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Engineer Research and Development Center

*Coastal Inlets Research Program*

# Evaluation of Proposed Channel on Circulation and Morphology Change at Kawaihae Harbor and Pelekane Bay, Island of Hawaii, HI

Honghai Li, Mitchell E. Brown, Thomas D. Smith, and Jessica H. Podoski

December 2009

Kawaihae Harbor and Pelekane Bay, HI (photograph courtesy of Hawaiian Images Photography and Video).

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# Evaluation of Proposed Channel on Circulation and Morphology Change at Kawaihae Harbor and Pelekane Bay, Island of Hawaii, HI

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**Abstract:** This study was conducted as a joint effort between the U.S. Army Engineer District, Honolulu; the State of Hawaii Department of Transportation, Harbors Division; and the Coastal and Hydraulics Laboratory (CHL), U.S. Army Engineer Research and Development Center, to examine the consequences of creating a new circulation channel connecting Kawaihae Deep Draft Harbor to Pelekane Bay. The study site is located on the western side of the island of Hawaii. The concept of the channel was proposed to increase water circulation, promote sediment removal, and improve water quality in the bay. The coupled wave, flow, and sediment transport model available in the Coastal Modeling System (CMS), developed by the Coastal Inlets Research Program at CHL, was applied as the main analysis method in this study.

Numerical simulations with the CMS were forced with wave parameters from Wave Information Study Pacific Station 113. Sensitivity tests revealed that wave forcing is dominant, and that tidal forcing and wind forcing are secondary in the study area. Four channel alternatives were constructed for a 15-day (non-storm) and a 6-month (winter storms) simulation with the CMS. The modeling analysis involved predicting channel performance, assessing change in water circulation in response to waves and hydrodynamics, and examining potential sediment transport and morphology change in the vicinity of the channel.

Simulation results indicate that consistent wave setup occurs in Pelekane Bay, as compared to within Kawaihae Harbor, and plays a decisive role in determining the direction and magnitude of the flow in the proposed channel. Along-channel flow is predominantly directed from Pelekane Bay to Kawaihae Harbor and is capable of mobilizing and transporting sand from Pelekane Bay to the mouth of and inside the proposed channel. Channel blockage occurred for the four channel alternatives before the end of the 6-month winter simulation, indicating that at least annual maintenance of the channel will be required. Based on the findings in the study, implementation of the circulation channel is not recommended.

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# Preface

This report evaluates the performance of a proposed circulation channel connecting Kawaihae Deep Draft Harbor to Pelekane Bay on the northwest coast of the Island of Hawaii, HI, with respect to water circulation and sediment transport. The study, which principally relied on simulations with the Coastal Modeling System (CMS), was conducted jointly by the Coastal and Hydraulics Laboratory (CHL), U.S. Army Engineer Research and Development Center (ERDC), and the U.S. Army Engineer District, Honolulu (POH), under funding provided by the POH and the State of Hawaii Department of Transportation (HDOT) as the local cost-sharing partner. The study was conducted from January through June 2009.

The POH Study Manager was Lorayne P. Shimabuku, and Thomas D. Smith, P.E., and Jessica H. Podoski, P.E. were the POH Technical Managers. The project team traveled to the Island of Hawaii for a site visit on 27 April 2009. During the site visit, sediment samples were collected in Kawaihae Harbor and Pelekane Bay, and a land profile survey was completed over the fill area between the harbor and the bay. A project review meeting was held in Honolulu, HI, on 29 April 2009 to discuss preliminary findings of the study with POH, HDOT Harbors Division, and local interests.

The study also benefited from Coastal Inlets Research Program (CIRP) technology and experience at coastal inlets. The CIRP is administered at CHL under the Navigation Systems Program for Headquarters, U.S. Army Corps of Engineers (HQUSACE). James E. Walker is HQUSACE Navigation Business Line Manager overseeing CIRP. Jeff Lillycrop, CHL, is the Technical Director for the Navigation Systems Program. Dr. Nicholas C. Kraus, Senior Scientist Group (SSG), CHL, is the CIRP Program Manager, and provided technical direction and review of this report. The mission of CIRP is to conduct applied research to improve USACE capability to manage federally maintained coastal inlets, which are present on all coasts of the United States, covering the Atlantic Ocean, Gulf of Mexico, Pacific Ocean, the Great Lakes, and U.S. territories. CIRP objectives are to advance knowledge and provide quantitative predictive tools to (a) make management of coastal inlet navigation projects, principally the design, maintenance, and operation of channels and jetties, more effective to reduce the cost of dredging, and (b) preserve the adjacent beaches and

estuary in a systematic approach that treats the inlet, beach, and estuary as a unit. To achieve these objectives, the CIRP is organized in work units conducting research and development in hydrodynamic, sediment transport and morphology change modeling; navigation channels, adjacent beaches, and estuary; inlet structures and scour; laboratory and field investigations; and technology transfer.

This report was prepared by Dr. Honghai Li, Coastal Engineering Branch, CHL, Mitchell E. Brown, SSG, CHL, and Thomas D. Smith, P.E. and Jessica H. Podoski, P.E., POH. The CHL portion of this study was performed under the general administrative supervision of Dr. Edmond J. Russo, Jr., P.E., former Chief, Coastal Engineering Branch (CEB), Navigation Division (ND), CHL; Dr. Rose M. Kress, Chief, ND; and Dr. William D. Martin, Director of CHL. J. Holley Messing, CEB, format-edited the draft report.

COL Gary E. Johnston was Commander and Executive Director of ERDC. Dr. James R. Houston was Director of ERDC.

# Unit Conversion Factors

| Multiply | By | To Obtain |
|---|---|---|
| cubic yards | 0.7645549 | cubic meters |
| feet | 0.3048 | meters |
| miles (U.S. statute) | 1,609.347 | meters |
| pounds (mass) | 0.45359237 | kilograms |

# 1 Introduction

In response to a request by the State of Hawaii Department of Transportation (HDOT), Harbors Division, the U.S. Army Engineer District, Honolulu (hereafter, the Honolulu District), and staff of the Coastal and Hydraulics Laboratory (CHL), U.S. Army Engineer Research and Development Center, U.S. Army Corps of Engineers (USACE) led a study to investigate the hydraulic and sediment transport consequences of dredging a channel between Kawaihae Deep Draft Harbor and Pelekane Bay, HI. The study was also supported through application of the most recent predictive modeling technology advances made by the Coastal Inlets Research Program (CIRP) conducted at CHL.

Kawaihae Deep Draft Harbor (hereafter referred to as Kawaihae Harbor) is located on the northwest coast of the Island of Hawaii, HI (Figure 1). Completed in 1959, Kawaihae Harbor consists of a 2,650-ft-long breakwater, and a 1,450-ft-wide by 1,050- to 1,750-ft-long basin that are under the jurisdiction of HDOT. Two small boat harbors, one at the north end of and the other at the southwest corner of the deep-draft harbor, outside the coral fill area, are under the jurisdiction of the State of Hawaii, Department of Land and Natural Resources. The harbor entrance channel is 3,270 ft long, 520 ft wide, and 40 ft deep. Sediment and coral rubble deposited from the harbor dredging created a 60-acre landfill on the south side of the harbor (HDOT 2009). Kawaihae Harbor has two commercial piers along the northeast rim of the harbor basin. The National Oceanic and Atmospheric Administration's (NOAA) Kawaihae tide gage (1617433) is located between Piers 1 and 2.

As the population grows and the local economy develops in West Hawaii, Kawaihae Harbor is expected to experience rapid development and enhancement. Pelekane Bay, located south of and adjacent to Kawaihae Harbor, receives runoff from the Kawaihae watershed and is sometimes considered as being murky. The bay has served as a historical and cultural center for native Hawaiians, and it is a breeding ground for many indigenous reef fish species (Tissot 1998).

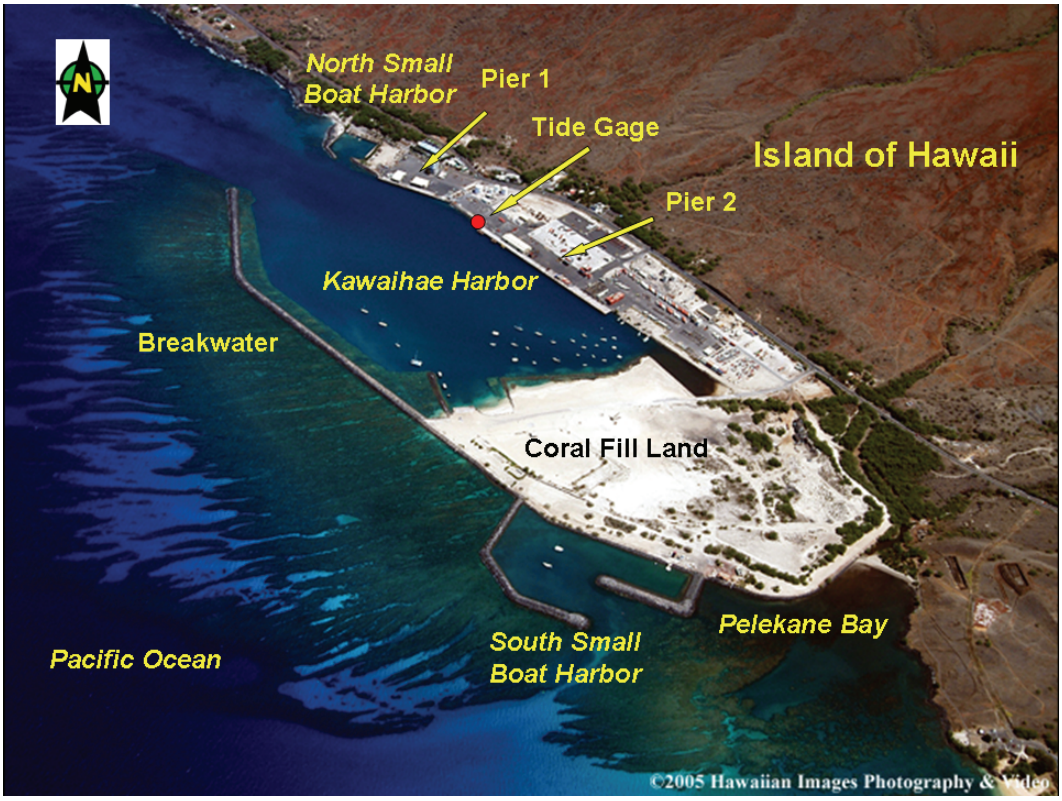


Figure 1. Kawaihae Harbor and Pelekane Bay (Hawaiian Images Photography and Video 2009). The red circle denotes the location of NOAA's Kawaihae tide gage (1617433).

## Background

Long-term changes in the marine habitat and biota of Pelekane Bay were studied over a 20-year period from 1976 through 1996 (Tissot 1998). Tissot noted that a major decline in the abundance of the marine biota had taken place. Possible causes of this deleterious change were associated with long-term sedimentation due to terrestrial runoff from the Kawaihae watershed and reduced ocean circulation in Pelekane Bay caused by construction of the deep- and shallow-draft harbors.

In an effort to improve water quality and restore marine habitats in Pelekane Bay, installation of a circulation channel connecting Pelekane Bay and Kawaihae Harbor through the coral fill area was proposed with the intent of improving water circulation in the bay through Kawaihae Harbor and, therefore, moving accumulated sediment out of the bay (College of Tropical Agriculture and Human Resources 2001, Tissot 1998).

## Objectives

The Honolulu District identified the need to evaluate the channel installation on water circulation and sediment movement, and proposed to employ a modeling tool for the present study.

The objectives of the study were to:

1. Quantify potential functioning of the proposed channel between Kawaihae Harbor and Pelekane Bay.
2. Understand the change in water circulation that the proposed channel would have, sediment transport, and morphology change in the harbor and the bay.
3. Assess changes in the nearshore environment under different wave, tide, and wind conditions.

Based on available resources, the study objectives were judged to be best met through numerical simulation and evaluation of waves, tide, current, and sediment transport. There is a limited amount of information for the site from previous studies and from data collection.

## Method

To achieve the study objectives, the Coastal Modeling System (CMS) developed in the CIRP was applied (Buttolph et al. 2006; Lin et al. 2008). The CMS interactively calculates wave transformation and wave-induced currents, water level change by tide, wind, and waves, interactive waves and currents, and sediment transport and morphology change. The approach taken for this modeling study is:

1. Assemble and review relevant historical data on bathymetry, tide, waves, wind, and sediment.
2. Select a 15-day period and a 6-month period from October to March for model simulations. The former is considered as a non-storm period. The latter is identified as a typical winter period based on wave climatology and should include multiple winter storms.
3. Drive the CMS with wind, waves and water surface elevation (WSE) data.
4. Develop four alternatives with different dimensions for the proposed channel between Kawaihae Harbor and Pelekane Bay.
5. Analyze and compare model simulation results under the existing conditions and the channel alternatives.

## Scope of report

This study proceeded by evaluating hydrodynamic and morphology change associated with the installation of the proposed circulation channel connecting Kawaihae Harbor and Pelekane Bay. Chapter 2 describes the data used to drive the model. Chapter 3 provides information on model framework, setup, and alternatives evaluated. Chapter 4 presents model results for two selected simulation periods, and Chapter 5 gives the conclusions of the study. Appendix A contains results of a sensitivity analysis of a proposed circulation channel to three sets of steady-state wave parameters and to different processes, and Appendix B shows plots of circulation fields under Alts 2, 3, and 4 for the non-storm and storm simulation periods.

# 2 Data Assembly and Analysis

## Coastline and bathymetry

Coastline information for Kawaihae Harbor and Pelekane Bay along the west coast of the Island of Hawaii was extracted for this study from a georeferenced image file downloaded from Google Earth 5.0 (http://earth.google.com). The aerial photographs used in the study were obtained from Hawaiian Images Photography and Video (2009).

Bathymetry data for the nearshore area surrounding Kawaihae Harbor and Pelekane Bay were provided by the Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) (Wozencraft and Lillycrop 2002). The SHOALS system, funded and operated by the USACE, fully surveyed the nearshore regions around the harbor and provided high-resolution and accurate bathymetry from the shoreline to a depth of about 115 ft, including mapping of the coral reef and harbor area (Thompson et al. 2006). The offshore bathymetry data were obtained from GEOphysical DAta System (GEODAS) database, which has been developed and managed by the National Geophysical Data Center (NGDC) of NOAA (NGDC 2009).

Figure 2 shows the depth contours, relative to mean sea level (MSL) from the combination of the two datasets for the study domain. With the SHOALS system, the GEODAS database supplements bathymetry data outside the harbor to the 1,400-ft isobath. Figures 2a and 2b are a far view and a near view of the study area, respectively. The figure displays the harbor basin and the harbor entrance channel with depths ranging from 40 to 50 ft. An area of about 500-1,000 ft wide and less than 10 ft deep is covered by coral reefs outside the breakwater. The shallow reef area is separated from the Pacific Ocean by a steep slope and deepens to 500 ft within 2,000 to 4,000 ft offshore. The figure also demonstrates smooth depth transition and consistency between the two datasets.

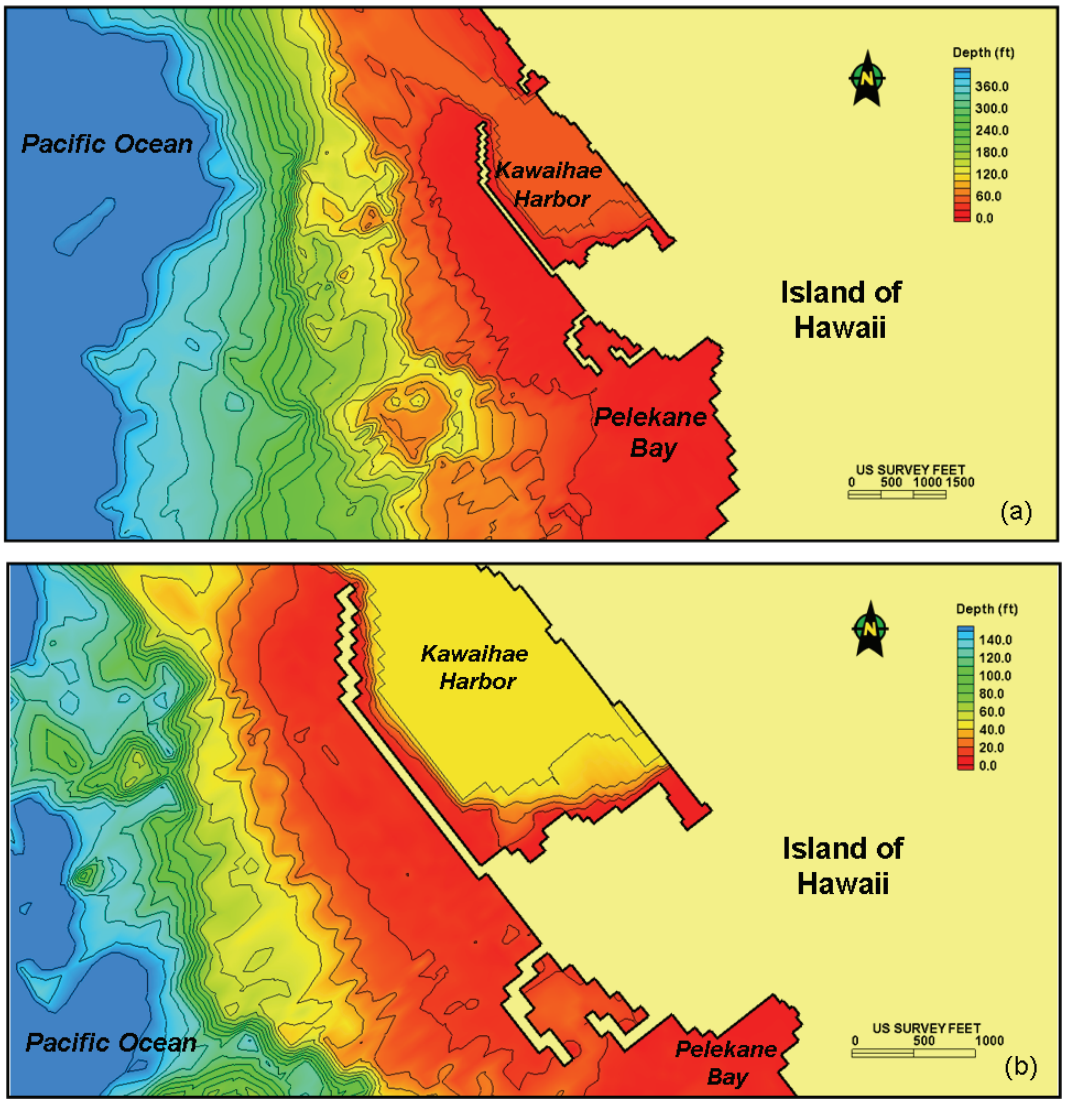


Figure 2. Depth contours (ft) of Kawaihae Harbor and Pelekane Bay (depths to local MSL), (a) far view, and (b) near view.

## Waves

Wave data from the National Data Buoy Center (NDBC 2009) and hindcast waves from the USACE Wave Information Studies (WIS) (Coastal and Hydraulics Laboratory 2009) were analyzed. Figure 3 shows the NDBC buoy locations and the WIS Pacific Stations 103-114 near the Island of Hawaii.

Data from several NDBC wave buoys in the study area were examined and found to either miss wave direction measurements or have ceased operation since the 1980s or 1990s. For example, Buoys 51002 and 51003 have presently no wave direction information in their dataset, and Buoys 51005 and 51027 stopped collecting data after 1988 and 1995. WIS hindcasts,

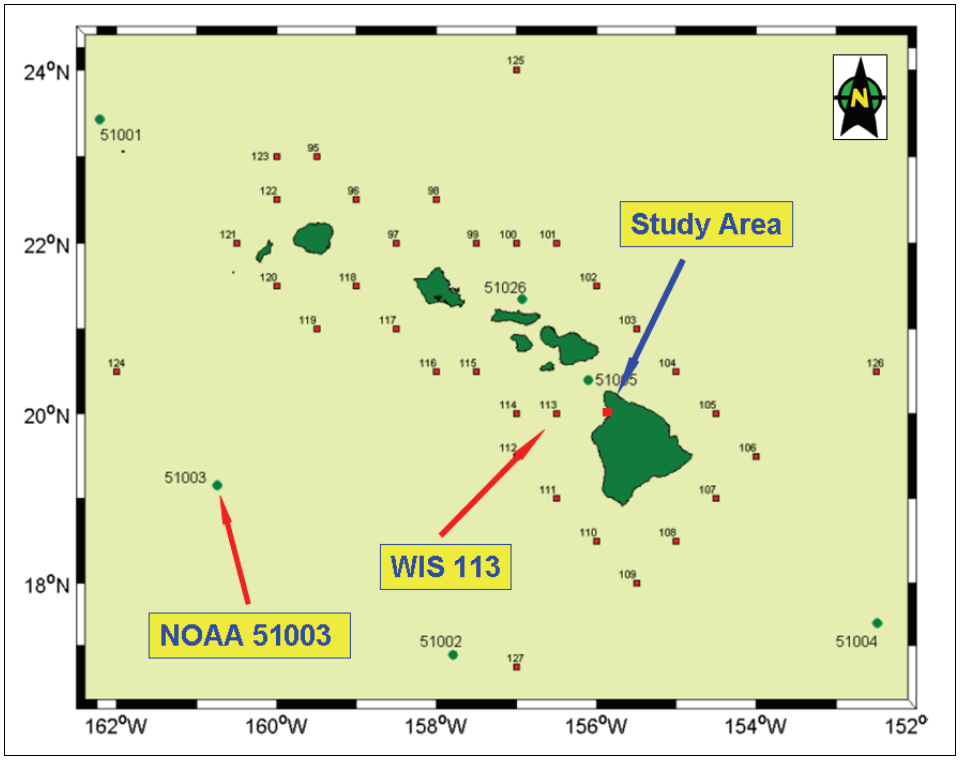


Figure 3. Locations of WIS Pacific stations and NDBC buoys surrounding Hawaiian Islands (large red square depicts the study area).

however, provide wave parameters in the Hawaiian Islands for the years 1981 through 2004. Because this dataset has met the selection criteria for the two simulation periods described in the previous chapter, it was analyzed and adopted in this study. According to the WIS website (http://www.frf.usace.army.mil/cgi-bin/wis/pac/pac_main.html), over-prediction of north Pacific storms and tropical events may result in an overestimate of extreme storm waves in the Pacific Basin hindcast. During the two periods selected for this study, especially the 6-month winter period, examination of WIS hindcast and buoys data did not indicate evidence of wave height over-prediction.

WIS Pacific Station 113 is located west of the Island of Hawaii and is the closest WIS station to Kawaihae Harbor (Figure 3). In relation to the geographic location of the project study area, this station is similarly sheltered from northerly waves by the Hawaiian Islands of Maui, Molokai, and Lanai, and from easterly waves by the Island of Hawaii. It does have a wider range of exposure to waves propagating from south-southeast clockwise to northwest (about 160-310 deg azimuth).

Figures 4 and 5 show the 1981-2004 wave height, $H_s$, and wave period, $T_p$, respectively, for WIS Pacific Station 113. The wave roses indicate that the predominant waves are from the south-southwest (about 200 deg azimuth) and west-northwest (about 290-310 deg azimuth) directions. The largest wave heights, occurring at an extremely small percentage (< 0.02 percent), are between 15 and 16.5 ft. More than 90 percent of the waves are swells that have periods between 10 and 30 sec. Those swells mostly correspond to the two predominant wave directions, whereas the short-period waves approach the station from east-northeast. The 24-year (1981-2004) average wave height and peak wave period are 3.9 ft and 12.7 sec, respectively.

## Water surface elevation

Water surface elevation data for NOAA tide gage 1617433 (Kawaihae, HI) are available on the NOAA website, http://tidesandcurrents.noaa.gov (see Figure 1 for the gage location). Hourly water surface elevation (tide) during 1-15 April 2004 is displayed in Figure 6. Water surface elevation at the gage indicates a mixed, predominately semi-diurnal tidal regime

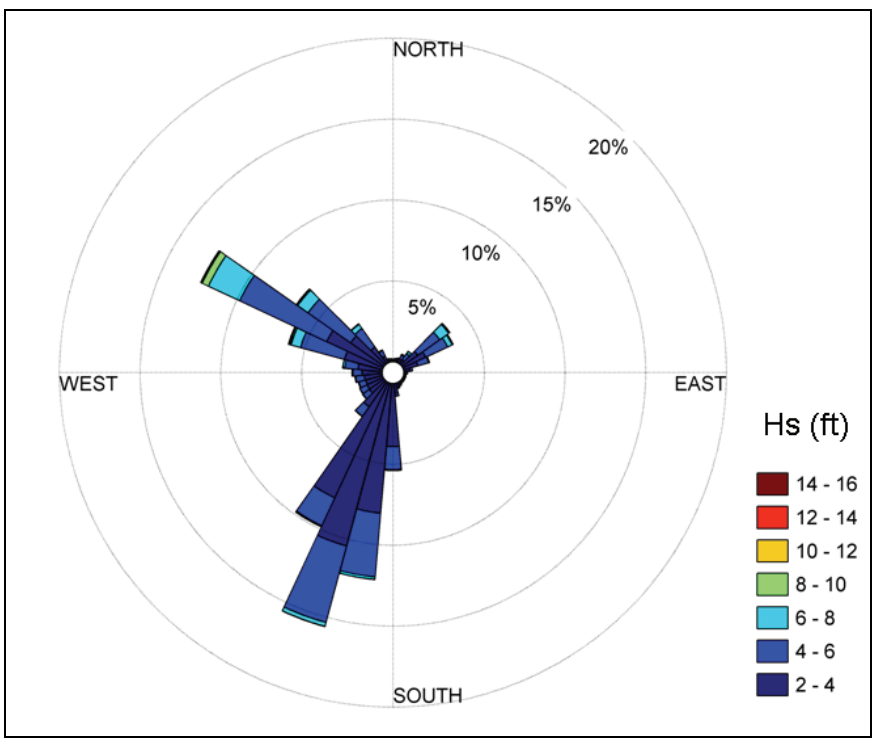


Figure 4. Wave height rose at WIS Pacific Station 113 for 1981-2004.

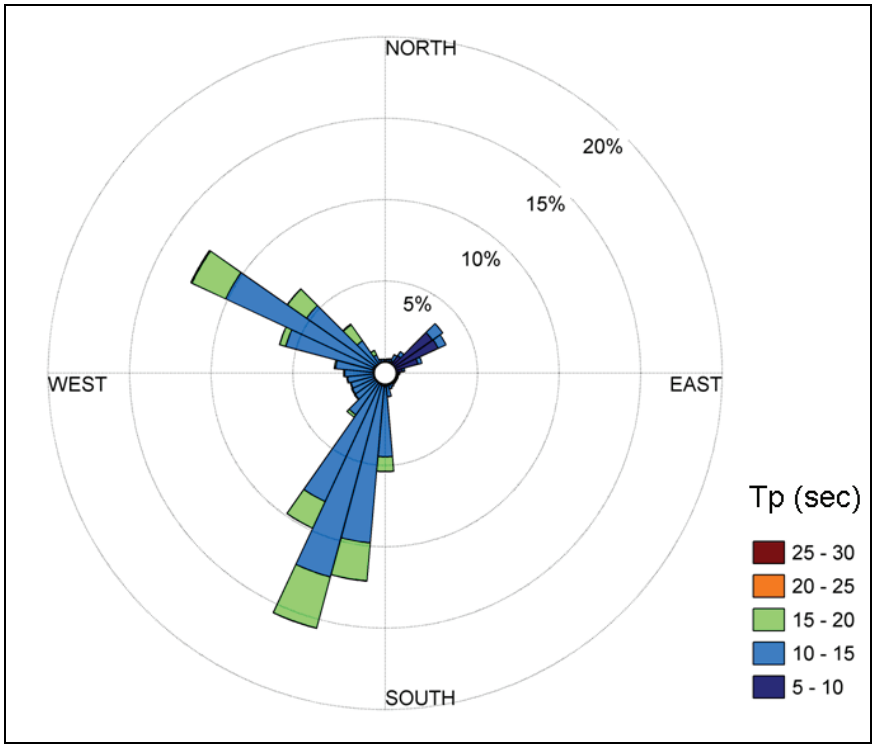


Figure 5. Wave period rose at WIS Pacific Station 113 for 1981-2004.

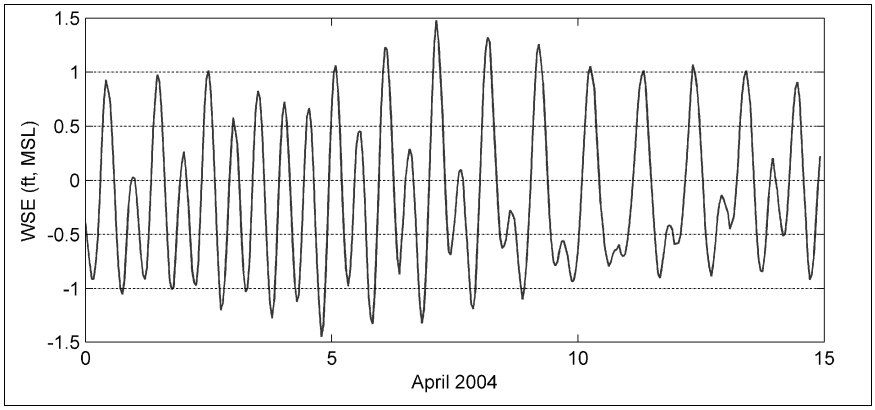


Figure 6. Water surface elevation at NOAA Kawaihae tide gage (1617433), April 2004.

surrounding the study area. The mean tidal range (mean high water – mean low water) is 1.5 ft and the maximum tidal range (mean higher high water – mean lower low water (MLLW)) is 2.2 ft. Therefore, the tidal range is considered relatively small in relation to energy produced by large waves incident to the site.

## Wind

Wind data were available from various sources, covering coastal and off-shore conditions. Local wind observations were taken from the NOAA

station at Kawaihae, HI, and offshore wind data were downloaded from three NDBC moored buoys west (Buoys 51002 and 51003) and south (Buoy 51028) of the Island of Hawaii. Hindcast wind information at WIS Pacific Station 113 was obtained together with the hindcast wave parameters and analyzed as another offshore wind source. The wind data were retrieved from the NOAA station and NDBC buoys for year 2004, and the hindcast wind from WIS Pacific Station 113 was for years 1981 through 2004.

Figures 7 and 8 show wind roses for the Kawaihae station and Buoy 51003. There are distinct wind patterns at the onshore and offshore locations in the study area. The 2004 wind direction at the NOAA gage is characterized by either west-southwesterly to west-northwesterly (about 250-310 deg azimuth) or east-northeasterly to easterly (about 50-80 deg azimuth). It was found that the diurnal cycle of the wind direction corresponds well to the sea breeze. A relatively calm coastal region is indicated by the mean wind speed of 9.2 ft/sec at this location. At the offshore buoy, east-northeasterly to easterly winds are predominant (about 50-90 deg azimuth), which is clearly associated with the northeast trade wind system in the region. In relation to the wind at the coastal station, the offshore wind is much stronger, and the mean wind speed is close to 19.7 ft/sec.

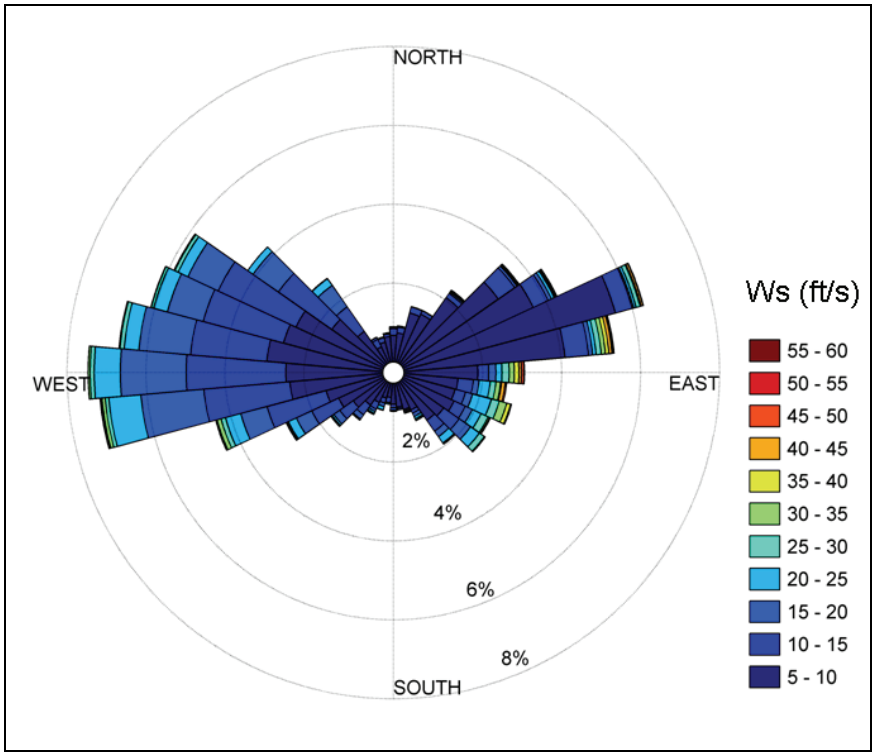


Figure 7. Wind rose at NOAA Kawaihae tide gage (1617433) for year 2004.

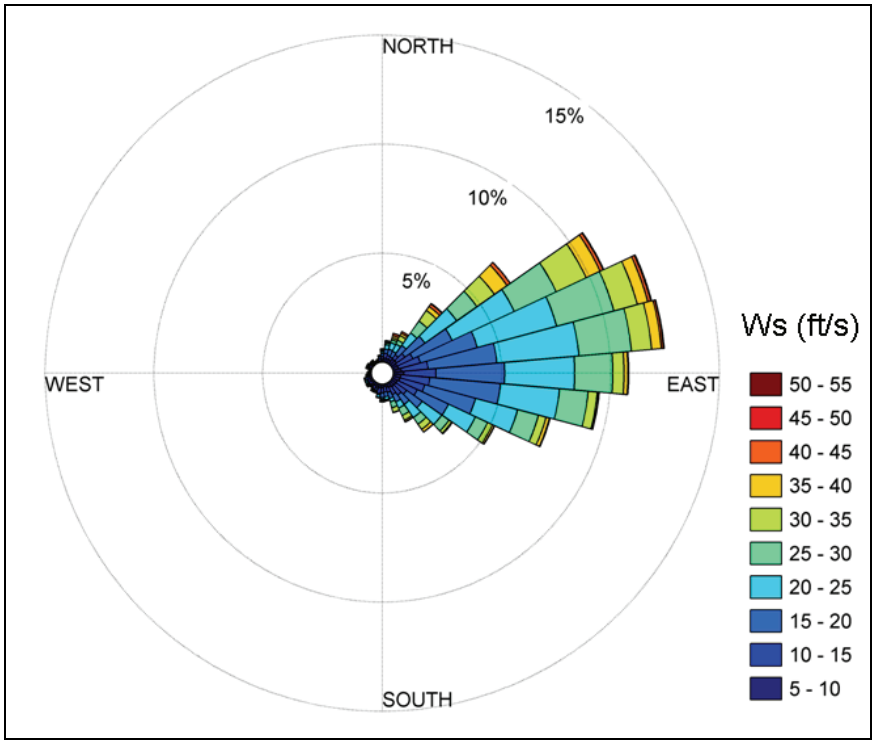


Figure 8. Wind rose at NDBC buoy 51003 for year 2004.

## Sediment

Sediment grab samples were taken from the notched area on the southeast side of Kawaihae Harbor over the coral fill area, and on the perimeter of Pelekane Bay (Figure 9) during the site visit on 27 April 2009. Six samples were sent to the sediment laboratory at CHL for analysis of grain size. Median grain size, $D_{50}$, was determined in the laboratory and is tabulated in Table 1.

Figure 9 shows the locations of two (KH-1 and KH-2) and three (PB-1, PB-2, and Stream) samples taken in the harbor and the bay area and one sample (Upland) on land. Table 1 presents the analyzed median grain size $D_{50}$. The average mean grain size of the six samples is 289 µm with a standard deviation of 33 percent. One large grain size at site KH-2 is responsible for the higher standard deviation. Excluding this sample, the average median grain size is 248 µm with a standard deviation of 10 percent.

Figure 9. Sediment surface sampling locations at Kawaihae Harbor and Pelekane Bay.

Table 1. Median grain sizes of sediment grab samples taken in Kawaihae Harbor and Pelekane Bay.

| Sample Location | Median Grain Size, $D_{50}$ (μm) |
|---|---|
| KH-1 | 288 |
| KH-2 | 492 |
| PB-1 | 239 |
| PB-2 | 220 |
| Stream | 231 |
| Upland | 264 |

# 3 Modeling Strategy

For this study, the CMS was applied for simulating waves, circulation, and sediment transport in the vicinity of Kawaihae Harbor and Pelekane Bay. The hydrodynamic and wave models, CMS-Flow and CMS-Wave, were coupled and operated through a Steering Module developed within the Surface-water Modeling System (SMS), which can also interact dynamically in simulating sediment transport and morphology change (Buttolph et al. 2006; Lin et al. 2008).

## Model description

CMS-Flow is a three-dimensional (3D) finite-volume model that solves the mass conservation and shallow-water momentum equations of water motion. The model can run in a two-dimensional (2D) mode based on the depth-integrated continuity equation. The wave radiation stress and wave information entering the flow and sediment transport formulas are supplied to CMS-Flow through coupling with CMS-Wave. Calculated currents and water level change are returned to the wave model to increase the accuracy of the wave transformation predictions.

