH361 bridge opening, this section would be expected scour to about 13 to 15 ft (MSL).

Velocities at the Intersection of Packery Channel and GIWW

Packery Channel intersects the GIWW to the north of the J.F.K. Causeway. During strong wind conditions, the authors have observed a strong current in Packery Channel resulting in a cross-channel current in the GIWW. Potential changes in velocities at this intersection associated with the opening of Packery Channel are a concern for navigation safety and sedimentation rates in this section of the GIWW. Figure 19 shows the flow across the GIWW at this intersection during summer conditions for the existing condition and with Packery Channel open. Model simulations indicate that there will not be significant changes in the currents at the intersection of the GIWW and Packery Channel if Packery Channel is re-opened for conditions similar to those simulated (typical summer and storm conditions).

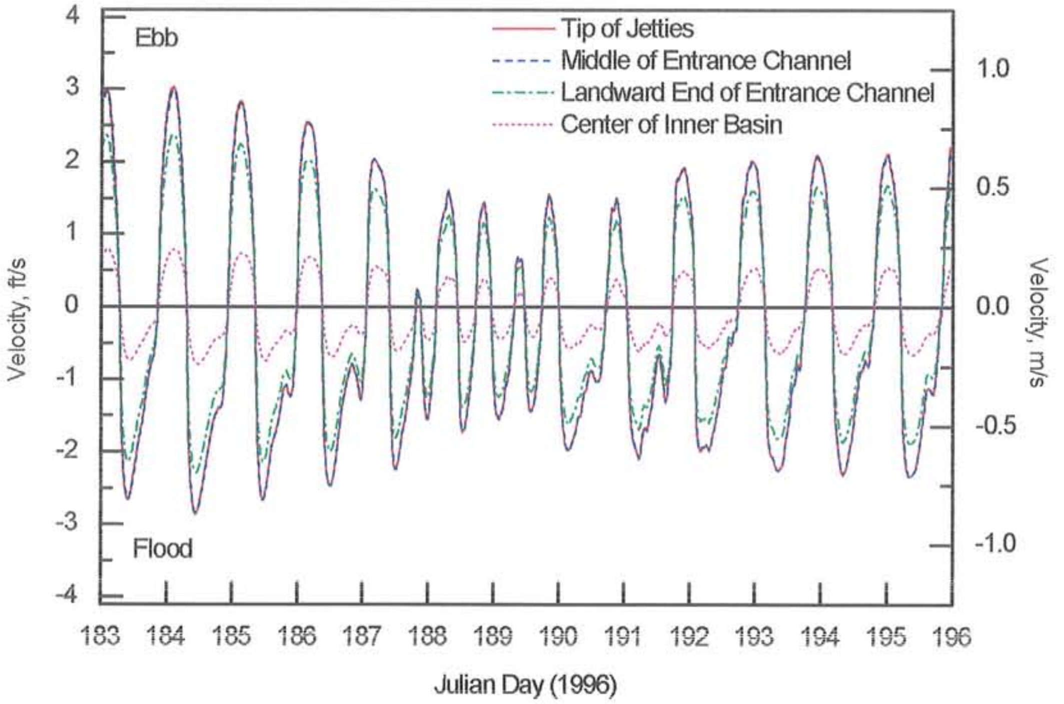

Figure 15. Velocity along entrance channel and in inner basin for summer conditions (Case 2A).

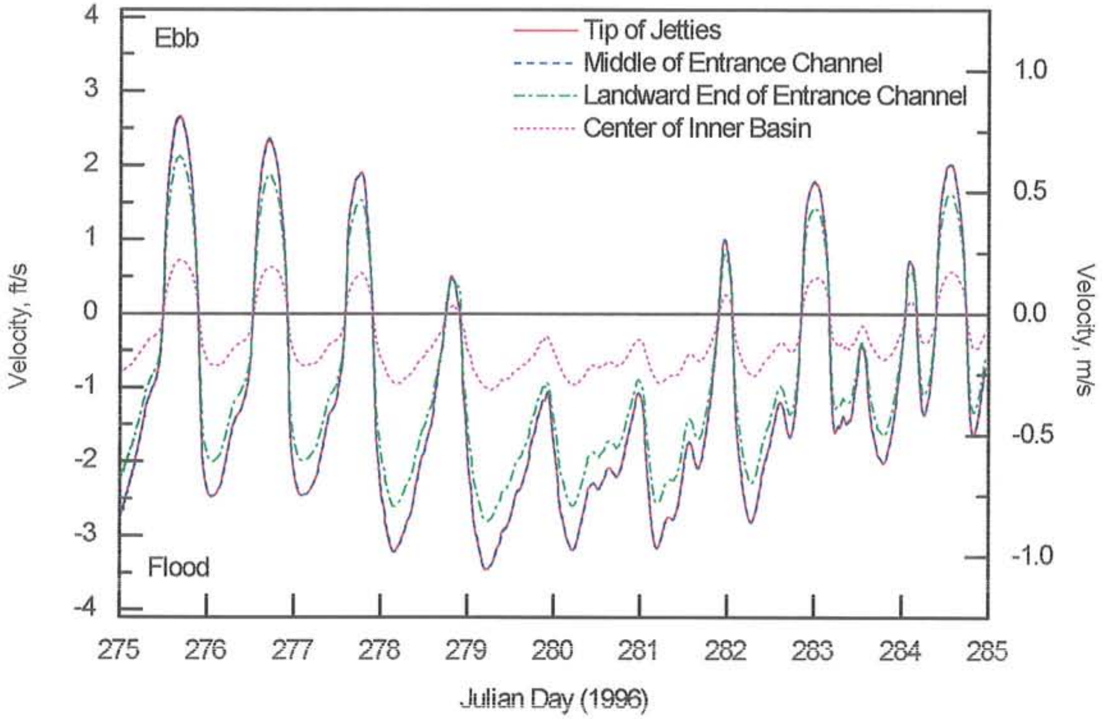

Figure 16. Velocity along entrance channel and inner basin for storm conditions (Case 2B).

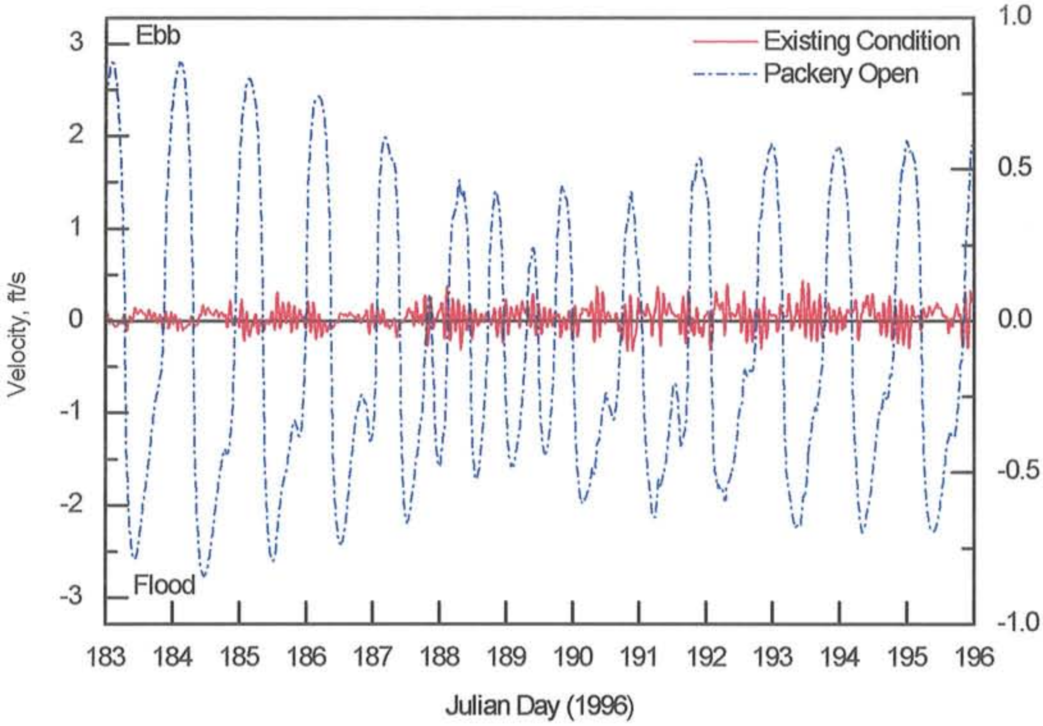

Figure 17. Current at SH361 Bridge for summer conditions (Case 2A).

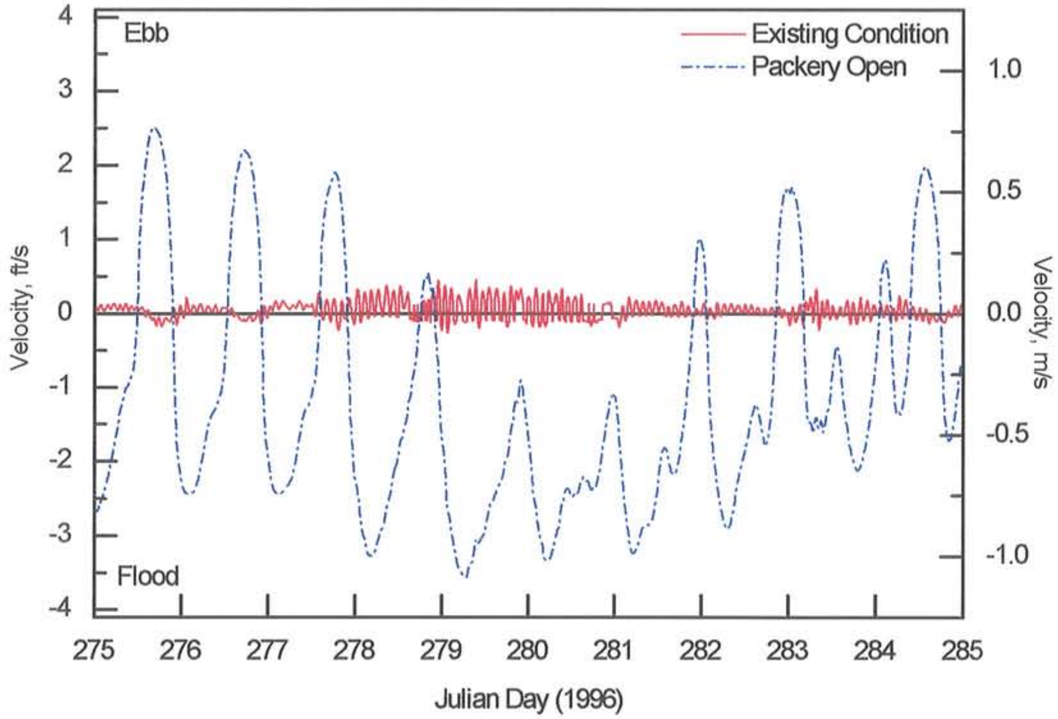

Figure 18. Current at SH361 Bridge for storm conditions (Case 2B).

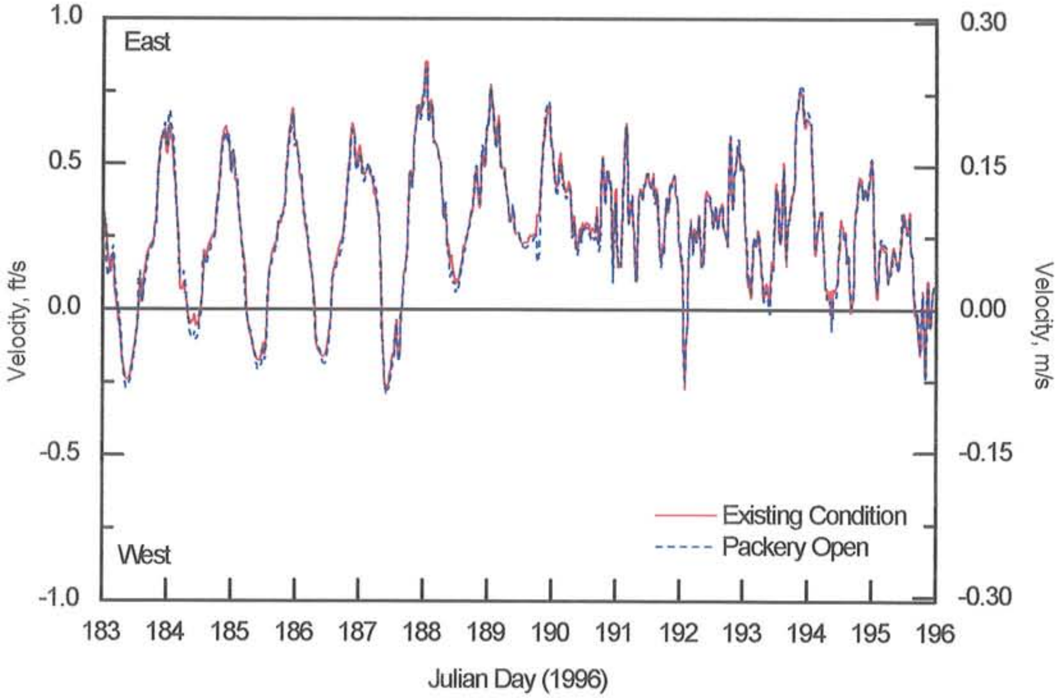

Figure 19. Cross-channel flow at intersection of Packery Channel and GIWW during summer conditions (Case 2A).

