MIAMI BEACH 32ND STREET HOT SPOT: NUMERICAL MODELING AND DESIGN OPTIMIZATION

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ABSTRACT

The shoreline in the vicinity of 32nd street, Miami Beach has been established as an erosional hot spot. A coastal processes analysis performed by Coastal Systems International, (Coastal Systems), determined that the highly localized levels of erosion were due to the presence of a shoreline protrusion at the hot spot. Numerical modeling of the 32nd Street area confirmed that prevailing wave conditions could generate a strong gradient in wave energy capable of causing localized erosion. This earlier study recommended the use of three artificial headlands to gradually transition the shoreline and to dissipate much of the localized wave energy.

This paper presents the results of numerical two-dimensional wave and current modeling that was conducted to determine the effect of the proposed artificial headlands on the existing longshore currents. The results of the wave current modeling coupled with the Parabolic Bay Theory (Hsu and Silvester, 1993) showed that the configuration of the structures could be optimized to increase the stabilized area and mitigate down-drift impacts.

INTRODUCTION

Erosional hot spots are areas within a littoral cell that experience higher than average levels of erosion. Therefore, the erosional activity at hot spots can govern the frequency of beach re-nourishments for a stretch of shoreline. The mechanisms for the localized levels of higher erosional activity, while not fully defined, are speculated to include irregularities in the shoreline, offshore bathymetry, coastal development, etc. The study of the causes of hot spots can provide design criteria to increase the performance of beach renourishment projects. This hot spot countermeasure approach can provide construction cost savings over the life of a project.

The Miami Beach littoral cell extends from Baker's Haulover Inlet to Government Cut, a distance of approximately 3 miles. The 32nd Street shoreline is part of The Beach Erosion and Hurricane Protection Project for Dade County - a federally sponsored project. A study of the Dade county regional sediment budget (Coastal Systems, 1997) that considered the performance of beach nourishments since the inception of the federal project determined the existence of several hot spots within the county. One of the more severely eroding areas within the county was the 32nd Street area of Miami Beach, where the shoreline receded an average of 17 feet per year (5.2 m/yr) from 1980 to 1996. It was concluded that the higher localized levels of erosion of the shoreline near 32nd Street were due to a protrusion of the shoreline resulting from post-war development beyond the historical dune line. Furthermore, it was concluded that an overall change in the shoreline orientation near 32nd Street could be partly responsible for the increased erosion rate.

A more detailed study of the 32nd Street hot spot (Coastal Systems, 2000) examined possible stabilization alternatives based on predicted performance, construction cost, and potential downdrift and environmental impacts. The study used numerical models including GENESIS and REF-DIF to predict shoreline response to the various stabilization schemes. The results of the REF-DIF modeling demonstrated that offshore bathymetry coupled with the change in shoreline orientation did promote the focusing of wave energy in the 32nd Street area. These factors were predominantly responsible for the presence of the hot spot. In addition, the study concluded that the protrusion of the shoreline would potentially cause any unprotected beach fill to be 'sheared off' rapidly. The use of structures to 'step' the change in shoreline orientation would result in better beach fill performance. The study recommended the construction of three artificial headlands coupled with beach fill as the best alternative for meeting the project goals.

In this study, the possible impacts of headland construction on the waves and currents were examined to determine the effects of the structures on the existing longshore currents and the corresponding littoral drift in the region. Two-dimensional numerical wave models were applied to offshore hindcast wave data in order to predict the nearshore wave field. The results of the wave model were used to simulate the longshore currents at the site, both before and after the construction of the artificial headlands. The current model demonstrated the headlands did not block or significantly redirect longshore currents. However, the testing of alternate configurations permitted the optimization of the headland configuration, minimizing the interference of the structures on the longshore drift, while enhancing the protection at the hot spot.

Procedure

The MIKE 21 wave and hydrodynamic modeling package developed by the Danish Hydraulic Institute (DHI) was used to simulate waves and currents at the hot spot. Several components of the MIKE 21 package were used.