CMS-Flow is forced by changes in offshore water surface elevation (e.g., from tide), wind, river discharge, and wave radiation stress. Physical processes pertinent to the present study calculated by CMS-Flow are current, water surface elevation, sediment transport, morphology change, and representation of non-erodible bottom (reef). Additional capabilities include flooding and drying, space-varying bottom-friction, salinity transport, efficient grid storage in memory, and hot-start options.

CMS-Wave is a 2D wave spectral transformation model implemented in CMS. It is a phase-averaged model, which averages changes in the wave phase in calculating wave properties. CMS-Wave contains theoretically derived approximations for wave diffraction, reflection, and wave-current interaction, and therefore, is appropriate for conducting wave simulations at coastal inlets with jetties and breakwaters. It employs a forward-marching, finite-difference, steady-state (time-independent) Eulerian method to solve the wave action conservation equation. The model operates on a coastal half-plane, so primary waves can propagate only from the seaward boundary toward shore. If the seaward reflection option is

activated, CMS-Wave performs backward-marching for seaward reflection after the forward-marching calculation is completed.

## Model domain

The main bathymetric features surrounding Kawaihae Harbor have been described in Figure 2. The harbor entrance channel has a depth of 45 ft, and the harbor basin has a depth of 40 ft. A coral reef extends along the breakwater and forms a 500- to 1,000-ft-wide and 3- to 10-ft-deep strip outside the harbor (Thompson et al. 2006). Nearshore regions, including Pelekane Bay and the coastal area north of the harbor, are shallow with depths ranging from 1.5 to 10 ft. The offshore area deepens to a few thousand feet and is open to the Pacific Ocean.

In the application of CMS to the Kawaihae Harbor and Pelekane Bay, a variable-resolution grid system was created to discretize the entire harbor, bay, and the offshore region. The model domain extends approximately 8.7 miles alongshore and 5 miles offshore, and the offshore boundary of the domain reaches to the 1,410-ft isobath. Figure 10(a) illustrates the entire CMS domain, a rectangular grid of $141 \times 167$ cells and bathymetric features of Kawaihae Harbor, Pelekane Bay, and adjoining nearshore and continental shelf. The grid permits much finer grid resolution in areas of high interest such as the back of the harbor, Pelekane Bay, and the coral-fill area of the proposed circulation channel, as shown in Figure 10b.

## Simulation period and model forcing

As described in Chapter 1, the model simulations were conducted for both a 15-day, non-storm period (sensitivity tests) and a 6-month, storm period (production runs for evaluation of sediment transport and channel stability). Based on the WIS dataset, a time period was chosen for the non-storm case from 1-15 April 2004. Figure 11 illustrates the wave parameters at WIS Pacific Station 113 for this time interval. The mean significant wave height is 3.9 ft. All wave heights for the time interval are less than 5.3 ft. The mean wave period is 13.9 sec, and the predominant wave direction is west-northwest. Clearly, 1-15 April 2004 represents the mean wave condition and corresponds well to a non-storm period at the location.

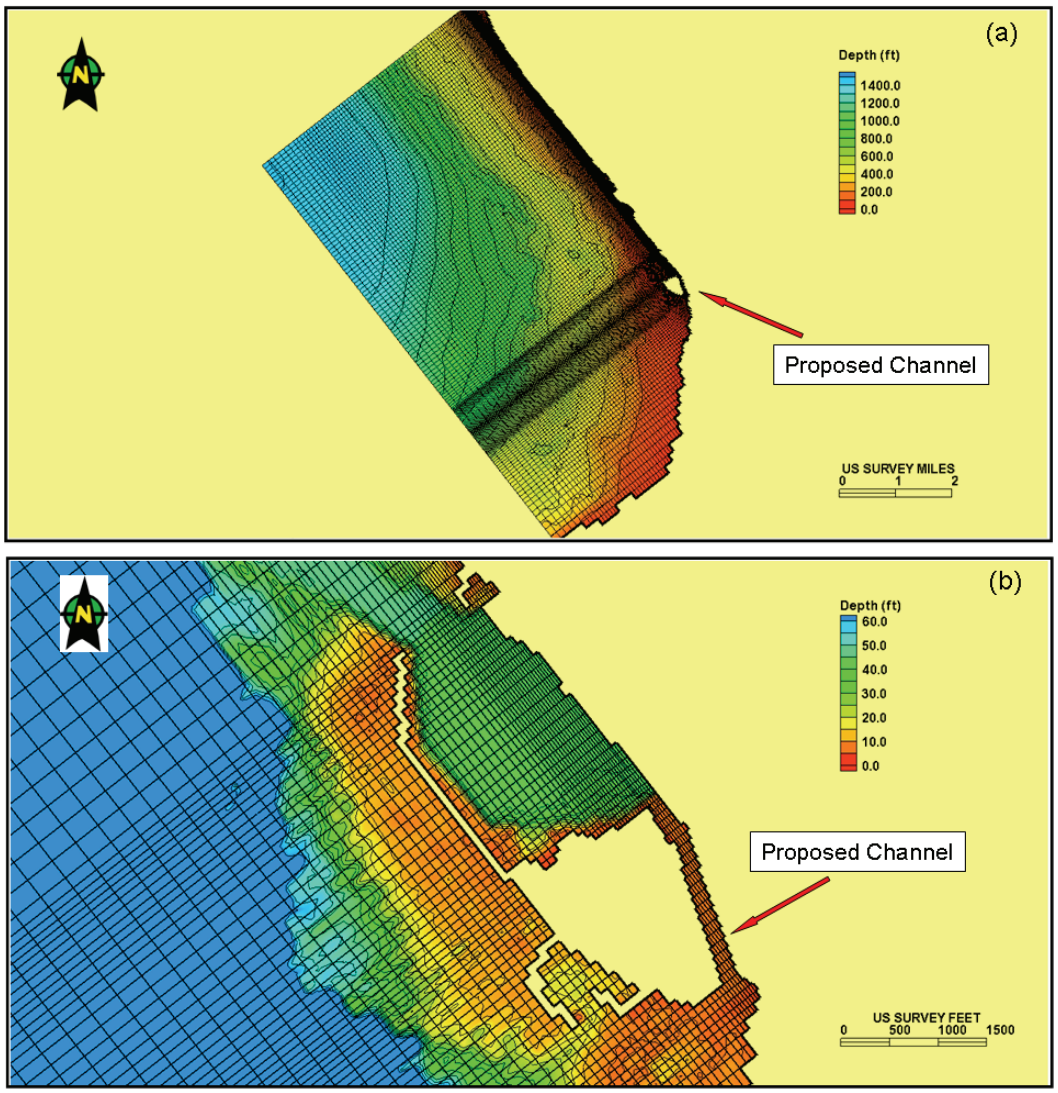


Figure 10. CMS computational grid and bathymetric contours surrounding Kawaihae Harbor, Pelekane Bay, and proposed channel (depths to local MSL), (a) far view and (b) near view.

Selection of the typical winter, storm period, was based on wave climatology. By comparing wave heights, periods, and directions between each of 24 annual wave roses and the 24-year wave roses, as shown in Figures 4 and 5, the representative 6 months chosen runs from October 1992 through March 1993. Figure 12 illustrates the wave parameters at WIS Pacific Station 113 for this period. As shown in the figure, the simulation period spans about 4-5 winter swell events, considering the events produced wave heights close to or exceeding 8.2 ft. All those high swells propagate from the west-northwest directions. Aucan (2006) studied wave climatology of the Hawaiian Islands for the years 1957-2002 and identified three to four high-swell events for the 1992-1993 winter season (November-March), indicating that high winter swells were generated by distant North Pacific storms.

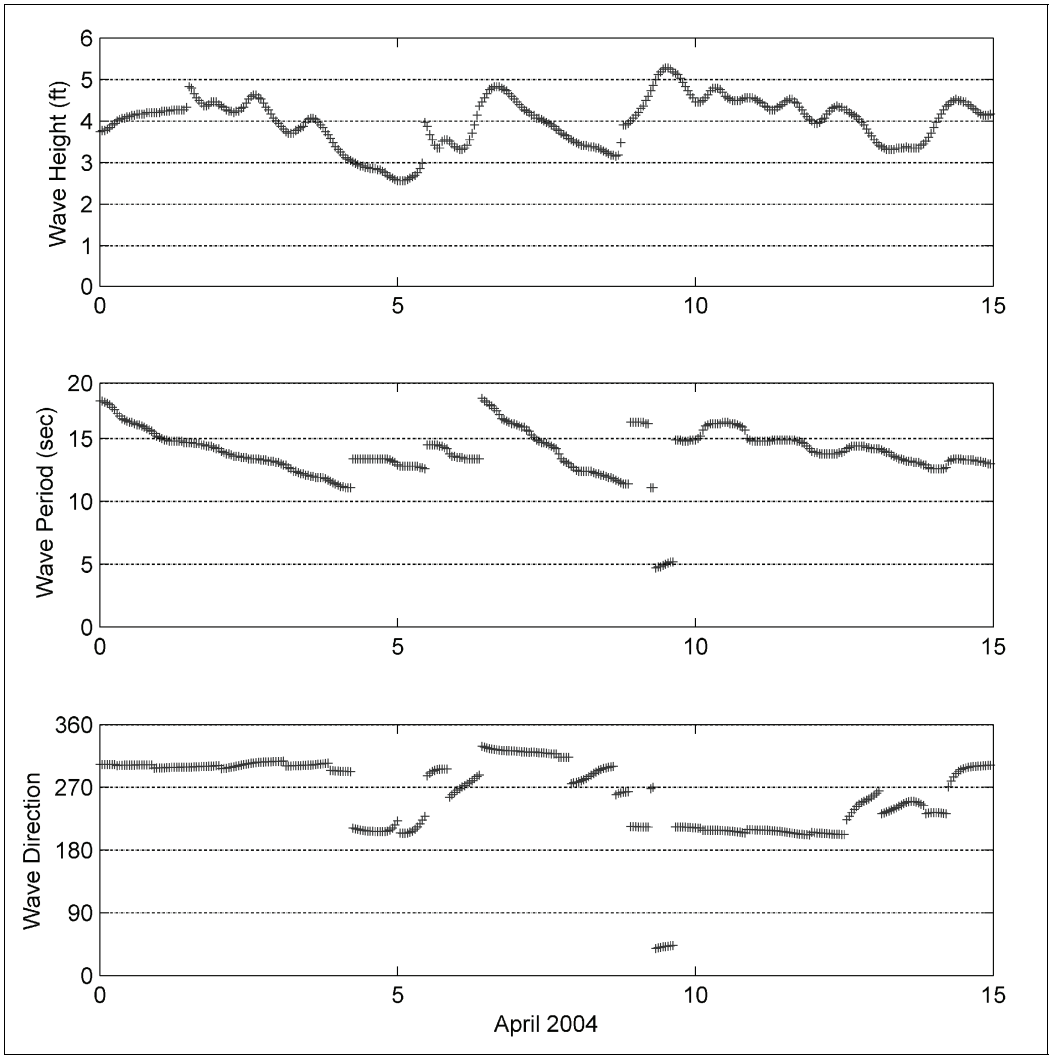


Figure 11. Significant wave height, peak wave period and wave direction at WIS Pacific Station 113 for non-storm period 1-15 April 2004.

The forcing datasets required by CMS-Flow and CMS-Wave come from a variety of sources. The time-dependent water surface elevation data at open boundary locations were specified through water level observations at Kawaihae, HI (Figures 1 and 6). Time varying significant wave height, peak spectral wave period, and wave direction were based on the WIS hindcasts (Figures 11 and 12). Wind forcing data were retrieved from the offshore NDBC Buoy 51003 (Figures 3 and 8).

## Study alternatives

Bodge and Howard (2006) described the digging of a channel at an island in the North Malé atoll, Maldives. The channel effectively divided the island into two sections. The purpose of the channel construction was to improve water exchange in a semi-enclosed bay, not unlike present study

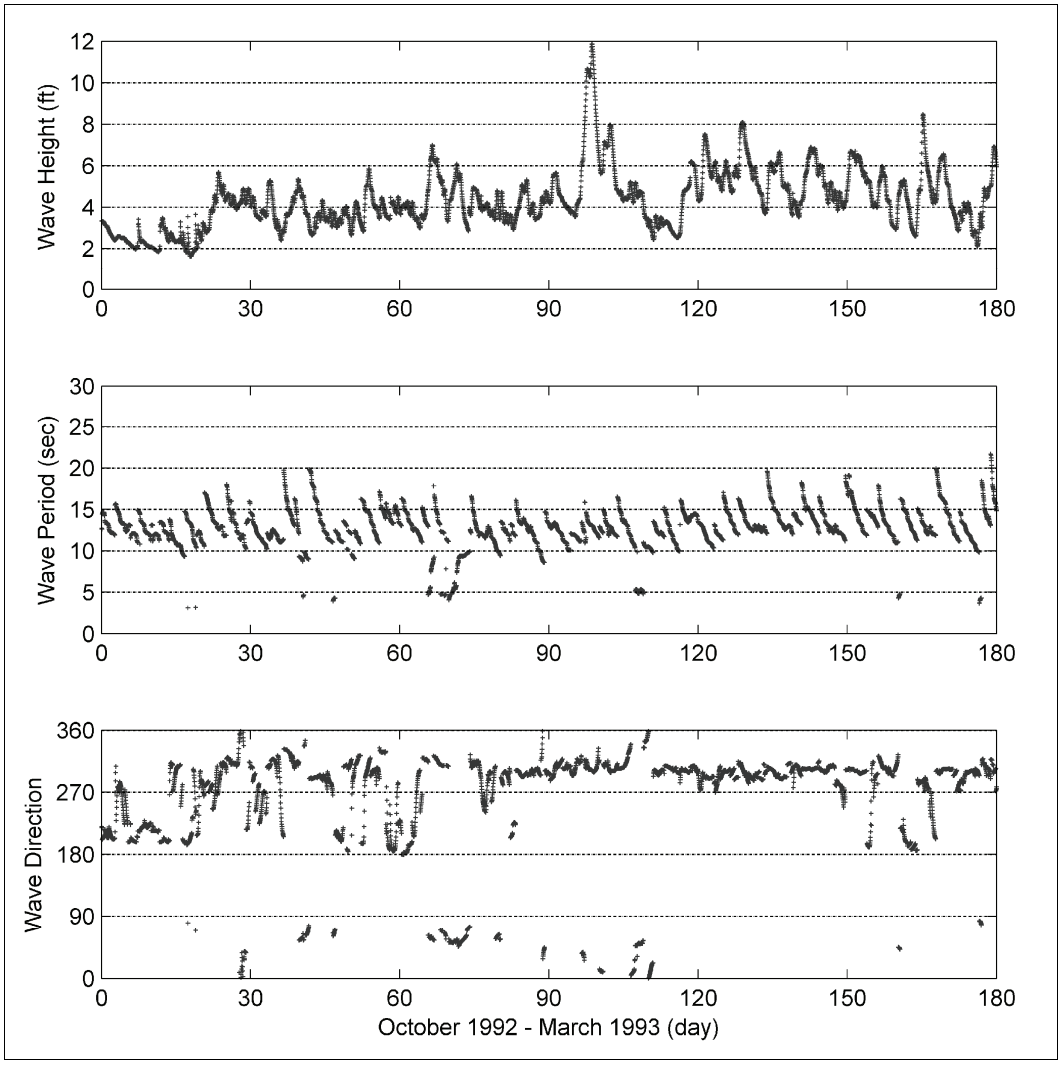


Figure 12. Significant wave height, peak wave period and wave direction at WIS Pacific Station 113 for multi-storm period October 1992 – March 1993.

objectives. Forcing of the current through the channel in their coastal engineering study was through a phase difference in the tide on each side of the island, with an average phase difference of 66 sec, giving a 0.16-0.66 ft/sec flow along the 660-ft-long channel. In the present study, because Kawaihae Harbor and Pelekane Bay are relatively close as compared to the length of a tidal wave, it was concluded that a differential in water elevation by wave setup or other mechanism related to waves, if present, would have to provide the necessary forcing.

Figure 10 illustrates the proposed circulation channel connecting Kawaihae Harbor and Pelekane Bay with the CMS grid. To configure the channel for model simulations, tidal level and coastline features around the harbor and the bay were examined.

### Channel alternatives

Water surface elevation data at the Kawaihae gage indicate that MLLW is located about 1 ft below MSL. Therefore, two channel depths, 3.3 and 4.9 ft relative to MSL, were specified to assure the channel would be kept wet under different tidal conditions. A dry channel was considered undesirable because potential circulation would be reduced and periodic wetting and drying might tend to promote erosion or deposition. Two channel widths, 98 and 164 ft, were selected referring to the scale of the "notched" area on the southeast side of the harbor. As shown in Figure 10, the proposed channel extends about 1,550 ft from the bottom of the notch, through the coral fill, to Pelekane Bay. The harbor and the bay areas near the channel's two ends are adjusted to the designed depth for a certain channel configuration if the original depth there is shallower (Figure 2).

Four alternatives were developed in consultation with the Honolulu District for the proposed circulation channel, and the dimensions are summarized in Table 2.

Table 2. Proposed channel alternatives between Kawaihae Harbor and Pelekane Bay.

| Alt | Width (ft) | Depth (ft) | Length (ft) |
|---|---|---|---|
| 1 | 98 | 3.3 | 1,550 |
| 2 | 98 | 4.9 | 1,550 |
| 3 | 164 | 3.3 | 1,550 |
| 4 | 164 | 4.9 | 1,550 |

### Incident wave conditions

In addition to forcing the CMS with offshore waves to conduct simulations for the 15-day, non-storm period, three steady-state incident wave conditions were specified to examine channel hydraulic performance in a systematic manner. In this sensitivity analysis, model responses (water level changes and along-channel flows) to wave, wind, and tide forcing in the vicinity of the harbor and the bay were examined. Appendix A presents the sensitivity test results.

## Simulation alternatives

Investigation of the performance of a channel connecting Kawaihae Harbor and Pelekane Bay requires a series of simulations for the non-storm and the storm periods. CMS results before and after the channel

installation as well as on harbor and bay responses to different channel configurations are evaluated.

CMS-Flow and CMS-Wave coupled hydrodynamics and sediment transport simulations were conducted for the channel alternatives for the non-storm and storm wave conditions, including tide and wind. Employing WIS waves, five simulations were performed for the non-storm and multi-storm periods, respectively. The primary model parameters selected for those simulations are presented in Table 3.

Table 3. Primary parameters for CMS-Flow and CMS-Wave.

| Parameter | Value |
|---|---|
| Manning's *n* | 0.025 |
| Advection | Included |
| Wall Friction | Included |
| Wetting and Drying | Included (Minimum Wet Depth: 0.1 m) |
| Wave Spectral Energy | Half Plane |
| Forward Reflection | 0.5 |
| Wave Breaking | Extended Goda Formula (Goda 1973) |
| Diffraction Intensity | 4.0 |
| Directional Spreading (nn value) | 20.0 |
| Peak Enhancement Factor (γ) | 4.0 |
| $D_{50}$ (mm) | 0.25 |
| Sediment Density (kg/m$^3$) | 2,650.0 |
| Sediment Porosity | 0.4 |
| Hard Bottom | Partial (in coral reef areas) |
| Transport Equation | Lund-CIRP (Camenen and Larson 2005, 2008) |

# 4 Results and Discussion

## Non-storm condition

### Water surface elevations

Figure 13 shows a snapshot of water surface elevation under Alt 4, surrounding Kawaihae Harbor and Pelekane Bay on 15 April 2004 at 10:00 GMT, when waves approached the study area from west-northwest (293 deg azimuth). Upon reaching the coral reef area outside the harbor breakwater, and the semi-enclosed and shallow Pelekane Bay, incident waves broke and water level rose due to wave setup, a rise in the mean water surface above the still-water elevation of the sea caused by wave breaking on the beach. The breakwater blocked the waves, so there was no wave setup inside the harbor. Comparing water surface elevations in the offshore region and Kawaihae Harbor, an approximate 0.1 ft setup was produced under this channel alternative outside the breakwater and in Pelekane Bay.

Figure 13. Time series stations in Kawaihae Harbor (E1 and E2), the proposed channel (E3), and Pelekane Bay (E4) (depths to local MSL). CMS-computed water surface elevations under Alt 4 surrounding Kawaihae Harbor and Pelekane Bay during the non-storm period on 15 April 2004 at 10:00 GMT.

Water surface elevations are also analyzed at four time-series stations denoted as E1, E2, E3, and E4 and located at Kawaihae Harbor, the proposed channel, and Pelekane Bay, respectively, as shown in Figure 13.

Figure 14a illustrates the computed water surface elevations at Pelekane Bay (E4) for the existing condition and four channel alternatives over the 15-day simulation from 1-15 April 2004. Figure 14b shows the corresponding water elevation differences between the alternatives and the existing condition. Tidal signals at the bay coincide with tidal forcing implemented at the model open boundaries.

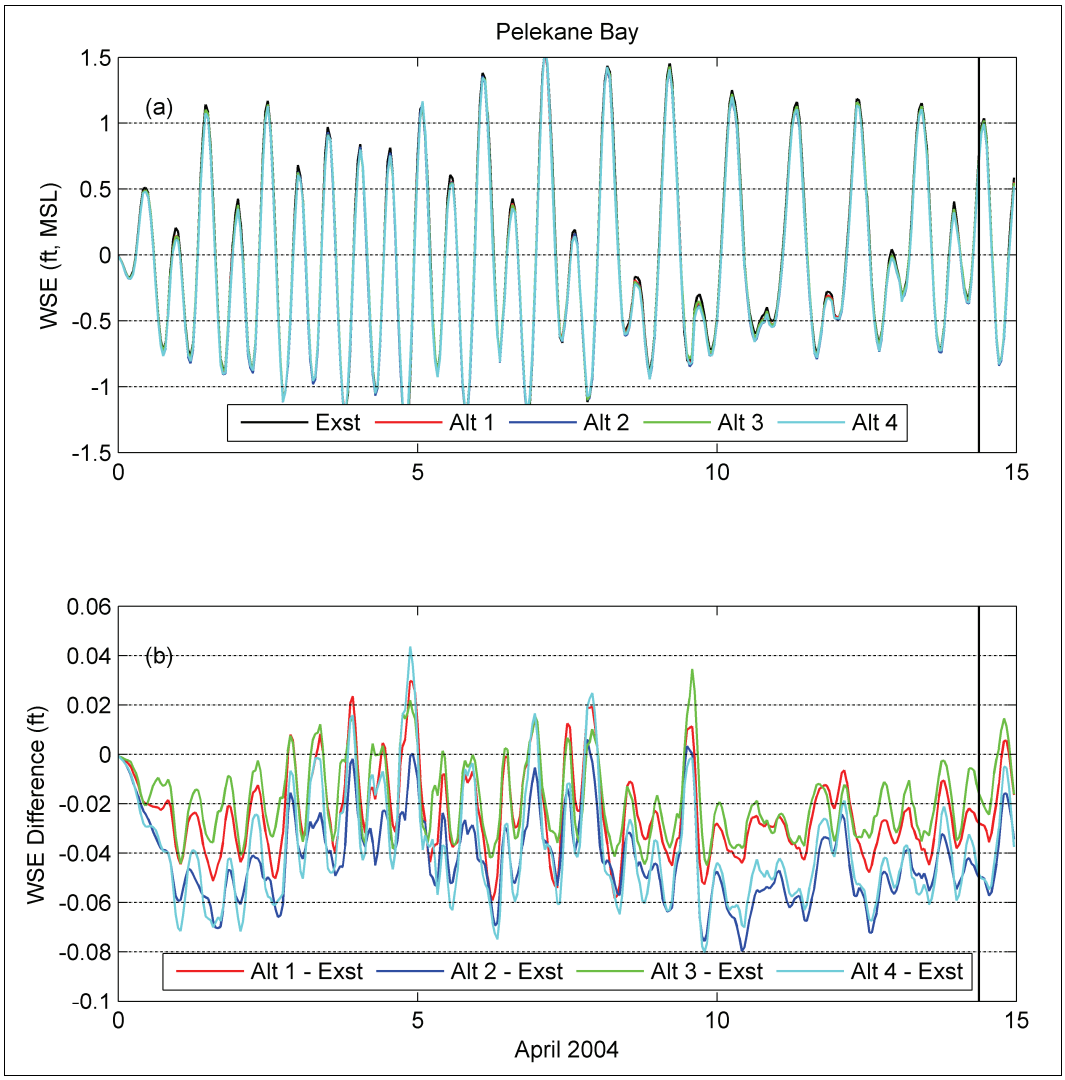


Figure 14. (a) WSE at Pelekane Bay, and (b) WSE differences between channel alternatives and the existing condition (Exst). Vertical lines indicate time when Figure 13 was plotted.

The maximum wave setup occurred under the existing condition in Pelekane Bay. With the channel opening, the setup is less by an average of 0.05-0.07 ft under Alts 2 and 4, and an average of 0.02-0.03 ft under Alts 1 and 3. Therefore, installation of the proposed channel will result in an along-channel flow from Pelekane Bay to Kawaihae Harbor and reduce the wave setup in Pelekane Bay.

Figure 15 plots temporally averaged water surface elevations from the 15-day simulation for the channel alternatives along a section formed by E1 to E4 from Kawaihae Harbor to Pelekane Bay. Inside the harbor at E1, water surface elevation is not affected by the proposed channel. From E2 through the channel to the bay, the water level is seen to rise under the four channel alternatives. Similar to the water level changes indicated by Figure 14 at Pelekane Bay, less elevated water levels are presented under the deeper channel alternatives (Alts 2 and 4), and greater elevated water levels under the shallower channel alternatives (Alts 1 and 3). The water rise along the proposed channel shows an average differential wave setup of 0.07-0.1 ft between Pelekane Bay and Kawaihae Harbor, with the water level in Pelekane Bay being higher. Wave setup in Kawaihae Harbor is greatly reduced or absent, because the breakwater prevents depth-limited wave breaking on the beach as at Pelekane Bay and the associated transfer of momentum that raises the water level.

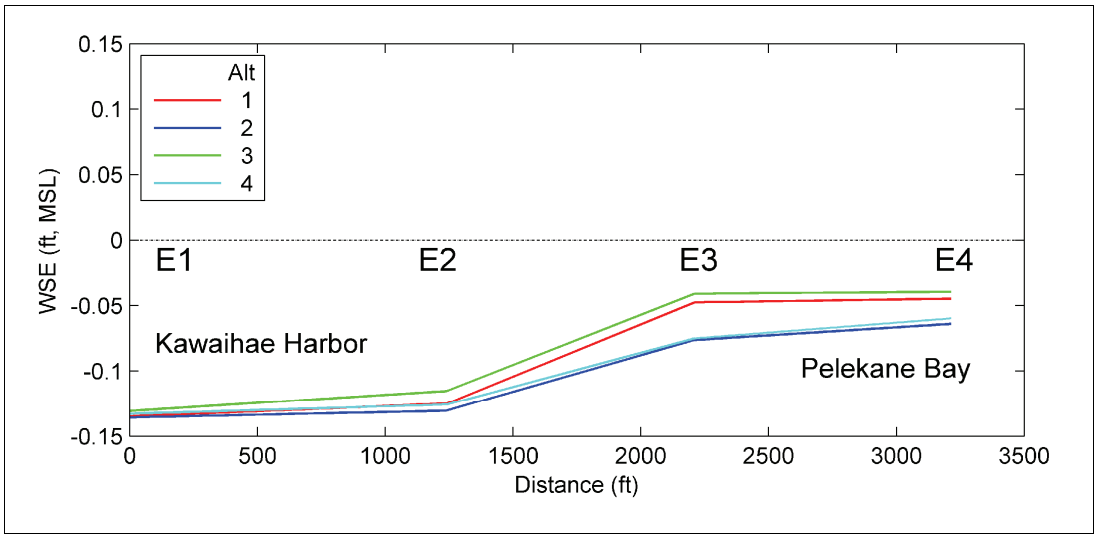


Figure 15. Temporally averaged water surface elevation along section composed of four stations from Kawaihae Harbor to Pelekane Bay, as shown in Figure 13.

### Current

CMS-Flow and CMS-Wave simulations were performed for 1-15 April 2004. Depth-averaged circulation fields surrounding Kawaihae Harbor and Pelekane Bay were retrieved from four snapshots of outputs corresponding to 2 April 2004 at 16:00 GMT, 7 April 2004 at 18:00 GMT, 10 April 2004 at 18:00 GMT, and 15 April 2004 at 10:00 GMT, when relatively large waves were propagating from west-northwest (300 deg azimuth), north-northwest (323 deg azimuth), south-southwest (213 deg azimuth), and west-northwest (293 deg azimuth), respectively (Figure 11).

Figures 16-19 show the four snapshots under the existing coastline features and Figures 20-23 under channel configuration Alt 1. The current plots for channel Alts 2, 3, and 4 are presented in Appendix B.

Under the existing condition, strong currents occur outside the harbor (Figures 16-19). The current speed is approximately 2.6-3.3 ft/sec along the breakwater over the shallow coral reef area on all occasions. Following the breakwater, the current tends to flow in two directions. The north current travels north passing the tip of the breakwater, meets the alongshore current from the northwest near the harbor entrance channel, and flows away from the harbor. The alongshore current from the northwest splits and produces a weaker current with a speed of 0.33 ft/sec and continues to flow into the harbor. The southwest current extends toward the south-southwest, and passes the small boat harbor and the outer Pelekane Bay. Interacting with the coastline, this current can have direct contributions to form two anti-clockwise gyres outside of Pelekane Bay. The corresponding current speed is between 1.3 and 2.0 ft/sec. In the inner bay, a small, clockwise gyre appears with a weaker current of 0.33-1.0 ft/sec.

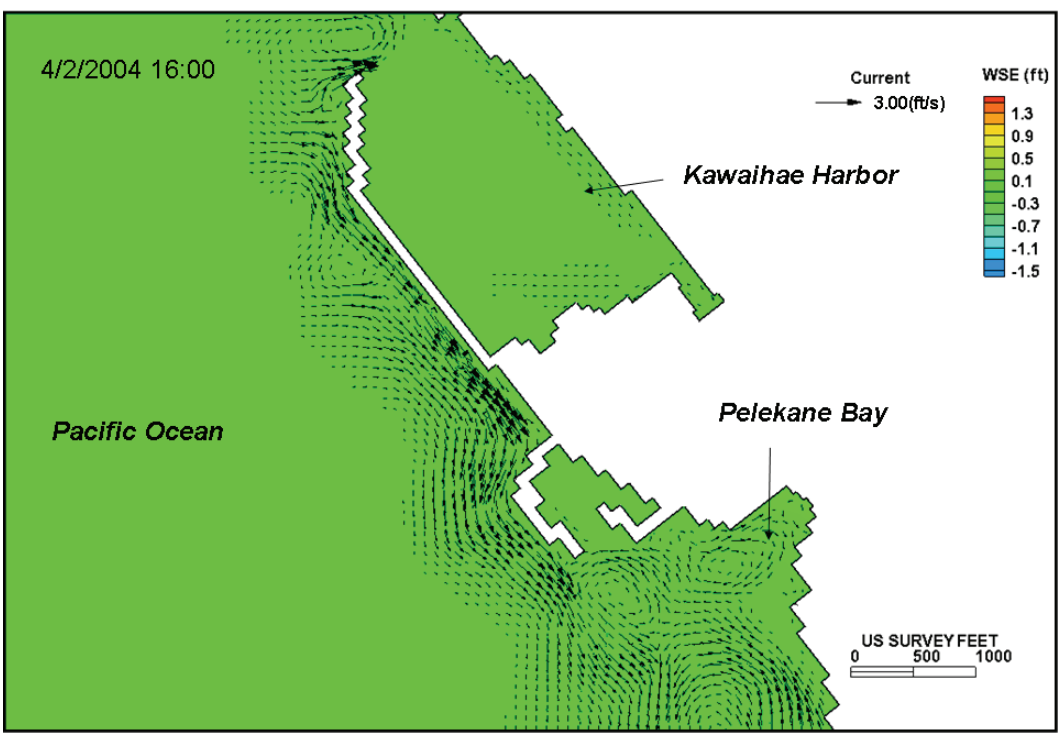


Figure 16. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under existing condition during 2 April 2004 at 16:00 GMT. Corresponding to this time, significant wave height is 4.5 ft, wave period 14.6 sec, and wave direction 300 deg azimuth.

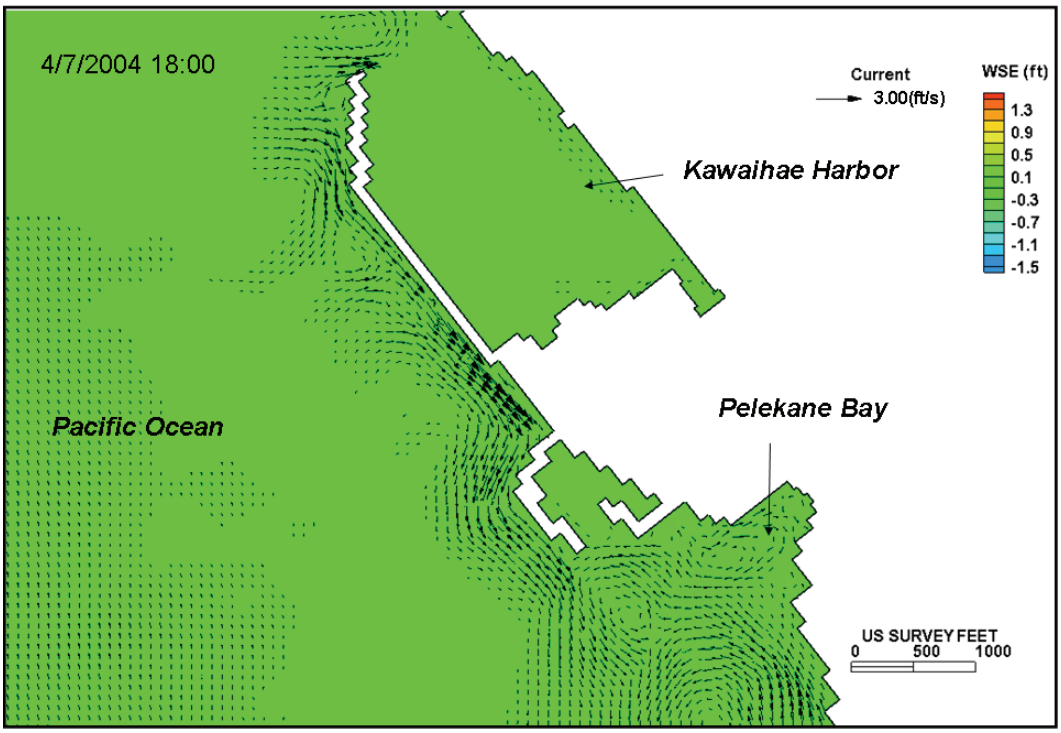


Figure 17. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under existing condition on 7 April 2004 at 18:00 GMT. Corresponding to this time, significant wave height is 4.8 ft, wave period 16.6 sec, and wave direction323 deg azimuth.

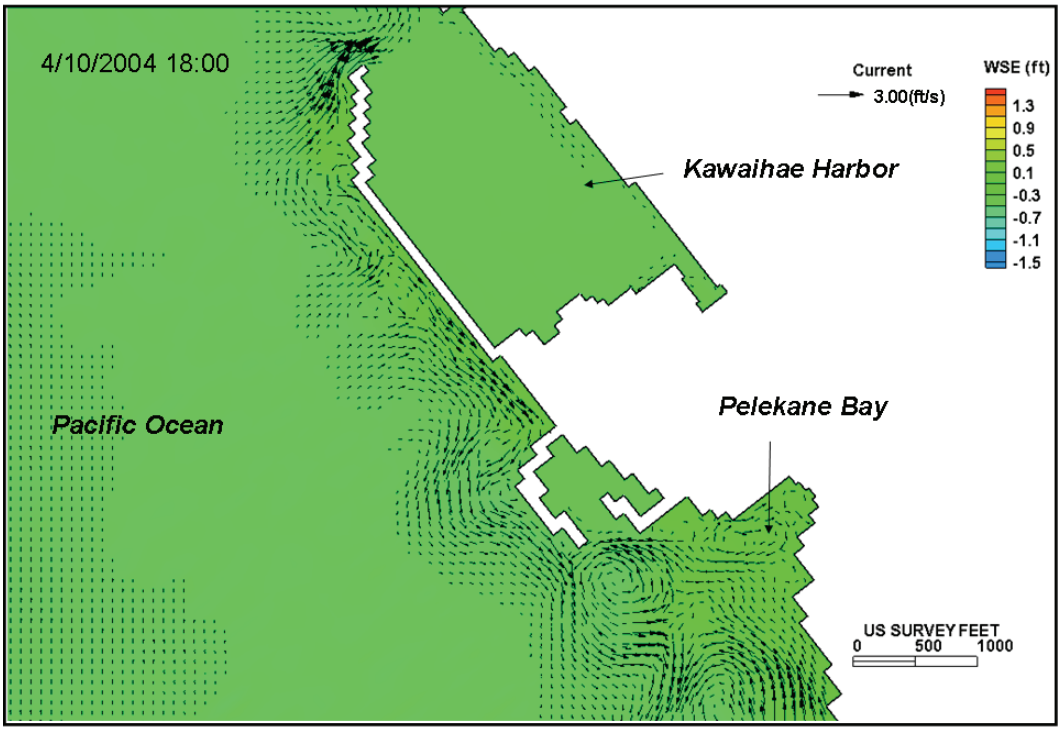


Figure 18. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under existing condition on 10 April 2004 at 18:00 GMT. Corresponding to this time, significant wave height is 4.8 ft, wave period 16.6 sec, and wave direction 213 deg azimuth.