Sensitivity Tests

The 2D model is expected to overpredict the currents at the Gulf entrance, transition losses at the entrance associated with turbulence were not included. Transition losses are typically incorporated in two-dimensional models by increasing the Manning coefficients around the entrance based on flow measurements; however, because this is a feasibility study for opening of a new pass and current measurements are not available, the Manning coefficients were not increased. For this modeling study, the Manning coefficients were varied over the range of coefficients published in literature and measured at Fish Pass. Tests were performed to determine the sensitivity of varying the Manning coefficient on the simulated velocities for the summer conditions (Case 2A). Model simulations were performed by varying the Manning coefficient in Packery Channel by ± 20% (n = 0.020 sec/ft$^{1/3}$ and 0.030 sec/ft$^{1/3}$), which approximates the range of the Manning coefficients measured at Fish Pass (Behrens, *et al.* 1977, Behrens and Watson 1977). Increasing the Manning coefficients in Packery Channel from $n = 0.025$ sec/ft$^{1/3}$ to $n = 0.030$ sec/ft$^{1/3}$ decreased the peak velocities along the centerline of the channel from the Gulf entrance to the SH361 bridge by approximately 0.5 ft/sec (12 to 15 cm/sec) or 15% for summer conditions. Decreasing the Manning coefficients from $n = 0.025$ sec/ft$^{1/3}$ to $n = 0.020$ sec/ft$^{1/3}$ increased the peak velocities along the centerline by 0.5 to 0.65 ft/sec (15 to 20 cm/sec) or about 20%.

Landward of the SH361 bridge, Packery Channel narrows and is aligned at an angle of approximately 45 deg relative to the grid, making it difficult to represent in a two-dimensional model with rectangular cells (see Figure 6). Because the majority of the attenuation of the Gulf tidal signal propagating through Packery Channel occurs landward of the SH361 bridge, sensitivity tests were performed to determine if the model representation of the angled channel was contributing to the attenuation of the signal. Model simulations were performed with Packery Channel straightened landward of the bridge. Simulation results show that there was no difference in water level and current velocities between the proposed design and the test case simulated with Packery Channel straightened.

Change in Water Level

Changes in bay water elevation associated with the re-opening of Packery Channel are a concern for safety reasons and can have both beneficial and detrimental environmental impacts. Because of the low elevation of the study area, a small increase in water elevation can inundate a large area, resulting in flooding of roadways and limiting access. During the passage of Tropical Storm Josephine, the J.F.K. Causeway, which is one of two evacuation routes for the barrier island, was closed due to flooding of the roadway.

Because of the small cross-sectional area of Packery Channel relative to the cross-sectional area of the Corpus Christi Ship Channel and the volume of the bay system, the opening of Packery Channel is expected to have minimal influence on the bay water level. Figures 20 and 21 show comparisons of the water elevation at the Packery Channel gauge for the existing condition and with Packery Channel open for summer and storm conditions, respectively. Model simulations indicate that there will not be a substantial change in water elevation at the Packery Channel gauge (located on the north-east side of the J.F.K. Causeway) during either simulated condition. This relatively insignificant change in water level is consistent with the findings of Duke (1987), who estimated that for a 14-ft (4.3 m) bay storm surge, the opening of Packery Channel would only result in a 0.8- to 2.5-inch (2- to 6.3-cm) increase in surge height. Based on model simulations, the opening of Packery Channel will not significantly increase the incidence or rate of flooding of the causeway.

Figure 22 shows the water elevation in the deeper region to the north of Packery Channel at the bay entrance for the existing case and with Packery Channel open. Changes in water level variations at this location are minimal. Regions experiencing significant changes in water elevation associated with the re-opening of Packery Channel were restricted to regions directly connected to Packery Channel, such as at the SH361 bridge, in the inner basin, and in the Lake Padre subdivision. Figure 23 shows that there will be an increase the magnitude of tidal water level fluctuations at the SH361 bridge during storm conditions, as well as a phase shift. There will be an approximately 5- to 6-hour advance in the water level fluctuations associated with the opening of Packery Channel due to the proximity of the Gulf tidal forcing. With Packery Channel open, tidal fluctuations in water level are superimposed on the storm surge, producing

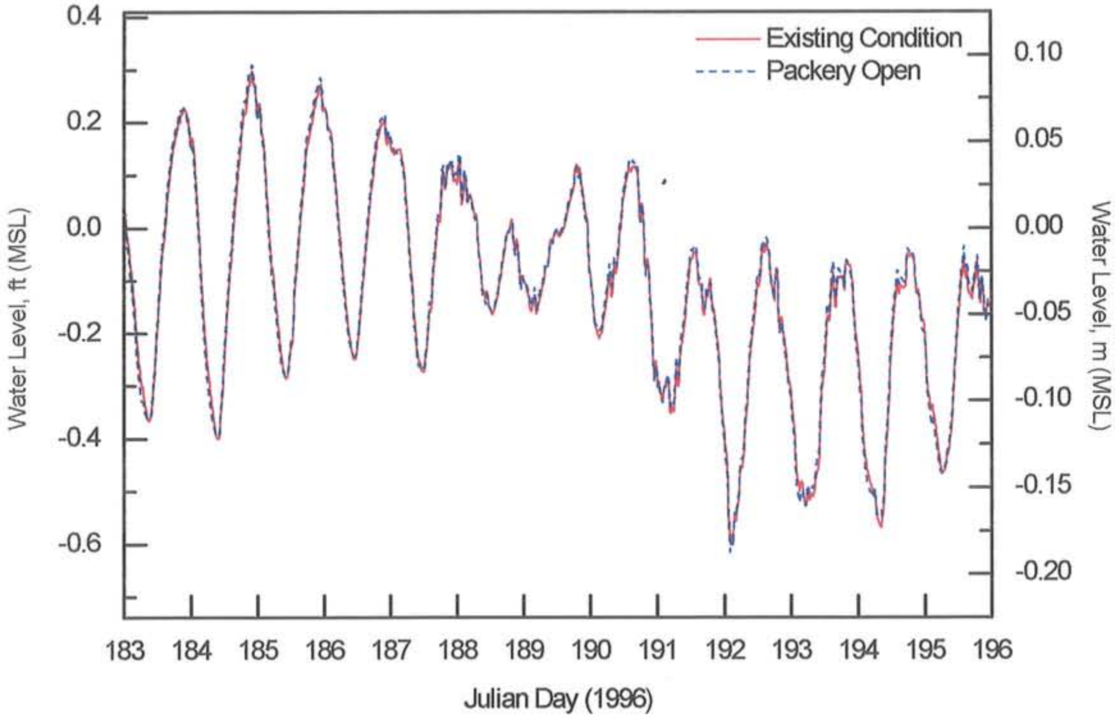

Figure 20. Water elevation at Packery Channel gauge with and without Packery Channel open for summer conditions (Case 2A).

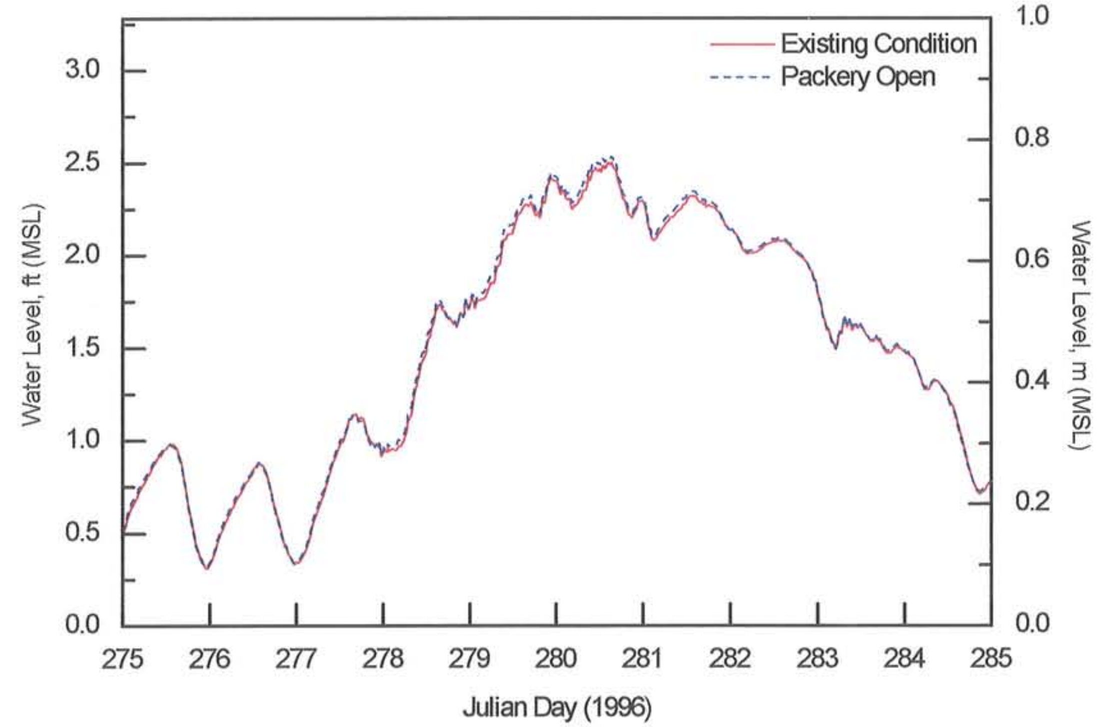

Figure 21. Water elevation at Packery Channel gauge with and without Packery Channel open for storm conditions (Case 2B).

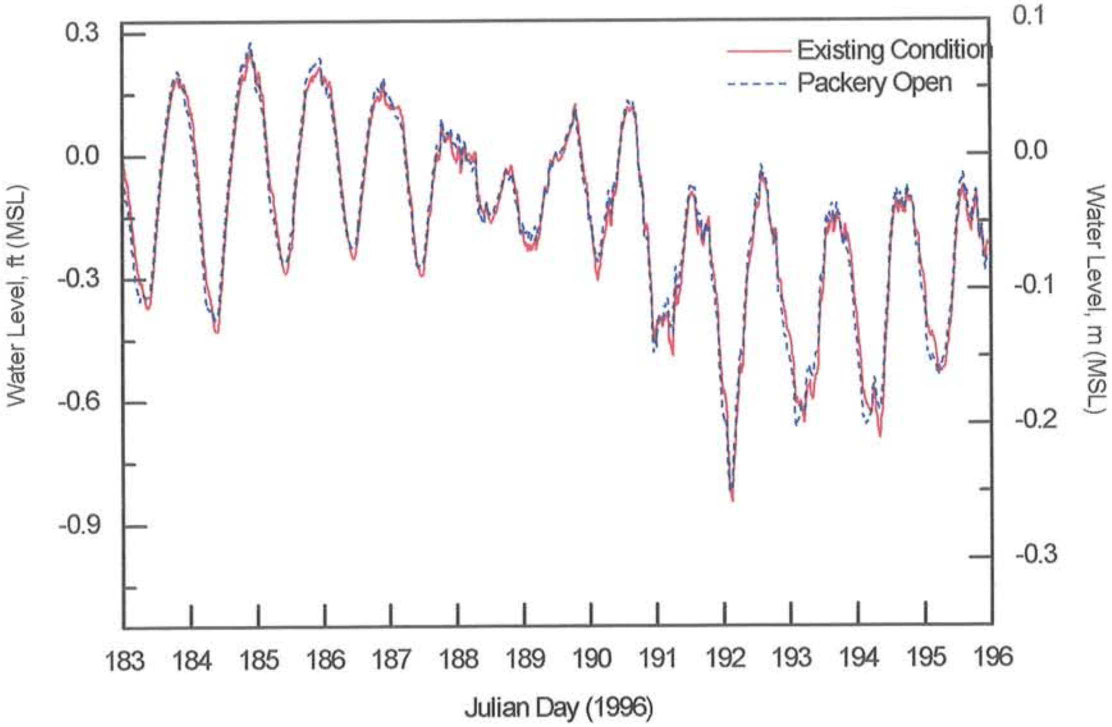

Figure 22. Water elevation to the north of Packery Channel at bay entrance during summer conditions (Case 2A).