Beach, and the average hindcas wave conditions are presented in Figure 2. The average wave condition was found to be a significant wave height The Nearshore Spectral Wave (NSW) module was used to simulate the transformation of offshore waves to the nearshore region. The NSW model encompassed 7.2 miles by 7.8 miles, centered on the hotspot including an alongshore resolution of 250 feet (75 m). The results of the NSW model were transferred to a more localized Parabolic Mild Slope (PMS) model, which was better able to simulate wave refraction, diffraction and breaking processes on a finer scale. Finally, the wave radiation stress field derived from the PMS model was used to simulate wave-driven currents with the Hydrodynamic (HD) model. The modeled area for the PMS and HD models was 1.5 miles by 1.1 miles, centered on the hotspot, and an alongshore resolution of 8 feet (2.5m) feet. The layout of both model areas relative to the hot spot is shown in Figure 1. Initially the entire procedure was performed for the present conditions and then was repeated with the structures in place to gauge the impact of the headlands.

Bathymetry

Nearshore bathymetric data was collected by a hydrographic survey conducted in December 1999 by Coastal Systems. Offshore bathymetry data from the June 1998 Morgan & Eklund survey and National Oceanographic and Atmospheric Administration (NOAA) bathymetric charts were used to supplement the Coastal Systems' data for the NSW model.

Structures

The bathymetry data was adjusted within MIKE21 to incorporate the artificial headlands and the pre-filled shoreline. Several configurations of the structures were simulated, and two configurations are presented herein: the original configuration as recommended by the 1997 study and an optimized configuration. Both configurations consist of three artificial headlands of approximate crest lengths of 210, 180 and 75 feet and breadth at the mean water line of 25 feet. The structures are arranged to step the shoreline through its change in orientation. In the original configuration the northern two structures had hooks to extend the diffraction point further offshore and minimize downdrift impacts. The optimization process determined that straightening the structures by removing the hooks created a more favorable profile with respect to the predominant longshore drift.

Wave Information

The wind and wave data for the analysis were obtained from the U.S. Army Corps of Engineers through their Wave Information Study (WIS) and Coastal Field Data Collection Program. This data is based on the results of an 18 year (1976-1993) hindcast that included the effects of hurricanes and tropical storms. Data collected at WIS Station #8 was analyzed in order to obtain representative conditions offshore of Miami of Hs = 3.3 feet (1.0m), and average wave period of 5.4 seconds from the Northeast. However, a wide range of periods are associated with this wave height and direction, therefore simulations were also performed for wave periods of 7.4, 9.4, and 11.4 seconds, respectively.

Offshore waves were modeled by generating irregular directional wave spectra, and applying this condition along the offshore boundary. Directional rather than unidirectional waves were used in this study to prevent over-focusing of wave energy during the refraction calculations.

Wave Transformation Results

Present Conditions: Figure 3, shows the results of the Parabolic Mild Slope wave model (Hmo=1.0 m, Tp=5.4 sec, NE) [note that north is oriented downward for all figures]. Wave heights are shown by colored contours and the wave direction is shown by the vectors. The refraction of the waves is apparent from intermediate depths. The refraction occurs gradually until very near the shoreline. The wave breaking process is visible in the decay of wave height nearshore, the breaking wave height was found to range from 2.3 to 3.0 feet (0.7 to 0.9 m). There is a longshore variation in the breaking wave height because irregular bottom contours focus and diffuse wave energy. Under this wave climate the breaker line ranges from 200 to 250 feet (60 to 75 m) offshore. Note that at the breaker zone the waves remain angled with respect to the shoreline. This difference in wave direction is the driving force for longshore currents. The results of the wave model were validated with small amplitude wave theory. The modeled shoaling, refraction and breaking processes compared well with analytical theory.

Original Headland Configuration: Figure 4 shows the wave field in the presence of the hooked headlands (Hmo=1.0 m, Tp=5.4 sec, NE). Note the shadow zone, in the lee of the headlands where minimal wave energy is present. Refraction and diffraction around the headlands can be observed in the direction of wave propagation. Wave heights inside the bays are much smaller than just offshore of the headlands as a result of the shelter provided by the headlands.

Optimized Headland Configuration: Figure 5 shows the wave field in the presence of the artificial headlands. As in Figure 4, a shadow zone can be observed in the lee of the headlands. However, in the latter case the sheltered area is not as large due to the lack of hooks, though the calculated wave heights inside the bays are not significantly larger. This constancy of wave height is a result of the height of broken waves being solely determined by water depth.