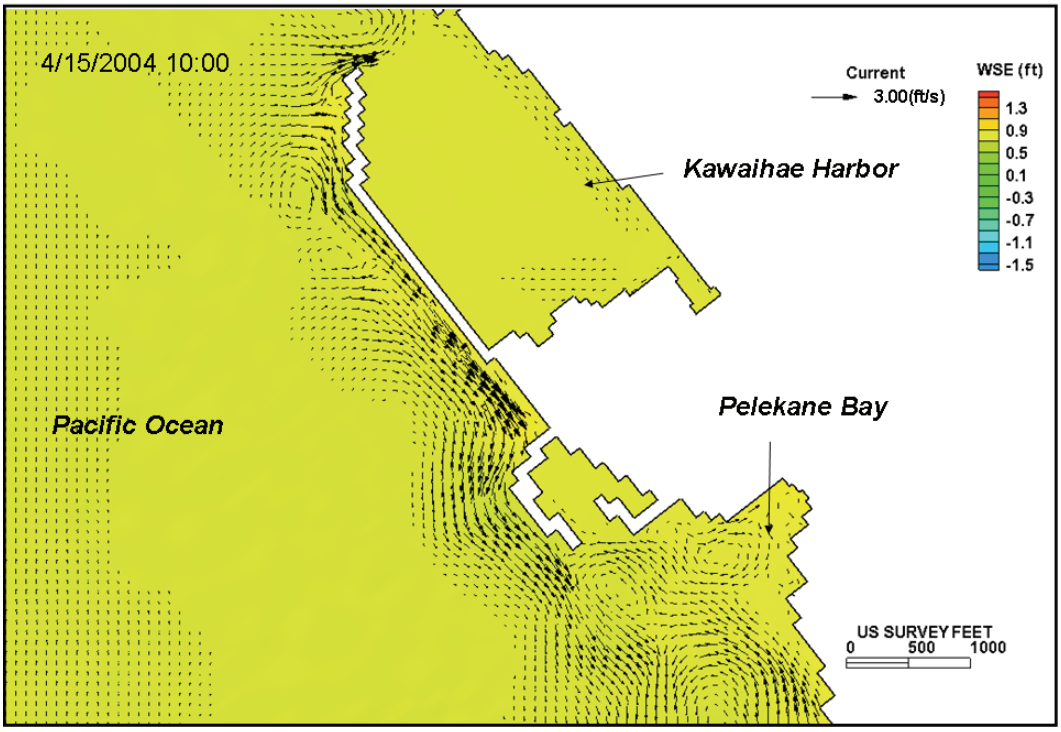


Figure 19. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under existing condition on 15 April 2004 at 10:00 GMT. Corresponding to this time, significant wave height is 4.5 ft, wave period 13.4 sec, and wave direction 293 deg azimuth.

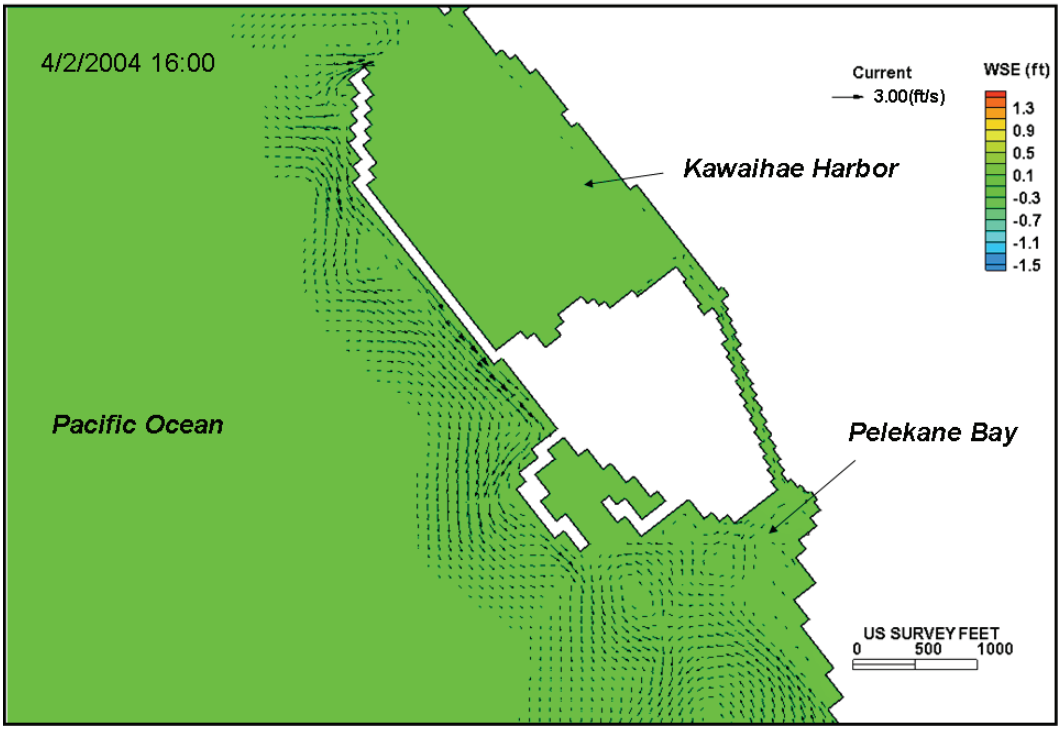


Figure 20. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 1 on 2 April 2004 at 16:00 GMT.

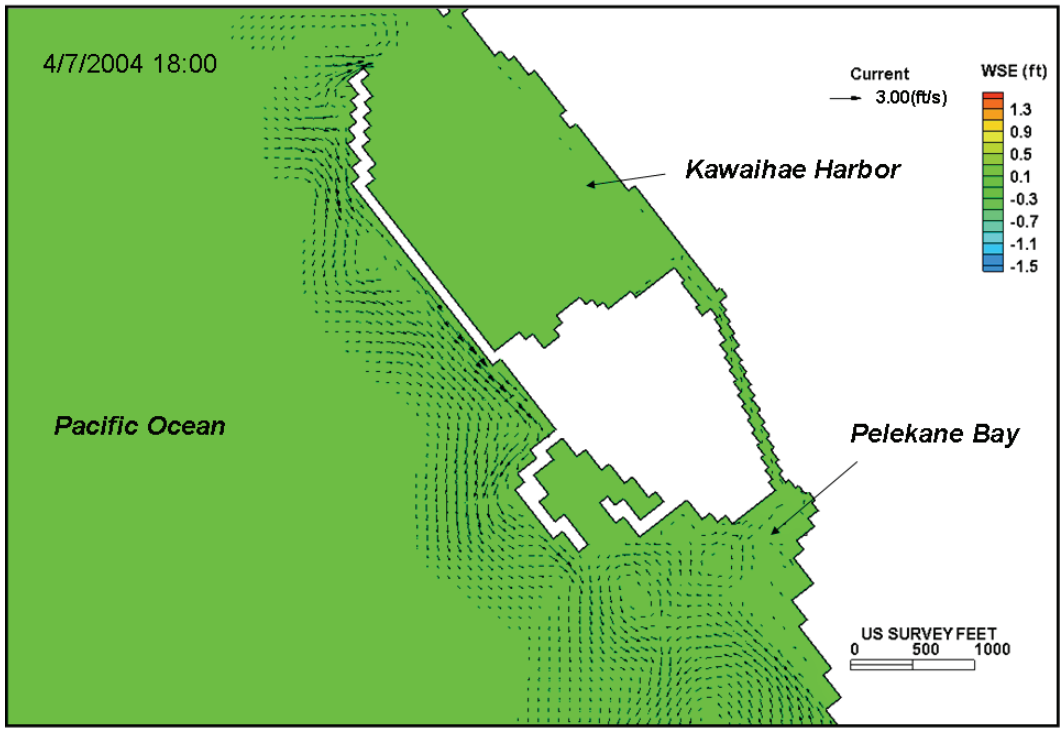


Figure 21. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 1 on 7 April 2004 at 18:00 GMT.

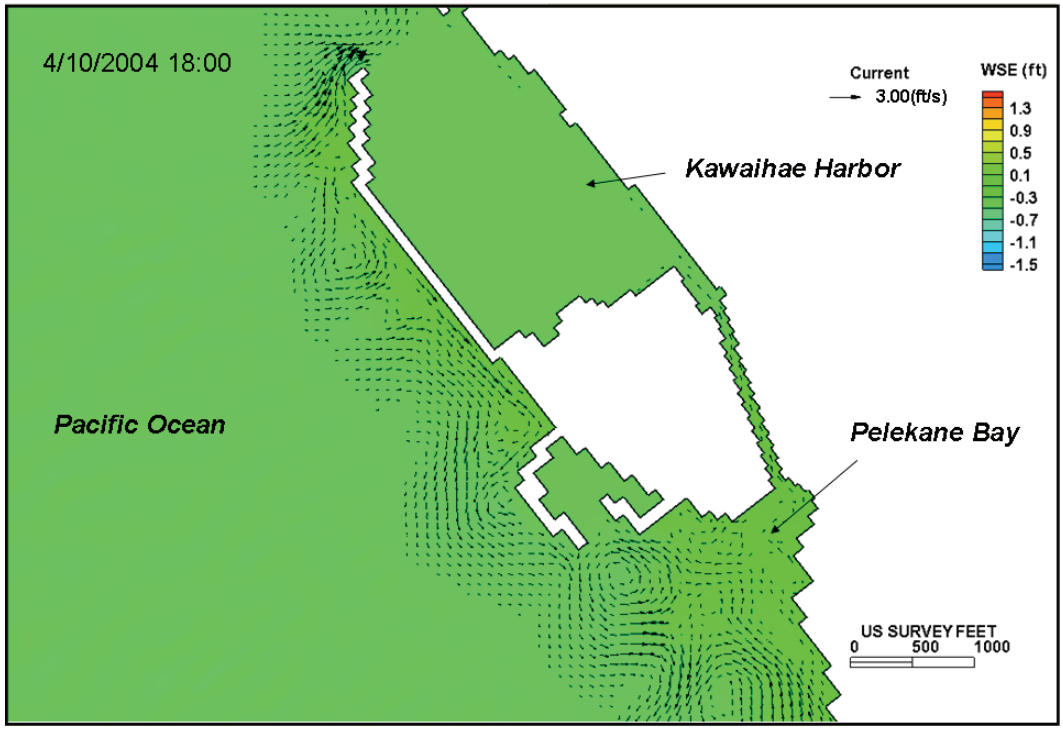


Figure 22. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 1 on 10 April 2004 at 18:00 GMT.

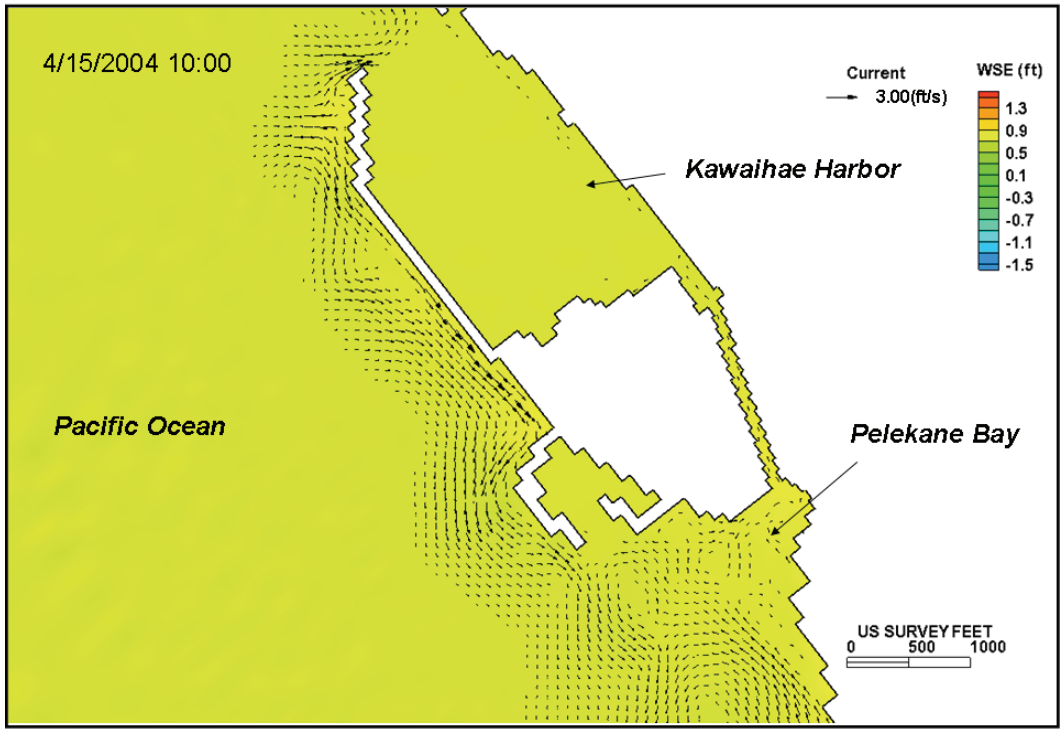


Figure 23. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 1 on 15 April 2004 at 10:00 GMT.

Figures 16, 17, and 19 present similar flow patterns as waves approach the study area from the west-northwest and north-northwest. The north current becomes stronger and the southwest current weaker as waves propagate from the south-southwest on 10 April 2004 at 18:00 GMT (Figure 18). The comparison demonstrates that wave forcing controls the nearshore circulation near Kawaihae Harbor and Pelekane bay.

Figures 20-23 show that circulation patterns within the harbor, outside the breakwater, and at the outer Pelekane Bay are not affected by installation of the proposed Alt 1 channel. The weak gyre in the inner bay seems to have disappeared, and the channel induces a persistent flow from the bay to the harbor at the four selected times. Similar flow features are revealed under the other channel alternatives in Appendix B. Figure 24 shows the time series of along-channel flow speeds at E2 under Alt 1-4 (positive for the bay-to-harbor direction). During this 15-day period, the along-channel current almost always flows from Pelekane Bay to Kawaihae Harbor. The model domain receives the smallest offshore waves during the early hours of 6 April (Figure 11) and waves approach the study area from the north-northeast (12 deg azimuth) on 10 April. At these two times the along-channel speed is reduced significantly and the flow directions reverse for a

few hours on 10 April. The 15-day averaged speed is 0.36 ft/sec for Alts 1 and 2, and 0.62 ft/sec for Alts 3 and 4.

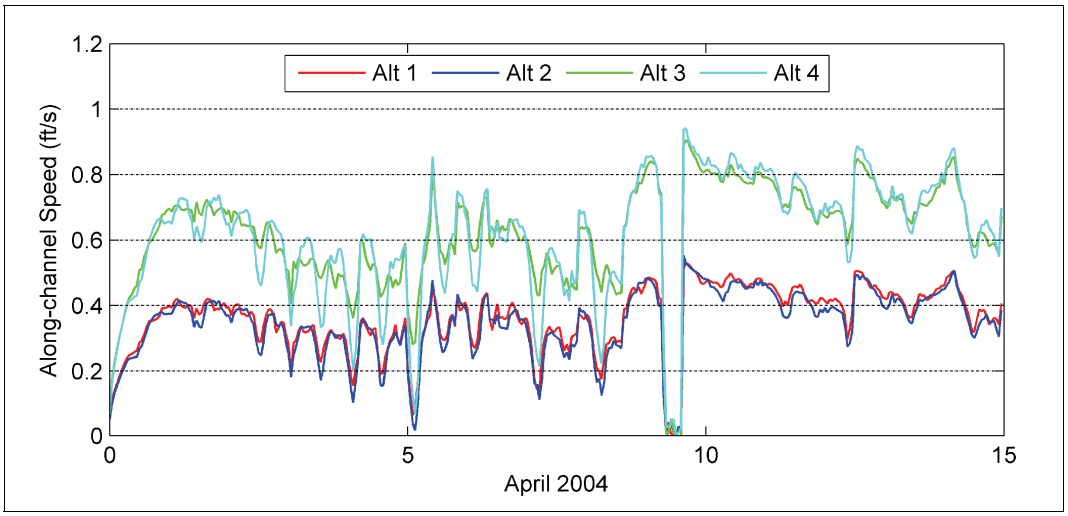


Figure 24. Along channel speed under four channel alternatives. Positive indicates water flow from Pelekane Bay to Kawaihae Harbor.

Other sensitivity analysis of the current near the harbor and the bay in response to various incident wave conditions (constant wave parameters) is presented in Appendix A.

### Sediment transport

Aerial photographs provided by Hawaiian Images Photography and Video (2009) indicate that the nearshore areas of Kawaihae Harbor contain extensive coral reef. For sediment transport in CMS, the median grain size of 0.25 mm was specified based on the samples collected in Kawaihae Harbor and Pelekane Bay (Tables 1 and 2). The sand bottoms at Pelekane Bay and the notched area on the southeast side of Kawaihae Harbor represented as erodible bottom and the coral cover area and the offshore as hard bottom (non-erodible).

Calculated morphology changes in the proposed channel and Pelekane Bay are shown in Figures 25-29. The spatial distributions show the results under the existing condition and the proposed channel alternatives at the end of the 15-day simulation. Under the existing condition, the erosion is usually followed by immediate deposition in Pelekane Bay. The relatively weak circulation in the inner bay produces less transport of sediment (Figure 25). The channel installation, however, alters the pattern of sediment transport in the bay. Stronger circulation is able to carry eroded sand

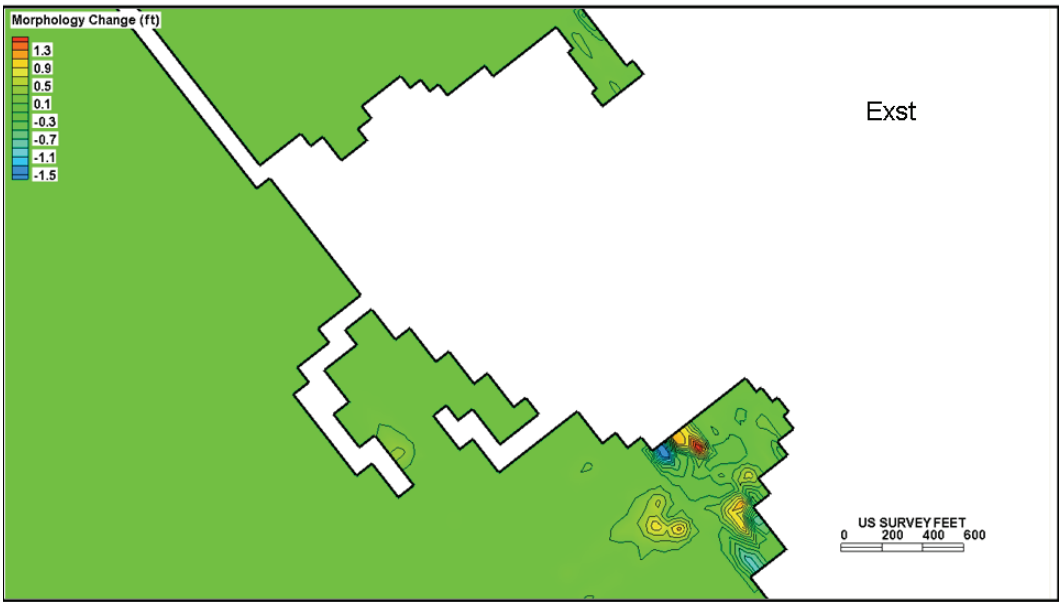


Figure 25. Morphology change for existing condition (Exst) after 15-day simulation.

Figure 26. Morphology change for Alt 1 after 15-day simulation.

Figure 27. Morphology change for Alt 2 after 15-day simulation.

Figure 28. Morphology change for Alt 3 after 15-day simulation.

Figure 29. Morphology change for Alt 4 after 15-day simulation.

near the outer bay a longer distance and deposit it in the vicinity of the channel mouth. Persistent current flowing from the bay to the harbor is moving sediment into the channel, most of which is deposited within 400 ft from the bay (Figures 26-29).

Table 4 presents the maximum computed erosion and deposition and total sediment volume change in Pelekane Bay and in the proposed channel under the existing condition and the proposed channel alternatives. The maximum erosion is approximately 2.0 ft in Pelekane Bay. The maximum deposition in the channel ranges between approximately 0.4 and 0.9 ft under different alternatives at the end of the simulation. For the same channel depth, a wider channel (Alts 3 and 4) would lead to a 75-80 percent increase in the maximum deposition inside the channel and a 1.6-1.8 times increase in sediment volume transported from the bay into the channel compared to a narrow channel (Alts 1 and 2). Based on the values in the last column of the table, the volume of sand that would have to be dredged from the channel to maintain the designed channel depth is 311 cu yd for Alt 1 and about 900 cu yd for Alt 4.

Figure 30 shows five station locations, two in Pelekane Bay and three in the proposed channel. Time series of depth change at those stations is plotted for the four channel alternatives (Figure 31).

Table 4. Depth change (ft) due to non-storm waves in Pelekane Bay and proposed channel under existing condition (Exst) and four channel alternatives. Negative represents erosion and positive deposition.

| Scenario | Maximum Erosion in Pelekane Bay and Channel (ft) | Maximum Deposition in Pelekane Bay and Channel (ft) | Maximum Deposition near Mouth of Channel (ft) | Maximum Deposition in Channel (ft) | Sediment Volume Transported in Channel (cu yd) |
|---|---|---|---|---|---|
| Exst | -2.0 | 1.8 | 0.0 | N/A | N/A |
| Alt 1 | -1.6 | 1.1 | 0.9 | 0.4 | 311 |
| Alt 2 | -1.3 | 1.7 | 0.4 | 0.5 | 348 |
| Alt 3 | -1.9 | 1.6 | 0.9 | 0.7 | 857 |
| Alt 4 | -1.6 | 2.3 | 2.3 | 0.9 | 904 |

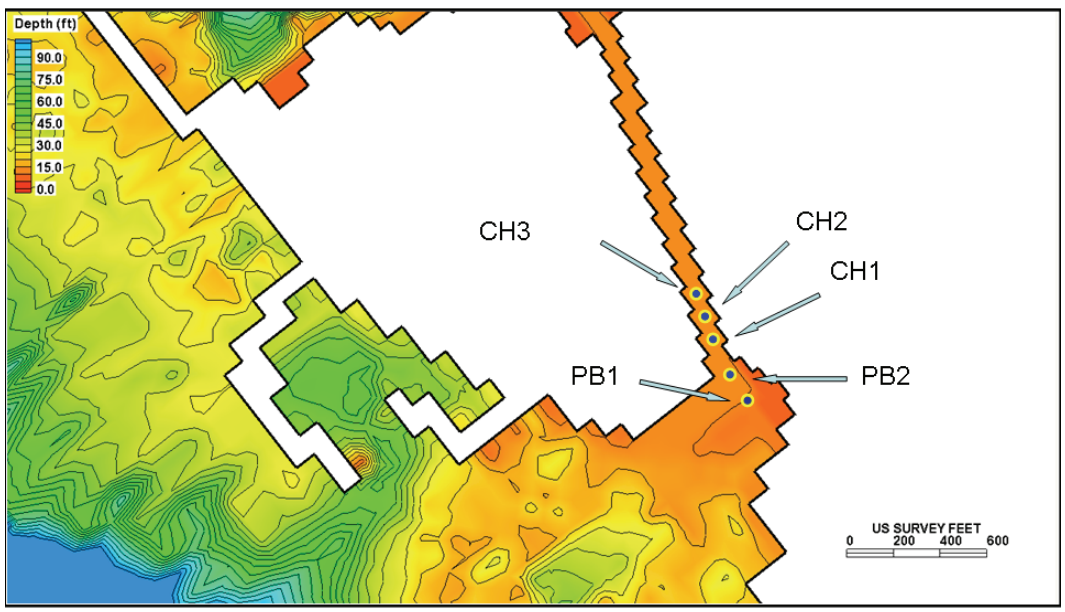


Figure 30. Time series stations in Pelekane Bay (PB1 and PB2 and proposed channels (CH1, CH2 and CH3).

Figure 31 indicates that a linear increase of deposition appears at all five locations. The channel stations, CH2 and CH3, have higher deposition rates under Alts 3 and 4 than under Alts 1 and 2; the bay stations, PB1 and PB2, have higher deposition rates under Alts 2 and 4 than that under Alts 1 and 3. Assuming that a linear trend of deposition continues as indicated in Figure 31 at CH1, CH2, and CH3, the proposed channel would be filled up within approximate 130, 157, 80, and 119 days under Alts 1 through 4, respectively.

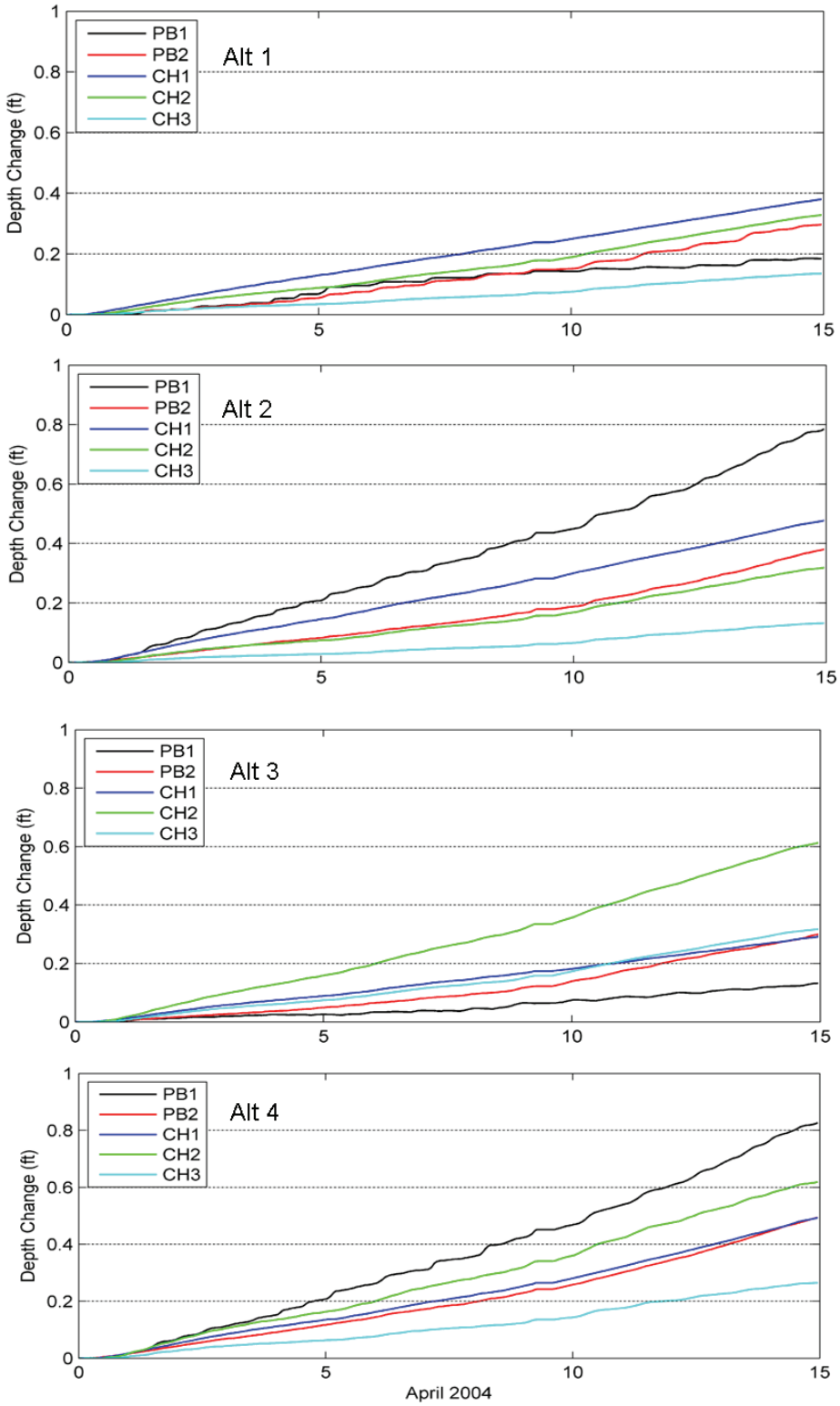


Figure 31. Depth change due to non-storm waves under different channel alternatives in Pelekane Bay and proposed channel.

## Storm condition

Based on the descriptions of wave climatology in Chapter 3, five winter storms were identified for the 6-month storm period from October 1992 through March 1993. Wave parameters of these events are listed in Table 5. Peak wave heights are greater than 7.5 ft, and waves approach the study area from the west-northwest direction (287-304 deg azimuth) during each storm. The maximum wave height is approximately 12 ft and occurred on 7 January 1993 at 16:00 GMT. The following analysis of hydrodynamics and sediment transport concerns these five storms.

Table 5. Wave parameters of five selected winter storms from October 1992 through March 1993.

| Date (1993) | Wave Height (ft) | Wave Direction (deg, azimuth) | Wave Period (sec) |
|---|---|---|---|
| 01/07 16:00 GMT | 11.88 | 302 | 13.1 |
| 01/11 08:00 GMT | 7.97 | 299 | 12.9 |
| 01/30 09:00 GMT | 7.51 | 292 | 12.1 |
| 02/06 23:00 GMT | 8.10 | 304 | 14.8 |
| 03/15 06:00 GMT | 8.46 | 287 | 13.3 |

### Water surface elevation

Water surface elevations were analyzed at Kawaihae Harbor, Pelekane Bay, and the proposed channel (Figure 13). Figure 32 illustrates the computed water surface elevations for the four alternatives at Pelekane Bay (E4), and Figure 33 shows water elevation differences between the four channel alternatives and the existing condition in the 6-month storm period, 1 October 1992 to 31 March 1993. Table 6 lists the computed water surface elevations at Kawaihae Harbor (E1), Pelekane Bay (E4), and an offshore location during the five winter storms.

Pelekane Bay has higher water elevation under the existing condition than under the channel alternatives except when significant sediment infilling appears in the channel or the bay after 6 January 1993 under Alt 3, 21 February 1993 under Alt 4, and 11 March 1993 under Alt 1. The average water level setup under the existing condition is 0.01-0.06 ft higher than that under channel alternatives during the storms, and 0.01-0.03 ft higher during non-storm times (Table 6). Comparing the channel alternatives to the existing condition, a deeper channel, Alts 2 and 4, has less water level setup by an average of 0.03 ft and a shallower channel, Alts 1 and 3, by an average of 0.01 ft. The setup with the channel installed can be 0.06-0.07 ft less without significant shoaling in Pelekane Bay during the storms.

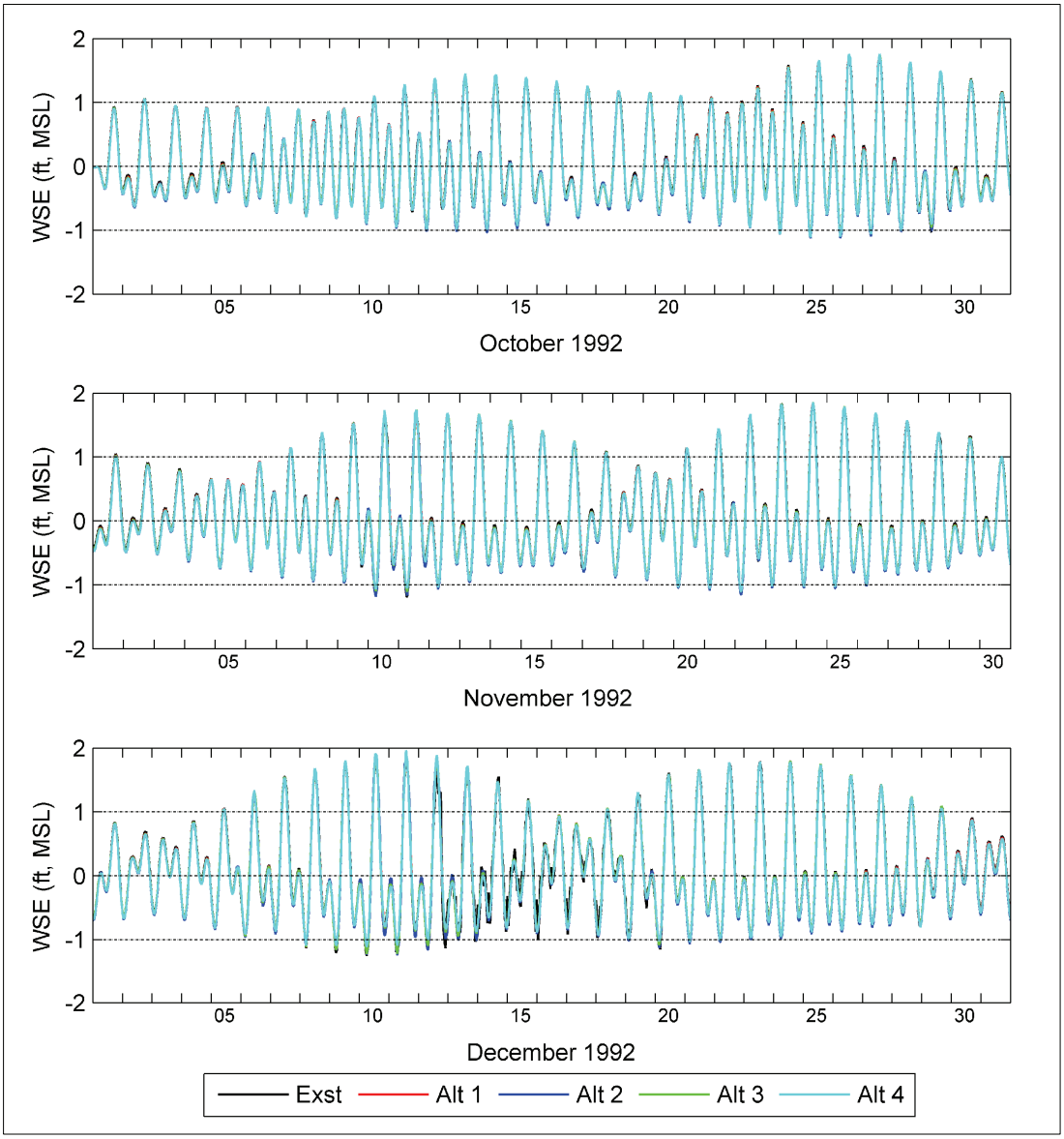


Figure 32. WSE at Pelekane Bay, sta E4, see Figure 13 (continued).

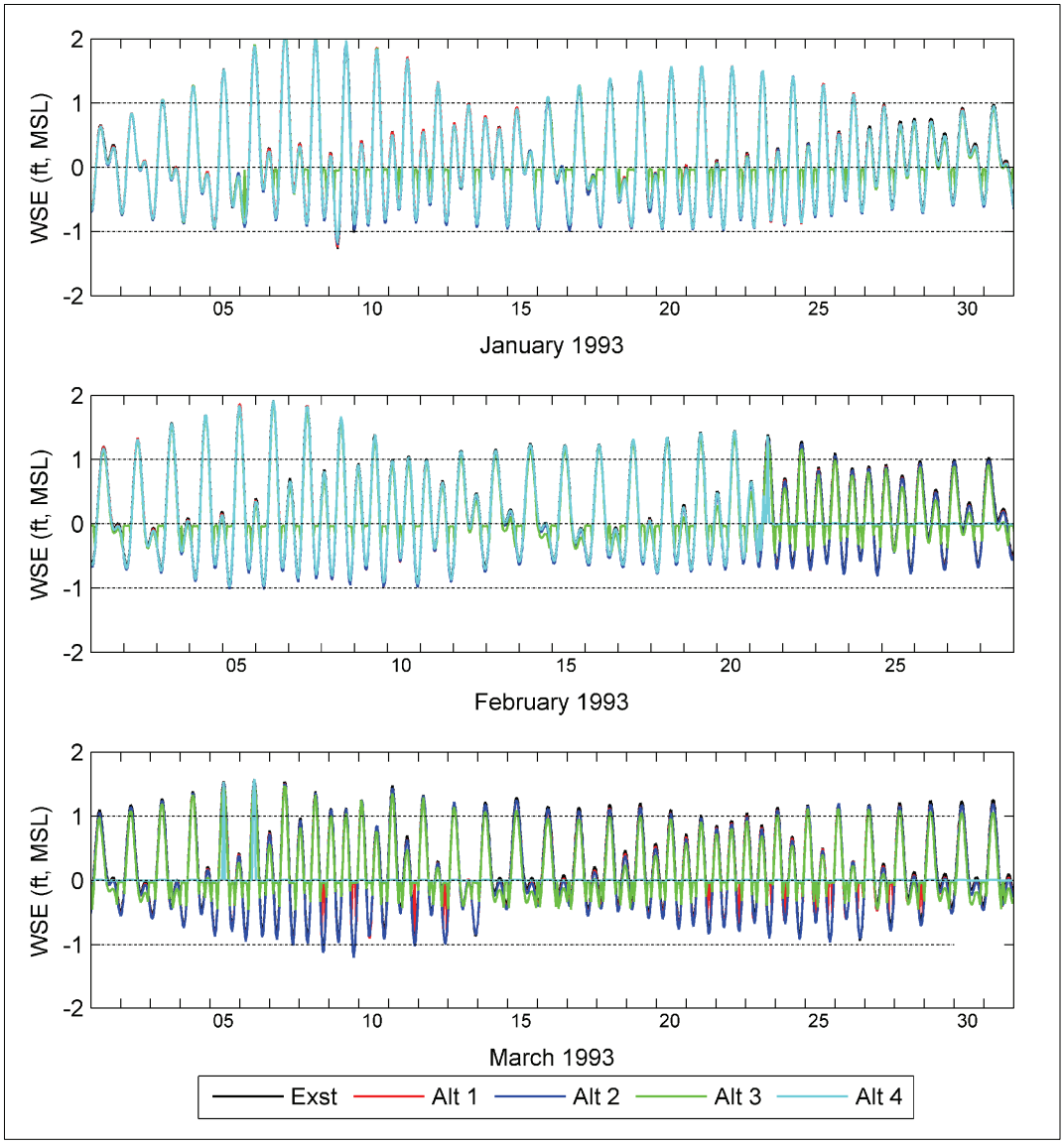


Figure 32. (Concluded).