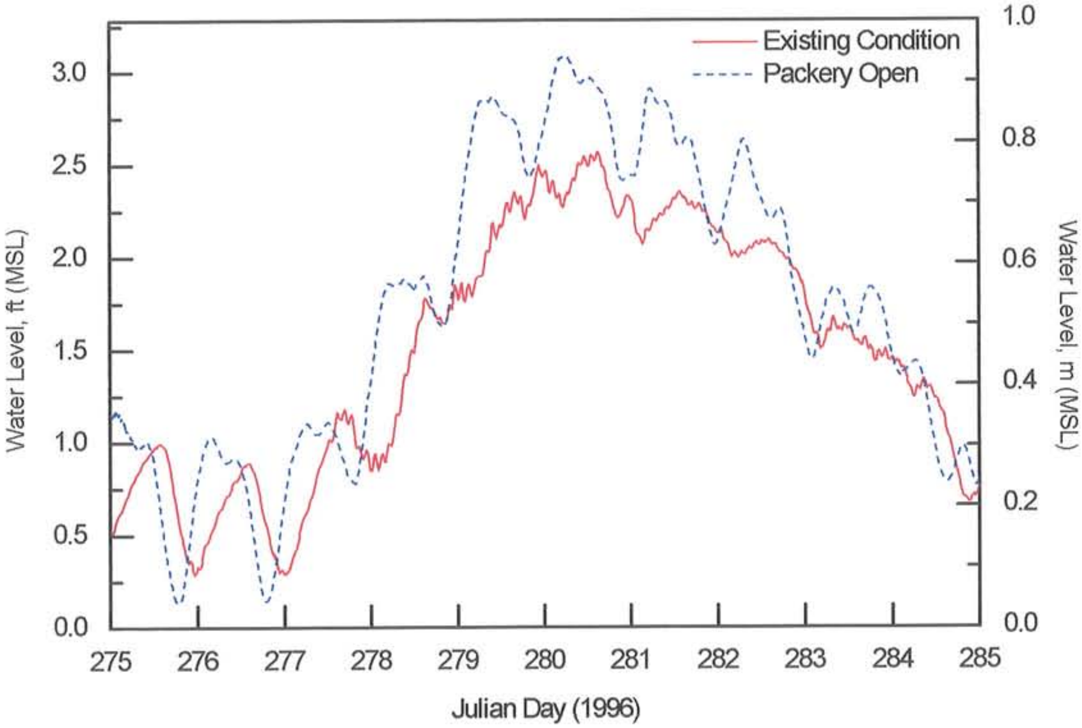

Figure 23. Water elevation at SH361 for storm conditions (Case 2B).

approximately 0.5 ft (0.2 m) higher peak water levels during storm conditions. Because of the low elevation of the surrounding region, there may be increased chance of flooding of the approaches of SH361 bridge during high-water events, such as during the passage of storms.

Figures 24 and 25 show the simulated water elevations for summer and storm conditions in the Lake Padre subdivision located south of the seagate (Figure 2). In the canals of Lake Padre subdivision, the magnitude of the water-level fluctuations will approximately double during non-storm conditions, increasing the tidal exchange in this restricted area, improving water quality through an increase in water exchange and circulation. Model calculations showed that a limited area (SH361 bridge, inner basin, and Lake Padre subdivision) will have increased magnitude of water-level fluctuations and in the Laguna Madre changes in water level fluctuations are minimal and within the variability of present fluctuations; therefore, long-term changes in water elevation associated with the opening of Packery Channel were inferred to be negligible.

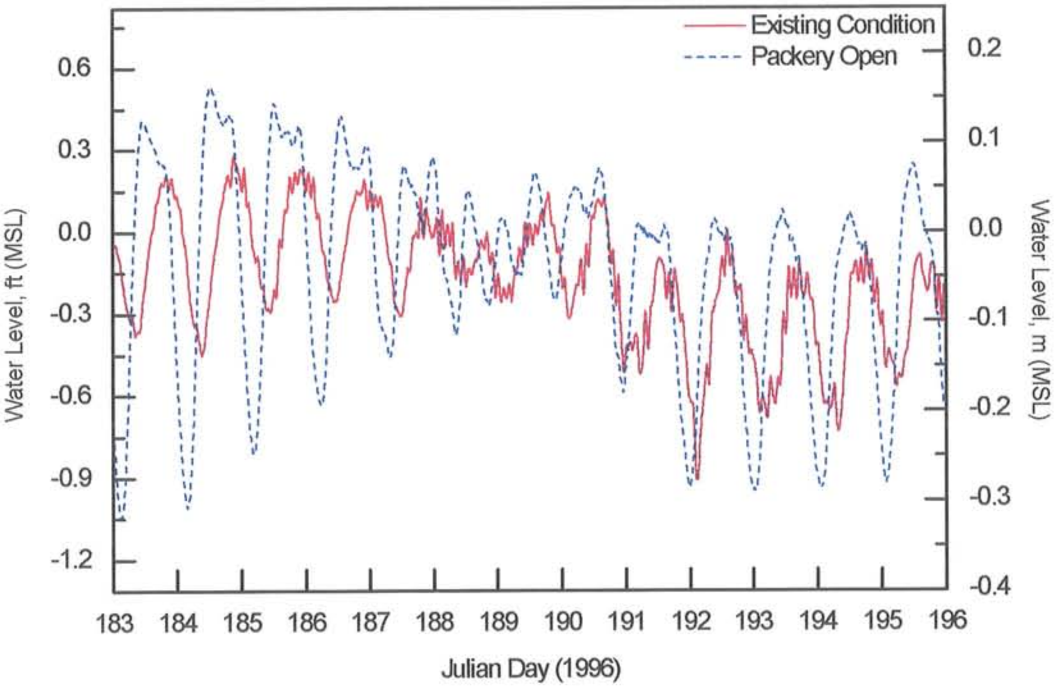

Figure 24. Water elevation in Lake Padre subdivision with and without Packery Channel open for summer conditions (Case 2A).

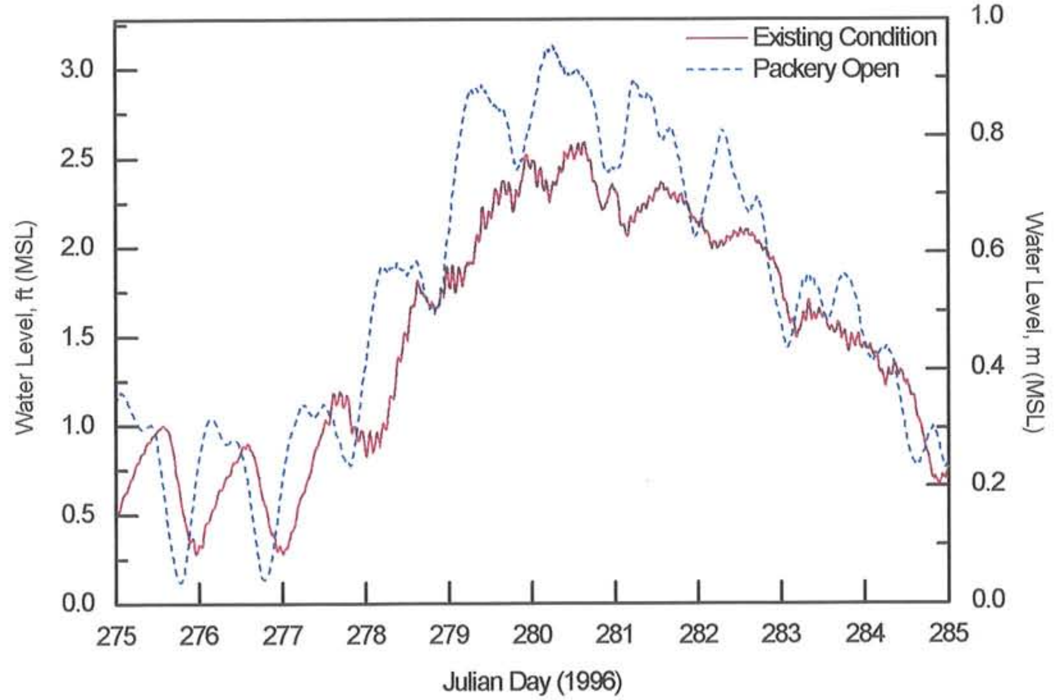

Figure 25. Water elevation in Lake Padre subdivision with and without Packery Channel open for storm conditions (Case 2B).

Discharge Through Packery Channel

The discharge through a pass, such as Packery Channel, has implications for water quality, sediment transport, and the transport of marine larvae. Figure 26 shows a time-series of the total discharge at Packery Channel during summer conditions (Case 2A). The peak discharge through Packery Channel is approximately 4,600 cubic feet per second (cfs) (130 m^3/sec) during ebb tide and 5,650 cfs (160 m^3/sec) during flood tide for summer conditions simulated. These discharge values are consistent with discharge values measured at Fish Pass (Behrens, *et al.* 1977). Figure 27 shows the total discharge through Packery Channel during one tidal cycle for summer conditions illustrating that the magnitude and duration of the flood tide is greater than the ebb. During this tidal cycle, the duration of the flood is approximately 1.5 times as long as the ebb duration, and the magnitude of the flood discharge is about 25% greater than the ebb. A similar flood dominance in velocity, duration, and volume was observed at Fish Pass (Behrens and Watson 1977, Behrens 1979). As discussed previously, this flood dominance is probably driven by the set-up of water level along the Gulf coast and set-down on the bay-side of the inlet associated with the onshore component of the southeast winds (Behrens 1979).

Integration of the discharge rate yields the volume of water exchanged (discharge volume) through the inlet. Integration of the discharge rate over this tidal cycle yields that the net discharge volume in the flood direction is approximately 75% greater than the ebb. For this tidal cycle, the flood discharge volume is 148 x 10^6 ft^3 (4.2 x 10^6 m^3), the ebb discharge volume is 84 x 10^6 ft^3 (2.4 x 10^6 m^3), and the net total discharge volume is 64 x 10^6 ft^3 (1.8 x 10^6 m^3). At Fish Pass, discharge volumes computed from water-level records ranged from 84 to 104 (x 10^6 ft^3) for flood tides, from 35 to 93 (x 10^6 ft^3) for ebb tides, and from 46 to 82 (x 10^6 ft^3) for a tidal cycle (Behrens 1979). Mean values of discharge volumes at Fish Pass were 93 x 10^6 ft^3 (2.6 x 10^6 m^3) for flood, 57 x 10^6 ft^3 (1.6 x 10^6 m^3) for ebb, and 61 x 10^6 ft^3 (1.7 x 10^6 m^3) for a tidal cycle (Behrens 1979). Discharge volumes computed in this study are approximately within the range of values measured at Fish Pass. Integration of the total discharge over 12 days (Julian Days 183-195) indicates that the net total discharge volume associated with the re-opening will be approximately 475 million gallons per day (1.8 x 10^6 m^3 per day) into the Laguna Madre during summer conditions. To put this net inflow rate in perspective, the Barney Davis Power Plant located in Flour Bluff removes 540 million gallons per day from the Laguna Madre for cooling purposes. In a previous study (Brown, *et al.* 1995a, 1995b), the zone of influence of this intake was found to be restricted to the vicinity of the intake canal (less than 3000 ft radius).

During simulated storm conditions (Figure 28), the peak discharge rate through Packery Channel increases by approximately 70% to 8,830 cfs (250 m^3/sec). For four days (Julian Days 278-282), almost all of the flow through Packery Channel is directed into the Laguna Madre and there is a net inflow of 1,800 ft^3 into the Laguna Madre via Packery Channel. During north fronts, Packery Channel will probably experience enhanced ebb discharges, due to the offshore component of the wind raising the water level on the bay side of the inlet and set-down in the Gulf similar to that observed at Fish

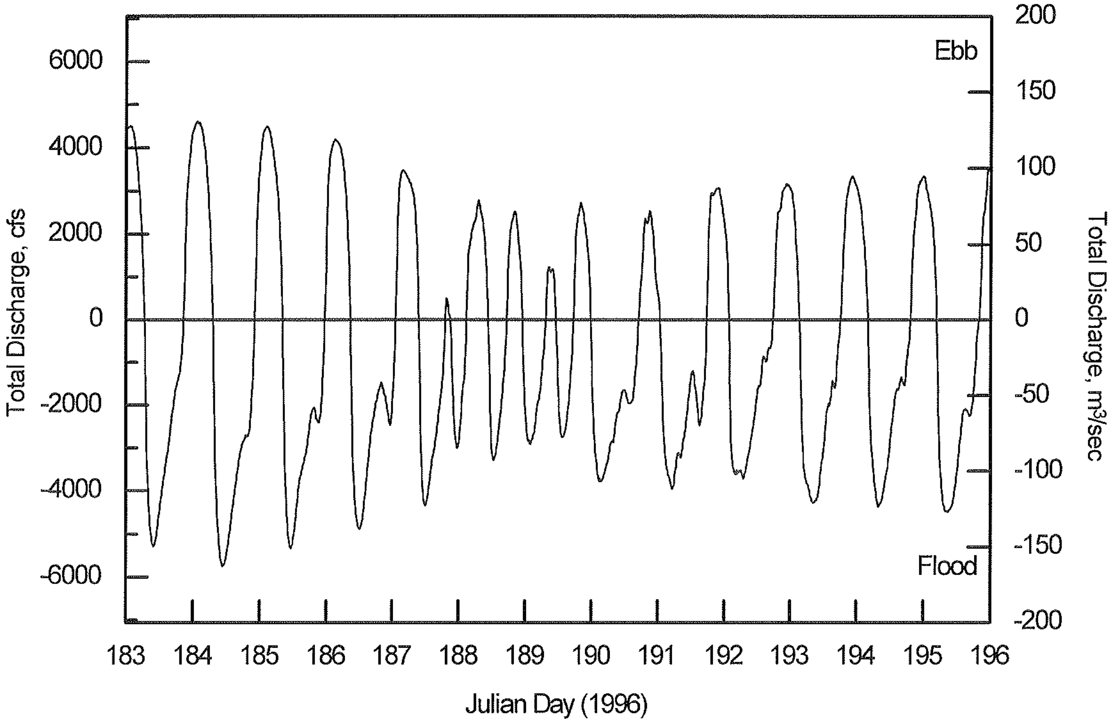

Figure 26. Total discharge through Packery Channel during summer conditions (Case 2A).