Effect of Wave Period: Compared with the shorter period waves, the longer period waves experienced more refraction, and the waves reached the shore in a more perpendicular manner. Additionally, shoaling effects were increased and the waves achieved larger breaking wave heights, to a maximum height of 3.8 feet (1.15 m). Consequently, the breakpoint was shifted offshore and the surf zone was wider. The water depth governs the height of the broken waves, thereby producing results inside the bays that are very similar for waves of all periods.

Current Model Results

Present Conditions: The HydroDynamic model results for the wave field in the absence of structures is shown in Figure 6. Current direction is represented by vectors and its speed by contours. The following observations can be made: in the surf zone the longshore current is strongest and is generally parallel to the shoreline; beyond the breaker zone there is some return flow though current speeds are much smaller. Surf zone current speeds reach a maximum of 1.5 feet/sec (0.45 m/s).

Original Headland Configuration: In Figure 7 the flow pattern near the headlands is shown. The predominant southern longshore current is redirected around the system of headlands. The total flow past the site is maintained when compared with the present conditions due to slower currents in deeper water. The effect of the structures is realized as far as 400 feet (125 m) north, as represented by the current pattern beginning to veer away from shore at this location.

The gap between the headlands is small enough that the longshore current bypasses each bay. This current pattern is advantageous from the standpoint of the stability of the bays, as the longshore current cannot erode the sand of the pocket beaches. Within the bay, eddies are observed with maximum currents of 1.5 feet/sec (0.44 m/sec). Furthermore, there is a small exchange of flow between the bay and the current at the seaward edge of the bays. There are no rip currents apparent nor do the currents near the headlands or inside the bays exceed those observed in the absence of structures.

Downstream of the headlands the currents turn shoreward, with the current pattern returning to the undisturbed condition approximately 200 feet (60m) to the south. It is expected that the point at which the flow regime returns to the undisturbed conditions effectively represents the limit of potential downdrift erosion.

Optimized Headland Configuration: The currents generated by the wave field can be found in Figure 8. The results are similar to those observed in Figure 7, but they are less disrupted with respect to the present condition. The simple headlands appear to present a less significant obstacle to the longshore current than the hooked headlands. When the current vector plots are compared, the streaming of the current around the three simple headlands is less disrupted than it is around the hooks. There is a greater extent of redirection of the longshore flow offshore by the hook - which could result in sediment being lost to the system. Secondly, the eddies within the bays are smaller and the associated currents of lesser magnitude (up to 1.0 feet/sec, 0.3m/s).

Effect of Wave Period: In general, currents and flows associated with longer period waves were of slightly higher magnitude - about 10% greater, though the current patterns were identical. The increased energy at the breakpoint, from the larger breaking wave heights, was offset by the lower angle of attack. Thereby resulting in longshore currents with approximately the same velocity for all periods.

CONCLUSIONS

The effect of the construction of three artificial headlands was examined through numerical modeling techniques. The original configuration proposed in an earlier study was optimized to effectively streamline the structures with respect to the predominant longshore currents. The structures were found to have an impact on the shoreline approximately 400 feet (120m) updrift and 200 feet (60m) downdrift. For the optimized configuration, the flow patterns were not significantly diverted or decelerated by the structures. The partial exchange of water from within the crenulate bays and the longshore current was observed.

The headland design was revisited in light of the findings of the hydrodynamic modeling, recent site surveys, and past coastal engineering research, specifically parabolic bay theory (Hsu and Silvester, 1993). In any shore protection scheme, two effects are certain: that up-coast of the structure sediment will be impounded, and that down-coast there will be some erosion. Thus, the most efficient design will maximize the positive impact of the accretion while minimizing the negative impact of the erosion.

Accretion of sand is needed most at the hot spot, not north of the hotspot. The current modeling showed that the effect of the structures was felt as far as 400 (120m) feet to the north. Repositioning the system of headlands further south would result in concentrating more accretion at the hot spot rather than areas to the north.

Repositioning the system of headlands to the south would also reduce the erosional impact down-coast of the headlands. The optimized headland system terminates in an area of coast where the beach is still marginal, and is transitioning from erosional to relatively stable. Since some recession of the shoreline is to be expected at the terminus, relocation to a wider, less eroding beach area would mitigate potential impacts.

Finally, relocating the southernmost headland closer to shore can reduce the amount of erosion at the terminus of the headlands. This effectively reduces the size of the shadow-zone behind the headland, and it is in this shadow-zone that erosion occurs. The system of headlands would then be more streamlined and longshore currents would more quickly transition back to the undisturbed patterns.