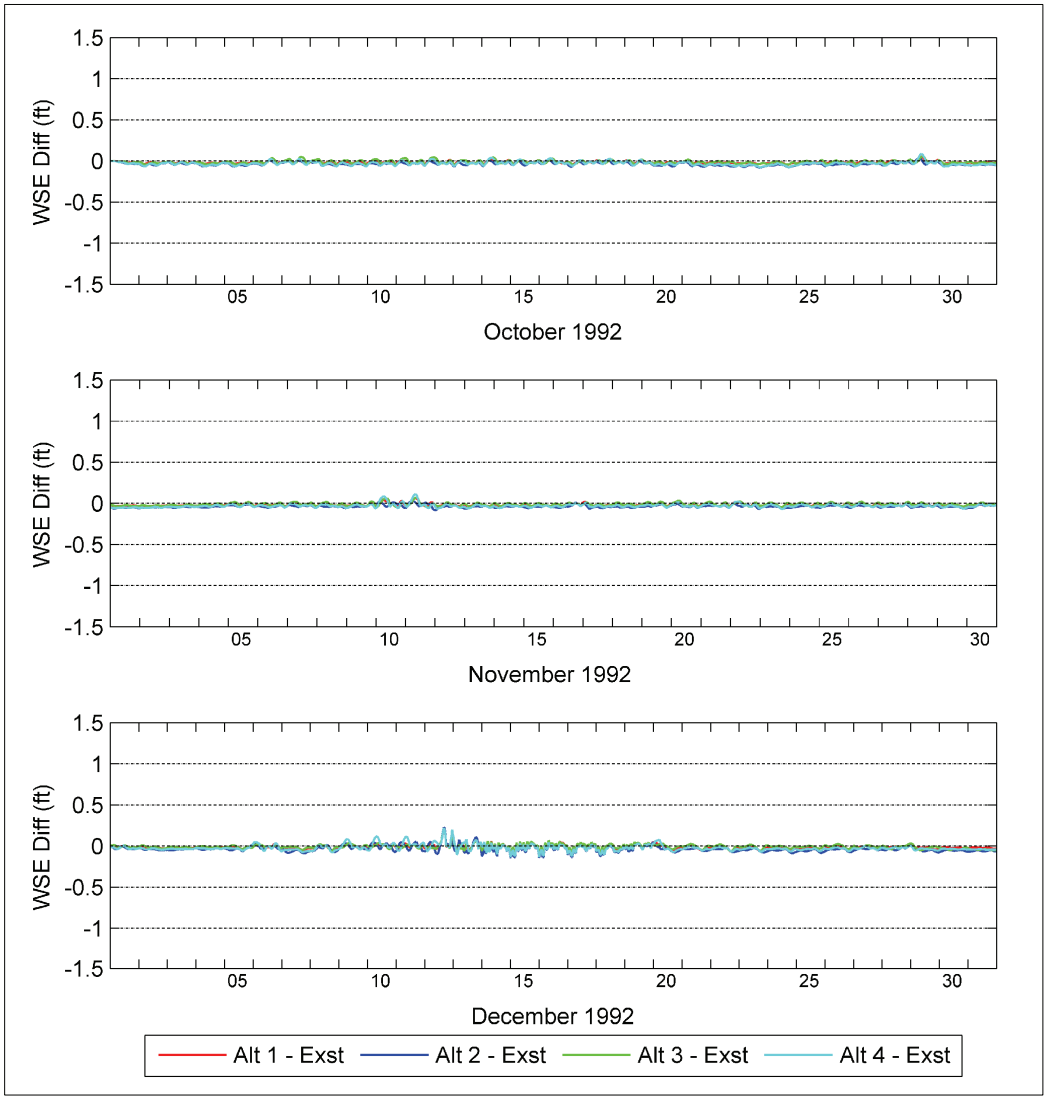


Figure 33. Moving average (5 hr). WSE difference at Pelekane Bay, sta E4, see Figure 13 (continued).

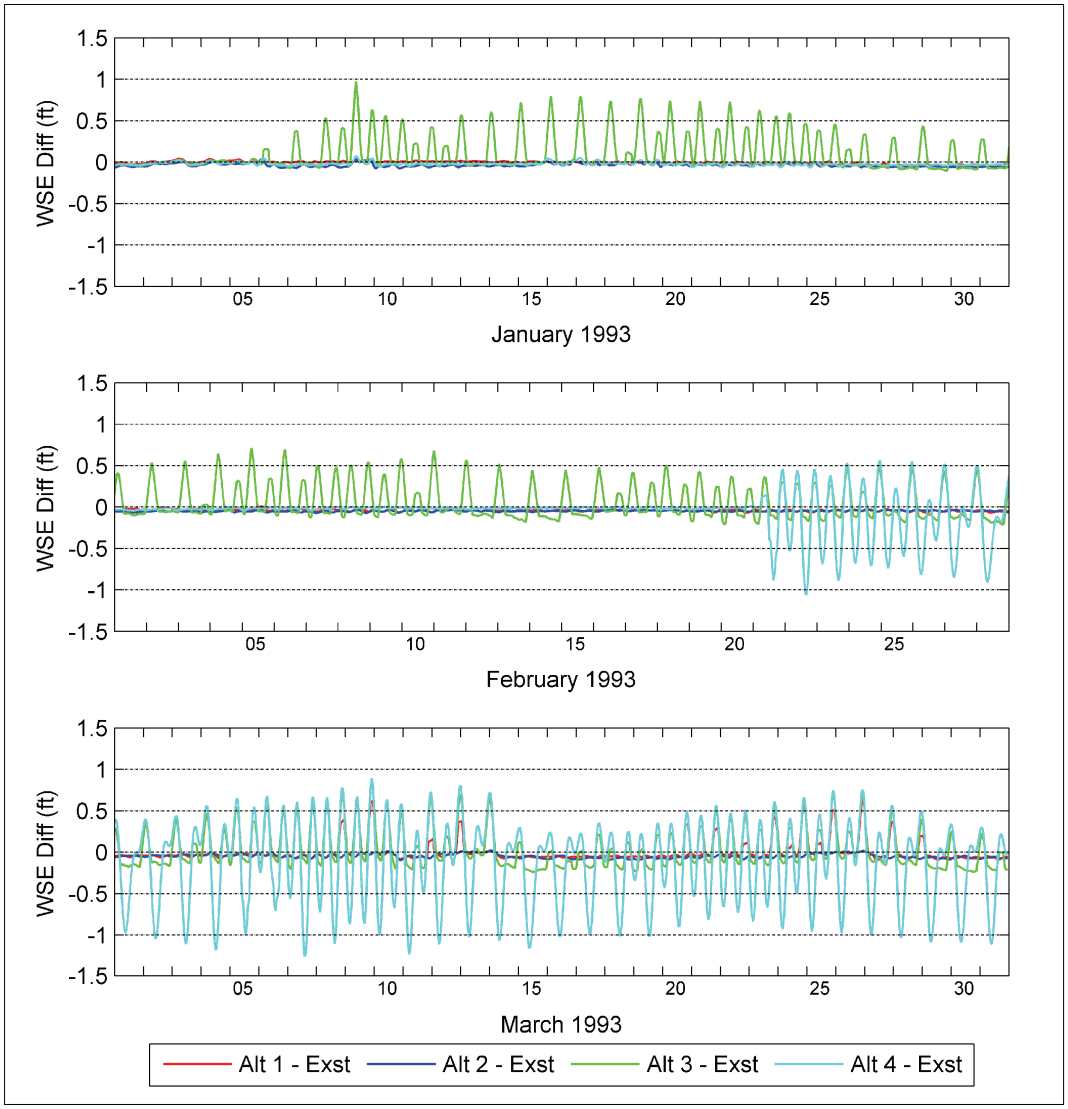


Figure 33. (Concluded).

Table 6. Calculated WSE for existing condition (Exst) and four alternatives at Kawaihae Harbor (E1) and Pelekane Bay (E4) during five winter storms from October 1992 through March 1993.

| Date (1993) | Kawaihae Harbor, E1 (ft, MSL) | | | | | Pelekane Bay, E4 (ft, MSL) | | | | | Offshore Location (ft, MSL) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Exst | Alt 1 | Alt 2 | Alt 3 | Alt 4 | Exst | Alt 1 | Alt 2 | Alt 3 | Alt 4 | Exst | Alt 1 | Alt 2 | Alt 3 | Alt 4 |
| 01/07 16:00 GMT | 1.19 | 1.20 | 1.17 | 1.20 | 1.18 | 1.48 | 1.45 | 1.42 | 1.43 | 1.44 | 1.02 | 1.00 | 1.02 | 1.0 | 1.02 |
| 01/11 08:00 GMT | -0.68 | -0.67 | -0.67 | -0.67 | -0.67 | -0.43 | -0.41 | -0.49 | -0.44 | -0.46 | -0.73 | -0.73 | -0.72 | -0.75 | -0.74 |
| 01/30 09:00 GMT | 0.67 | 0.68 | 0.67 | 0.67 | 0.68 | 0.86 | 0.82 | 0.81 | 0.79 | 0.81 | 0.60 | 0.59 | 0.62 | -0.60 | 0.59 |
| 02/06 23:00 GMT | -0.38 | -0.38 | -0.38 | -0.37 | -0.37 | -0.15 | -0.19 | -0.20 | -0.22 | -0.16 | -0.44 | -0.45 | -0.43 | -0.47 | -0.44 |
| 03/15 06:00 GMT | 0.75 | 0.75 | 0.74 | 0.76 | 0.75 | 0.98 | 0.93 | 0.93 | 0.76* | 0.76* | 0.64 | 0.66 | 0.64 | 0.65 | 0.65 |

Note: * depicts shoaling around sta E4 in Pelekane Bay.

By examining water surface elevation differences between Pelekane Bay and Kawaihae Harbor, the differential wave setup can be investigated for the time period that includes five major winter storms. Figure 34 shows the 6-month time series of WSE differences between E1 and E4. Variations of consistent wave setup in Pelekane Bay are displayed in the figure from October to December 1992. Beginning 6 January 1993, significant changes in WSE differences appear in Figure 34, which are related to storm-induced channel or bay infilling. Figure 35 shows the 3-month averaged WSEs for the channel alternatives along the section from E1 to E4 (Figure 13). In Kawaihae Harbor at E1, WSE is not affected by installation of a channel. Starting from E2 through the channel and into the bay, water level starts to rise under channel alternatives. Similar to the features of the non-storm condition indicated by Figure 15, less water level setup is presented under the deeper channel alternatives (Alts 2 and 4), and greater setup under the shallower channel alternatives (Alts 1 and 3) in Pelekane Bay. The water rise along the section results in an average water level difference of 0.04-0.06 ft between Pelekane Bay and Kawaihae Harbor.

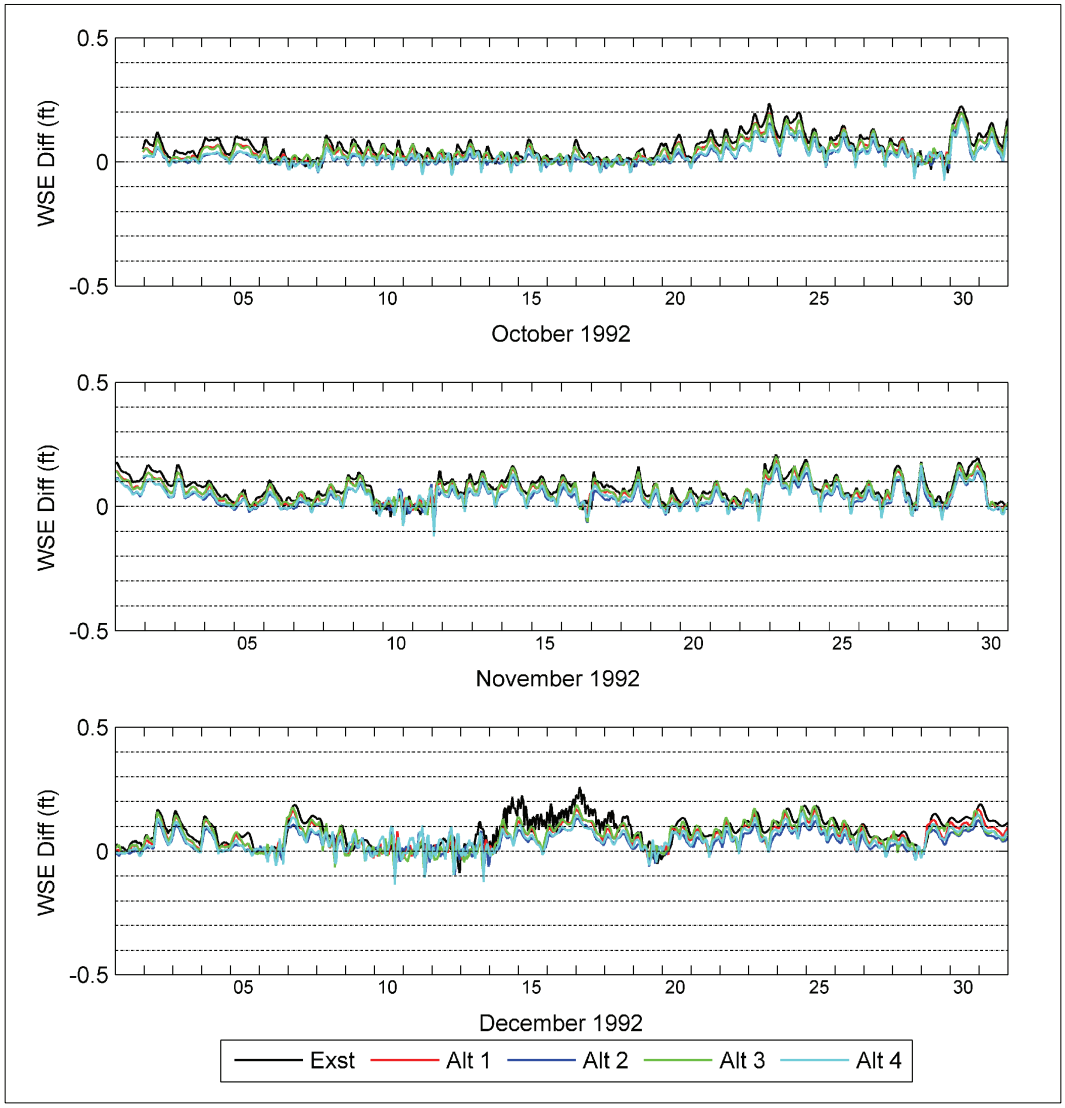


Figure 34. WSE difference between Kawaihae Harbor and Pelekane Bay (continued).

Table 7 indicates much larger WSE differences under different alternatives between Pelekane Bay (E4) and Kawaihae Harbor (E1) corresponding to the five winter storms. E4 is isolated from the rest of the bay due to sediment infilling under Alts 3 and 4 during the 15 March 1993 storm, but is still connected to Kawaihae Harbor through the channel. This scenario results in much smaller WSE differences between the bay and the harbor, and is not considered in the following analysis.

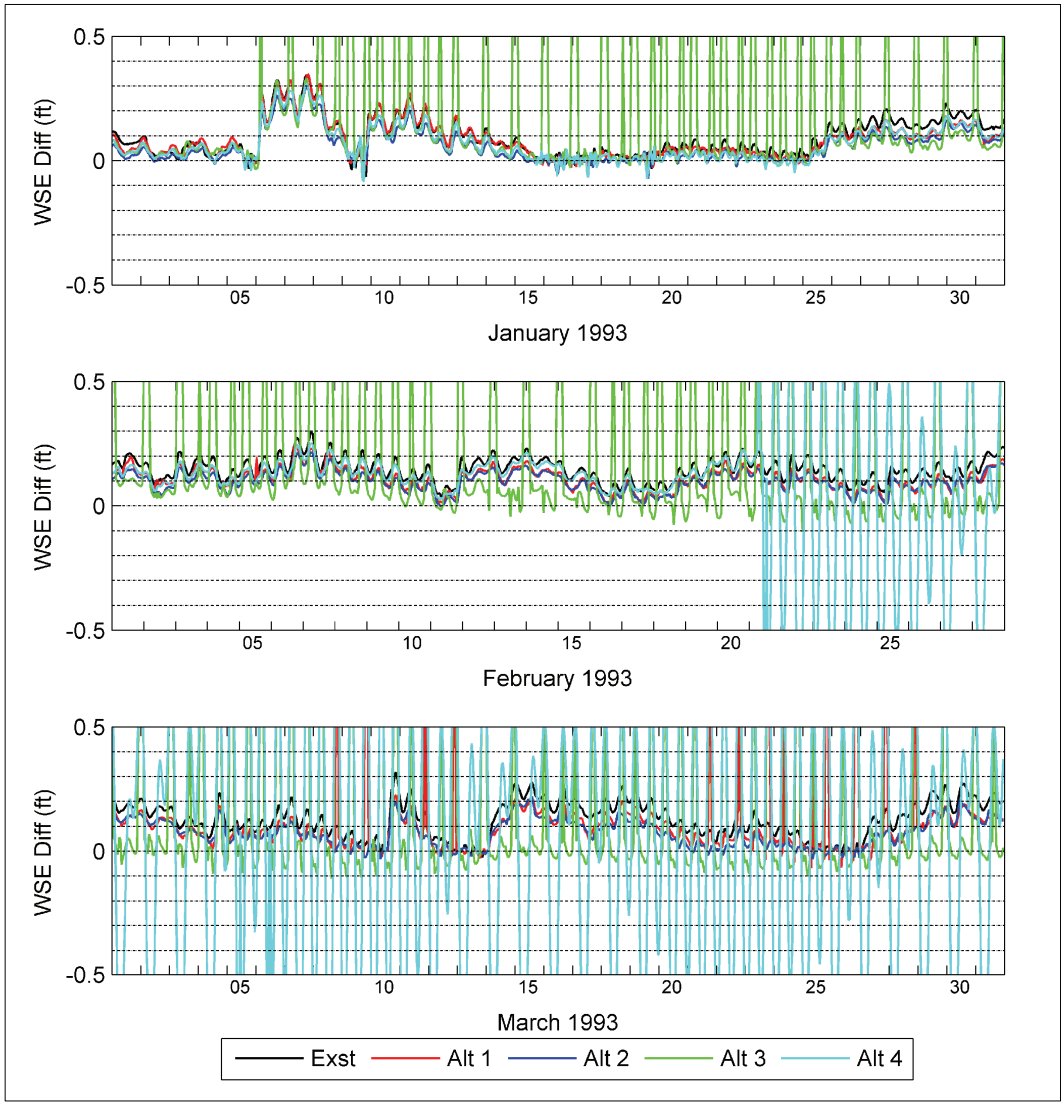


Figure 34. (concluded).

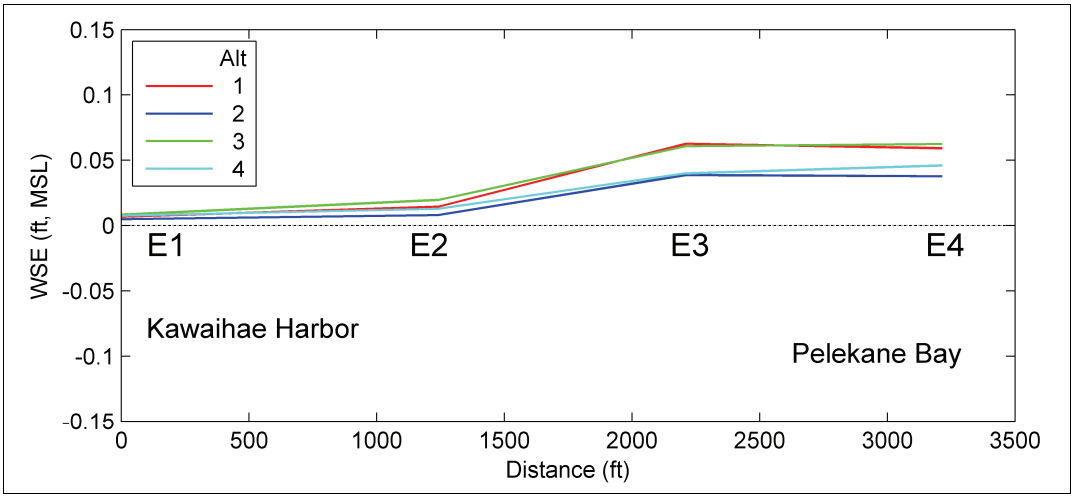


Figure 35. Temporally averaged water surface elevation (October-December 1992) along section composed of four stations from Kawaihae Harbor to Pelekane Bay, as shown in Figure 13.

Table 7. WSE differences under different alternatives between Pelekane Bay (E4) and Kawaihae Harbor (E1) during five winter storms from October 1992 through March 1993.

| Date (1993) | Pelekane Bay, E4 - Kawaihae Harbor, E1 (ft) | | | | |
|---|---|---|---|---|---|
| | EXST | Alt1 | Alt2 | Alt3 | Alt4 |
| 01/07 16:00 | 0.29 | 0.25 | 0.25 | 0.23 | 0.26 |
| 01/11 08:00 | 0.25 | 0.26 | 0.18 | 0.23 | 0.21 |
| 01/30 09:00 | 0.19 | 0.14 | 0.14 | 0.12 | 0.13 |
| 02/06 23:00 | 0.23 | 0.19 | 0.18 | 0.15 | 0.21 |
| 03/15 06:00 | 0.23 | 0.18 | 0.19 | 0.00* | 0.01* |
| Note: * depicts significant channel or bay infilling around sta E4 in Pelekane Bay. | | | | | |

The existing condition produces the largest water level setup in Pelekane Bay as compared to the alternatives. The water elevation difference between the bay and the harbor is about 0.3 ft for the 7 January 1993 storm. Depending on storm strength, measured by the significant wave height (Table 5), the WSE differences vary from 0.12 to 0.26 ft under the four channel alternatives. The weakest storm (judged by wave height), on 30 January 1993, produces the smallest water level setup and the strongest storm, starting on 7 January 1993, generates the largest.

### Current

During the storm time interval, October 1992 through March 1993, vertically averaged circulation fields surrounding Kawaihae Harbor and Pelekane Bay were retrieved from the five winter storms. The snapshots are presented between 7 January and 15 March 1993, and the corresponding incident waves are propagating from west-northwest (287-304 deg azimuth) (Table 5). Figures 36-40 show the five snapshots under the existing condition and Figures 41-45 under channel configuration Alt 1. Table 8 lists the extreme current speeds surrounding the harbor area and along the proposed channel during the storm periods. The circulation fields under Alts 2, 3, and 4 are given in Appendix A.

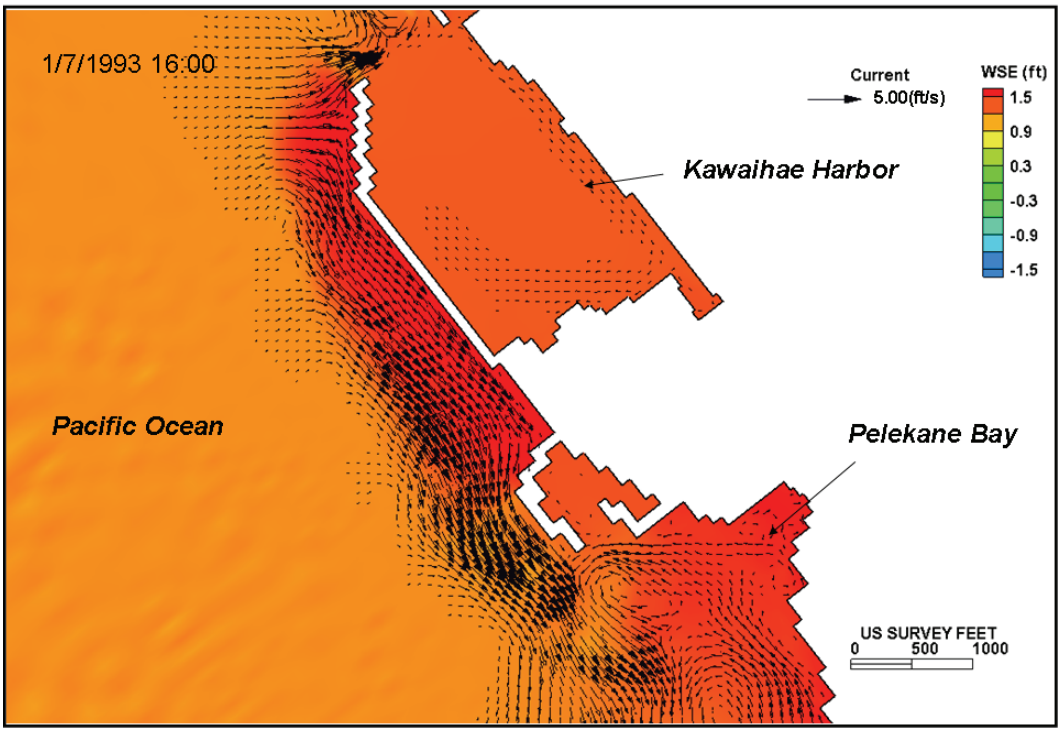


Figure 36. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under existing condition during storm on 7 January 1993 at 16:00 GMT.

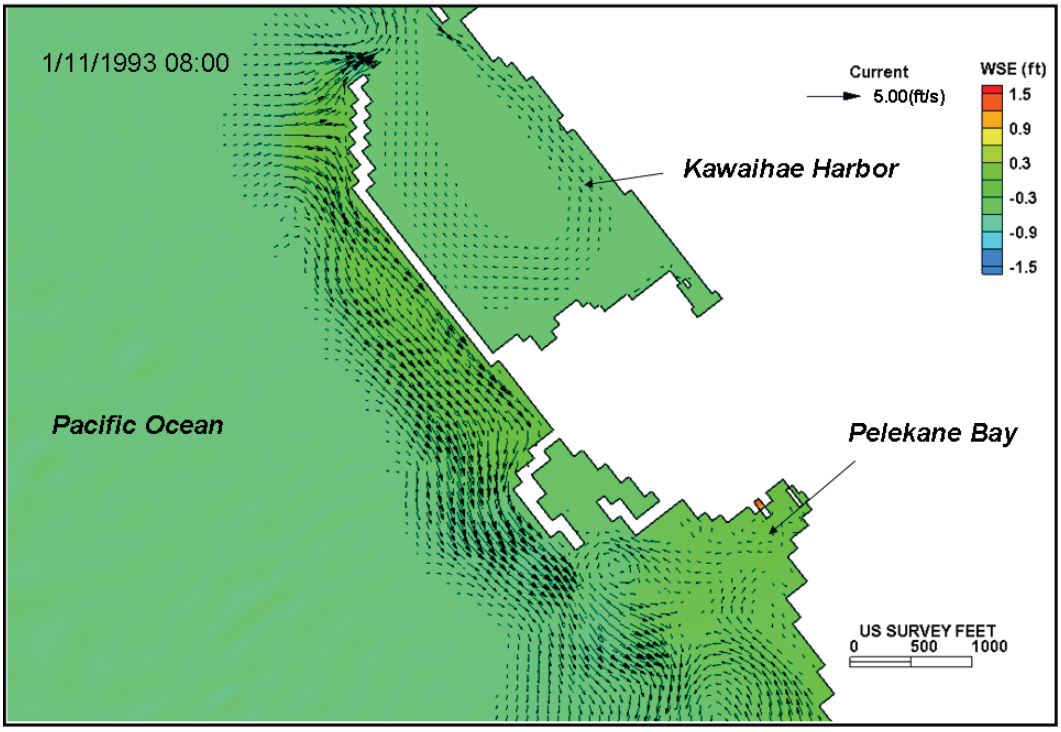


Figure 37. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under existing condition during storm on 11 January 1993 at 08:00 GMT.

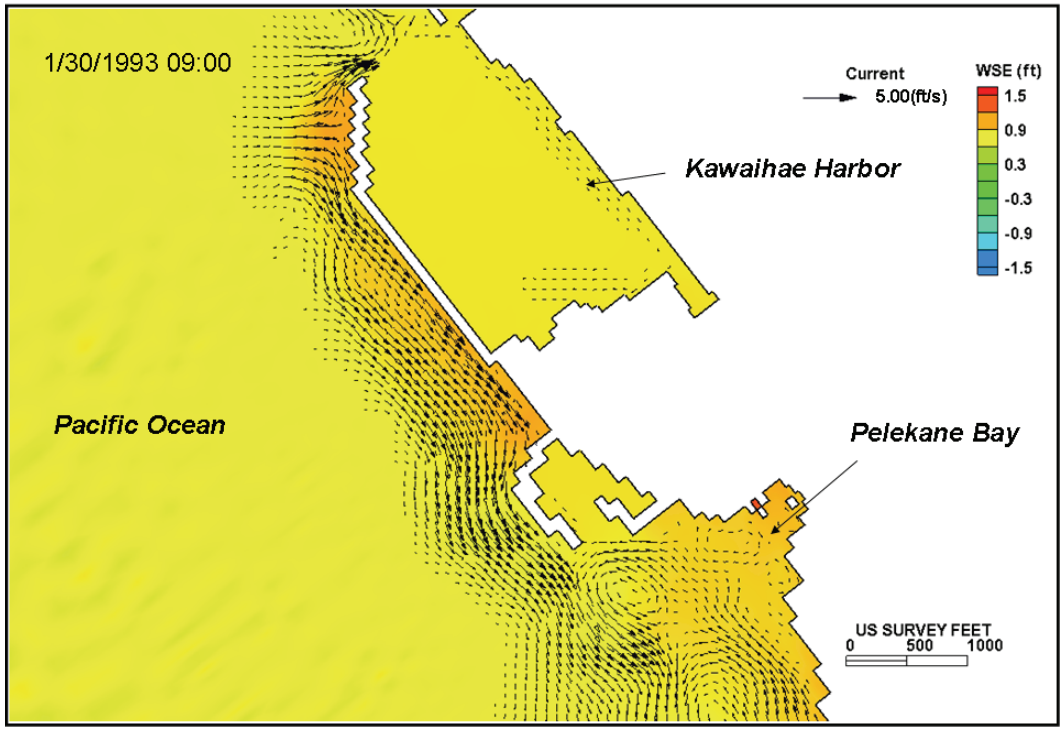


Figure 38. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under existing condition during storm on 30 January 1993 at 09:00 GMT.

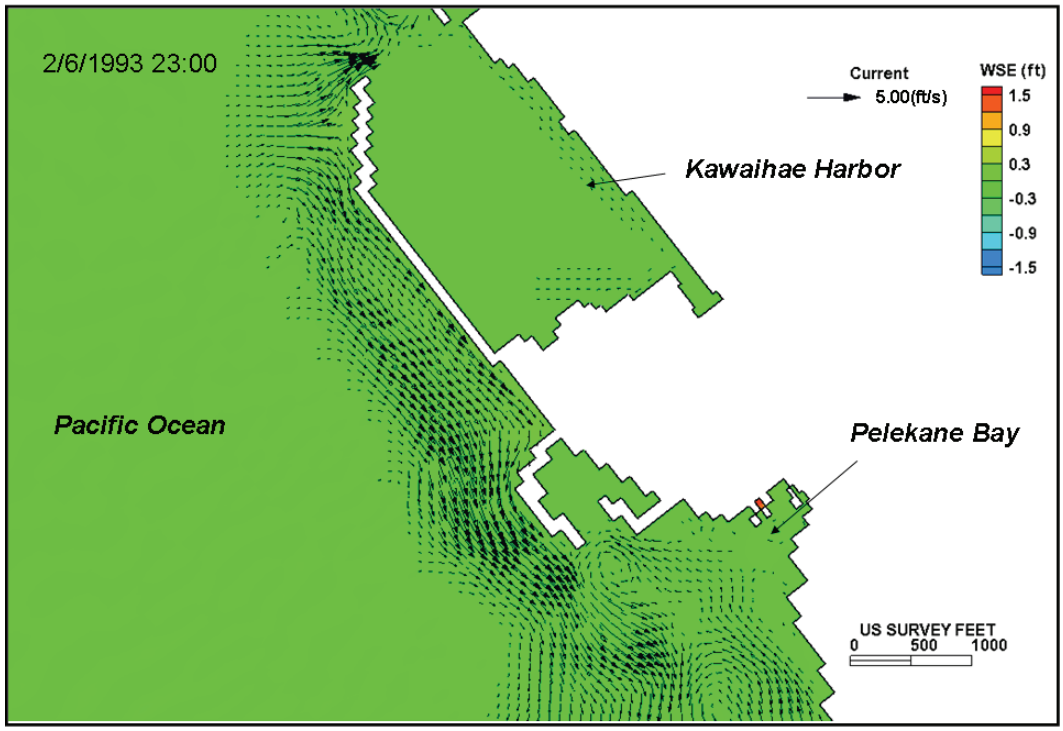


Figure 39. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under existing condition during storm on 6 February 1993 at 23:00 GMT.

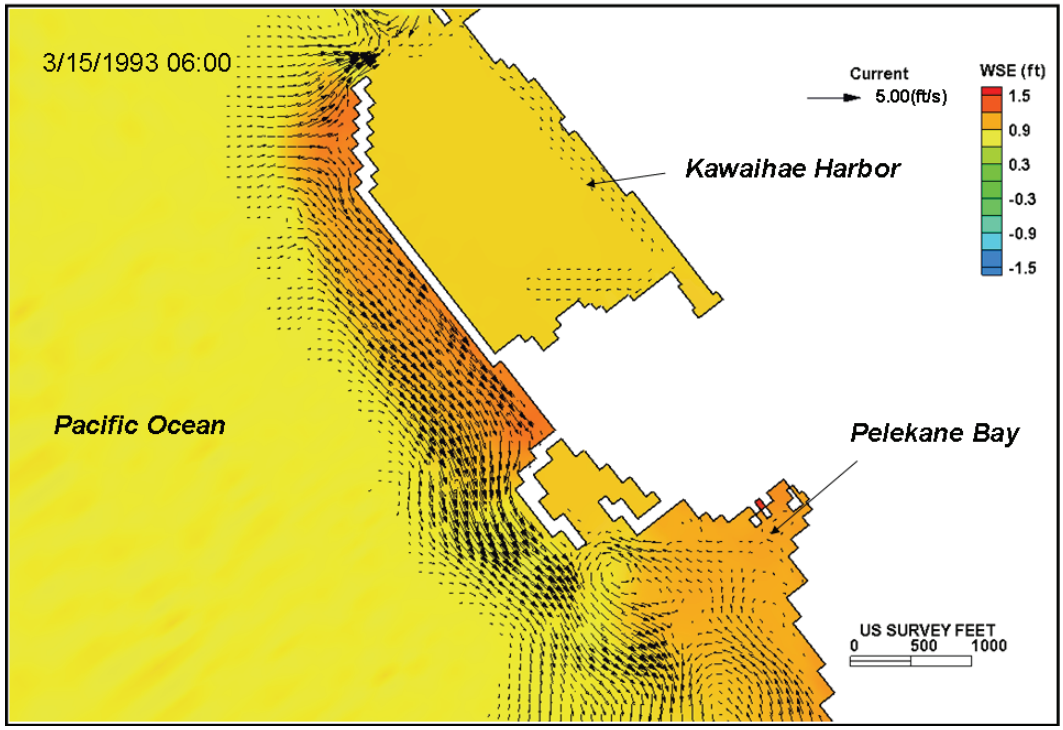


Figure 40. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under existing condition during storm on 15 March 1993 at 06:00 GMT.

Table 8. Maximum current speeds near Kawaihae Harbor and along proposed channel under existing condition (Exst) and four channel alternatives during five winter storms from October 1992 through March 1993.

| Date (1993) | Maximum Current Speed (ft/sec) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Kawaihae Harbor Area | | | | | Along-channel | | | | |
| | Exst | Alt 1 | Alt 2 | Alt 3 | Alt 4 | Exst | Alt 1 | Alt 2 | Alt 3 | Alt 4 |
| 01/07 16:00 | 4.43 | 4.51 | 4.27 | 3.53 | 4.29 | N/A | 0.92 | 0.95 | 1.31 | 1.57 |
| 01/11 08:00 | 3.24 | 3.24 | 3.26 | 3.07 | 3.26 | N/A | * | 0.79 | 0.82 | 1.41 |
| 01/30 09:00 | 3.19 | 3.19 | 3.23 | 2.90 | 3.14 | N/A | 0.95 | 0.79 | 0.89 | 1.05 |
| 02/06 23:00 | 3.19 | 3.19 | 3.10 | 3.22 | 3.12 | N/A | * | 0.75 | 0.59 | 1.05 |
| 03/15 06:00 | 3.38 | 3.38 | 3.22 | 3.11 | 3.33 | N/A | * | * | 0.10 | 0.23 |
| Note: * indicates channel blockage due to sediment infilling. | | | | | | | | | | |

Although circulation patterns during the winter storms (Figures 36-40) resemble those of snapshots analyzed during the spring swells (Figures 16-19), three differences are noted:

1. As shown in Figures 36-40, the maximum current speed, mostly occurring outside the breakwater near the small boat harbor, can reach 4.5 ft/sec during the 7 January 1993 storm. The peak speed along the proposed channel during this storm can be as large as 1.5 ft/sec.
2. The northwest swells associated with winter storms generate a strong alongshore current north of the harbor entrance, flowing towards the harbor. A weaker subcurrent of the alongshore current flows into the harbor and forms a harbor-scale clockwise gyre with a maximum speed exceeding 1 ft/sec.
3. The weak gyre appearing in the inner Pelekane Bay during the spring swells is not observed during winter storms.