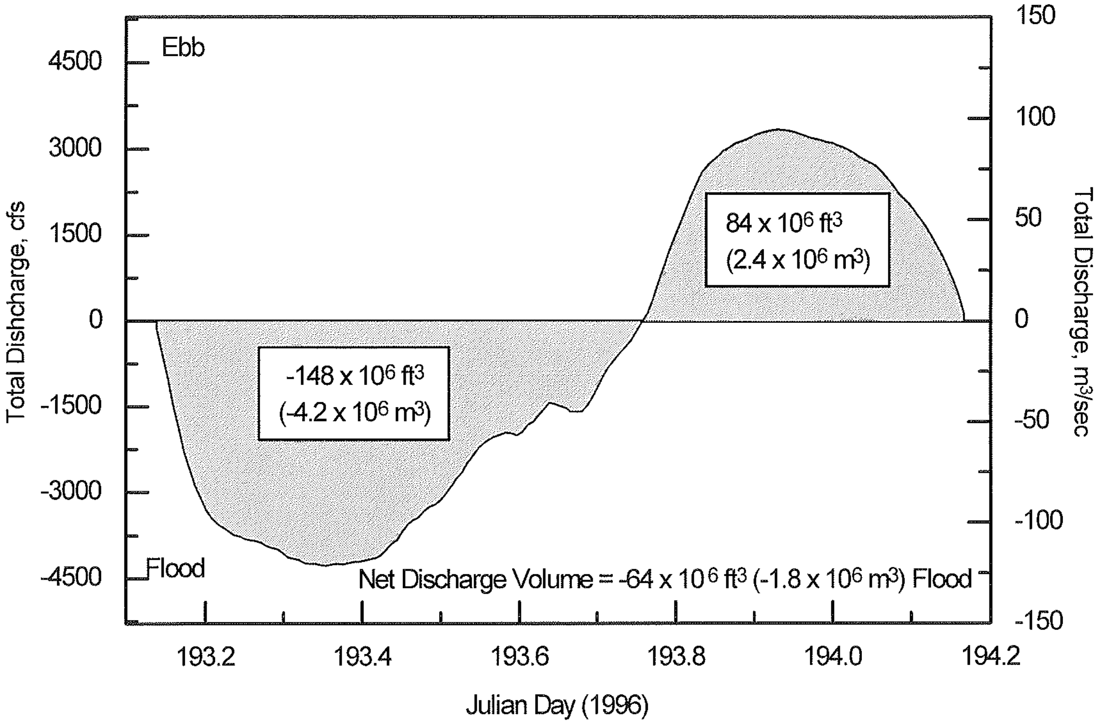

Figure 27. Discharge at Packery Channel during one tidal cycle for summer conditions.

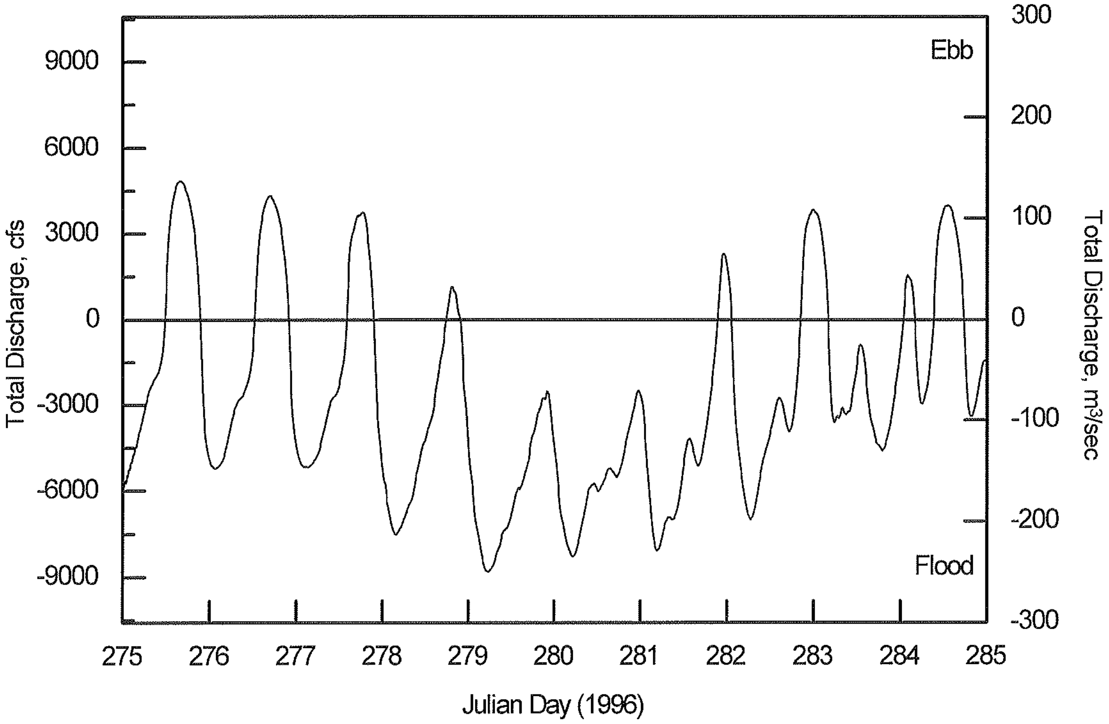

Figure 28. Total discharge through Packery Channel during storm conditions (Case 2B).

Pass (Behrens 1979). These periods of ebb enhancement would be of short duration, typically only a few days in duration. Based on the predominant southeast wind in the study area, Packery Channel would be expected to be a flood-dominated inlet, except for during the passage of north fronts. A one-year time-series of water level at Fish Pass indicated that twice as much water flooded into the bay than ebbed out (Behrens 1979).

Change in Circulation in the Laguna Madre

In addition to comparing time-series of currents and water level, it is necessary to look at circulation patterns to assess the influence of re-opening Packery Channel. Circulation patterns were studied during various representative conditions, including over a typical tidal cycle during summer conditions and during peak storm conditions. Figure 29 shows the water elevation at NAS-CC and Packery Gauge, and the current at the Gulf entrance of Packery Channel, in the GIWW by NAS-CC, and at the J.F.K. Causeway, over one representative tidal cycle during summer conditions with the tick marks indicating four hour intervals corresponding to the time associated with each of the vector plots presented in Figures 30 to 35. Figures 30 to 36 are comparisons of the circulation patterns in the vicinity of Packery Channel for the existing condition and with Packery Channel open, left and right panels, respectively, with the color in the background indicating the depth in meters, the length of the vector indicating the magnitude of the flow, and the orientation indicating the direction the current is flowing. For ease of comparison, the vectors in all of the panels are at the same scale.

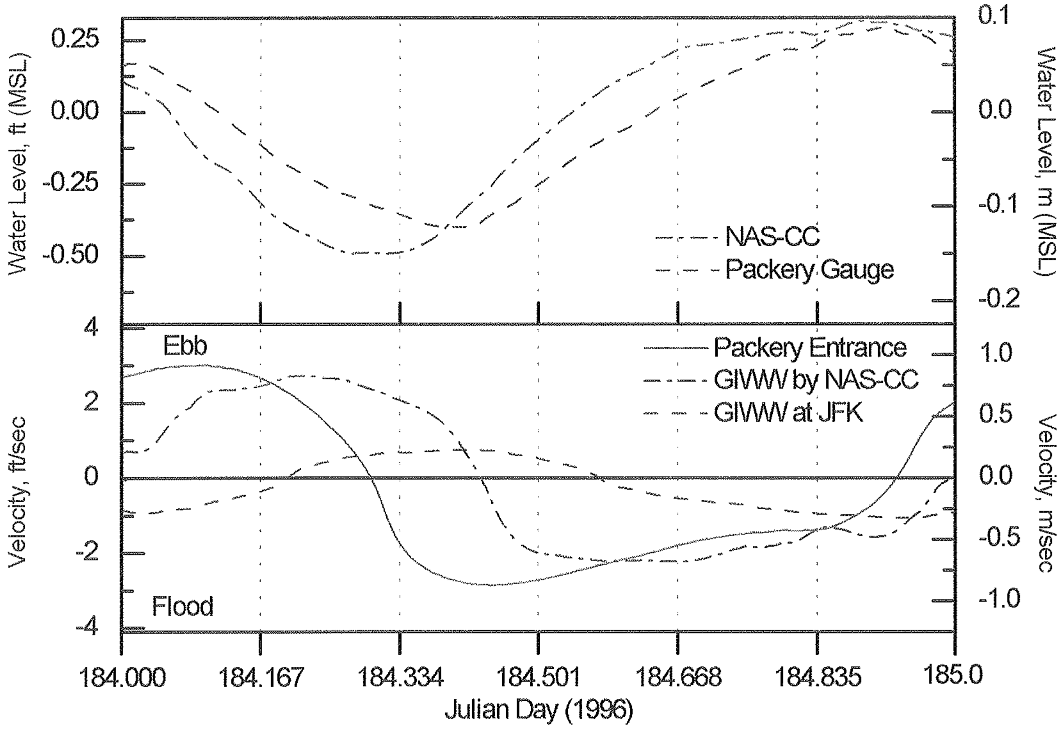

Figure 29. Time-series of water elevation and current over one tidal cycle for use in interpreting circulation patterns.

Figure 30 shows the circulation vectors at the beginning of the ebb stage (Julian Day 184.0). In the GIWW by the NAS-CC and in Packery Channel the flow is ebbing; however, at the openings in the J.F.K. Causeway the flow is directed towards the south, into the Laguna Madre. With Packery Channel opened, changes in circulation patterns are limited to the region adjacent to where Packery Channel opens into the Laguna Madre. The deeper region just to the north of Packery Channel experiences enhanced flows, and on the flats adjacent to this basin the currents have a more southward component driven by the ebbing current flowing out Packery Channel into the Gulf of Mexico. The majority of the flats adjacent to Packery Channel are unaffected by the opening of Packery Channel during this phase of the tidal cycle.

Figure 31 shows the circulation vectors four hours after those shown in Figure 30 (Julian Day 184.16), when the current is approaching the peak ebb by NAS-CC and continues to ebb in Packery Channel; however, the flow remains to the south at the J.F.K. Causeway but has weakened in magnitude. As in the previous figures, the largest changes in circulation occur immediately adjacent to Packery Channel; however, on the flats to the east of the GIWW north of Packery Channel there is a region of decreased flow with Packery Channel open (region indicated by white arrow). The region of decreased flow is a result of opposing flows driven by the southward-directed flow ebbing out Packery Channel and the northward-directed flow ebbing out Corpus Christi Bay.