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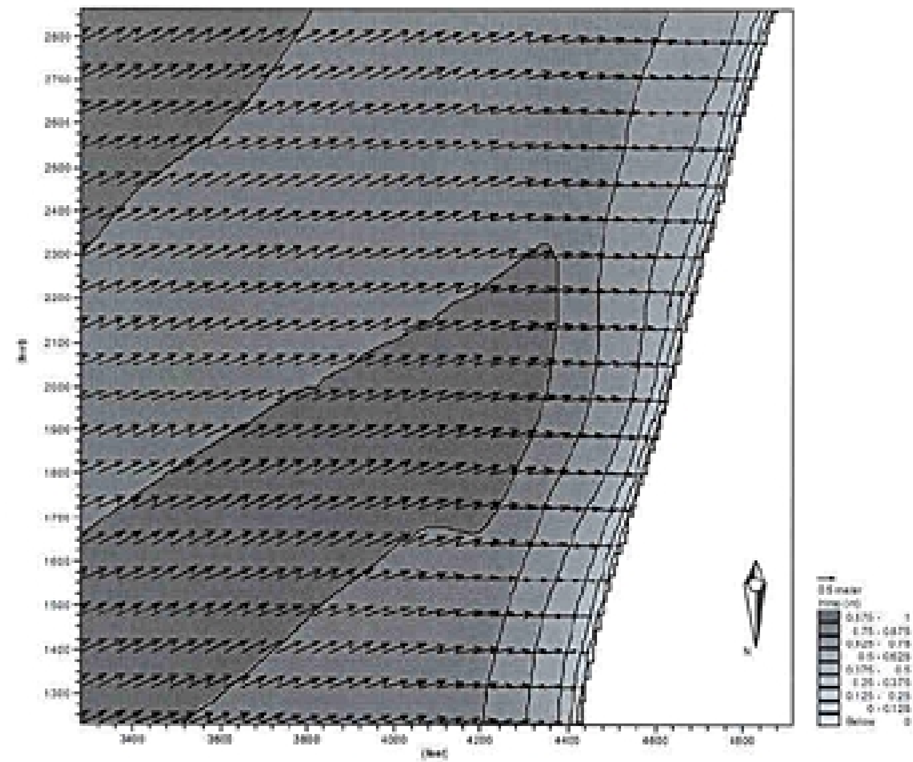