Figures 41-45 and Table 9 indicate that circulation patterns and the speed of the current surrounding the harbor are not affected by installation of the proposed channel under Alt 1. Circulation patterns in inner Pelekane Bay are slightly different due to both storm influence and channel installation. Similar flow features can be seen under the other channel alternatives in Appendix B.

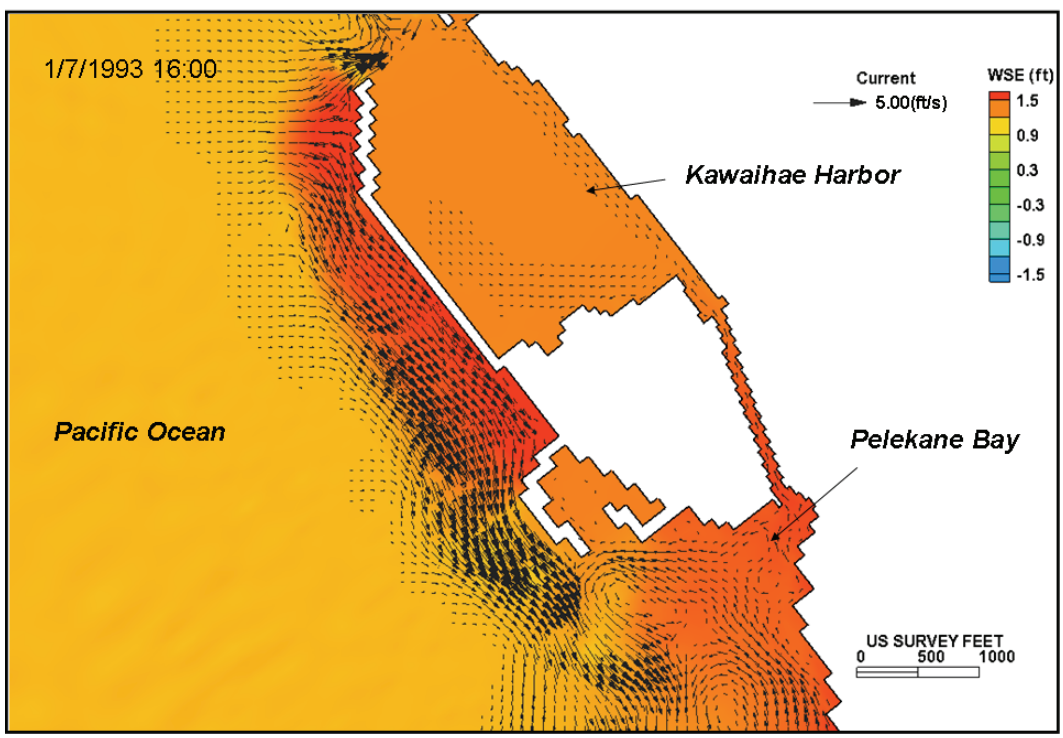


Figure 41. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under Alt 1 during storm on 7 January 1993 at 16:00 GMT.

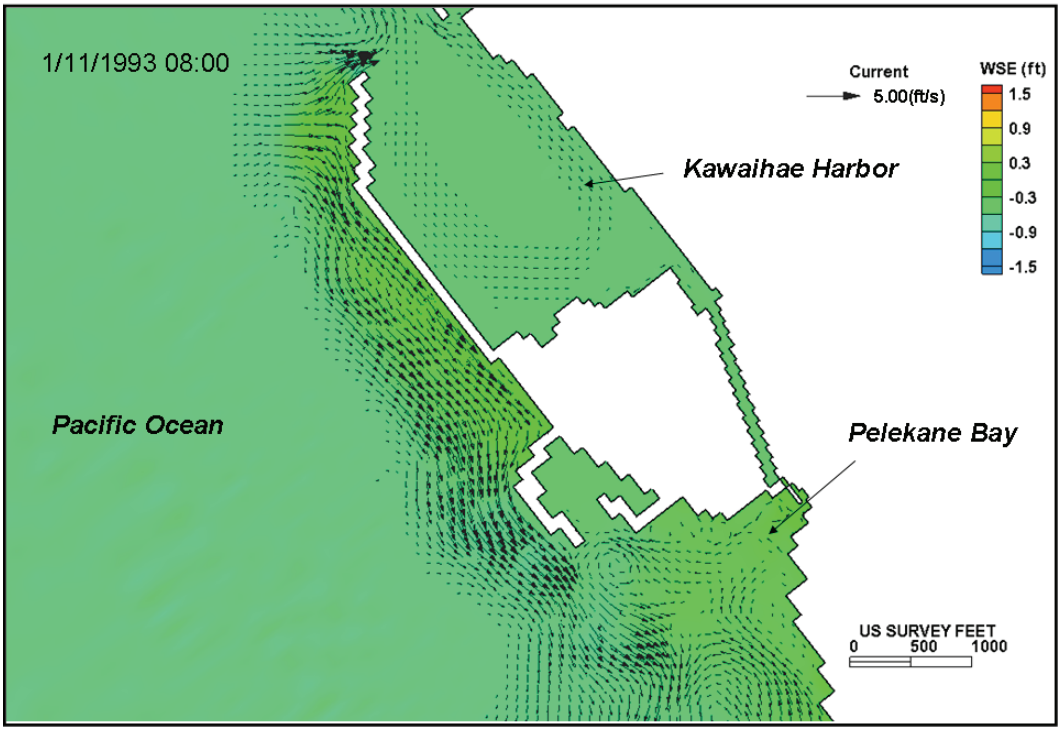


Figure 42. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under Alt 1 during storm on 11 January 1993 at 08:00 GMT.

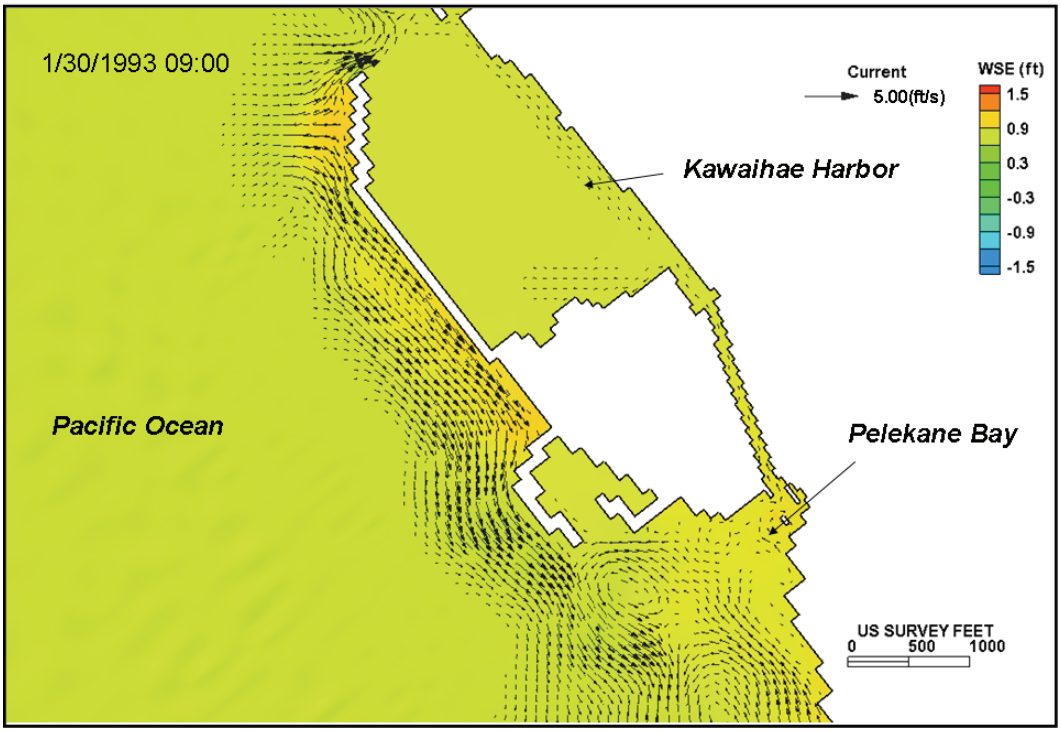


Figure 43. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under Alt 1 during storm on 30 January 1993 at 09:00 GMT.

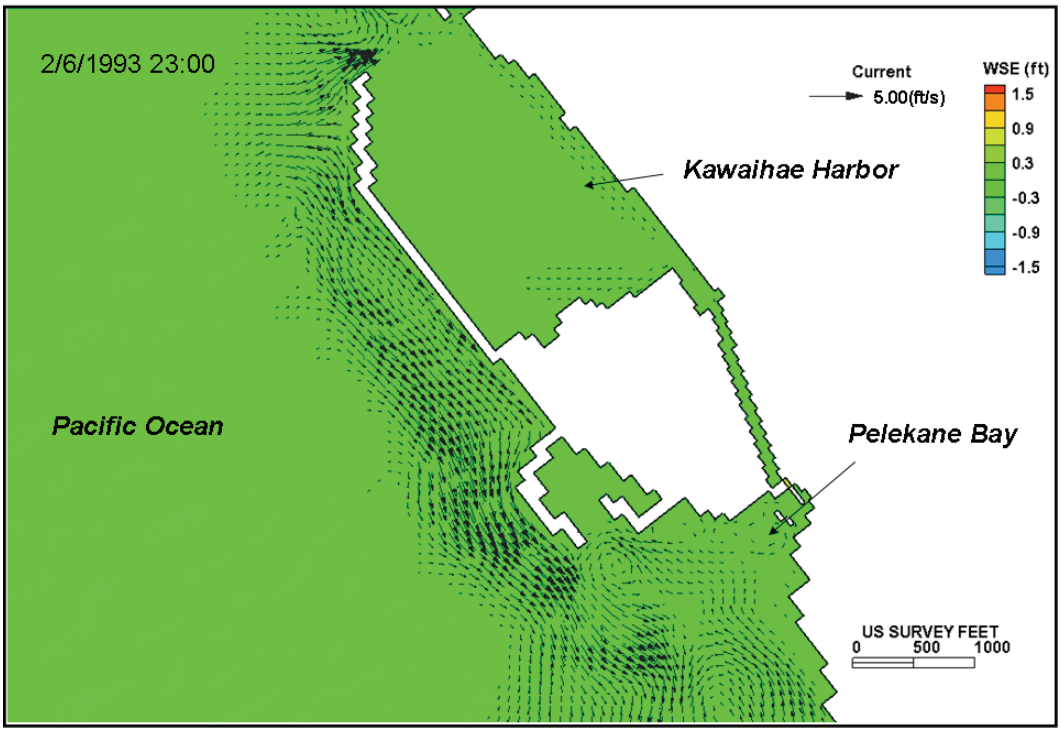


Figure 44. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under Alt 1 during storm on 6 February 1993 at 23:00 GMT.

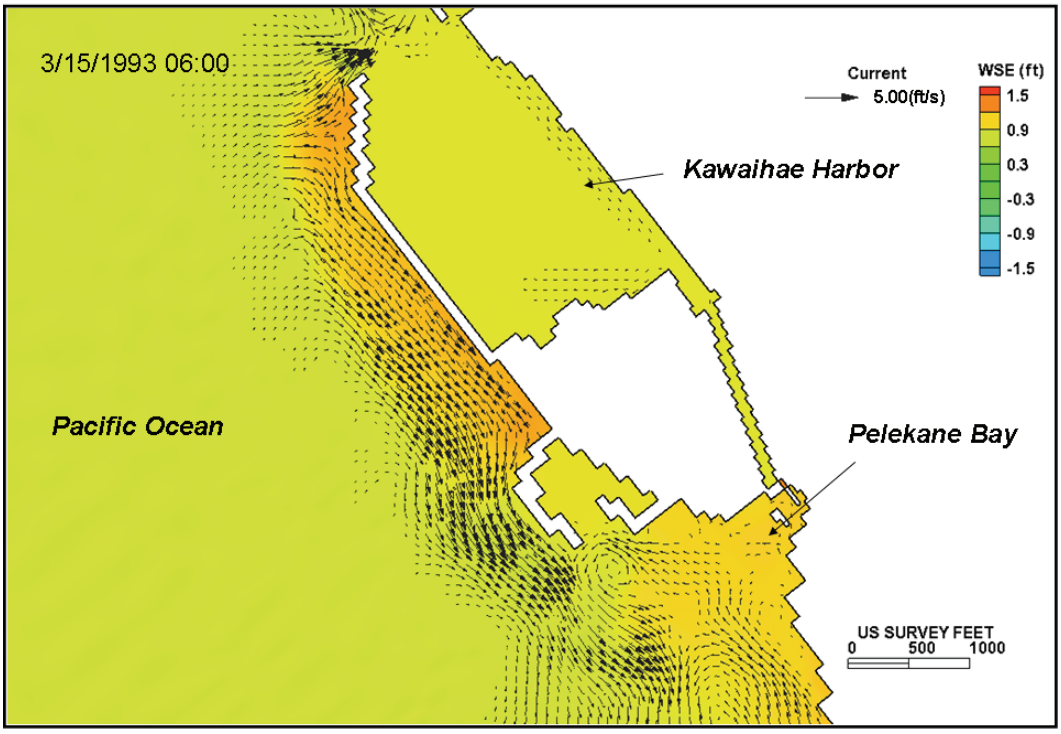


Figure 45. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under Alt 1 during storm on 15 March 1993 at 06:00 GMT.

Table 9. Along-channel flow velocity for different channel alternatives during storms from October 1992 through March 1993. Positive depicts flow direction from Pelekane Bay to Kawaihae Harbor.

| Period | Average Along-Channel Current Velocity (ft/sec) | | | |
|---|---|---|---|---|
| | Alt 1 | Alt 2 | Alt 3 | Alt 4 |
| 10/01/1992 to 01/09/1993 | 0.24 | 0.24 | 0.38 | 0.41 |
| 01/10/1993 to 02/07/1993 | 0.10 | 0.24 | 0.17 | 0.33 |
| 02/08/1993 to 03/31/1993 | 0.01 | 0.00 | 0.03 | 0.01 |

Figure 46 shows time series of along-channel flow velocities at E2 under Alts 1-4 (positive for the bay-to-harbor direction). The time series reveal three distinct flow patterns that correspond to three periods under the influence of winter storms and the different channel alternatives. The first period is between 1 October 1992 and 9 January 1993, as the 7 January swells just pass the study domain; the second period is between 9 January and 7 February 1993, after the 6 February storm; and the third period is between 7 February 1993 and the end of the simulation.

Table 9 presents temporally averaged along-channel speeds under different channel alternatives during these three periods. The along-channel flow is the strongest from Pelekane Bay to Kawaihae Harbor during the first period. The averaged flow speed is 0.24 ft/sec for Alts 1 and 2, and 0.38 and 0.41 ft/sec for Alts 3 and 4 (Table 9) with the maximum speed above 1.0 ft/sec on 7 January 1993. The peak speeds during the period correspond well with northwest swells with a significant wave height of about 4.5 ft and larger. Occasional small or negative (harbor-to-bay) flow corresponds to waves propagating from north to east (0-90 deg azimuth). Table 9 demonstrates that the along-channel speeds are reduced significantly under Alts 1, 3, and 4 for the second period, and close to zero under all four alternatives for the third period. This decrease in flow speed is an indication of different extent of channel blockage by frequent passages of northwest swells and swell-induced sediment movement.

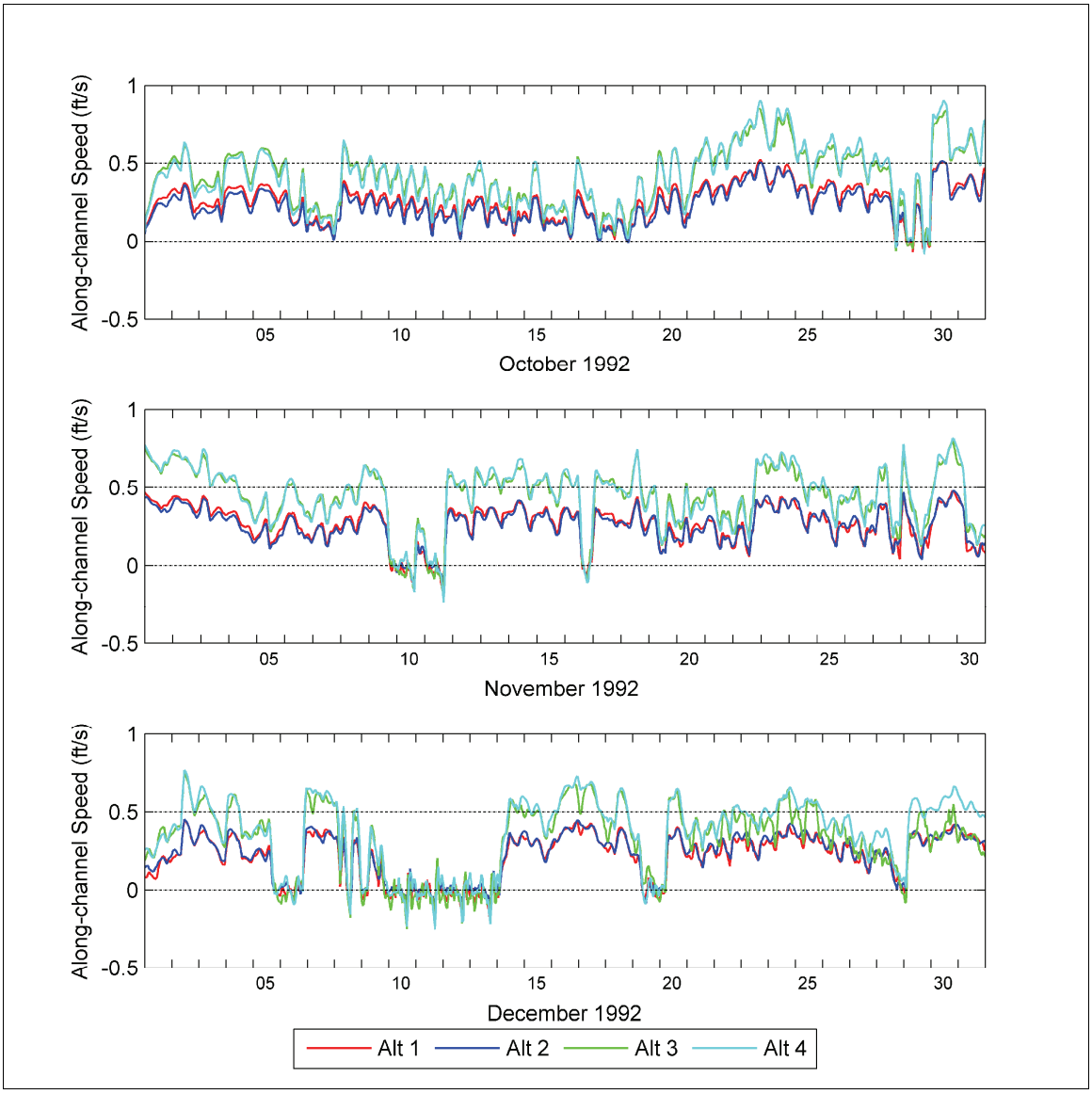


Figure 46. Along channel speed under different channel alternatives. Positive indicates water flow from Pelekane Bay to Kawaihae Harbor (continued).

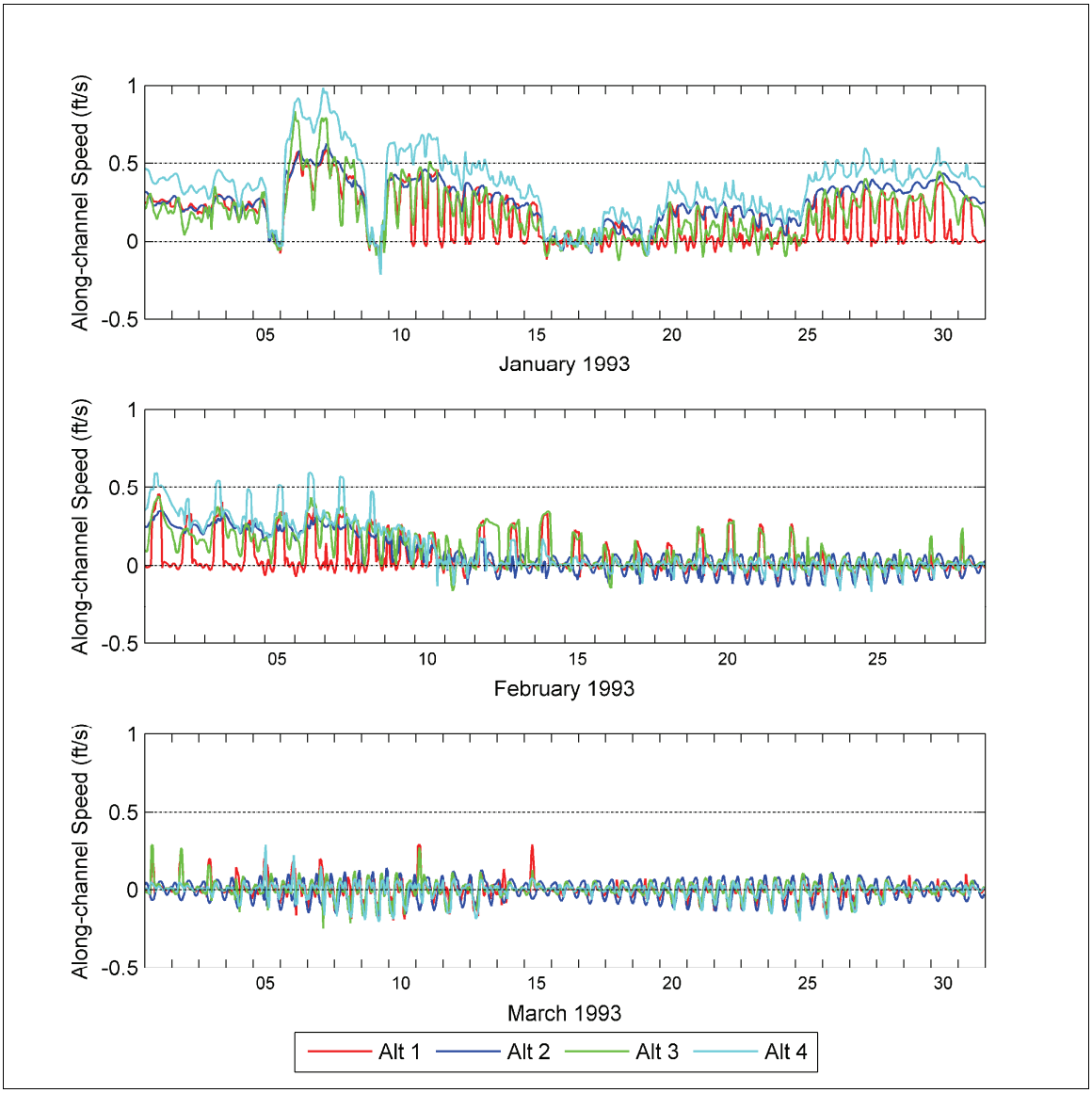


Figure 46. (Concluded).

## Sediment transport

Morphology change in Pelekane Bay and the proposed channel is shown in Figures 47-51. The spatial distributions are the results obtained under the existing condition and the proposed channel alternatives at the end of the storm simulations. Under the existing condition, erosion appears between the outer and the inner Pelekane Bay, and deposition appears in the inner bay, both occurring within a small area. Relatively weak circulation in the inner bay should be the reason for weak sediment transport (Figures 36 and 47). The channel installation, however, changes the patterns of sediment transport in the bay. Stronger and more persistent currents from the bay to the harbor can transport eroded sand near the outer bay and result

Figure 47. Morphology change under the existing condition (Exst) after 6-month simulation.

Figure 48. Morphology change under Alt 1 after 6-month simulation.

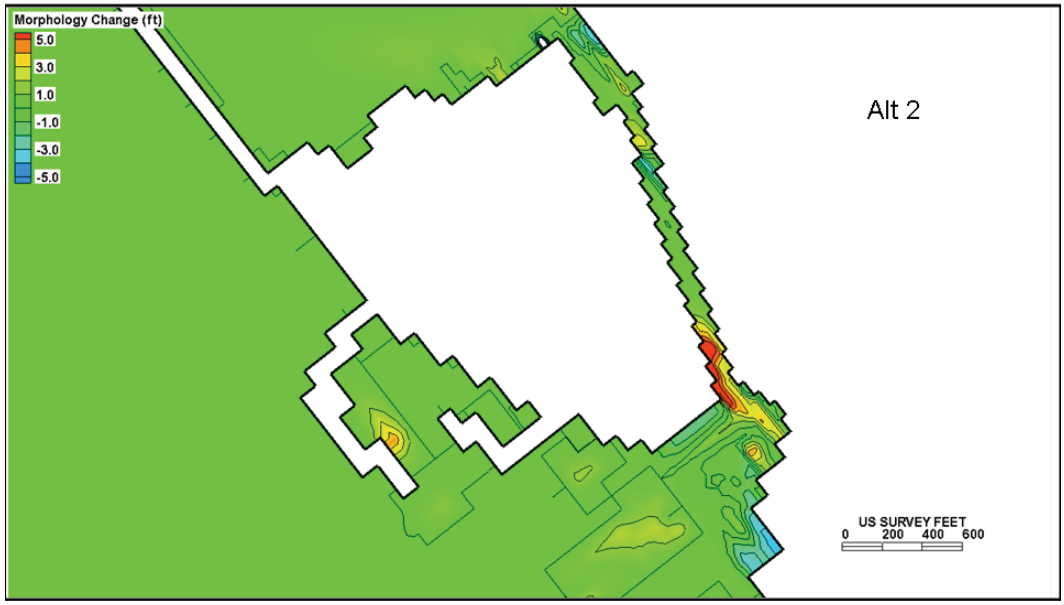


Figure 49. Morphology change under Alt 2 after 6-month simulation.

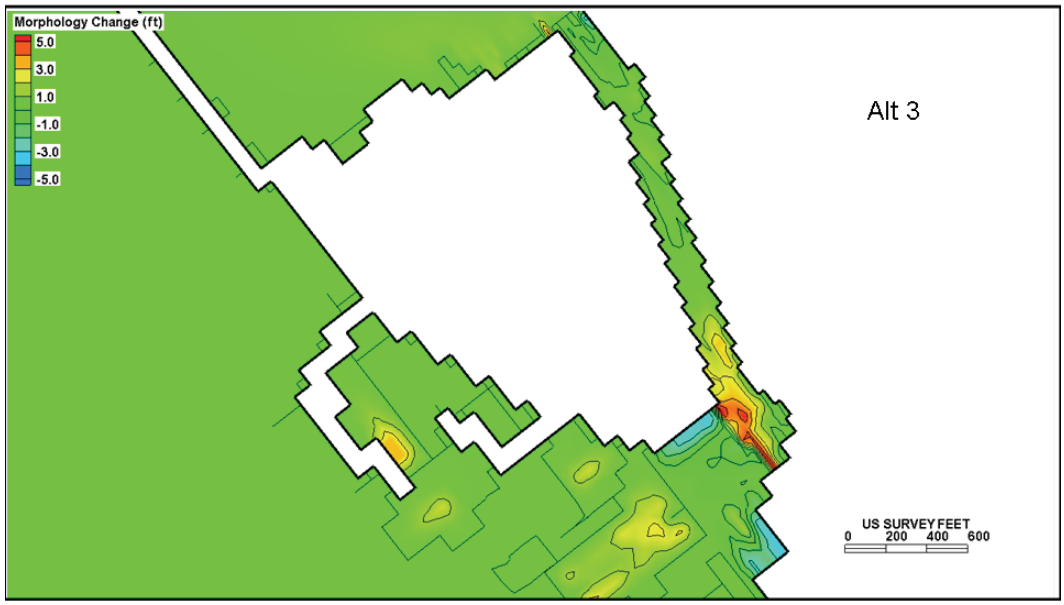


Figure 50. Morphology change under Alt 3 after 6-month simulation.

Figure 51. Morphology change under Alt 4 after 6-month simulation.

in greater deposition in the vicinity of the channel mouth. Under significant different alternatives, deposition can occur and reaches 500-600 ft into the channel (Figures 49-51). Different from the 15-day results of the non-storm condition, erosion and deposition patterns seem to be associated with channel depth. Eroded sand travels much further into the channel under Alts 2 and 4 than under Alts 1 and 3 (Figures 48-51).

Table 10 presents the maximum computed erosion deposition and total sediment volume changes in Pelekane Bay and in the proposed channel under the existing condition and the proposed channel alternatives for the storm period. The maximum calculated erosion and deposition are approximately 4.6 and 6.6 ft, respectively, and mostly occurs in Pelekane Bay. The maximum deposition in the channel ranges approximately between 2.3 and 6.6 ft under different alternatives at the end of the simulation. For the same width, a deeper channel alternative (Alts 2 and 4) would more than double the maximum deposition in the channel and sediment volume transported from the bay into the channel, than for a shallow channel alternative (Alts 1 and 3). Based on the values in the last column of the table, the volume of sand that would have to be dredged after a similar 6-month period to reestablish the designed channel depth is 1,730 cu yd for Alt 1 and close to 9,000 cu yd for Alt 4.

Table 10. Depth change (ft) in Pelekane Bay and proposed channel under existing condition (Exst) and four channel alternatives. Negative represents erosion, and positive represents deposition.

| Scenario | Maximum Erosion in Pelekane Bay and the Channel (ft) | Maximum Deposition in Pelekane Bay and the Channel (ft) | Maximum Deposition near Mouth of the Channel (ft) | Maximum Deposition in the Channel (ft) | Sediment Volume Transported in the Channel ($yd^3$) |
|---|---|---|---|---|---|
| Exst | -4.6 | 3.7 | 1.0 | N/A | N/A |
| Alt 1 | -3.8 | 5.1 | 5.1 | 2.3 | 1730 |
| Alt 2 | -4.3 | 6.6 | 5.8 | 6.6 | 5483 |
| Alt 3 | -3.8 | 5.1 | 5.1 | 2.7 | 3908 |
| Alt 4 | -3.9 | 6.3 | 6.0 | 6.3 | 8930 |

Time series of depth change at the five stations (Figure 30) is plotted for the four channel alternatives in Figure 52. A few rapid increases in erosion and deposition correspond to some northwest swells propagating into the study area. For example, the 7 January 1993 storm causes 0.2 ft of erosion under Alts 2 and 4 near the channel mouth at CH1 and 0.2-0.5 ft of deposition in the channel at CH3. Starting from 27 January 1993 (an unlisted storm with a wave height of 6.2 ft) through the 30 January and the 6 February storms, large deposition occurs at the bay and in the channel during the 11-day period. The depth change at PB1 is 0.8 ft under Alt 3 and at sta PB2 is 2.4 ft under Alt 4. In the channel, the change is up to 2.8 ft at CH1 under Alt 2 and 2.9 ft at CH3 under Alt 4. For Alts 2 and 4, the channel is essentially blocked and for Alts 1 and 3, a large amount of sand is either deposited near the channel mouth and/or in the bay, and no sand is transported into the channel after this storm (Figures 46-52).

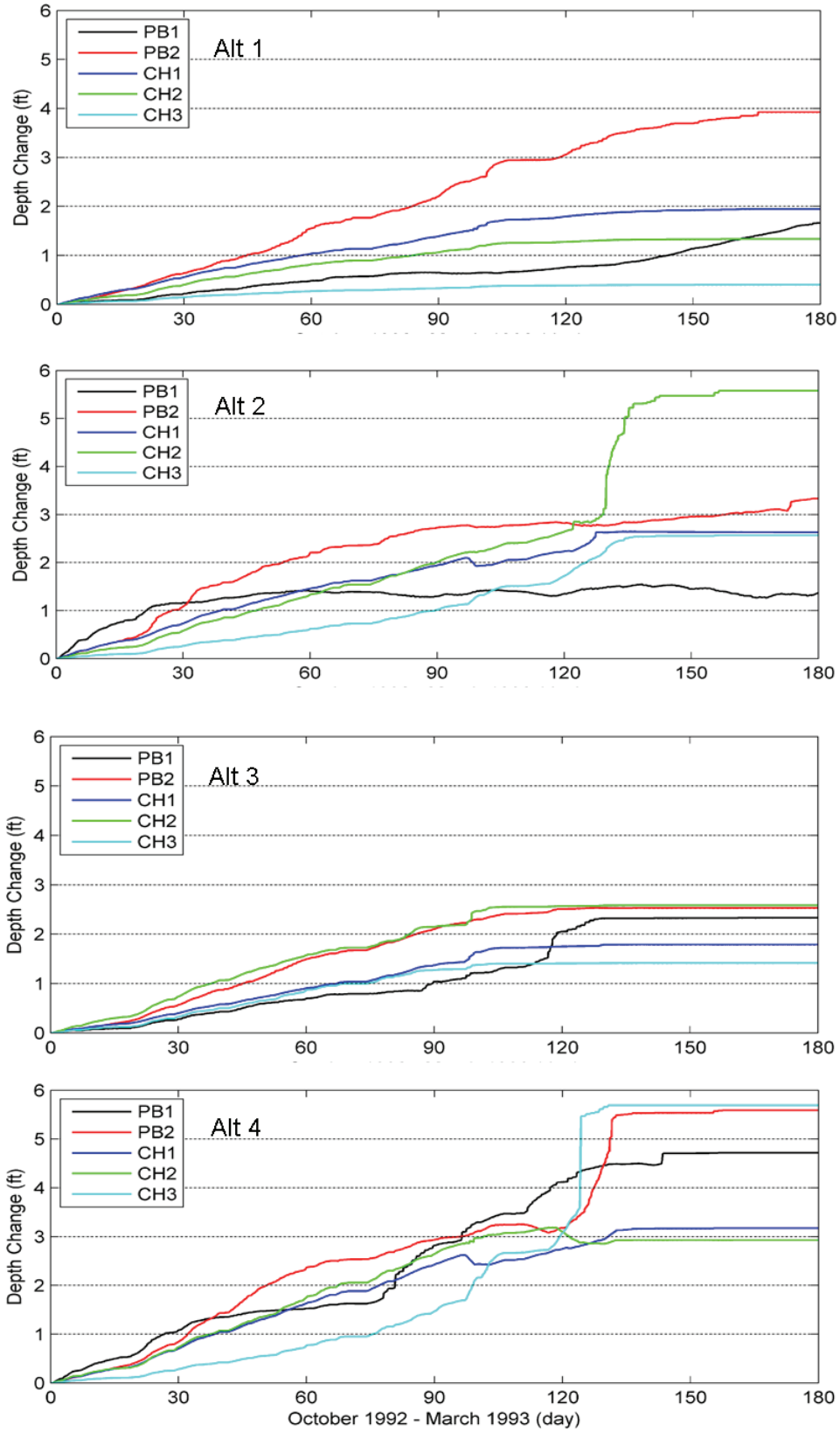


Figure 52. Depth change under different channel alternatives after 6-month simulation.

# 5 Conclusions

The CMS, a coupled wave, flow and sediment transport numerical modeling system was applied to evaluate the installation of a proposed circulation channel connecting Kawaihae Harbor to Pelekane Bay on the western side of the island of Hawaii. Analysis of the WIS hindcasts between 1981 and 2004 indicates that significant wave height is 3.9 ft, mean peak wave period is 12.7 sec, and the predominant waves are from south southwest (about 200 deg azimuth) and from west northwest (about 290-310 deg azimuth) at WIS Pacific Station 113. Sensitivity tests with the CMS reveal that the nearshore harbor area is located in an environment dominated by wave-driven currents, and wind and tidal forcing are secondary. The mean tide range is only 1.5 ft.

Four channel alternative configurations were developed and simulated. The alternatives covered two channel widths of 98 and 164 ft and two channel depths of 3.3 and 4.9 ft (Table 2). The numerical modeling analysis examined and quantified potential functioning of the proposed channel, assessed change in water circulation in response to wave conditions and hydrodynamics, and estimated potential sediment transport and morphology change in the vicinity of the channel.

CMS calculations indicate that significant wave setup appears in Pelekane Bay in comparison to that in Kawaihae Harbor. The setup difference is created by southwest to northwest incident waves and is greater under the existing condition than that under the channel alternatives because water cannot flow out of the bay without the channel. During swell, the greater setup under the existing condition is about 0.06-0.07 ft. Generally, deeper channel alternatives correspond to lower setup.

Differential wave setup results in consistent higher WSE in Pelekane Bay than in Kawaihae Harbor. Under the four channel alternatives, the temporally averaged elevation difference between the bay and the harbor ranges from 0.04 to 0.1 ft, and the value ranges from 0.12 to 0.26 ft during typical winter storms.