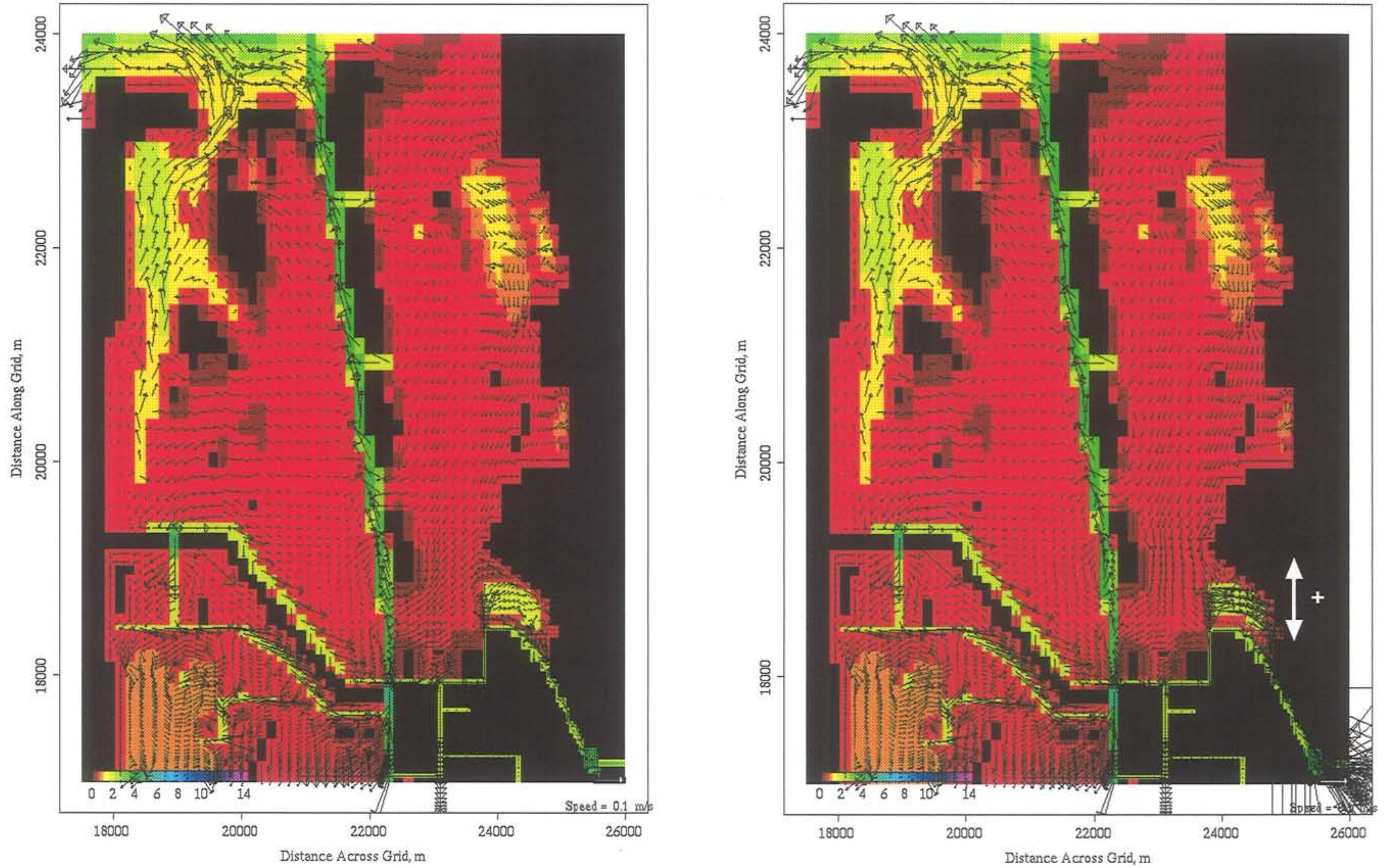

Figure 30. Circulation vectors for the existing condition and with Packery Channel open (Julian Day 184.0).

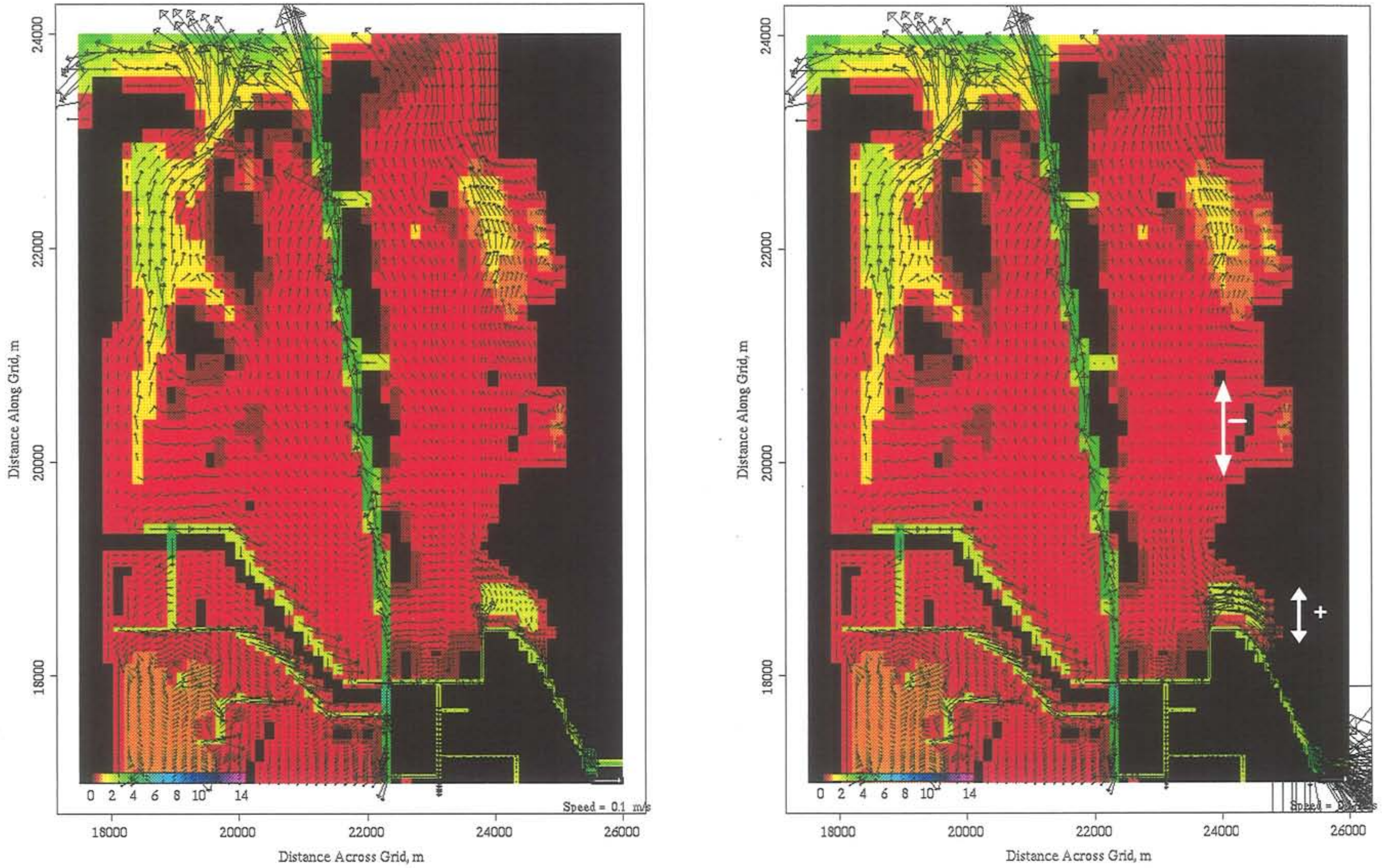

Figure 31. Circulation vectors for the existing condition and with Packery Channel open (Julian Day 184.16).

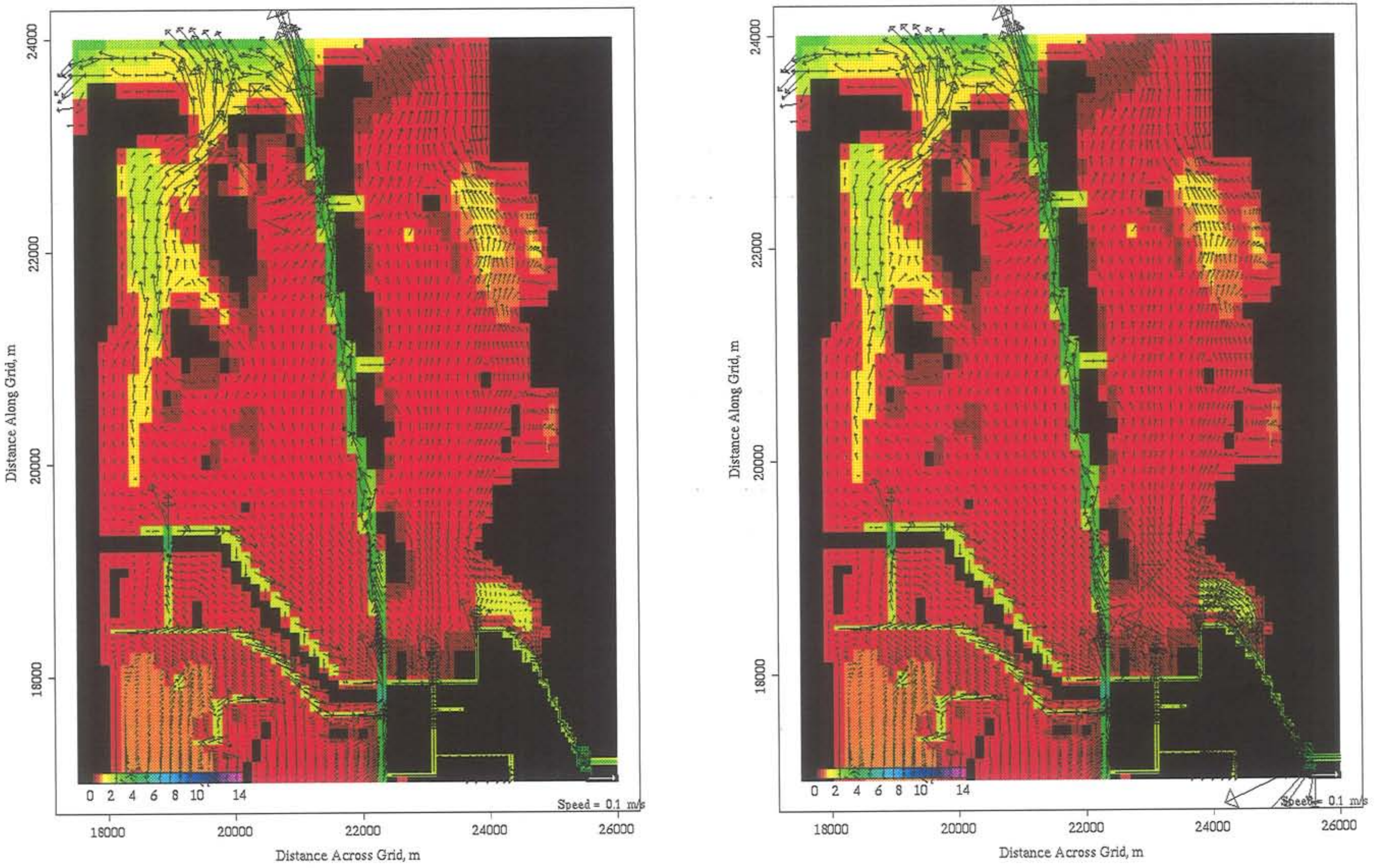

Figure 32. Circulation vectors for the existing condition and with Packery Channel open (Julian Day 184.33).

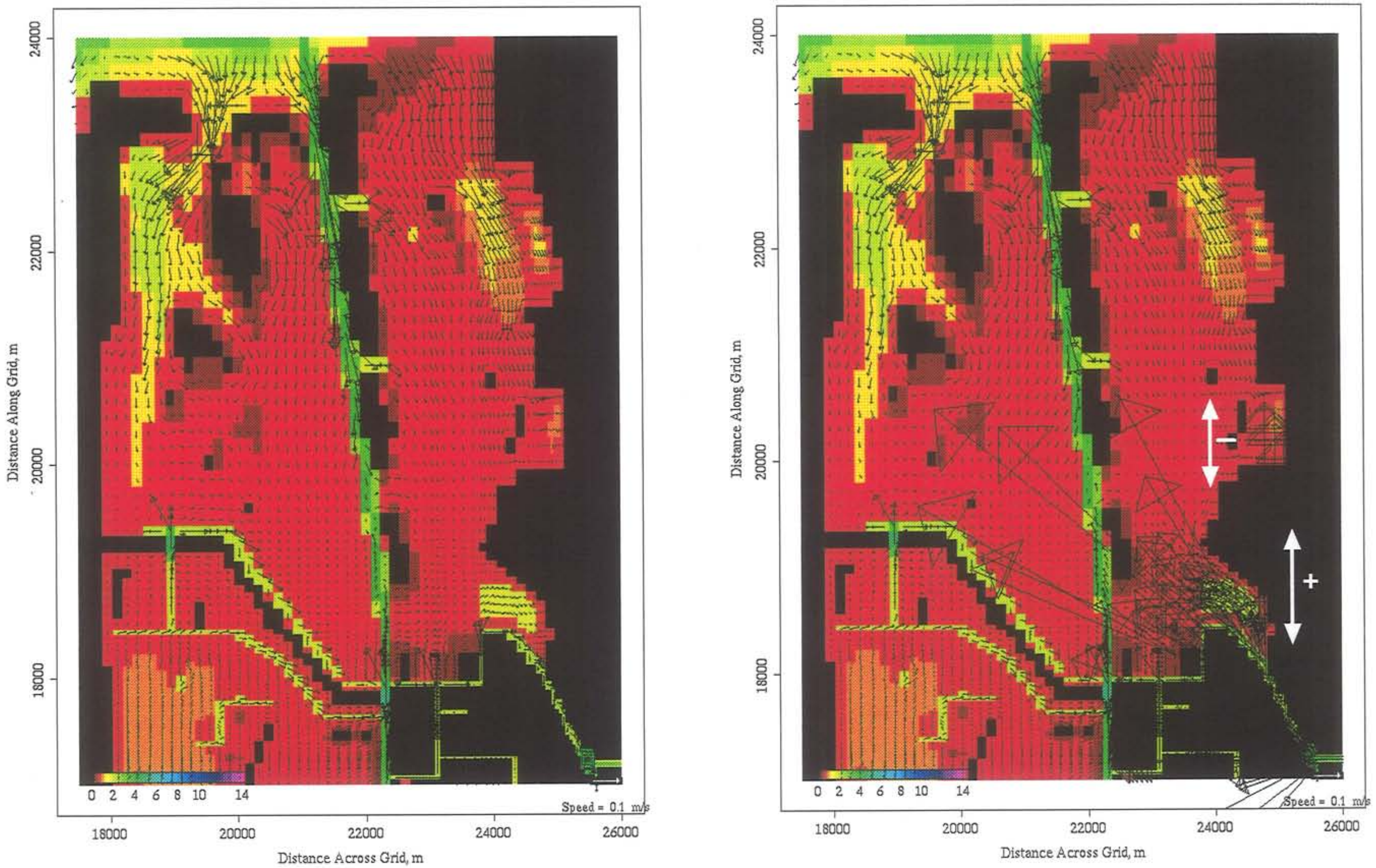

Figure 33. Circulation vectors for the existing condition and with Packery Channel open (Julian Day 184.5).