FIGURE 3 : Results of Wave Model-Present Condition

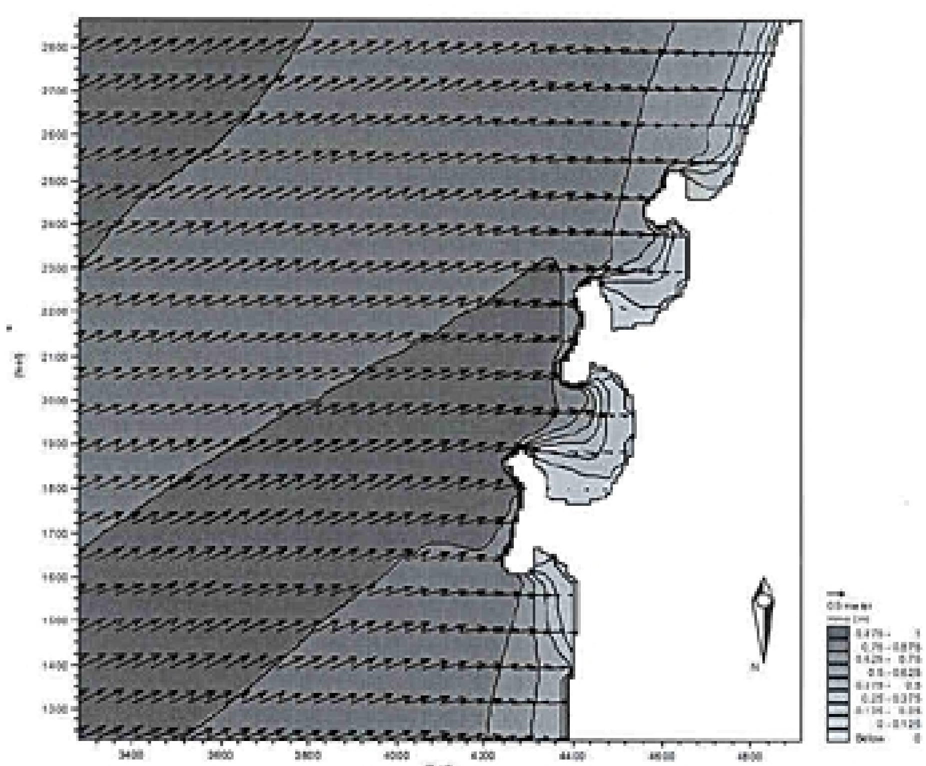

FIGURE 4 : Results of Wave Model-Proposed Configuration

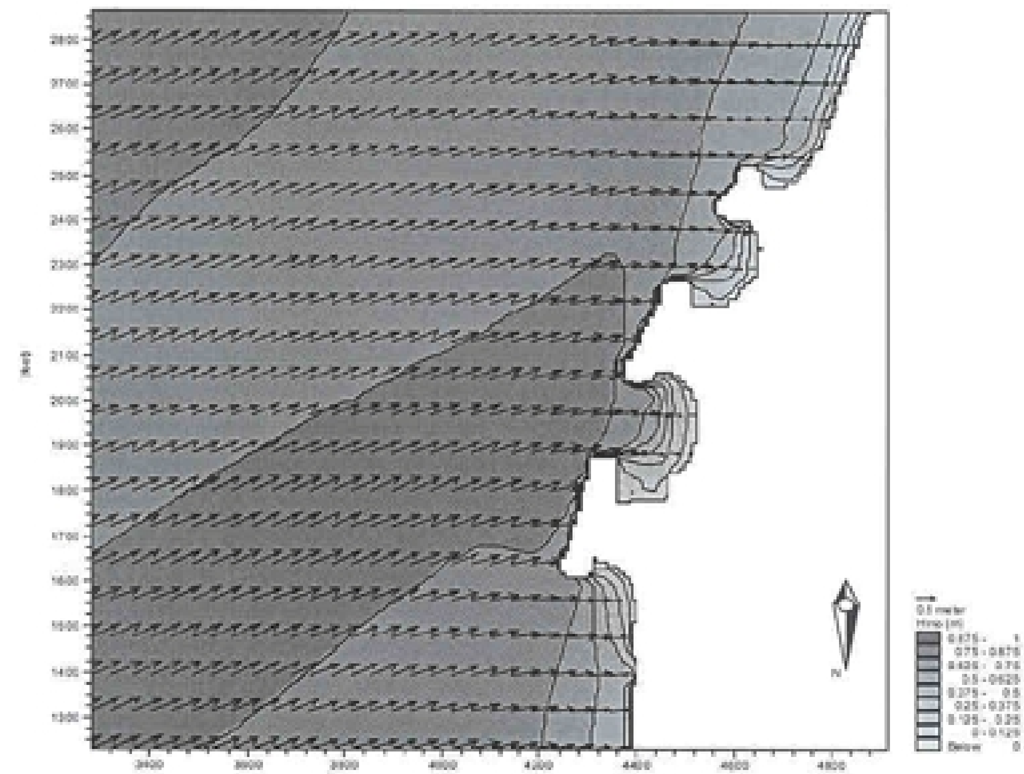

FIGURE 5 : Results of Wave Model-Optimized Configuration