Circulation patterns surrounding Kawaihae Harbor are produced by the incident waves, but do not exhibit much variability with the installation of the proposed channel. The only area in which circulation could be affected

by the channel is in inner Pelekane Bay. Due to differential wave setup between Pelekane Bay and Kawaihae Harbor, water in the proposed channel is predicted to flow from the bay to the harbor in nearly all of the alternatives modeled. The exceptions are some short periods of flow reversal associated with waves propagating from north to east. Without consideration of channel and bay infilling, temporally averaged along-channel flow speed ranges from 0.24 to 0.62 ft/sec, and the maximum speed can exceed 1.5 ft/sec during a winter storm. Comparing channel alternatives, a wider channel, Alts 3 and 4, corresponds to stronger along-channel current speed and a narrower channel, and Alts 1 and 2, to weaker current speed.

The spatial distributions of morphology change indicate weak and limited transport of sand under the existing condition in Pelekane Bay. However, with channel installation, flow erodes sand from Pelekane Bay and transports it to the mouth of and inside the proposed channel. Calculated time series of depth change at selected bay and channel stations show a steady deposition of sand, and that storms are a major cause in contributing to sand transport and accumulation (blockage of the channel). At the end of the multi-storm simulations, the predicted maximum deposition is greater than 6.0 ft, both in the bay and the proposed channel. More sand is deposited in the channel under the deeper channel alternatives, Alts 2 and 4. The channel or bay blockage appears under all four channel alternatives before the end of a 6-month simulation. To reestablish the designed channel depths following the 6-month simulation, the minimum amount of sand that would have to be dredged from the channel is 1,730 cu yd for Alt 1, and the maximum amount of sand is close to 9,000 cu yd for Alt 4.

The hydrodynamics, wave and sediment transport study for Kawaihae Deep Draft Harbor and Pelekane Bay indicates that construction of a circulation channel with different configurations would result in consistent flow from the bay to the harbor under normal and storm conditions. The bay-to-harbor flows would produce net sediment transport into the channel and the harbor. Based on these findings, implementation of the circulation channel would not serve the purpose of harbor water renewal and bay water quality improvement and, therefore, is not recommended.

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# Appendix A: Sensitivity Analysis

## Incident waves

Sensitivity analysis of CMS-Flow and CMS-Wave predictions to incident waves was conducted to understand systematic change in hydrodynamics and sediment transport in Kawaihae Harbor and Pelekane Bay associated with installation of the proposed circulation channel.

The specifications of wave parameters were based on wave analysis results performed at WIS Pacific Station 113. All three incident waves have a significant wave height of 4.9 ft and a peak wave period of 14 sec, but correspond to three different incident wave directions, 45 deg relative to shore normal, shore normal (0 deg), and -45 deg relative to shore normal (Figure 53). Based on the grid orientation of the present study, the three incident wave directions are approximately equivalent to about 185, 230, and 275 deg azimuth, respectively. Combined with the channel configurations, existing condition and Alts 1-4, 15 sensitivity simulations were performed for the non-storm condition.

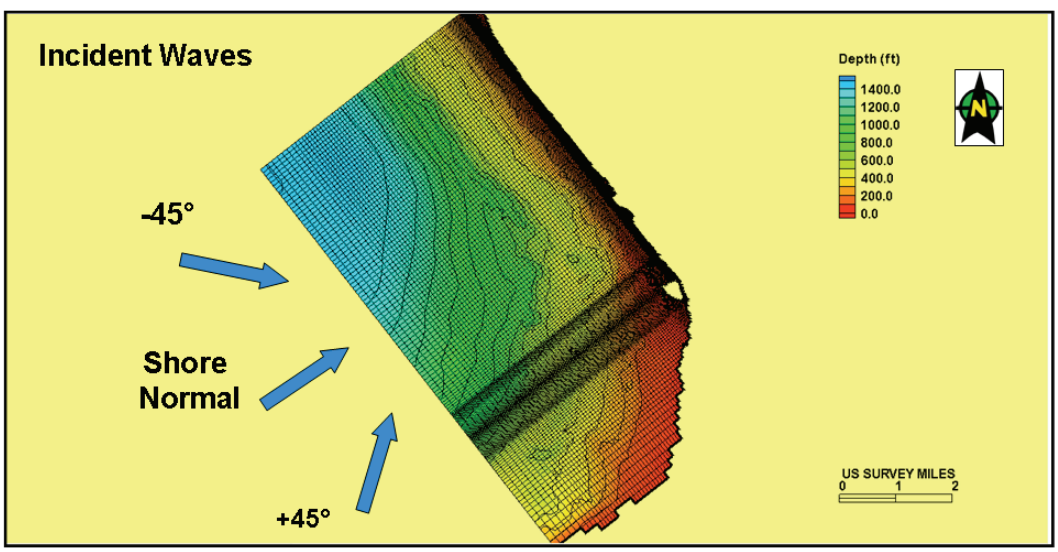


Figure 53. Three incident waves for sensitivity analysis.

Figures 54, 55, 56, and 57 show computed WSE for the designed and the WIS incident waves, and WSE differences between the designed and the WIS wave conditions under four channel alternatives at Pelekane Bay, sta E4, for the 15-day non-storm condition, 1-15 April 2004. Table 11 lists 15-day averaged WSE under different waves for the four channel alternatives at Pelekane Bay, sta E4. WSE calculated for the +45 deg incident waves shows the smallest wave setup, and under shore normal waves the largest wave setup. The maximum WSE difference under these incident waves is about 0.16 ft for channel Alts 1 and 3.

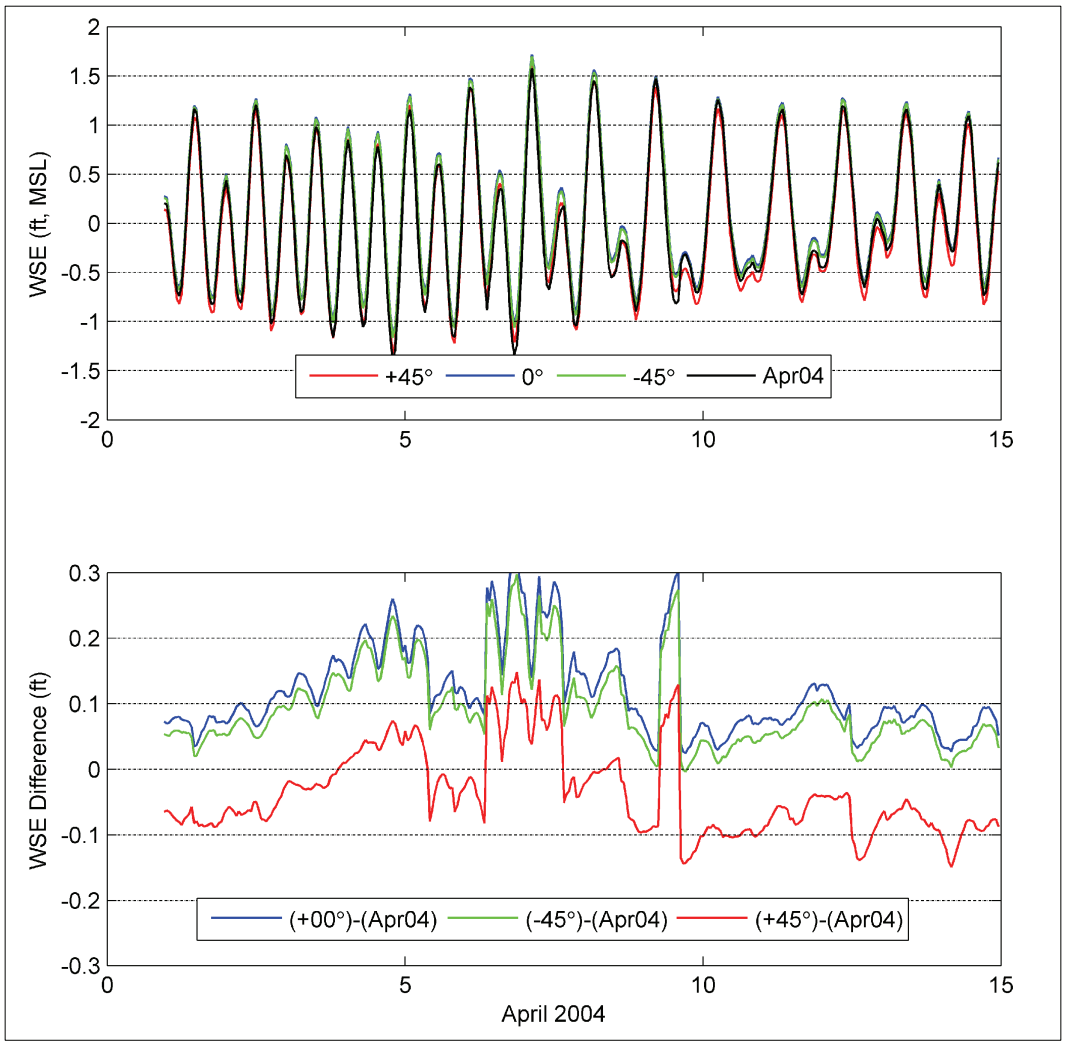


Figure 54. WSE under Alt 1 at Pelekane Bay, sta E4, corresponding to designed and WIS incident waves, 45 deg relative to shore normal, shore normal (0 deg), and -45 deg relative to shore normal, and WSE difference between designed and WIS waves.

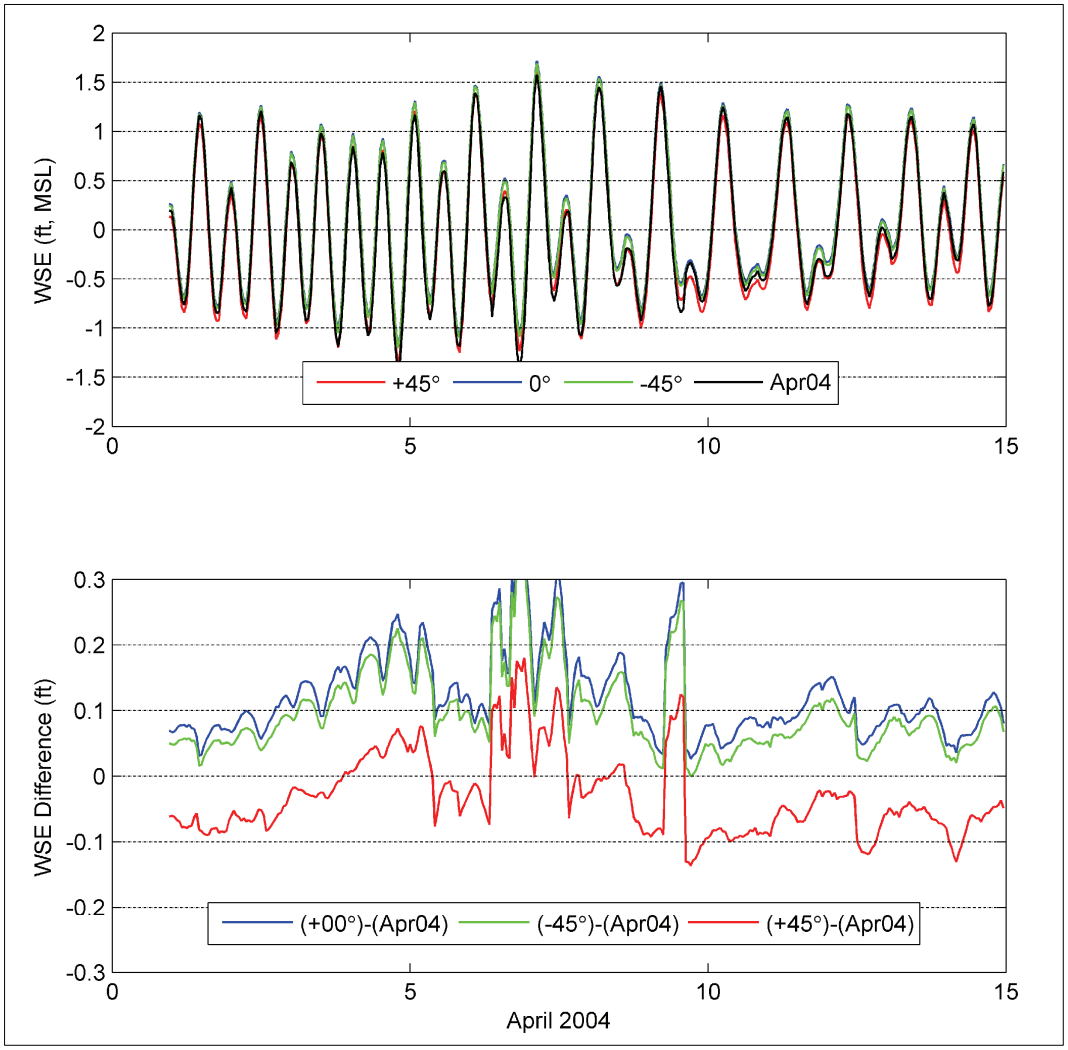


Figure 55. WSE under Alt 2 at Pelekane Bay, sta E4, corresponding to designed and WIS incident waves, 45 deg relative to shore normal, shore normal (0 deg), and -45 deg relative to shore normal, and WSE difference between designed and WIS waves.

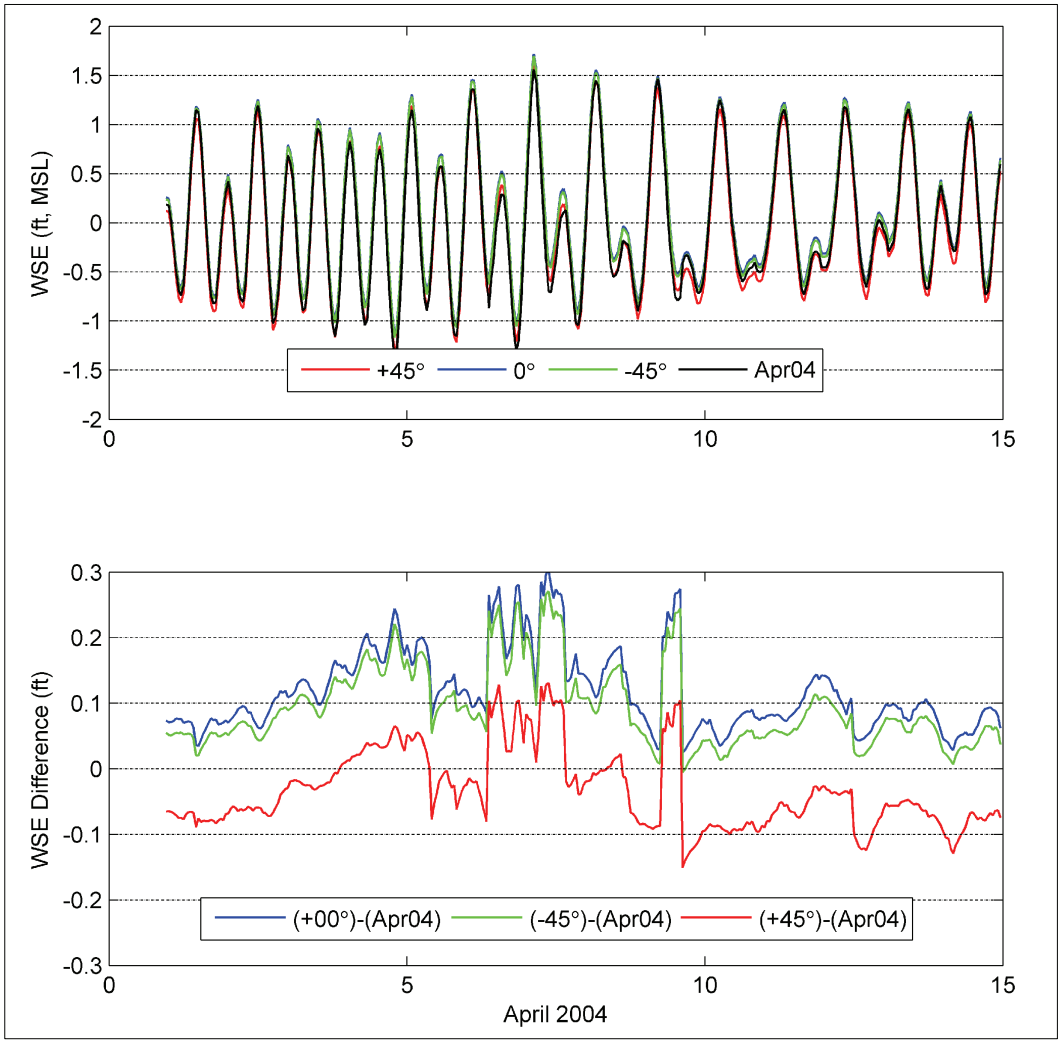


Figure 56. WSE under Alt 3 at Pelekane Bay, sta E4, corresponding to designed and WIS incident waves, 45 deg relative to shore normal, shore normal (0 deg), and -45 deg relative to shore normal, and WSE difference between designed and WIS waves.

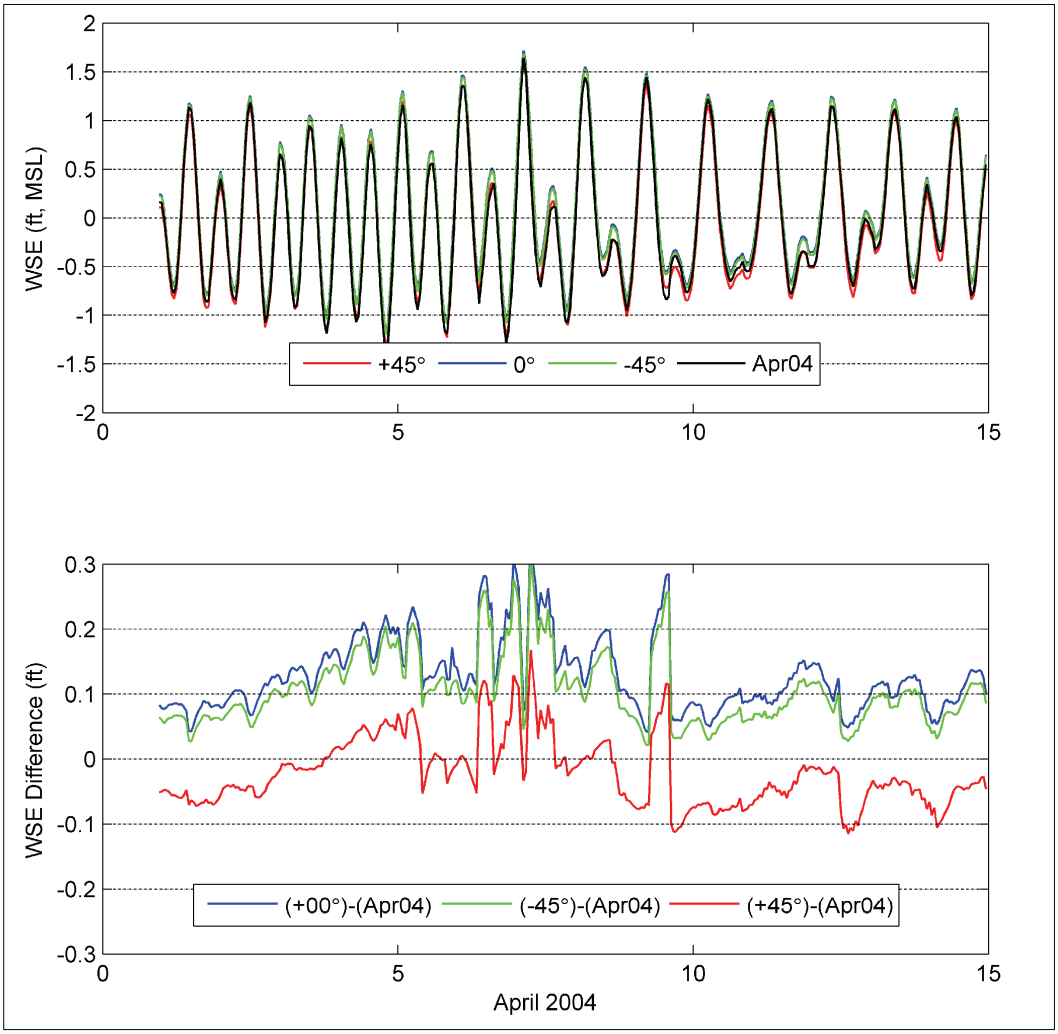


Figure 57. WSE under Alt 4 at Pelekane Bay, sta E4, corresponding to designed and WIS incident waves, 45 deg relative to shore normal, shore normal (0 deg), and -45 deg relative to shore normal, and WSE difference between designed and WIS waves.

Table 11. Temporally averaged WSE (ft) under different waves for four channel alternatives at Pelekane Bay, sta 4.

| Wave Direction (deg, to Shore Normal) | WSE (ft) | | | |
|---|---|---|---|---|
| | Alt 1 | Alt 2 | Alt 3 | Alt 4 |
| 4 April (WIS) | -0.01 | -0.03 | -0.01 | -0.05 |
| 45 deg | -0.05 | -0.06 | -0.05 | -0.07 |
| Shore Normal (0 deg) | 0.11 | 0.09 | 0.11 | 0.08 |
| -45 deg | 0.09 | 0.07 | 0.08 | 0.06 |

Figures 58, 59, 60, and 61 show 15-day averaged WSEs for the channel alternatives under different wave directions along a section formed by sta E1 to E4 (Figure 13). Kawaihae Harbor is on the left side and Pelekane Bay on the right side of the figure. Inside Kawaihae Harbor at E1, WSEs have about 0.01 ft changes corresponding to incident waves. Average water level differences between Pelekane Bay and Kawaihae Harbor are shown in Table 12. WSE differences are close to or above 0.20 ft under the shore normal and -45 deg waves.

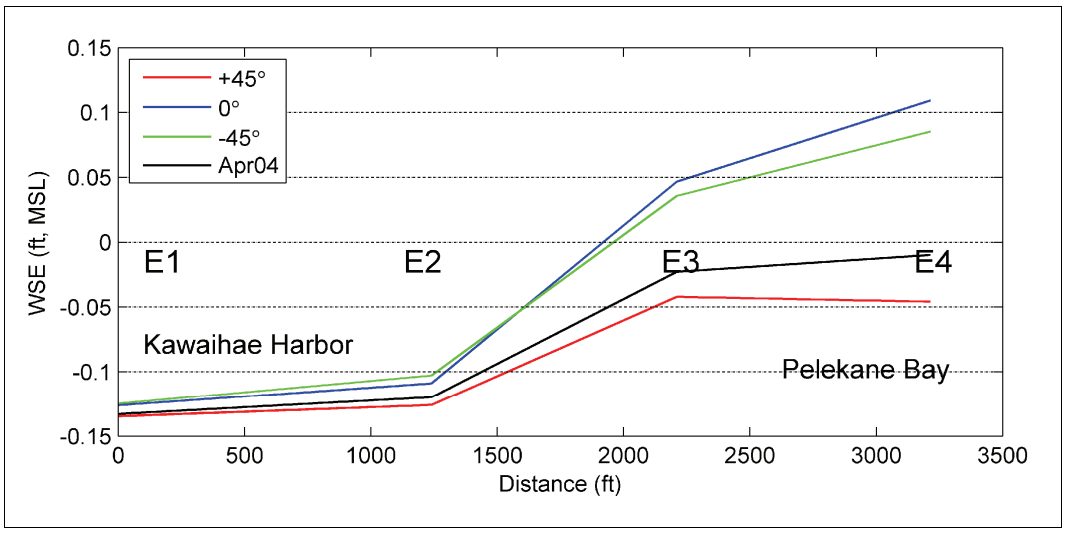


Figure 58. Temporally averaged WSE under Alt 1 corresponding to different waves along section composed of four stations from Kawaihae Harbor (E1) to Pelekane Bay (E4), as shown in Figure 13.

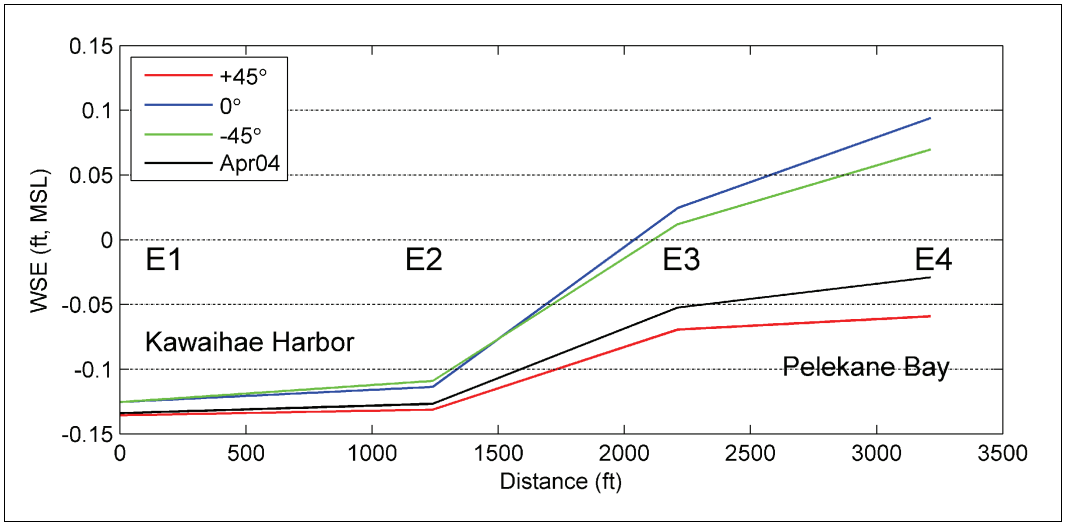


Figure 59. Temporally averaged WSE under Alt 2 corresponding to different waves along section composed of four stations from Kawaihae Harbor (E1) to Pelekane Bay (E4), as shown in Figure 13.

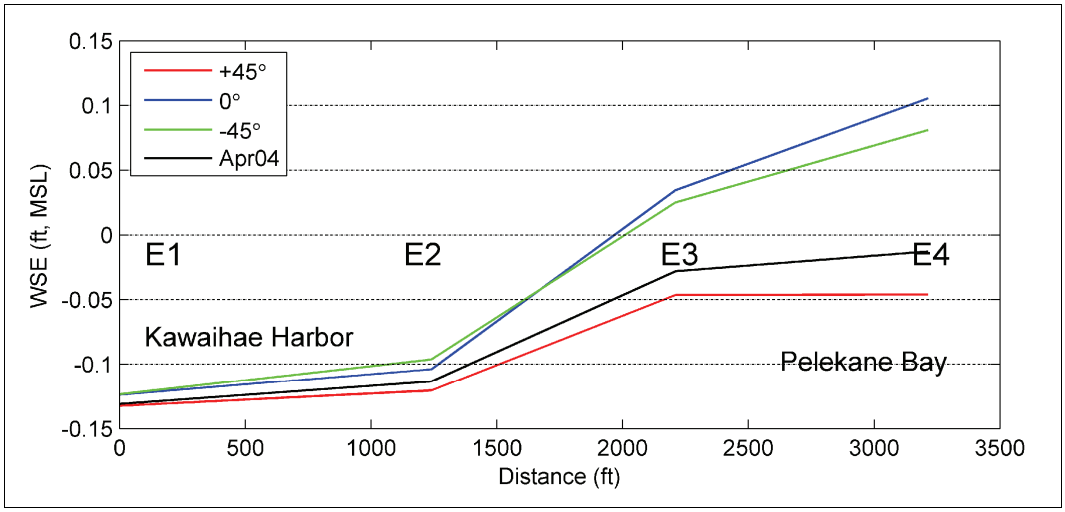


Figure 60. Temporally averaged WSE under Alt 3 corresponding to different waves along section composed of four stations from Kawaihae Harbor (E1) to Pelekane Bay (E4), as shown in Figure 13.

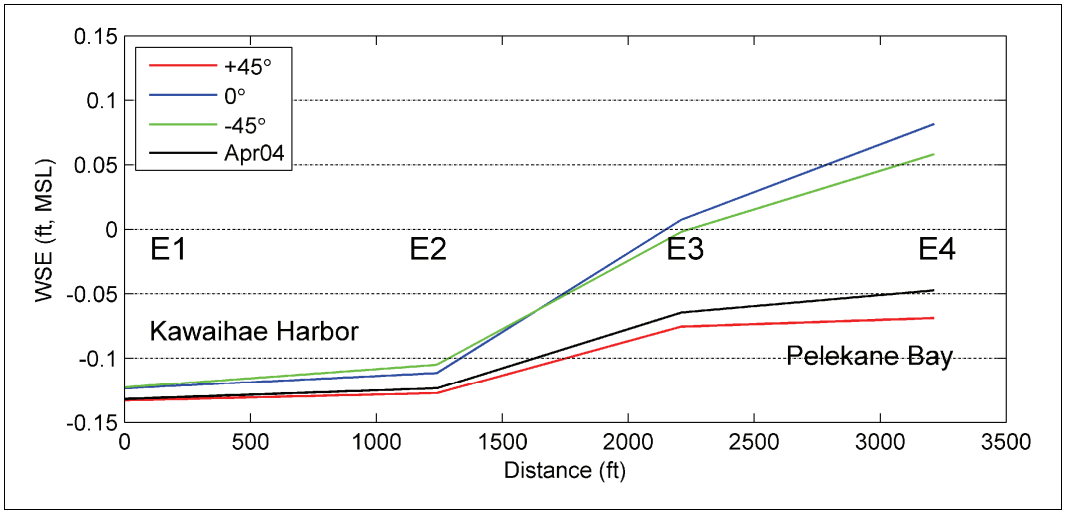


Figure 61. Temporally averaged WSE under Alt 4 corresponding to different waves along section composed of four stations from Kawaihae Harbor (E1) to Pelekane Bay (E4), as shown in Figure 13.

Table 12. Temporally averaged WSE differences (ft) between Pelekane Bay and Kawaihae Harbor under different waves for four channel alternatives.

| Wave Direction (deg, to Shore Normal) | WSE Difference (ft) | | | |
|---|---|---|---|---|
| | Alt 1 | Alt 2 | Alt 3 | Alt 4 |
| 4 April (WIS) | 0.12 | 0.10 | 0.12 | 0.08 |
| 45 deg | 0.09 | 0.08 | 0.09 | 0.06 |
| Shore Normal (0 deg) | 0.24 | 0.22 | 0.23 | 0.21 |
| -45 deg | 0.21 | 0.19 | 0.20 | 0.18 |

Figures 62, 63, 64, and 65 show time series of along-channel flow speeds at E2 under Alts 1, 2, 3, and 4 (positive for the bay-to-harbor direction) corresponding to the WIS and designed incident waves, 45 deg relative to shore normal, shore normal (0 deg), and -45 deg relative to shore normal. During this 15-day simulation, designed waves generate consistent along-channel flow from Pelekane Bay to Kawaihae Harbor. The WIS waves produce occasional reversed flow from Kawaihae Harbor to Pelekane Bay during two short time intervals when the smallest offshore waves occur on 6 April, or when waves approach the study area from north-northeast (12 deg azimuth) on 10 April. The 15-day averaged speed is listed in Table 13 under various incident waves for Alts 1, 2, 3, and 4.

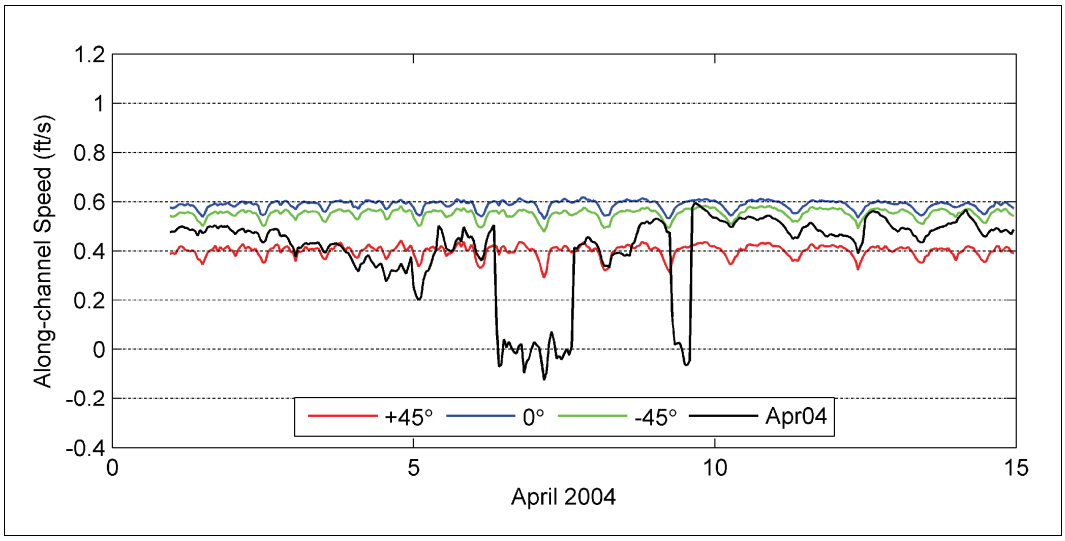


Figure 62. Along channel speed under Alt 1 corresponding to different incident waves. Positive indicates water flow from Pelekane Bay to Kawaihae Harbor.

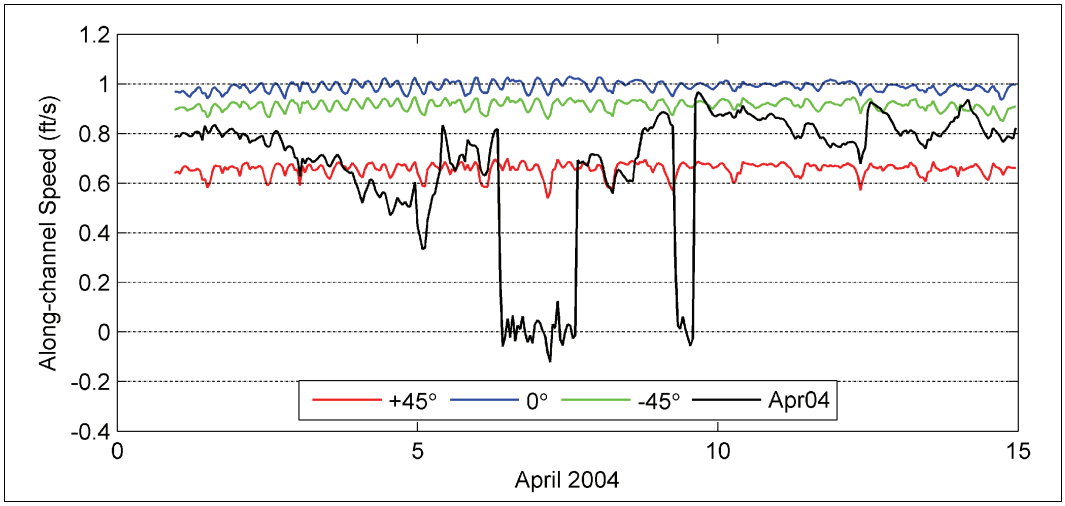


Figure 63. Along channel speed under Alt 2 corresponding to different incident waves. Positive indicates water flow from Pelekane Bay to Kawaihae Harbor.

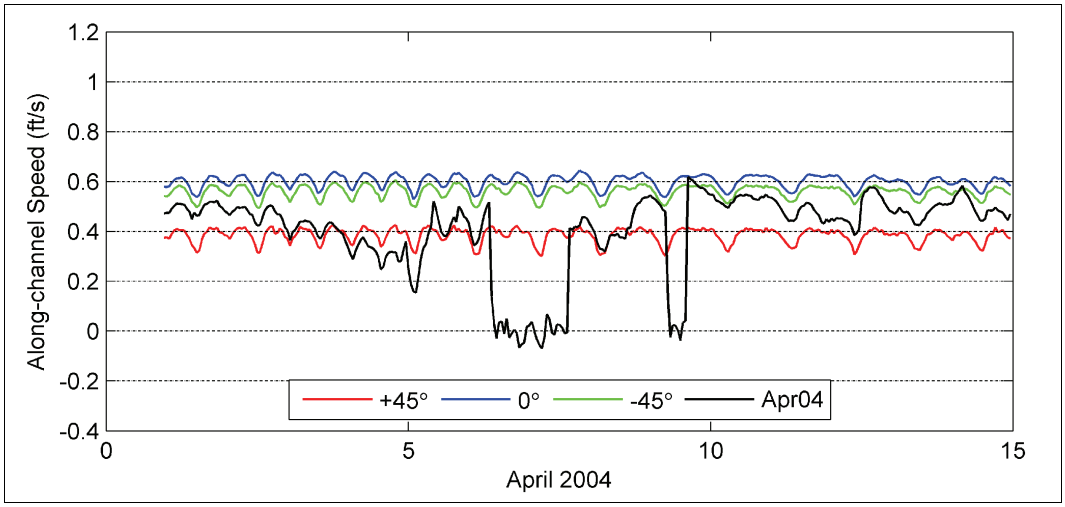


Figure 64. Along channel speed under Alt 3 corresponding to different incident waves. Positive indicates water flow from Pelekane Bay to Kawaihae Harbor.