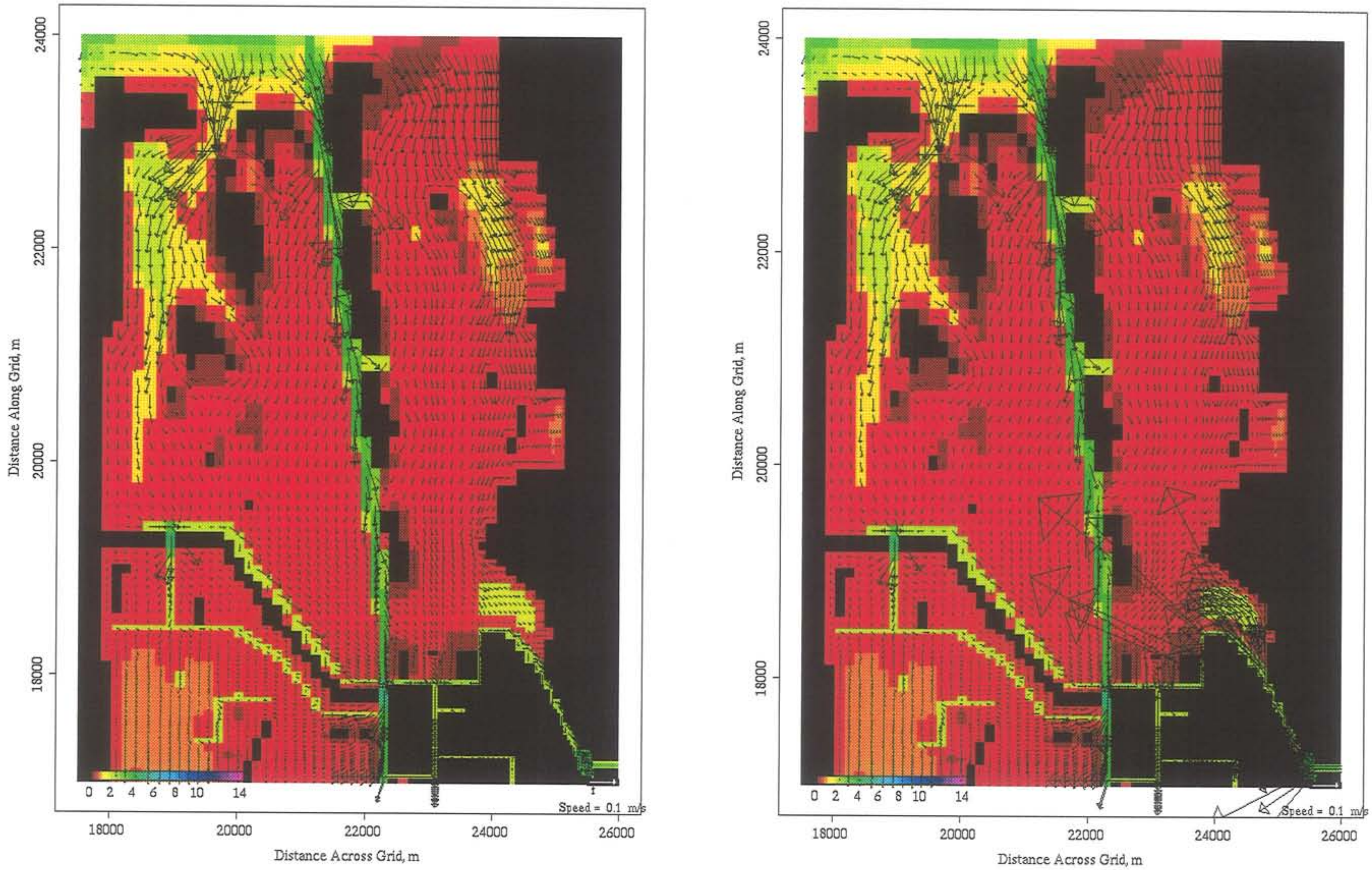

Figure 34. Circulation vectors for the existing condition and with Packery Channel open (Julian Day 184.67).

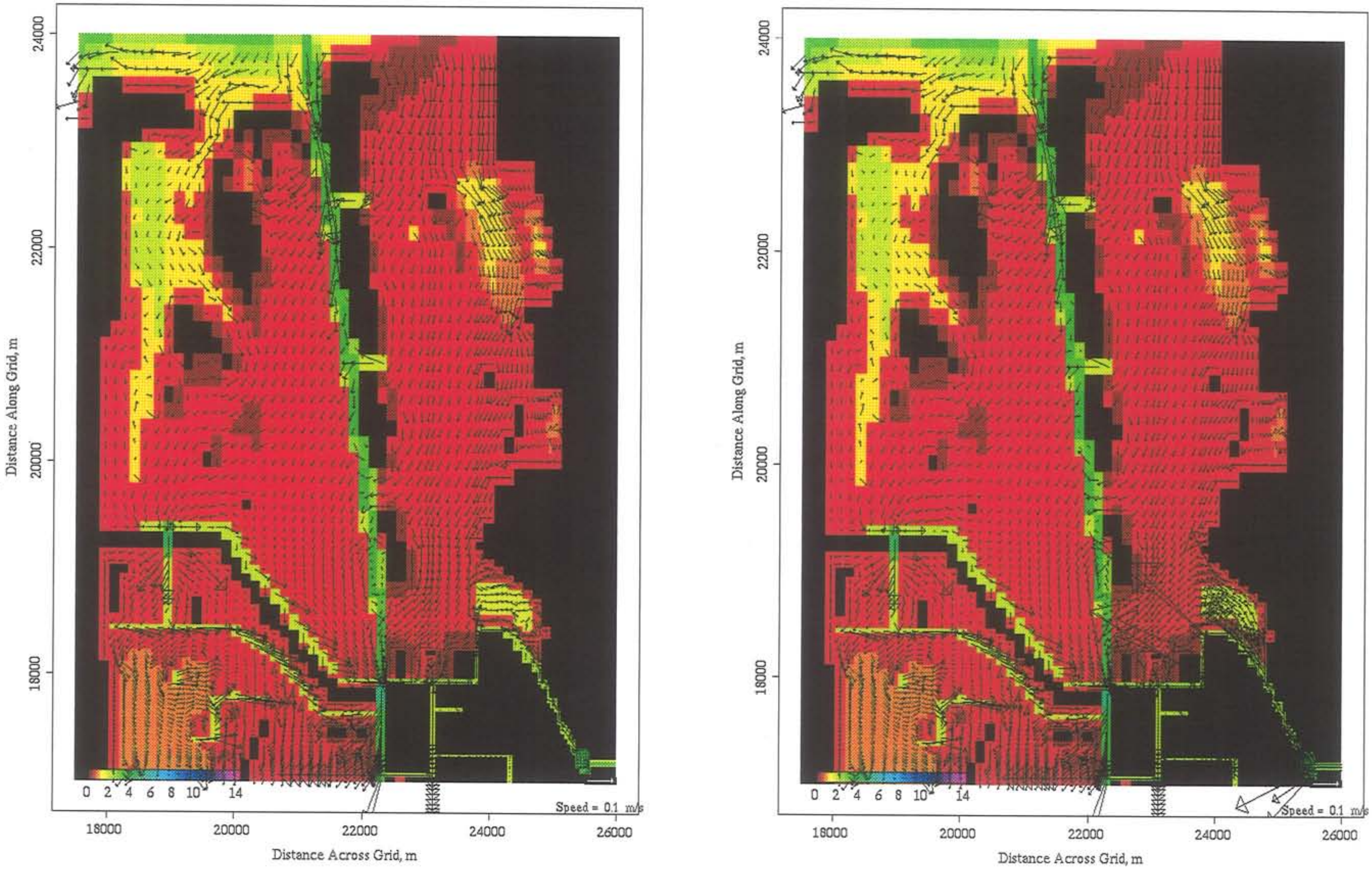

Figure 35. Circulation vectors for the existing condition and with Packery Channel open (Julian Day 184.83).

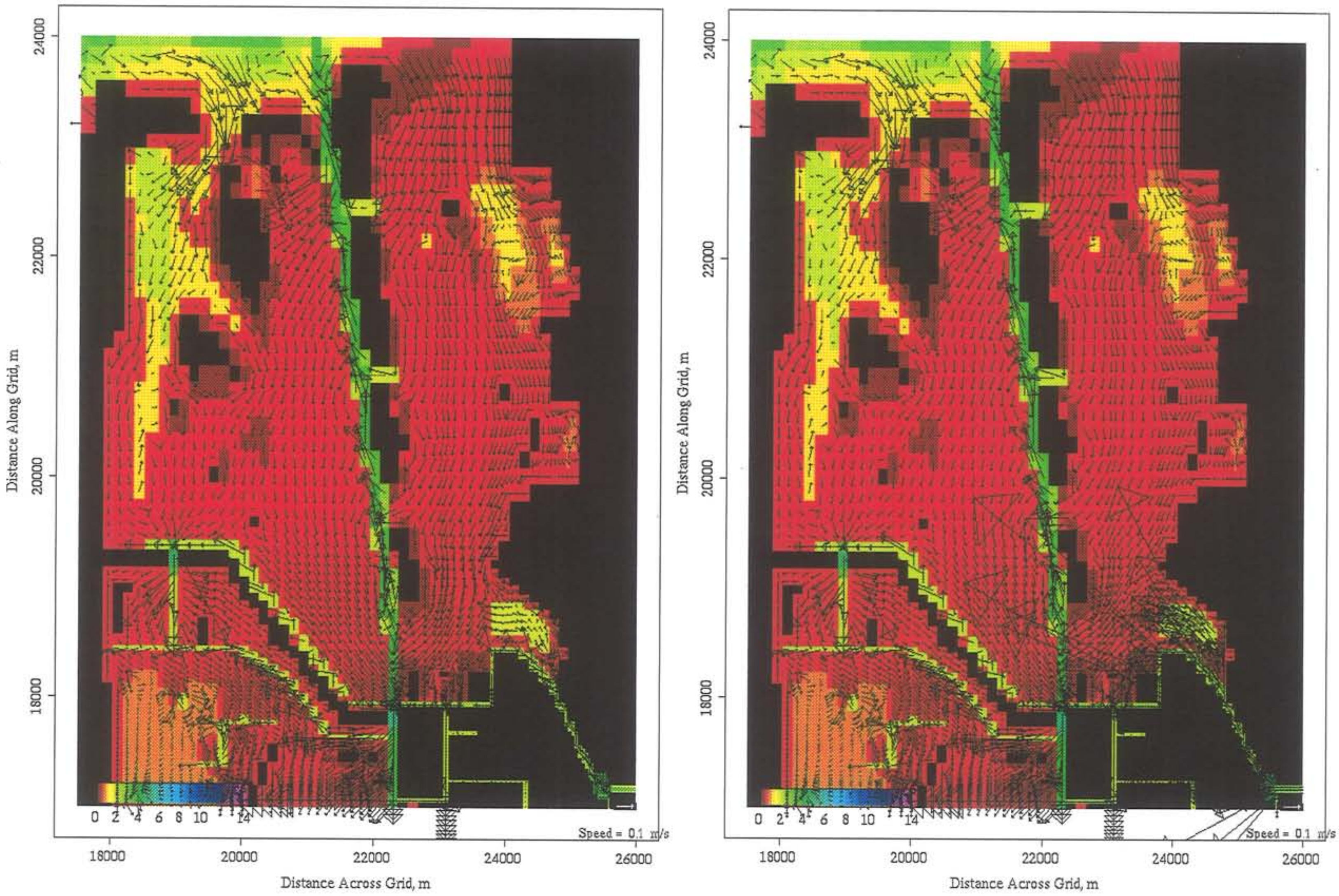

Figure 36. Circulation vectors for existing condition and with Packery Channel open for storm conditions (Julian Day 279.14).