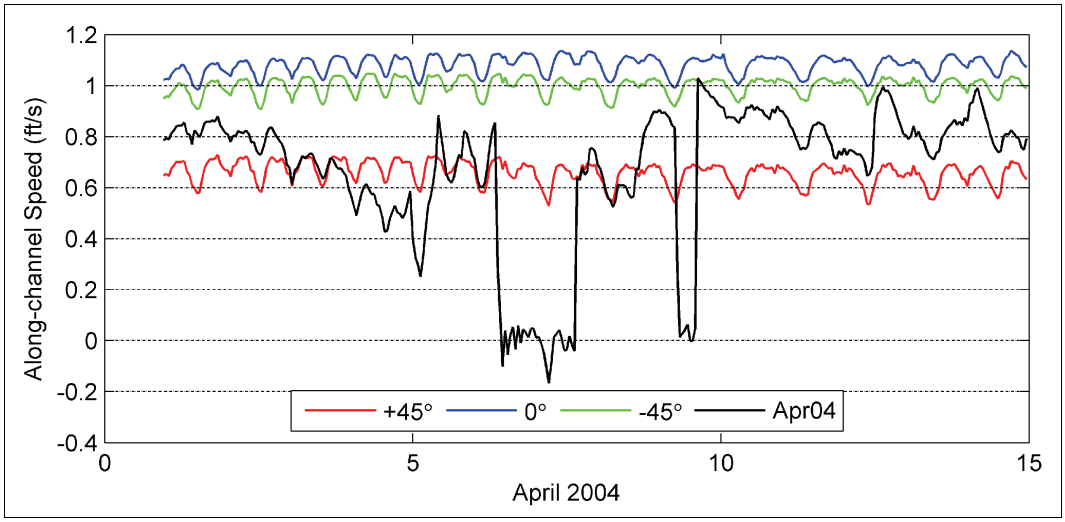


Figure 65. Along channel speed under Alt 4 corresponding to different incident waves. Positive indicates water flow from Pelekane Bay to Kawaihae Harbor.

Table 13. Temporally averaged along-channel current speed (ft/sec) under different waves for four channel alternatives.

| Wave Direction (deg, to Shore Normal) | Along-channel Flow Speed(ft/sec) | | | |
|---|---|---|---|---|
| | Alt 1 | Alt 2 | Alt 3 | Alt 4 |
| 3 April (WIS) | 0.40 | 0.40 | 0.67 | 0.67 |
| 45 deg | 0.40 | 0.38 | 0.66 | 0.66 |
| Shore Normal (0 deg) | 0.59 | 0.60 | 0.99 | 1.08 |
| -45 deg | 0.55 | 0.56 | 0.91 | 1.00 |

## Waves, tide and wind

Physical processes generally associated with water level change are wind driven setup, tide, and wave breaking in the nearshore. To understand the water level difference between Kawaihae Harbor and Pelekane Bay, three primary forcing terms, wind, tide, and waves were examined. Figure 66 shows the computed water surface elevation difference between the bay and the harbor under the existing condition from three CMS simulations: Simulation 1 was forced by waves only, simulation 2 by tide only, and simulation 3 by wind only. The figure illustrates that the tide alone as a model driving force at the site does not generate a consistent differential water level. The differential water level due to wind is negligible. A mean water level rise in Pelekane Bay is evidently associated with wave forcing and is induced by wave set-up.

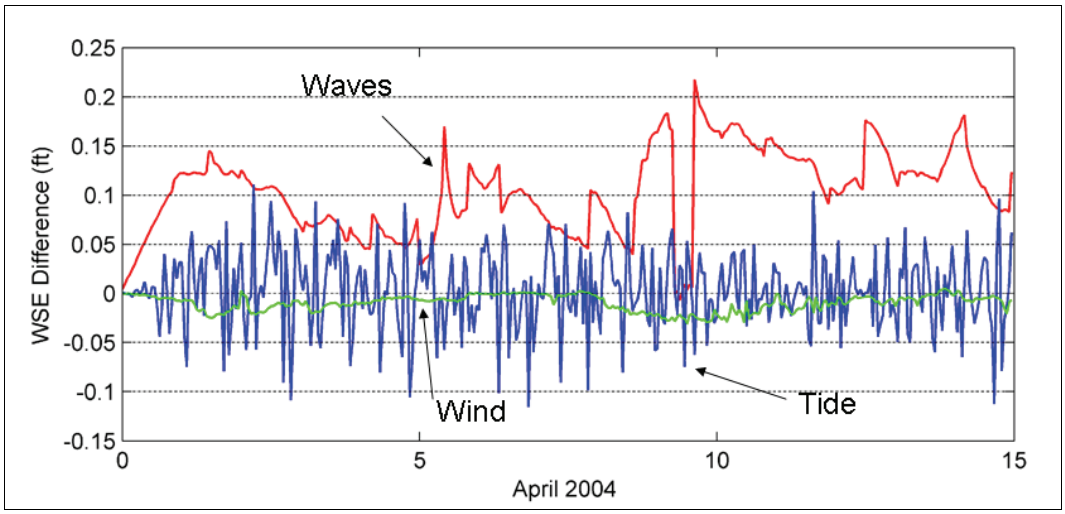


Figure 66. WSE difference (ft) between Pelekane Bay (E4) and Kawaihae Harbor (E1) in response to different model forcing.

All three incident waves result in higher wave set-up in Pelekane Bay than in Kawaihae Harbor, and generate along-channel flows from Pelekane Bay to Kawaihae Harbor. The shore-normal waves correspond to the maximum wave set-up in Pelekane Bay and produce the maximum along-channel flow from the bay to the harbor. Of three investigated physical processes, waves are found to be dominant in controlling the water level variation in the study area.

# Appendix B: Circulation Fields under Alts 2, 3, and 4

## Non-storm condition

Figures 67-78 show four snapshots of nearshore circulation fields for Alts 2, 3, and 4, respectively. Similar flow features to Alt 1, as described in the main text of this report, are revealed under those channel alternatives (Figures 20-23).

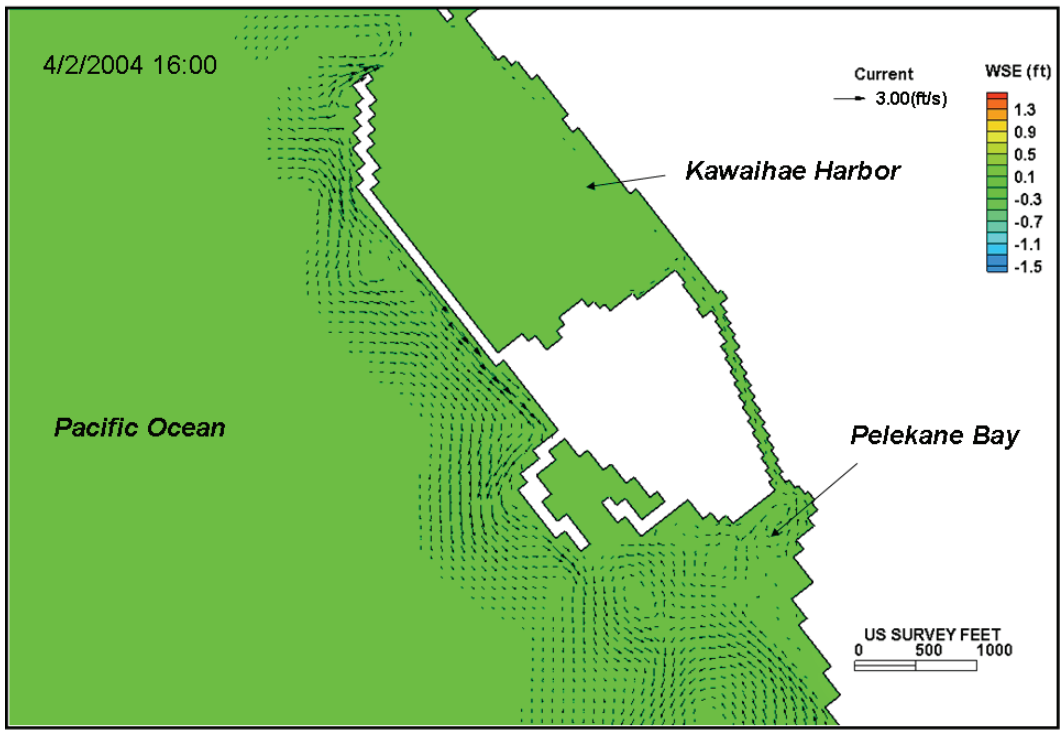


Figure 67. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 2 for non-storm condition on 2 April 2004 at 16:00 GMT.

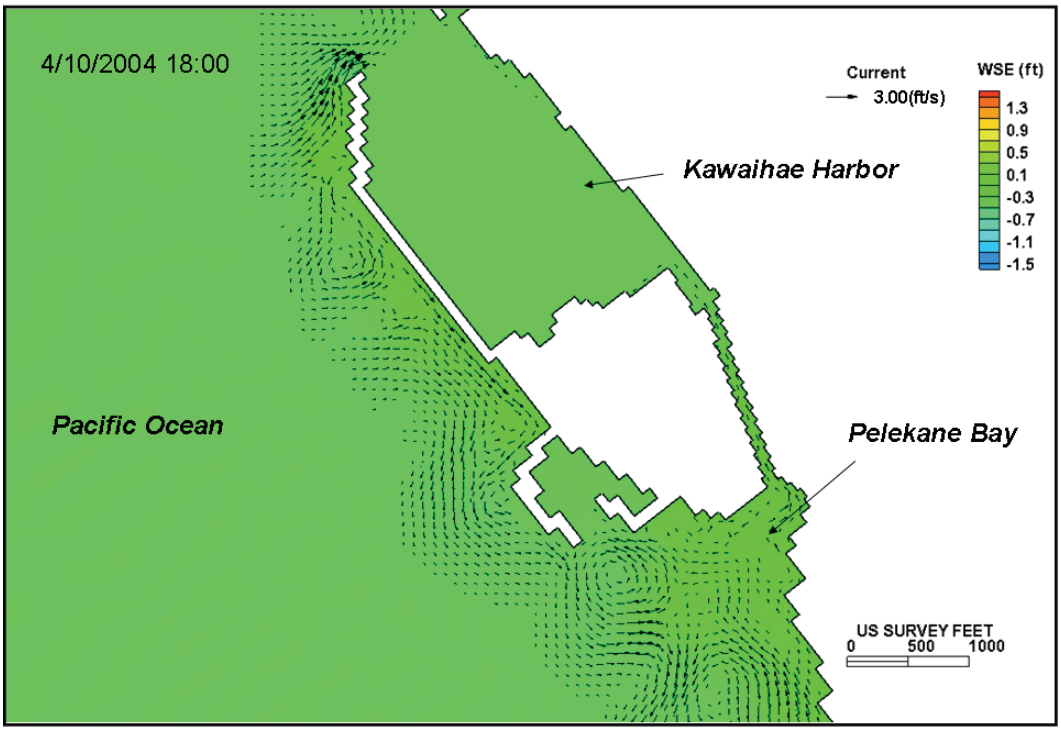


Figure 68. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 2 for non-storm condition on 7 April 2004 at 18:00 GMT.

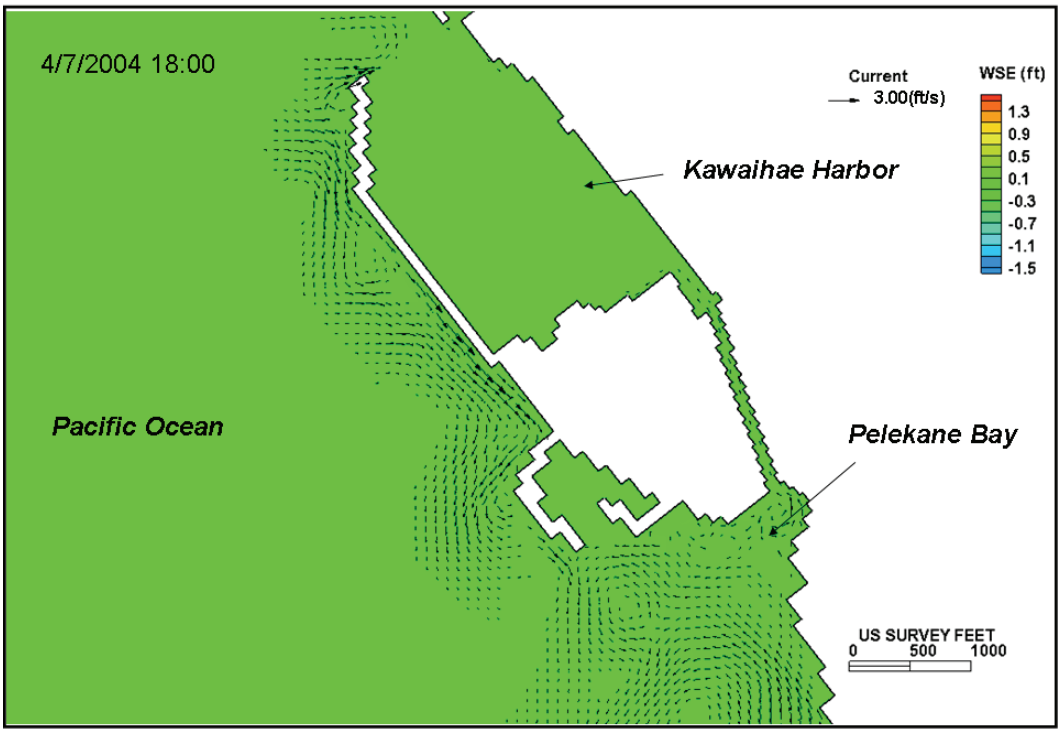


Figure 69. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 2 for non-storm condition on 10 April 2004 at 18:00 GMT.

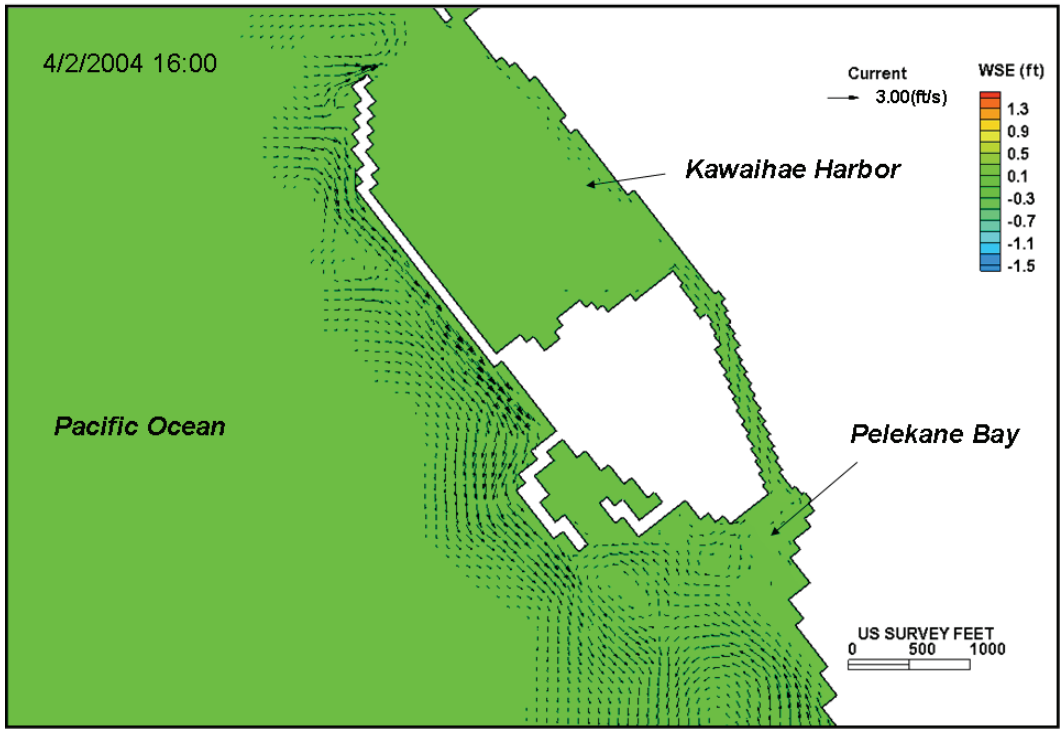


Figure 70. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 2 for non-storm condition on 15 April 2004 at 10:00 GMT.

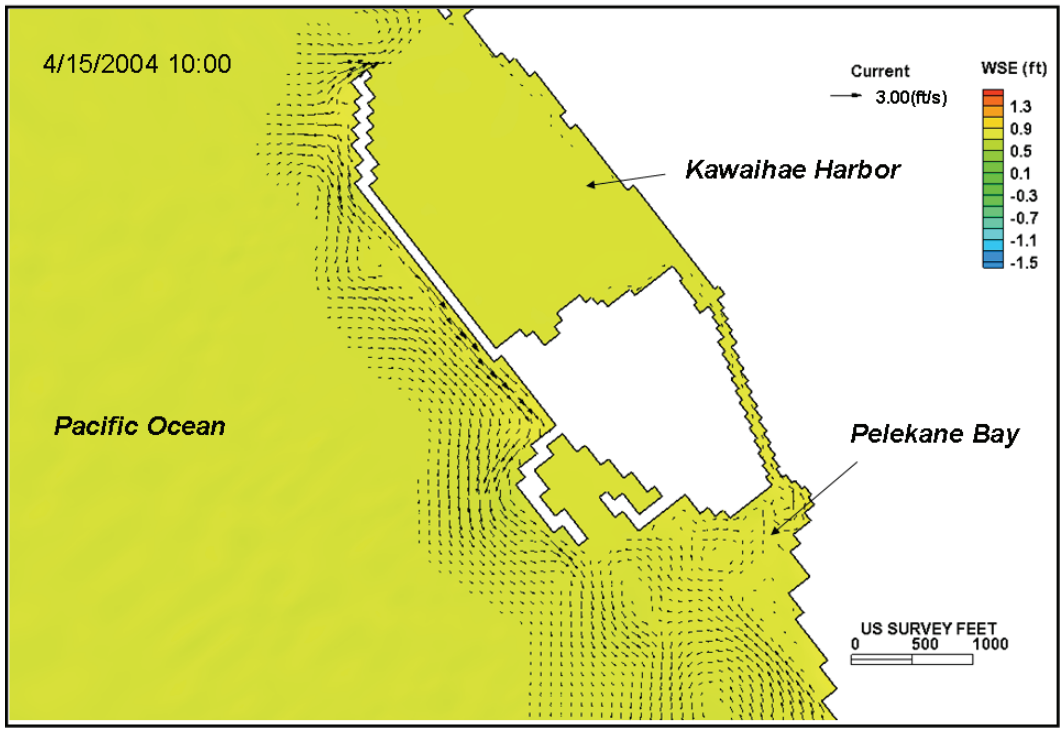


Figure 71. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 3 for non-storm condition on 2 April 2004 at 16:00 GMT.

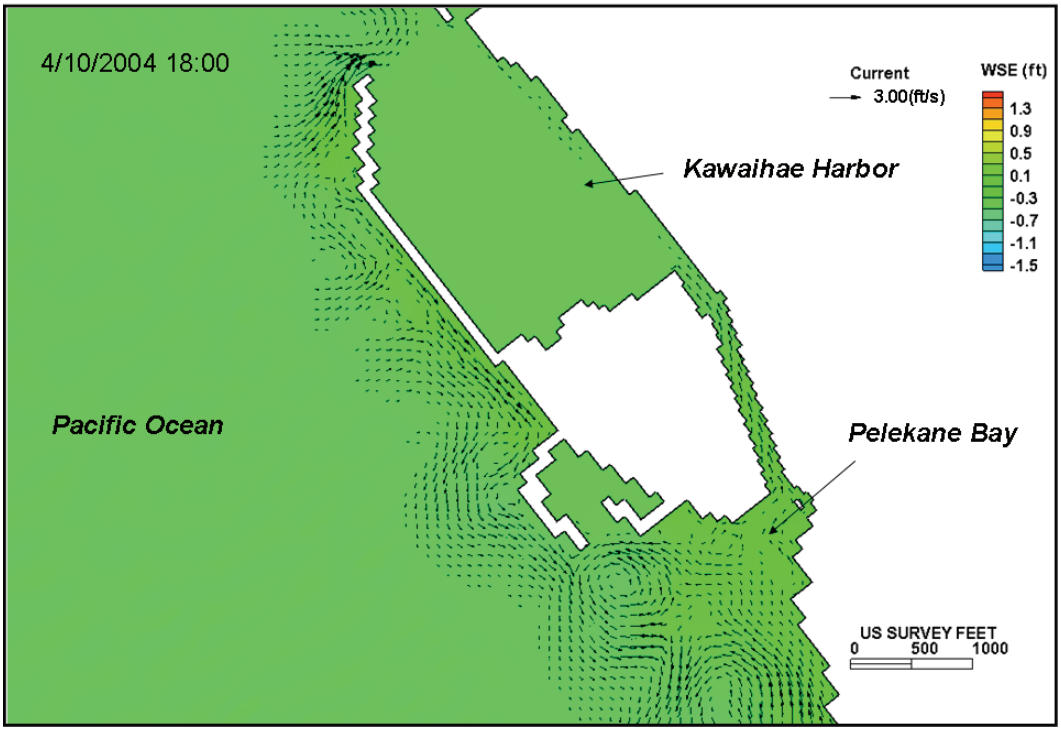


Figure 72. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 3 for non-storm condition on 7 April 2004 at 18:00 GMT.

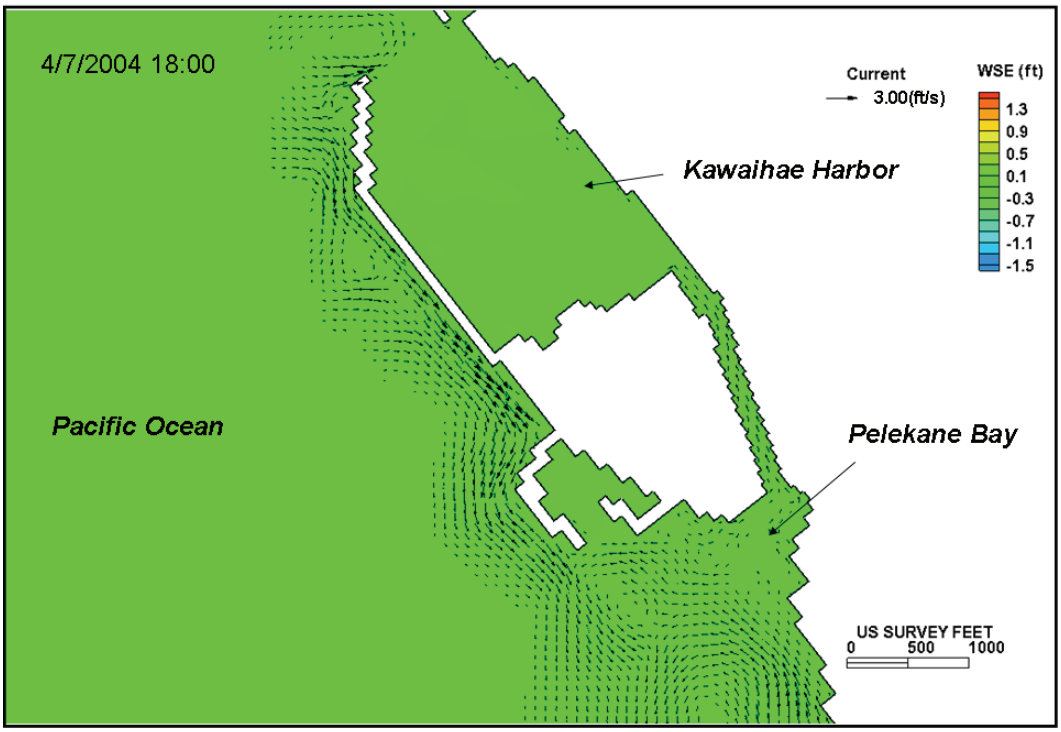


Figure 73. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 3 for non-storm condition on 10 April 2004 at 18:00 GMT.

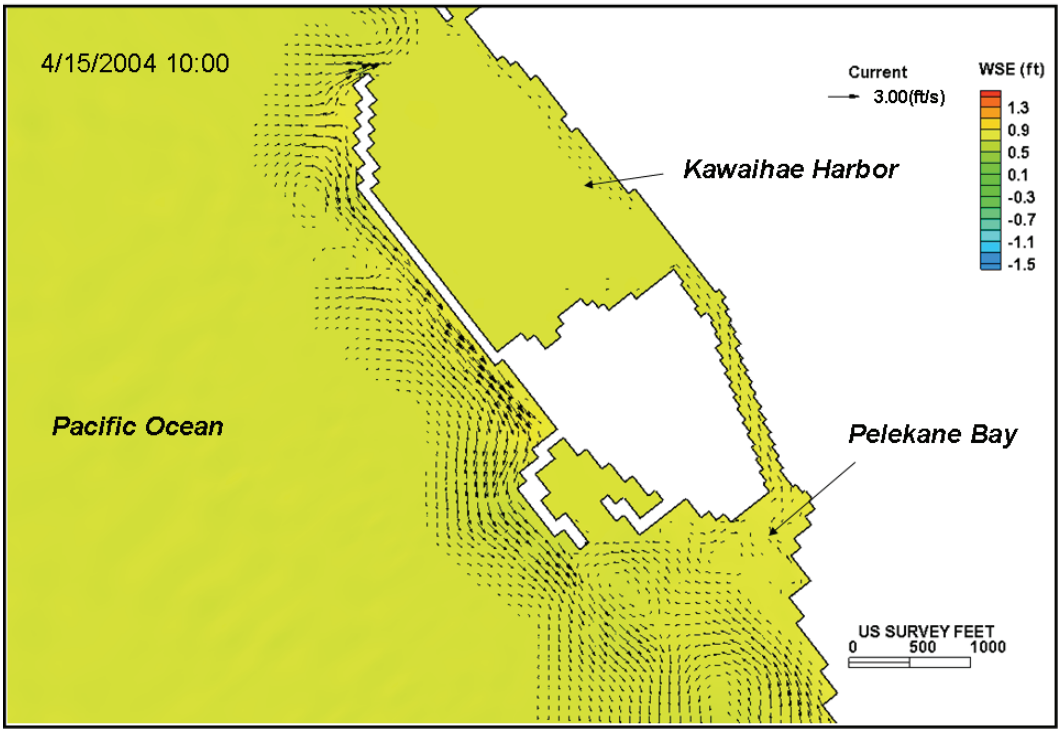


Figure 74. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 3 for non-storm condition on 15 April 2004 at 10:00 GMT.

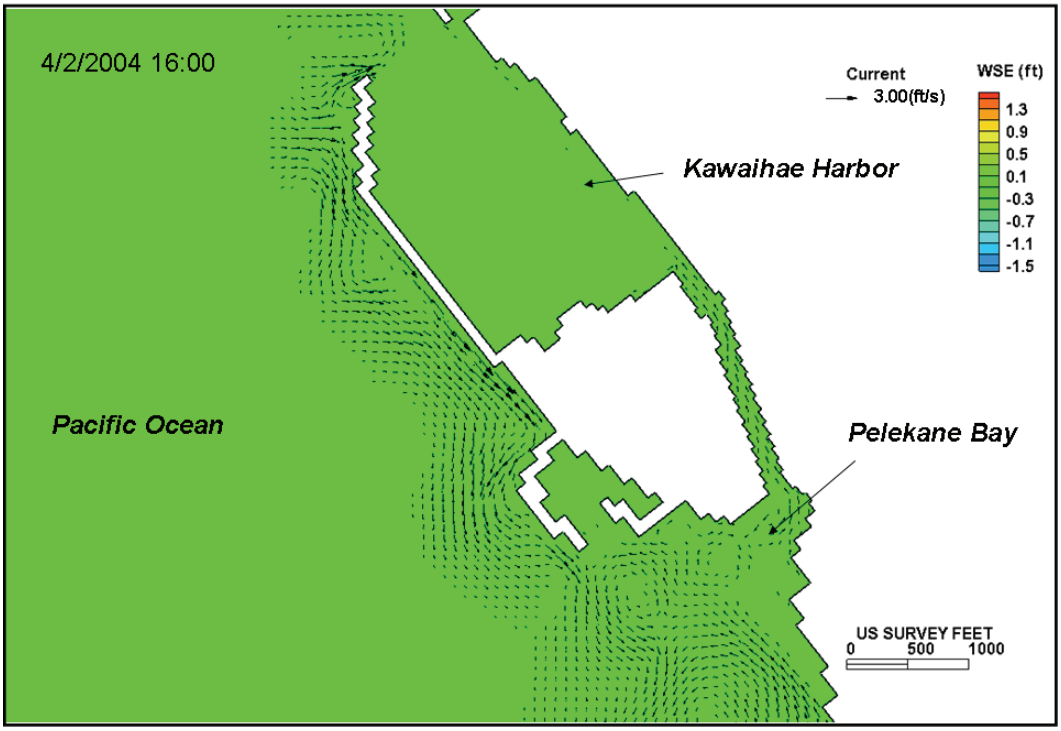


Figure 75. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 4 for non-storm condition on 2 April 2004 at 16:00 GMT.

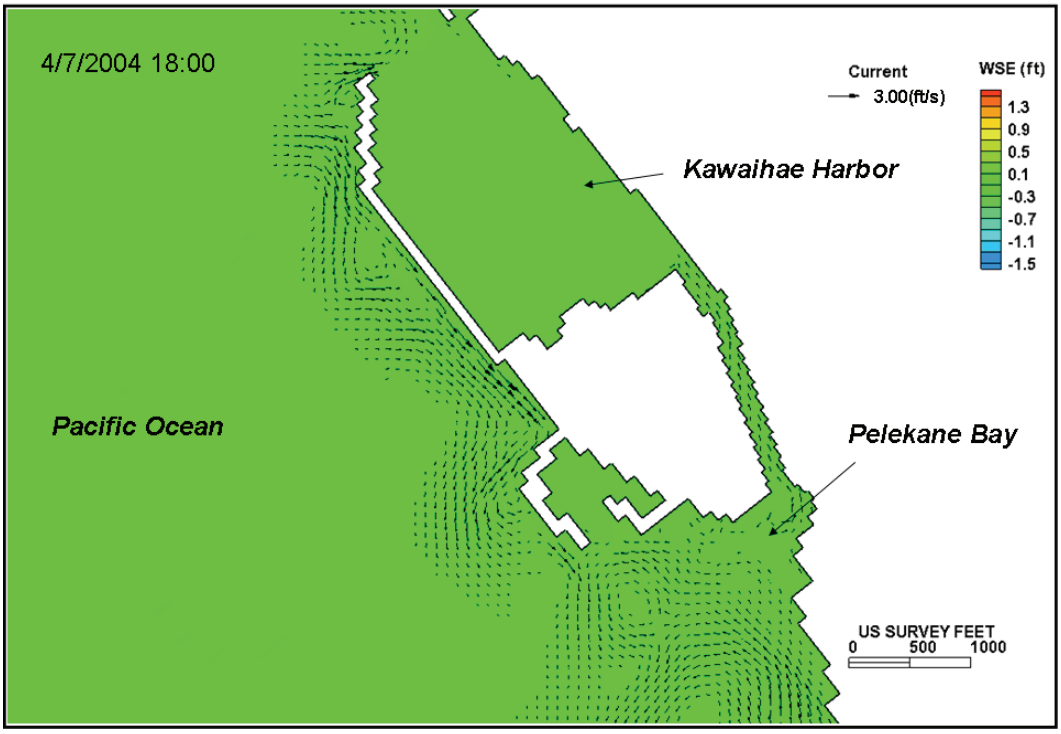


Figure 76. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 4 for non-storm condition on 7 April 2004 at 18:00 GMT.

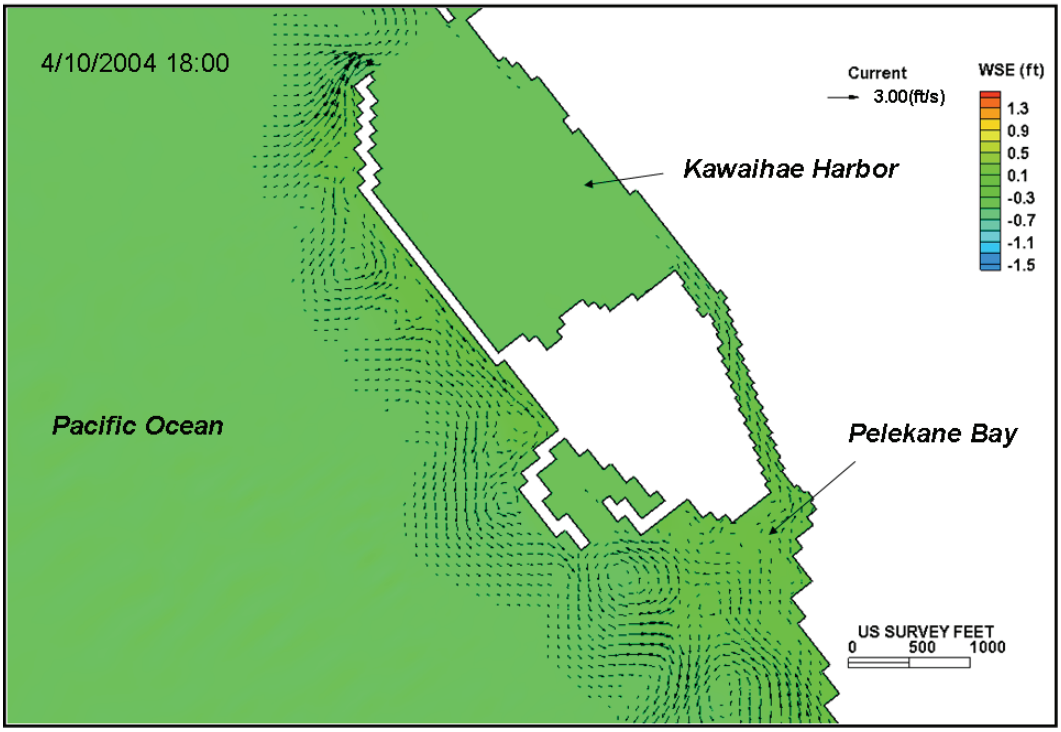


Figure 77. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 4 for non-storm condition on 10 April 2004 at 18:00 GMT.

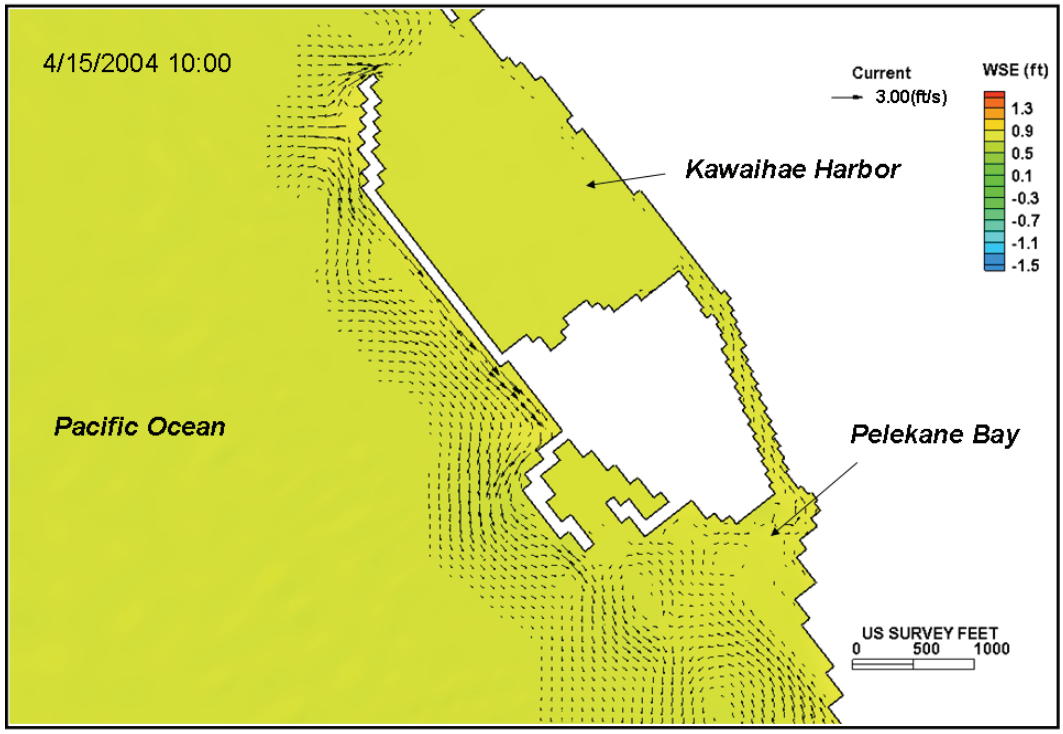


Figure 78. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 4 for non-storm condition on 15 April 2004 at 10:00 GMT.

## Storm condition

Figures 79-93 show five snapshots of nearshore circulation fields for Alts 2, 3, and 4, respectively. Similar flow features to Alt 1 are revealed under those channel alternatives (Figures 41-45).

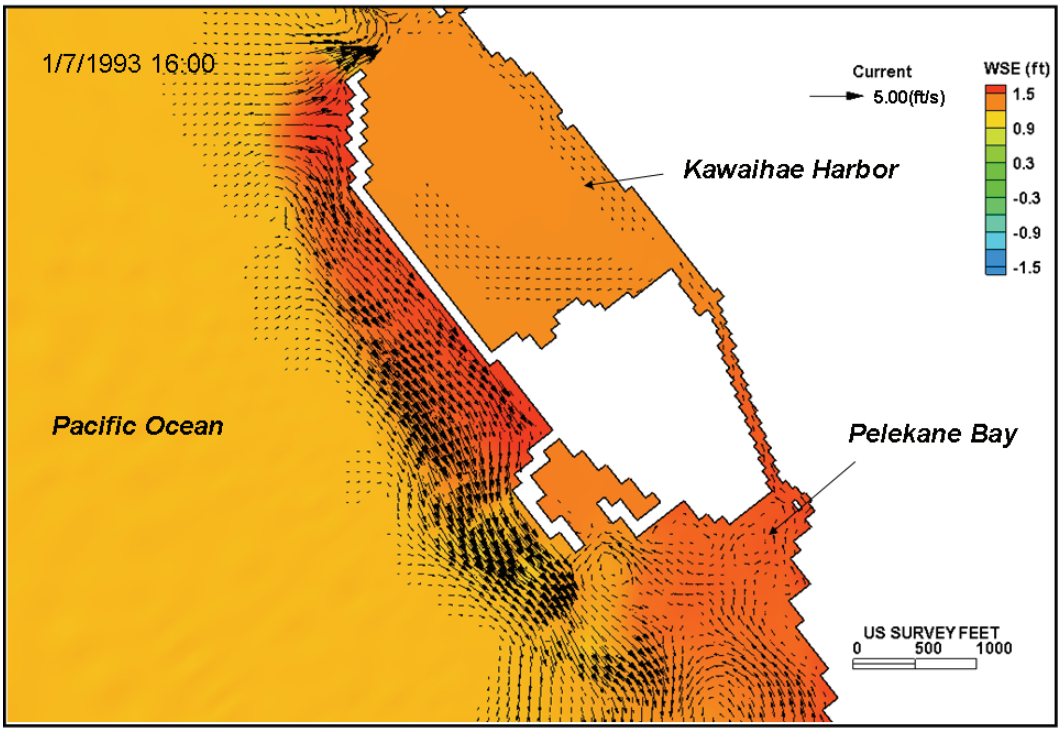


Figure 79. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 2 for multi-storm condition on 7 January 1993 at 16:00 GMT.