Figure 32 shows the circulation vectors when the flow is ebbing for entire region between NAS-CC and south of the J.F.K. Causeway, but the flow is flooding into the Laguna Madre in Packery Channel (Julian Day 184.33). During this phase of the tidal cycle, the opening of Packery Channel enhances the northward directed ebbing flow; however, the region experiencing increased flow is limited to the area adjacent to Packery Channel.

Figure 33 shows the circulation vectors when the flow is flooding at the northern part of the region and still ebbing at the southern part, and is flooding into the Laguna Madre from Packery Channel (Julian Day 184.5). As seen previously (see Figure 31), there is a region of decreased flow on the flats to the east of the GIWW where the opposing flood tide propagating into the Laguna Madre from Corpus Christi Bay and Packery Channel meet, and a region of enhanced flow immediately adjacent to where Packery Channel opens into the Laguna Madre. Figures 34 and 35 show the circulation patterns when the current is flooding for all of the region shown in the figure (Julian Day 184.67 and 184.83). The flow from the Gulf into Laguna Madre via Packery Channel is deflected to the west by the opposing flooding currents from Corpus Christi Bay.

Figure 36 shows the circulation patterns during peak simulated storm conditions. During peak storm conditions, the flow is primarily directed into the Laguna Madre driven by the strong north winds associated with the storm, and the elevated Gulf and bay water levels; however, in the GIWW, between the J.F.K. Causeway and NAS-CC, the flow is directed to the north. This northward flow is a return flow driven by the set-up of the water level against the J.F.K. Causeway and is present in the circulation patterns for Julian Days 278 to 281. Figure 37 shows a time-series of the simulated water level at Ingleside, located on the north side of Corpus Christi Bay, NAS-CC on the south side of the bay, and at Packery Channel. During Julian Days 277.8 to 281, the water level on the south side of Corpus Christi Bay is elevated, driven by the strong north winds. The set-up at Packery Channel is greater than the set-up at NAS-CC, because the water is driven into a restricted area with shallow water, producing a greater rise in water level. The return flow is restricted to the GIWW because of the deeper water and reduced effective wind stress as compared to the shallow flats. During the passage of this storm, the flow in the GIWW was most probably stratified with surface wind-driven currents towards the south and northward directed return flow along the bottom. During storm conditions, the inflow associated with Packery Channel is directed to the west by the southward directed flow on the flats and the region with increased velocities is restricted to the immediate vicinity of the opening.

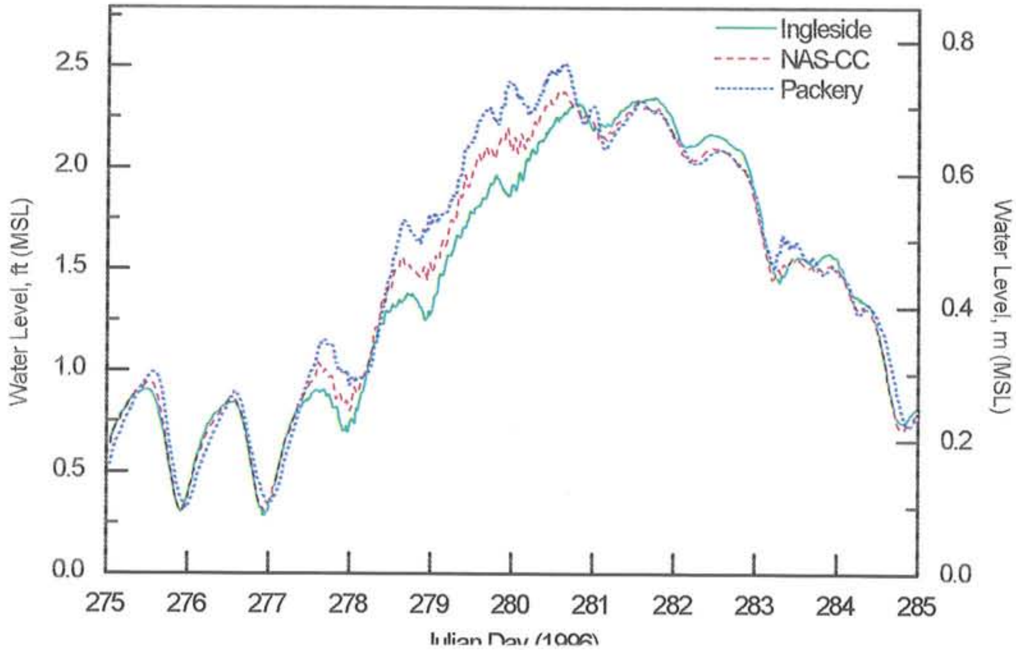

Figure 37. Simulated water level at Ingleside, NAS-CC and Packery Channel during storm conditions.

Water Exchange Between Lake Padre and Laguna Madre

The Lake Padre subdivision permit mandates the construction of a route for water exchange between Lake Padre and the canals of Padre Isles. Model simulations were performed to investigate the effect of this water exchange on circulation and inflow in the Laguna Madre in the vicinity of the Padre Isles subdivision. Figure 38 shows the circulation vectors without (left panel) and with (right panel) the connection between Lake Padre and the Laguna Madre with Packery Channel open during peak flood tide (Julian Day 184.50). The region with increased flow is limited to within 500 ft of the opening. Figure 39 compares the discharge through Packery entrance channel and between Lake Padre and the Laguna Madre. With the water exchange in place, the discharge between Lake Padre and the Laguna Madre is approximately 20% of the total discharge through the entrance channel with peak discharge levels of 1,060 cfs (30 m^3/sec).

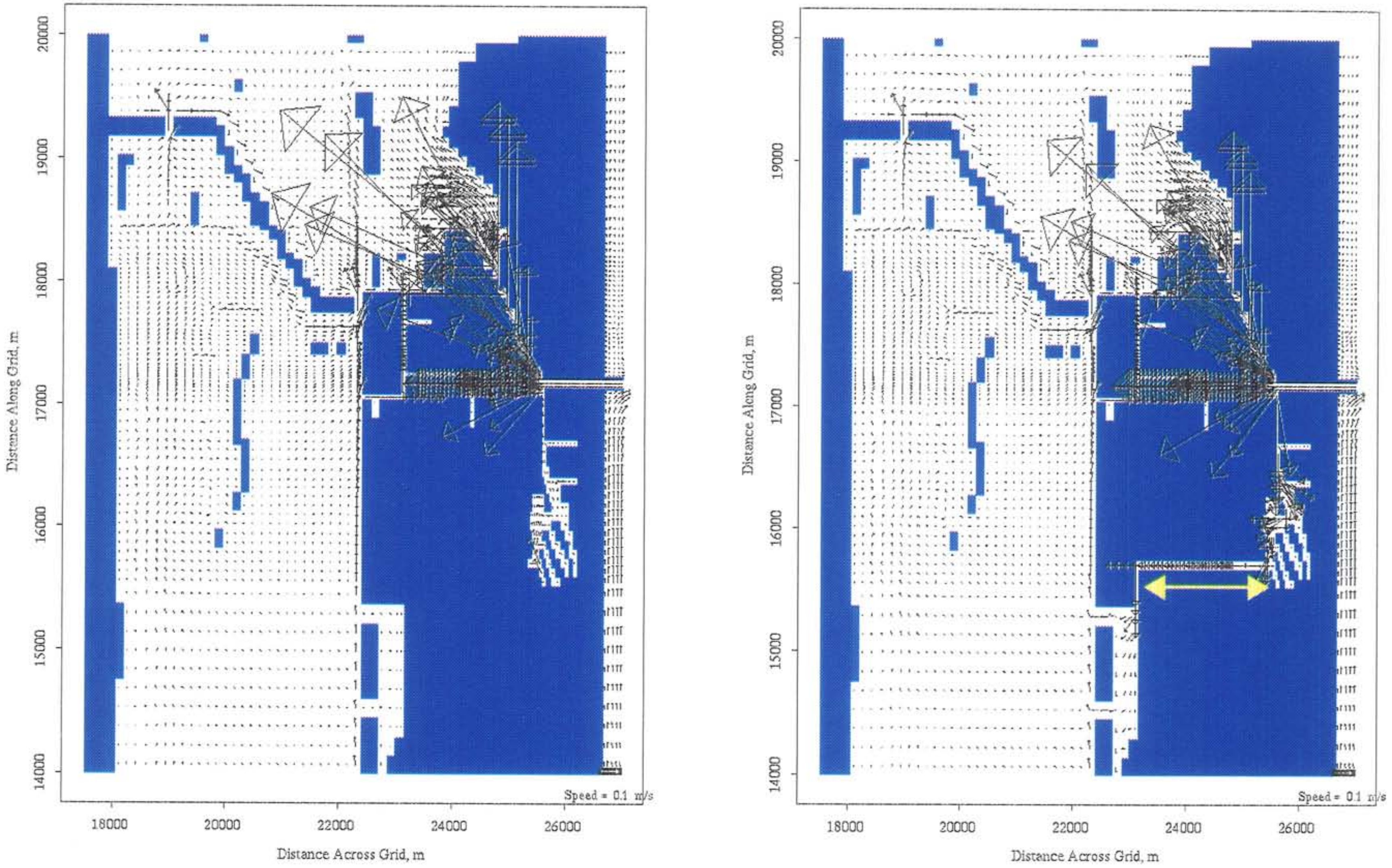

Figure 38. Circulation with Packery Channel open, with and without a water exchange between Lake Padre and Laguna Madre (Julian Day 184.5).

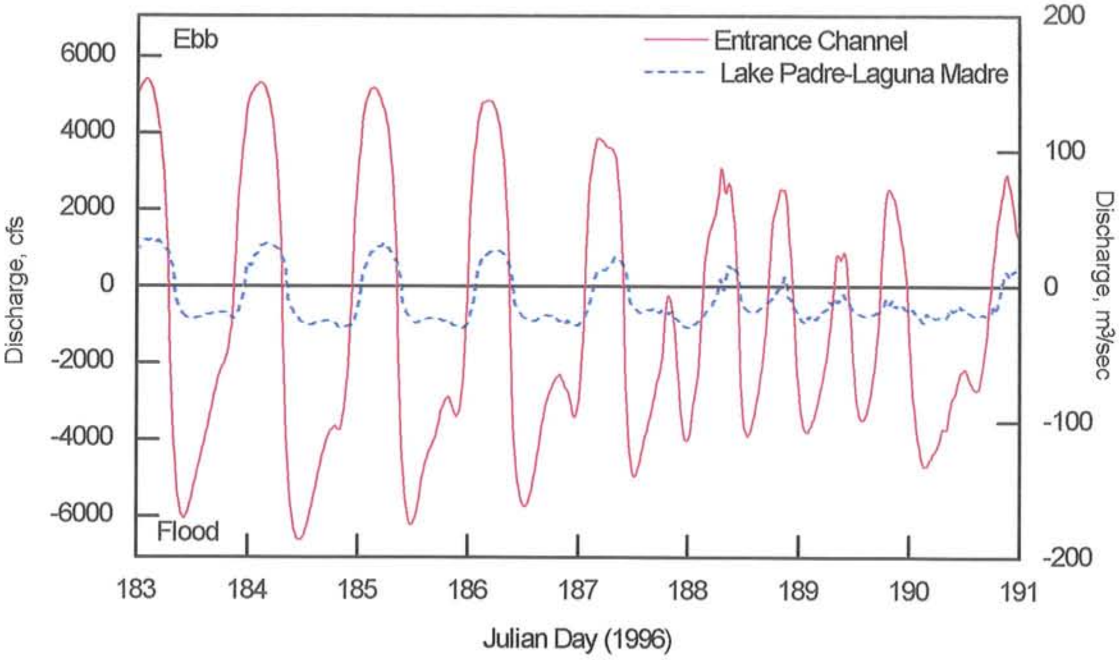

Figure 39. Discharge into Laguna Madre from Lake Padre.

4. CONCLUDING DISCUSSION

The objectives of the circulation and water-level component of the assessment were achieved using a two-dimensional numerical model of the circulation and water level change. Model simulations were performed for representative summer and storm conditions. Sensitivity tests were performed to investigate the influence of friction coefficients and channel configuration and alignment on model results.

Model simulations performed indicate that the influence of re-opening Packery Channel on water level and circulation would be limited to a relatively small region where Packery Channel opens into the Laguna Madre. Because of the small cross sectional area of Packery Channel relative to the cross section of the Corpus Christi Ship Channel and the volume of the bay system, changes in bay water level associated with the re-opening of Packery Channel are expected to be minimal. Approximately 1.5 miles from the proposed opening at the Packery Channel gauge changes in water elevation were insignificant and within the variability of water-level variations for this location. As a result, the opening of Packery Channel would not be expected to increase the incidence of or rate of flooding of the J.F.K. Causeway during storm conditions. Simulated storm conditions for the passage of Tropical Storm Josephine indicate that there will be no change in the rate of draining of the Laguna-Bay system after the passage of the storm as a result of opening Packery Channel.