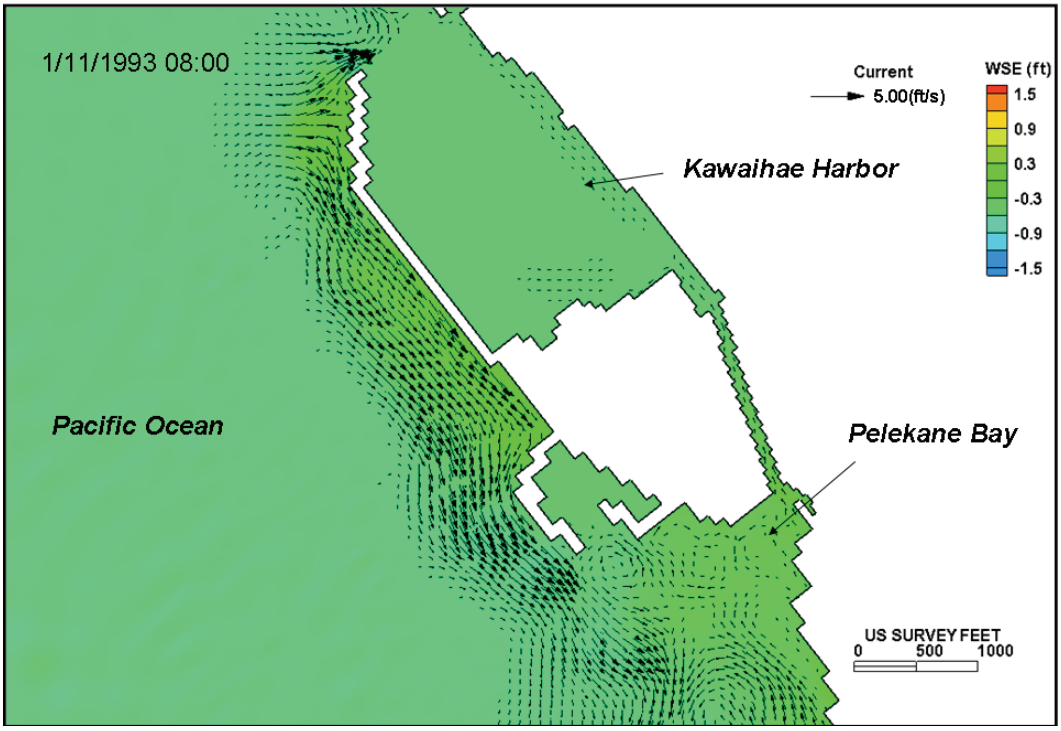


Figure 80. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 2 for multi-storm condition on 11 January 1993 at 08:00 GMT.

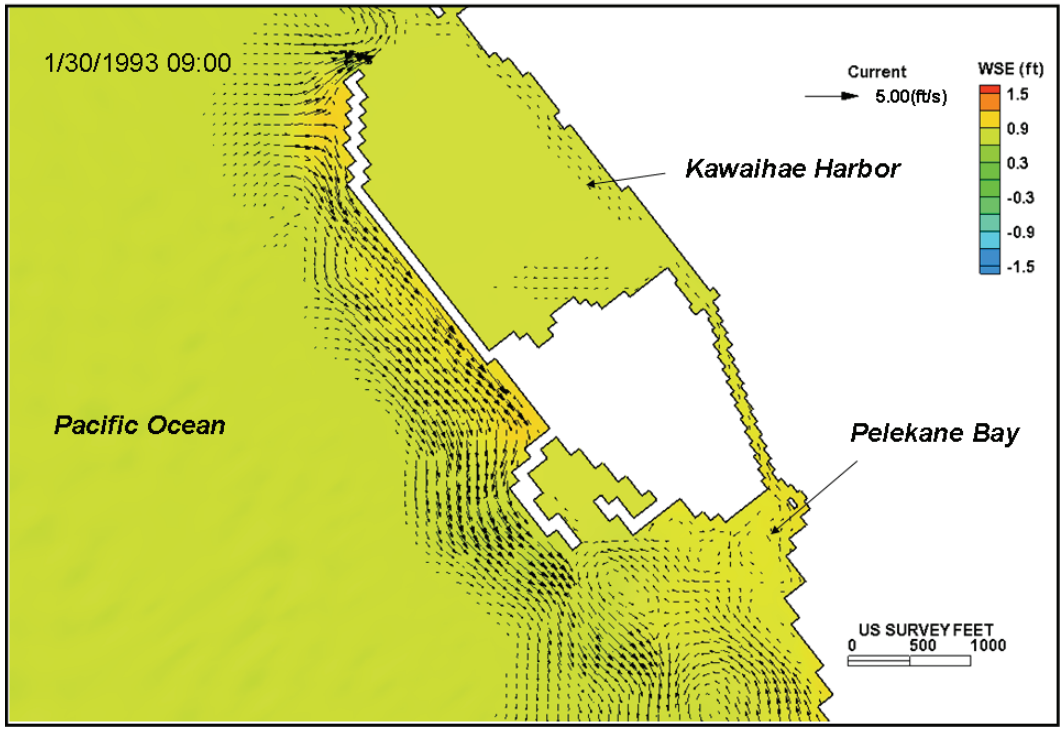


Figure 81. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 2 for multi-storm condition on 30 January 1993 at 09:00 GMT.

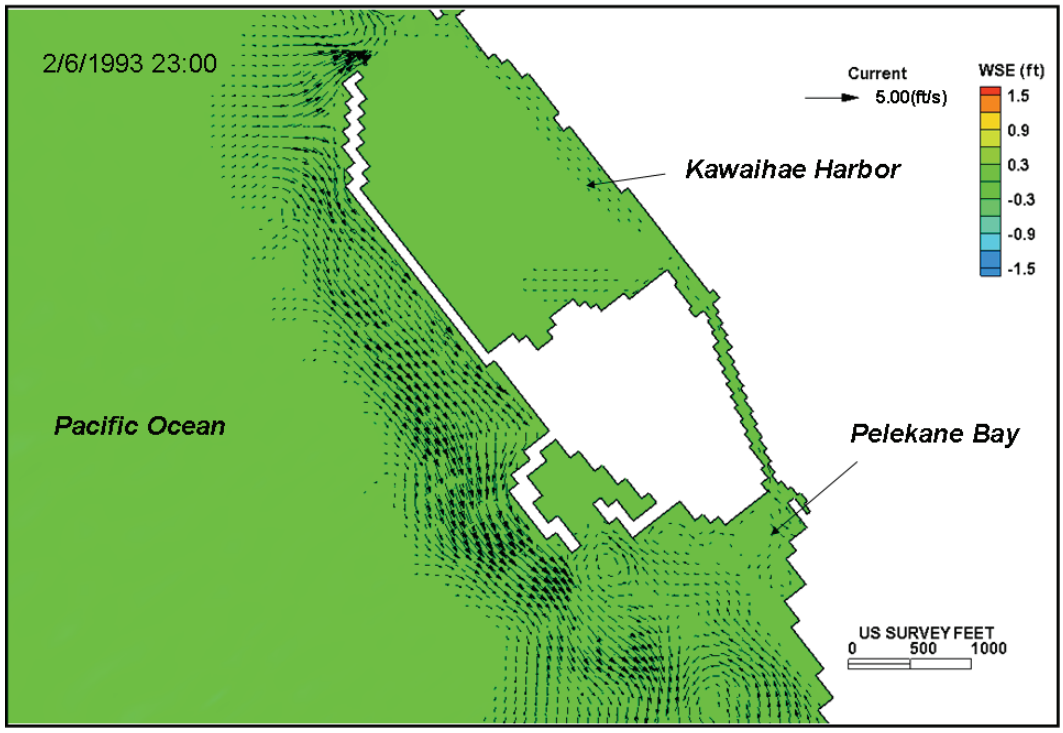


Figure 82. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 2 for multi-storm condition on 6 February 1993 at 23:00 GMT.

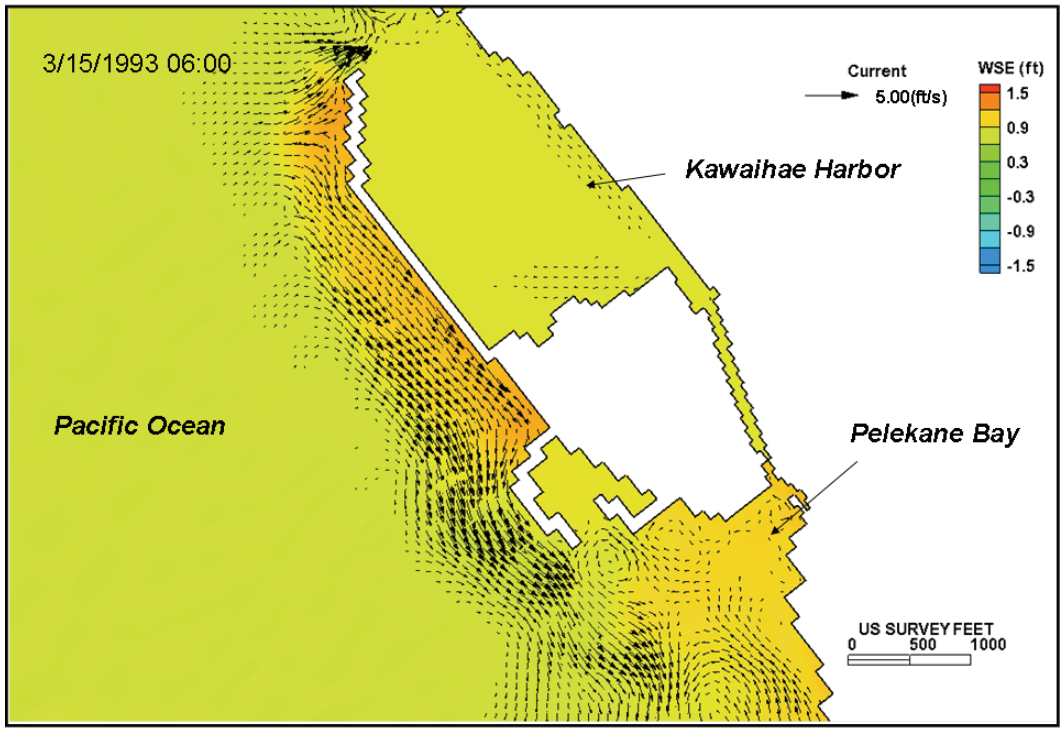


Figure 83. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 2 for multi-storm condition on 15 March 1993 at 06:00 GMT.

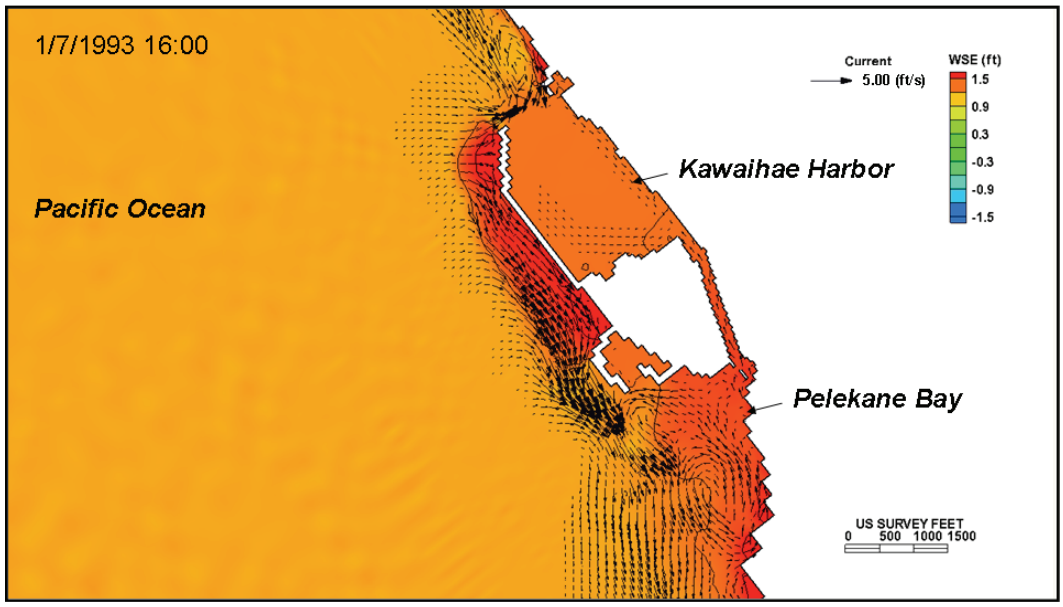


Figure 84. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 3 for multi-storm condition on 7 January 1993 at 16:00 GMT.

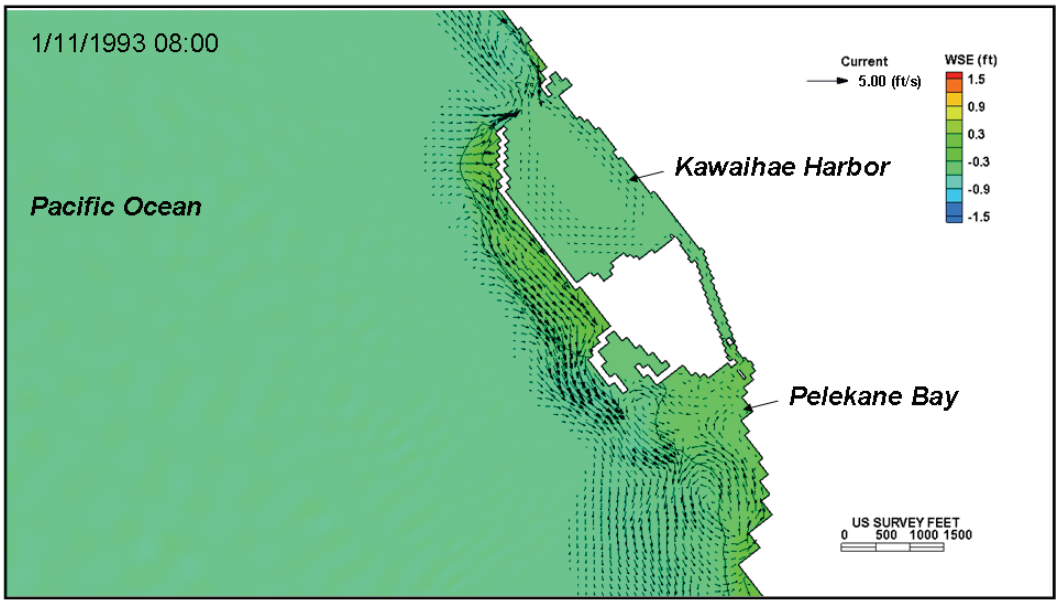


Figure 85. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 3 for multi-storm condition on 11 January 1993 at 08:00 GMT.

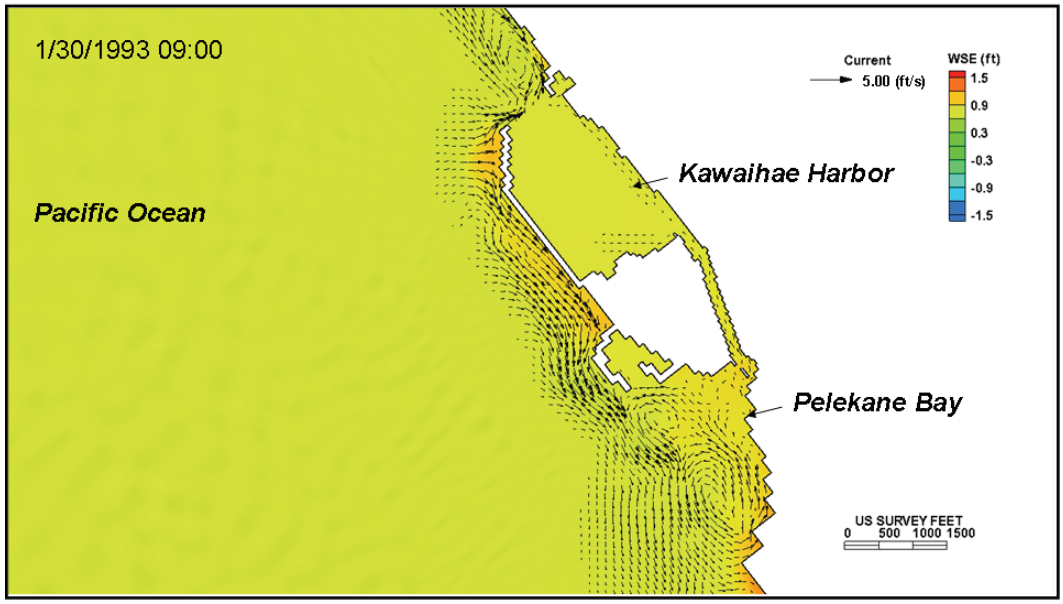


Figure 86. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 3 for multi-storm condition on 30 January 1993 at 09:00 GMT.

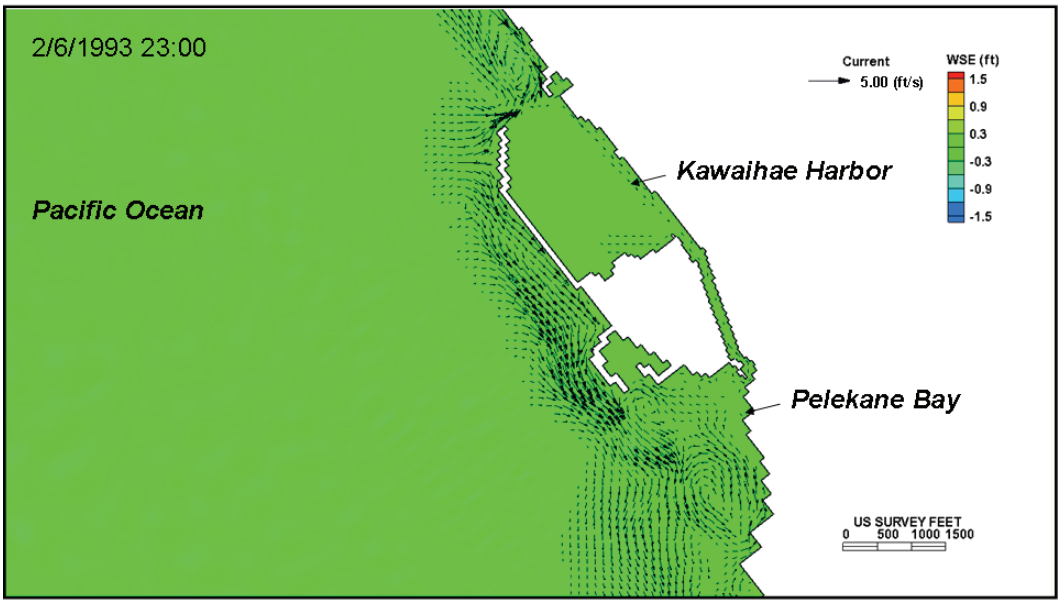


Figure 87. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 3 for multi-storm condition on 6 February 1993 at 23:00 GMT.

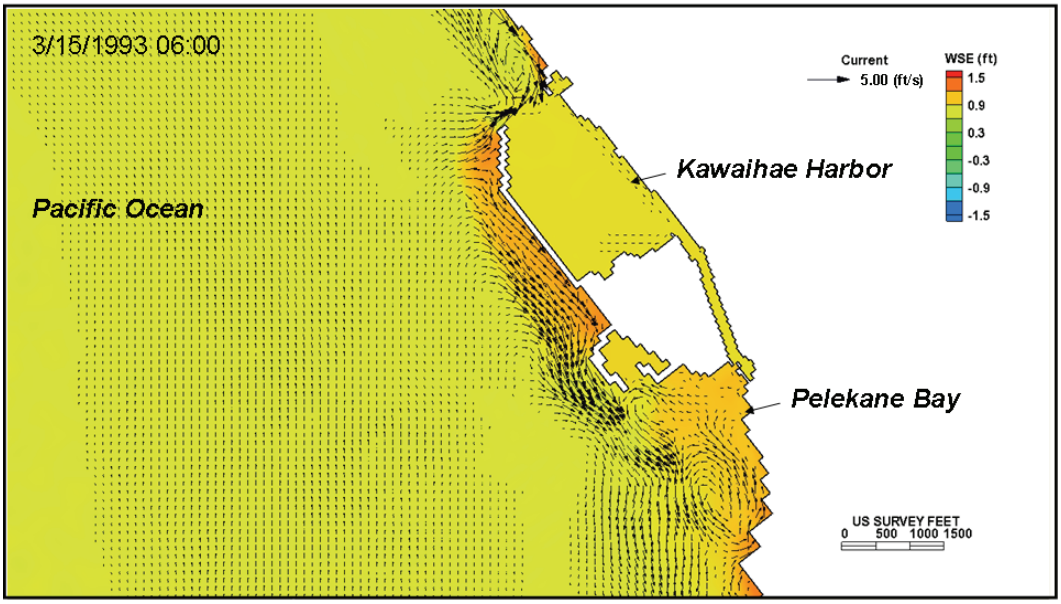


Figure 88. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 3 for multi-storm condition on 15 March 1993 at 06:00 GMT.

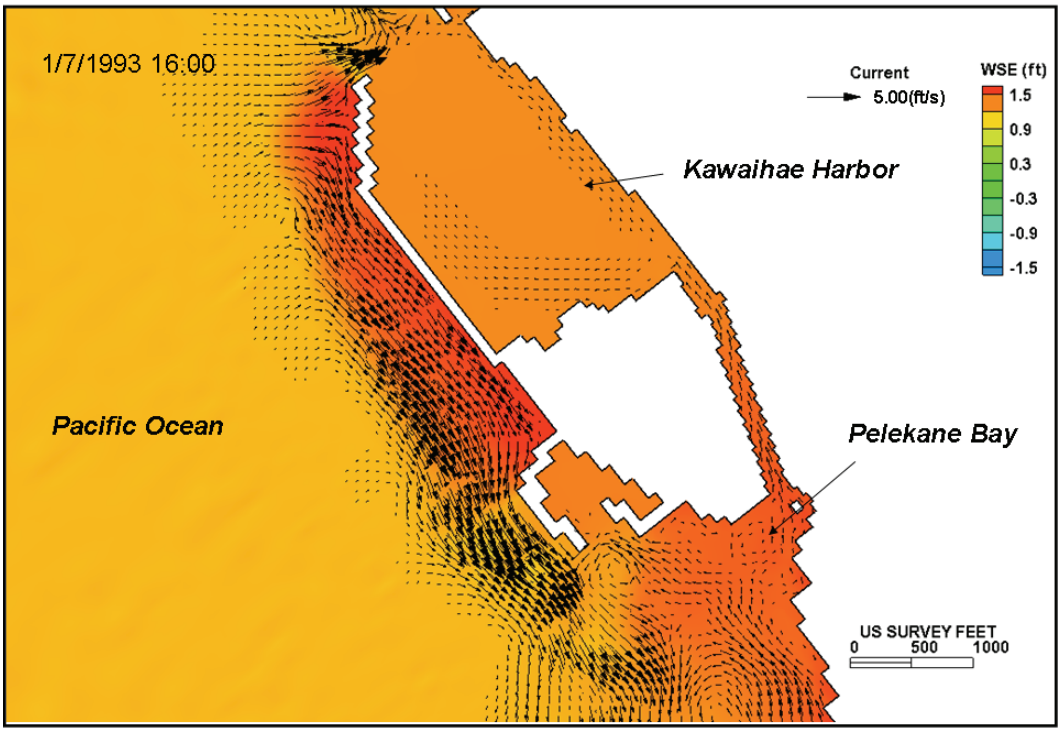


Figure 89. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 4 for multi-storm condition on 7 January 1993 at 16:00 GMT.

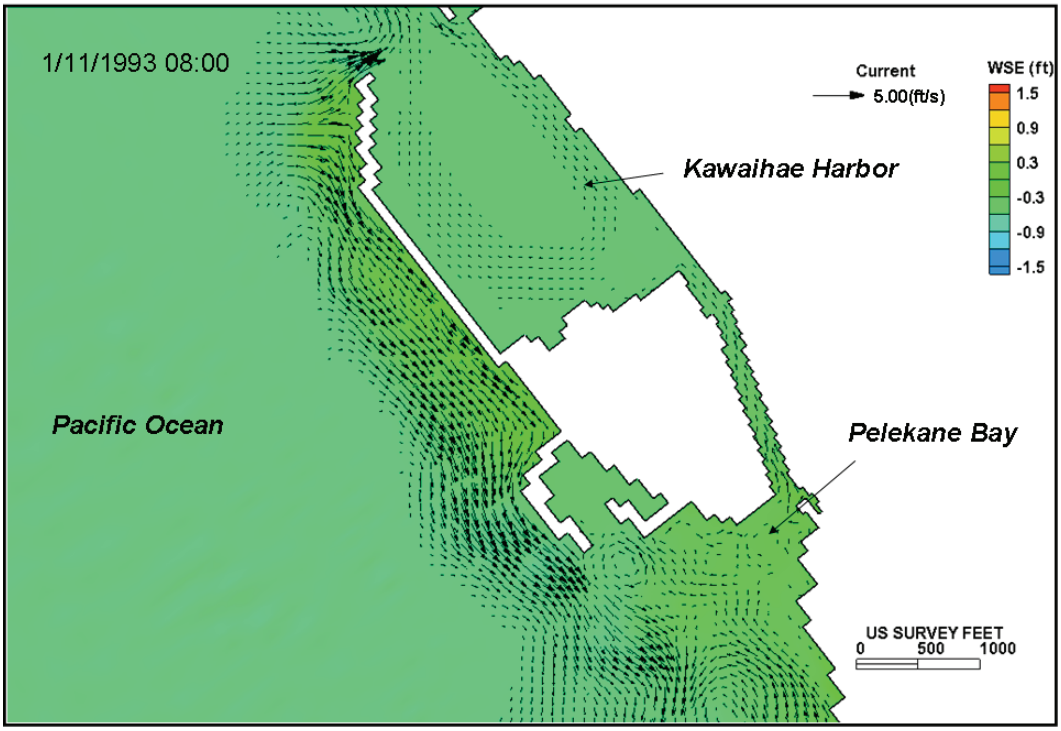


Figure 90. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 4 for multi-storm condition on 11 January 1993 at 08:00 GMT.

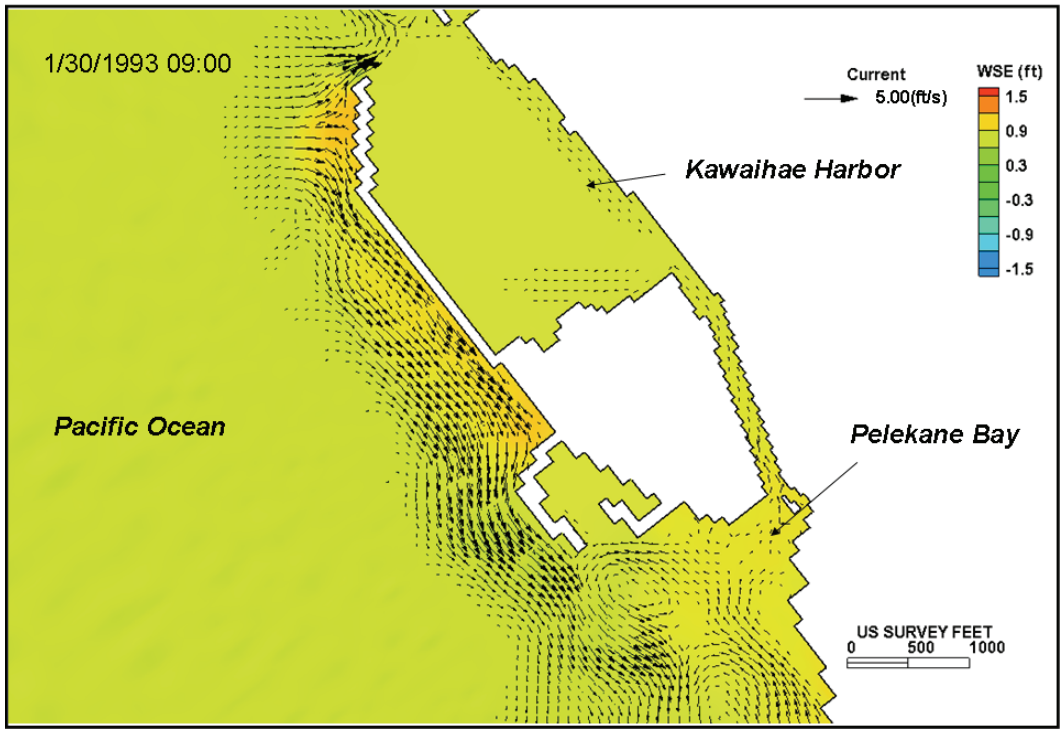


Figure 91. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 4 for multi-storm condition on 30 January 1993 at 09:00 GMT.

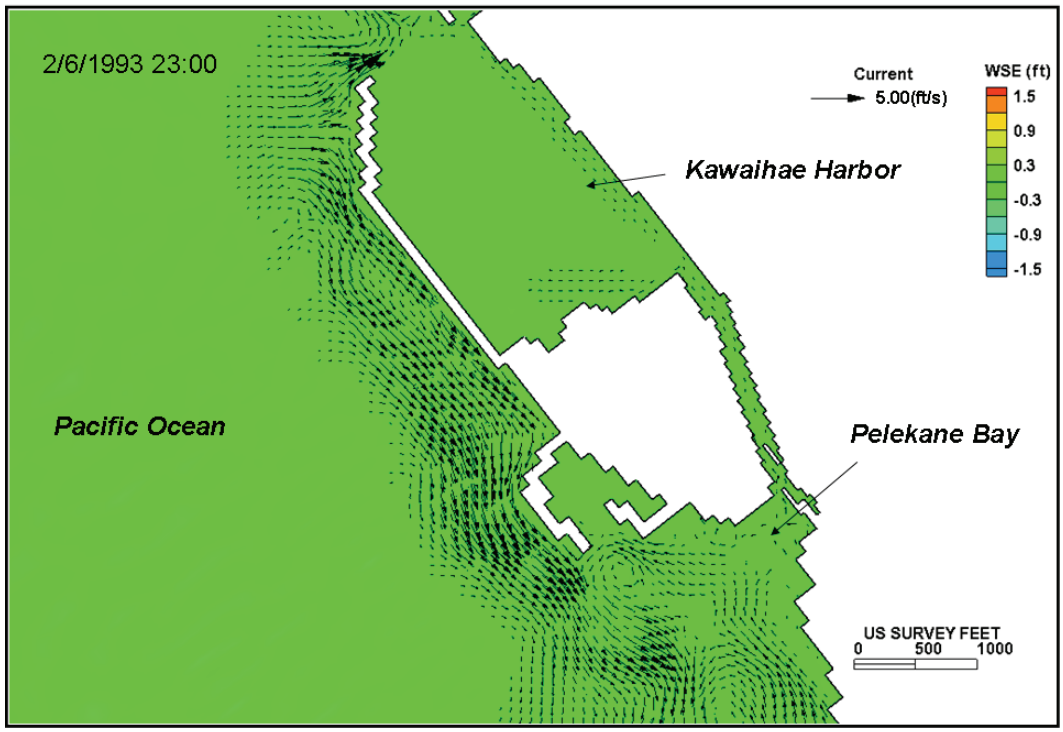


Figure 92. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 4 for multi-storm condition on 6 February 1993 at 23:00 GMT.

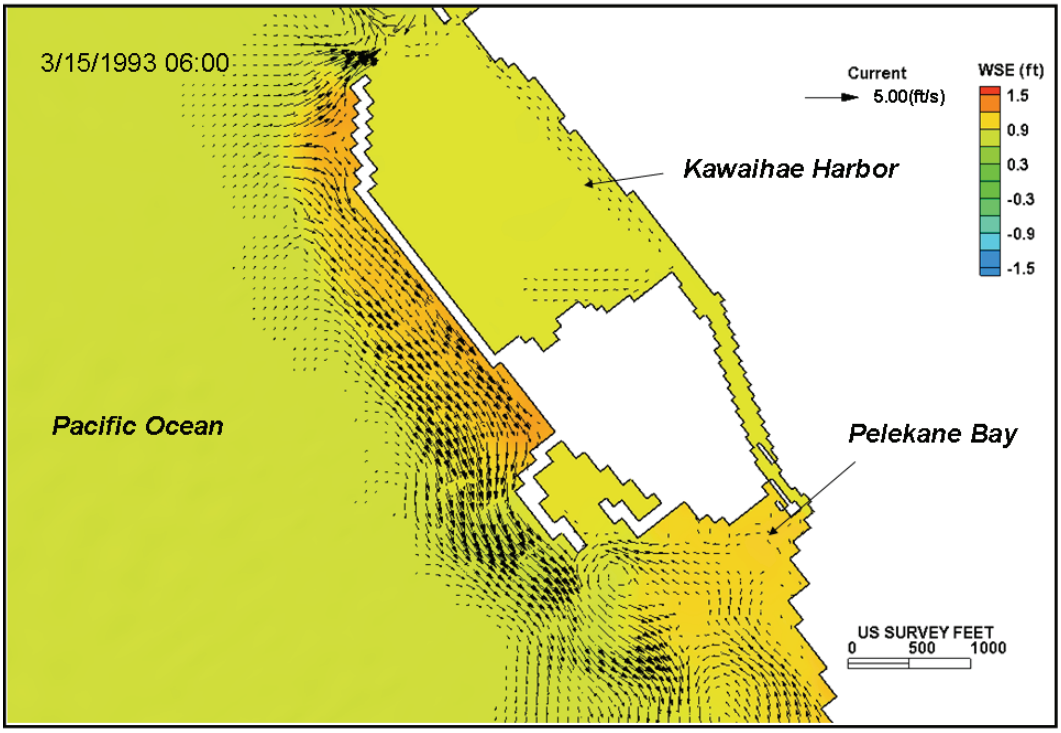


Figure 93. CMS computed depth-averaged current surrounding Kawaihae Harbor and Pelekane Bay under channel configuration Alt 4 for multi-storm condition on 15 March 1993 at 06:00 GMT.

# REPORT DOCUMENTATION PAGE

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Evaluation of Proposed Channel on Circulation and Morphology Change at Kawaihae Harbor and Pelekane Bay, Island of Hawaii, HI

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**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT NUMBER**

**6. AUTHOR(S)**
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**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT**

This study was conducted as a joint effort between the U.S. Army Engineer District, Honolulu; the State of Hawaii Department of Transportation, Harbors Division; and the Coastal and Hydraulics Laboratory (CHL), U.S. Army Engineer Research and Development Center, to examine the consequences of creating a new circulation channel connecting Kawaihae Deep Draft Harbor to Pelekane Bay. The study site is located on the western side of the island of Hawaii. The concept of the channel was proposed to increase water circulation, promote sediment removal, and improve water quality in the bay. The coupled wave, flow, and sediment transport model available in the Coastal Modeling System (CMS), developed by the Coastal Inlets Research Program at CHL, was applied as the main analysis method in this study.

Numerical simulations with the CMS were forced with wave parameters from Wave Information Study Pacific Station 113. Sensitivity tests revealed that wave forcing is dominant, and that tidal forcing and wind forcing are secondary in the study area. Four channel alternatives were constructed for a 15-day (non-storm) and a 6-month (winter storms) simulation with the CMS. The modeling analysis involved predicting channel performance, assessing change in water circulation in response to waves and hydrodynamics, and examining potential sediment transport and morphology change in the vicinity of the channel.

(Continued)

**15. SUBJECT TERMS**
Circulation model
Coastal inlets
Coastal Modeling System
Harbors
Hydrodynamics
Morphology change
Sediment transport

**16. SECURITY CLASSIFICATION OF:**

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**19a. NAME OF RESPONSIBLE PERSON**

**19b. TELEPHONE NUMBER** *(include area code)*

**14. ABSTRACT (Concluded).**

Simulation results indicate that consistent wave setup occurs in Pelekane Bay, as compared to within Kawaihae Harbor, and plays a decisive role in determining the direction and magnitude of the flow in the proposed channel. Along-channel flow is predominantly directed from Pelekane Bay to Kawaihae Harbor and is capable of mobilizing and transporting sand from Pelekane Bay to the mouth of and inside the proposed channel. Channel blockage occurred for the four channel alternatives before the end of the 6-month winter simulation, indicating that at least annual maintenance of the channel will be required. Based on the findings in the study, implementation of the circulation channel is not recommended.