Regions experiencing changes in current velocities will be limited to areas directly connected to Packery Channel (e.g., inner basin, SH361 bridge, Lake Padre subdivision) and the immediate vicinity of Packery Channel (Gulf and bay entrances). The opening of Packery Channel is not expected to have a substantial influence on velocities at the intersection of the GIWW and Packery Channel and should not be a concern for marine traffic in the GIWW. Changes in circulation on the shallow flats adjacent to Packery Channel would be limited to the region east of the GIWW and south of the "Bulkhead." The magnitude of the changes in circulation resulting from opening of the pass would depend on the phase of the tidal cycle and meteorological conditions; however, during all conditions simulated the circulation changes were minimal. During certain phases of the tidal cycle, there would be a small region on the flats to the east of the GIWW which would have reduced flow velocities due to the opposing flows from Corpus Christi Bay and Packery Channel. There would be increased tidal exchange in regions directly connected to Packery Channel, such as in the inner basin and in the canals of the Lake Padre subdivision. The increased exchange in these restricted regions would be expected to improve the water quality.

At the Gulf entrance, maximum current velocities of up to 3.3 ft/sec (1 m/sec) would be reached during peak spring tides and storm conditions. The ebb flow speed would decrease within a short distance from the seaward tip of the jetties, due to divergence of the flow. In the relatively wide and deep inner basin, the current velocities decrease to less than 1 ft/sec (30 cm/sec) in the expansion. This calm region would serve as a settling basin for suspended sediment entrained in the ebb and flood currents. Because of the constriction in Packery Channel at the SH361 bridge current velocities as great as 3 ft/sec (1 m/sec) would be reached during typical conditions and as great as 4 ft/sec (1.5 m/sec) during storm conditions. As a result of these stronger velocities, scour is expected to occur at this location until equilibrium width and depth are achieved.

Model simulations and previous measurements at nearby Fish Pass indicate that, if opened, Packery Channel would be a predominantly a flood-dominated inlet, except for during the passage of north fronts. During typical summer conditions, the net inflow into the Laguna Madre will be approximately 475 million gallons per day (1.8×10^6 m^3 per day). Simulated discharge values are consistent with measurements from Fish Pass.

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APPENDIX A : MODEL CALIBRATION AND VERIFICATION

Presented in this Appendix are comparisons of measured and simulated water level used in calibration and verification of the two-dimensional model.

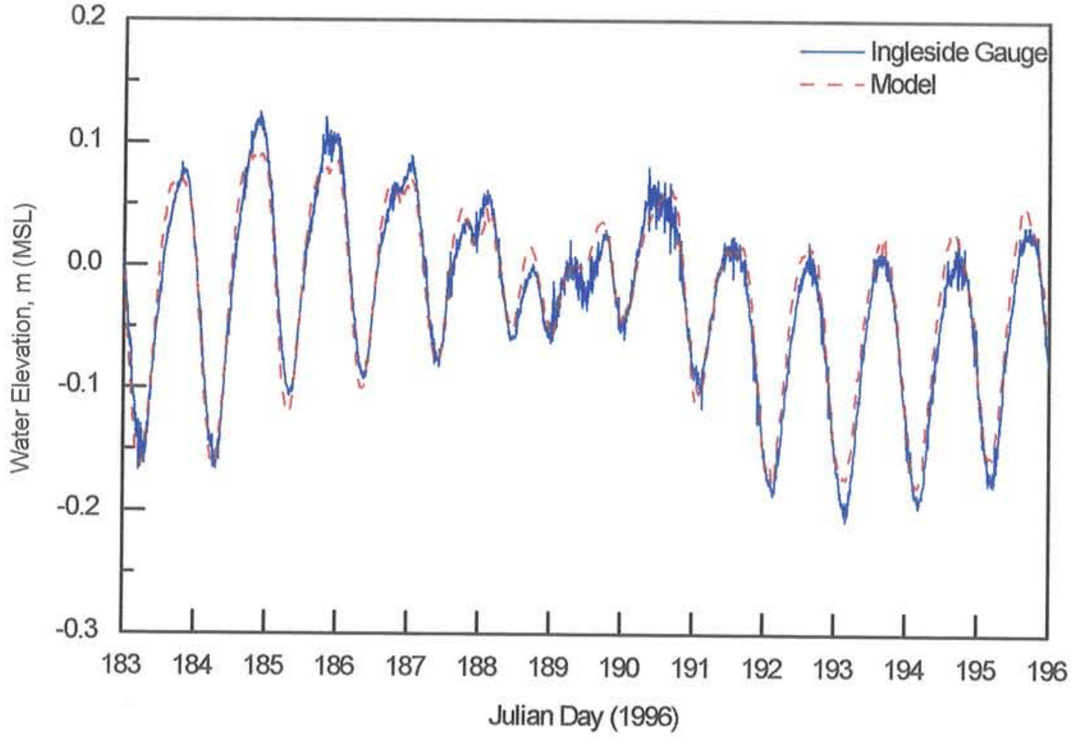

Figure A.1. Measured and modeled water elevation at Ingleside for summer conditions (Case 2A).

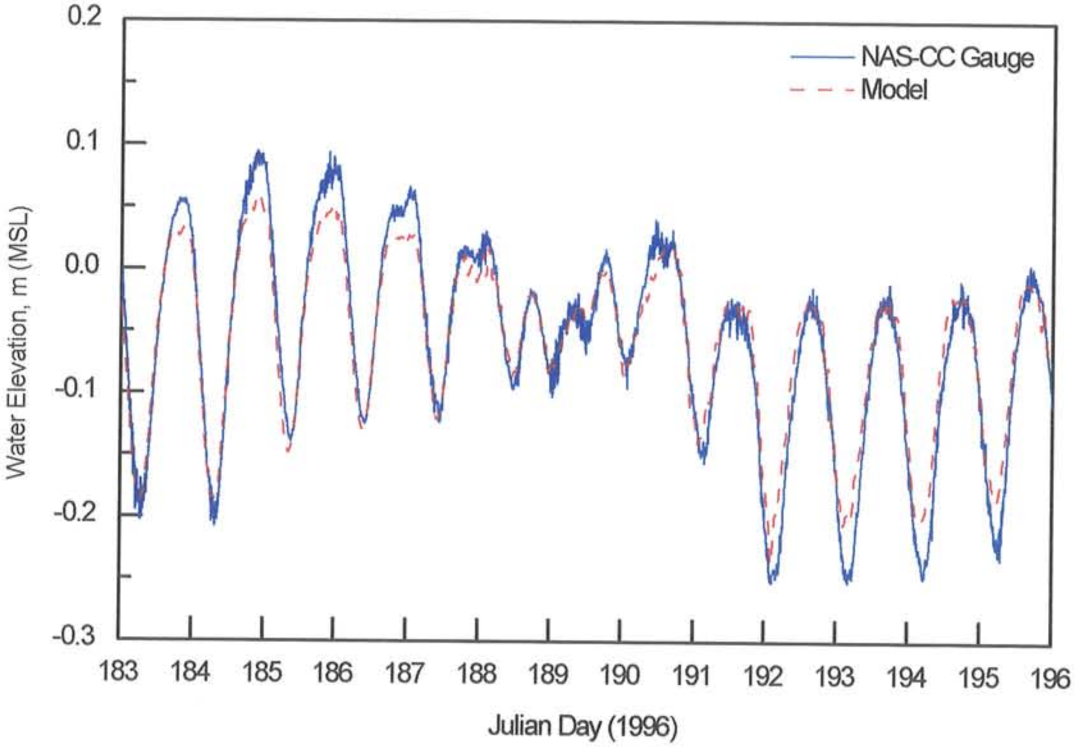

Figure A.2. Measured and modeled water elevation at NAS-CC for summer conditions (Case 2A).

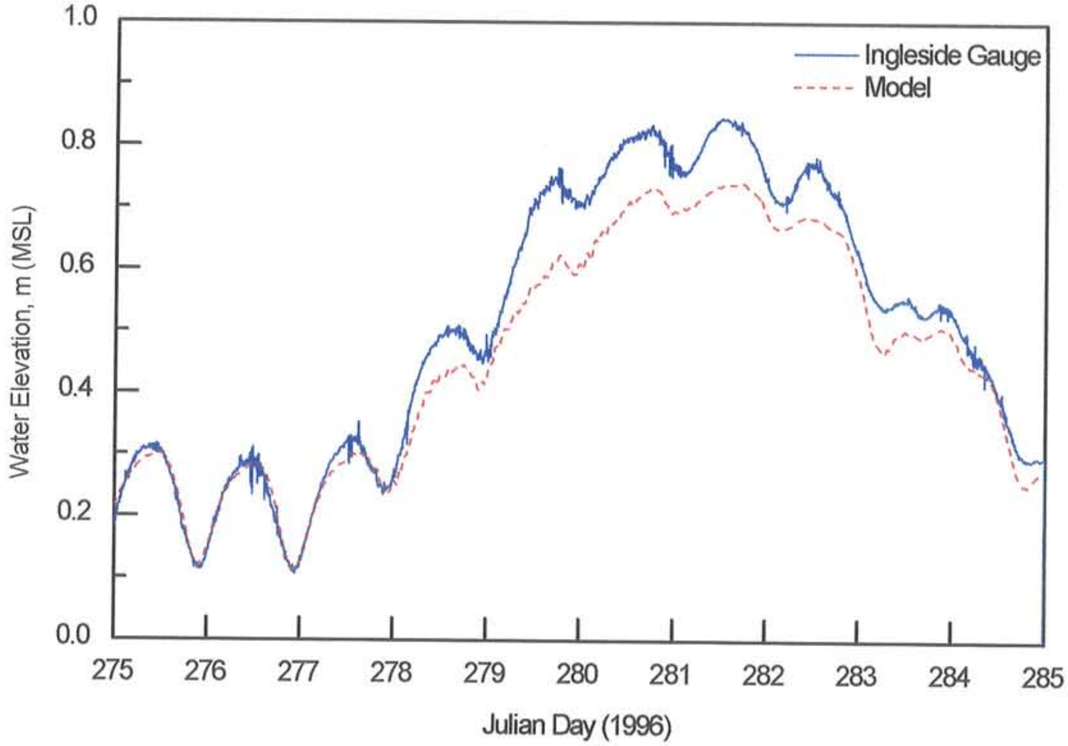

Figure A.3. Water elevation at Ingleside for storm conditions (Case 2B).

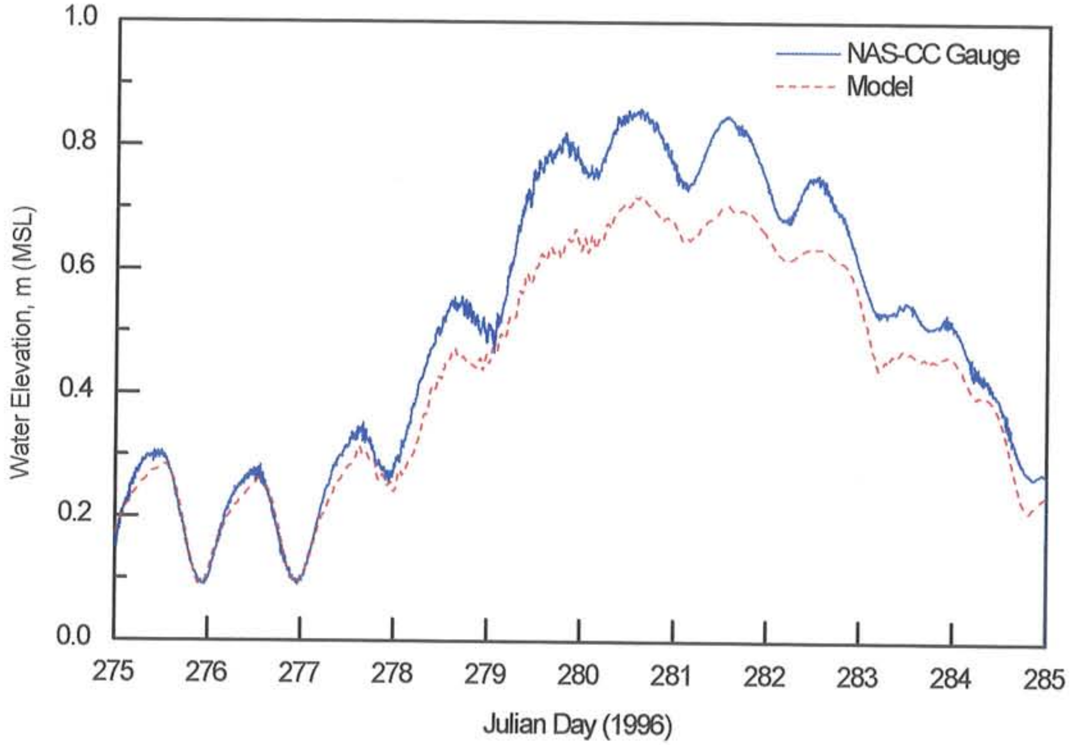

Figure A.4. Water elevation at NAS-CC for storm conditions (Case 2B).