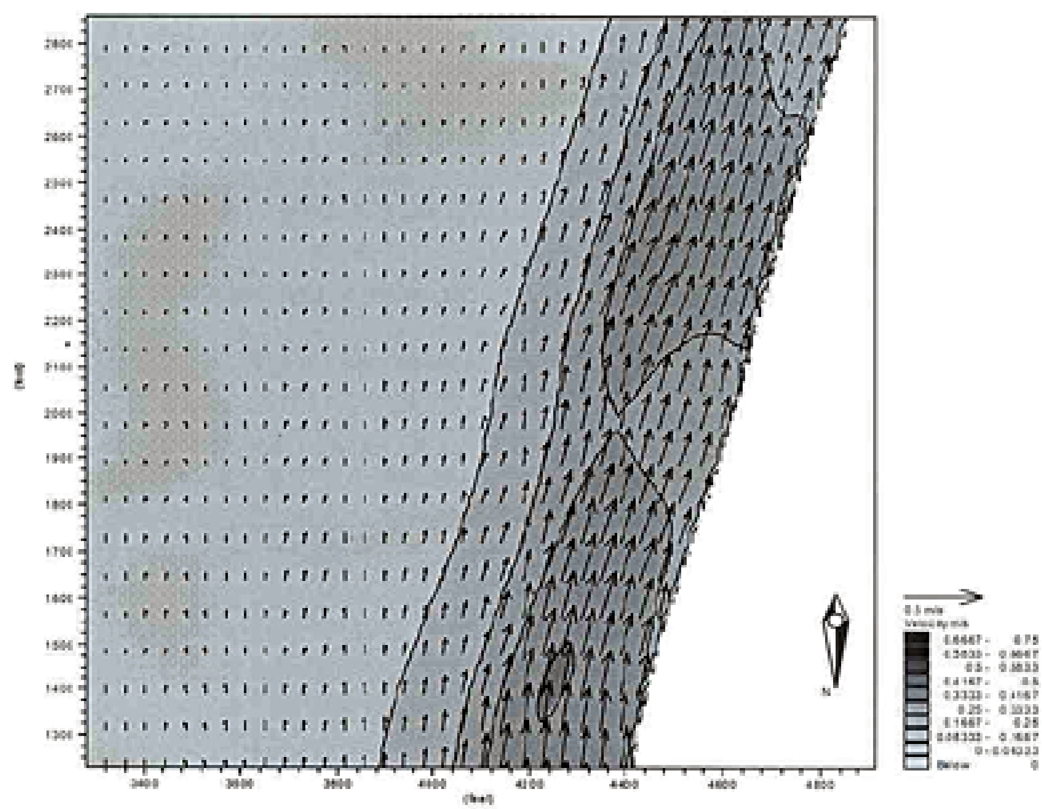

FIGURE 6 : Results of Current Model-Present Condition

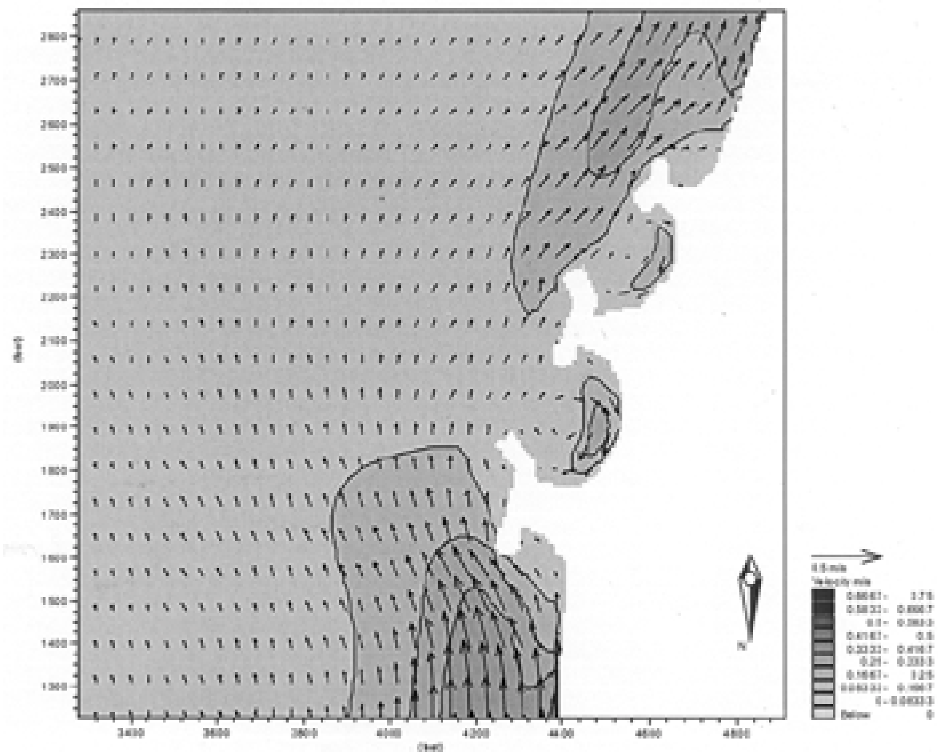

FIGURE 7 : Results of Current Model-Proposed Configuration

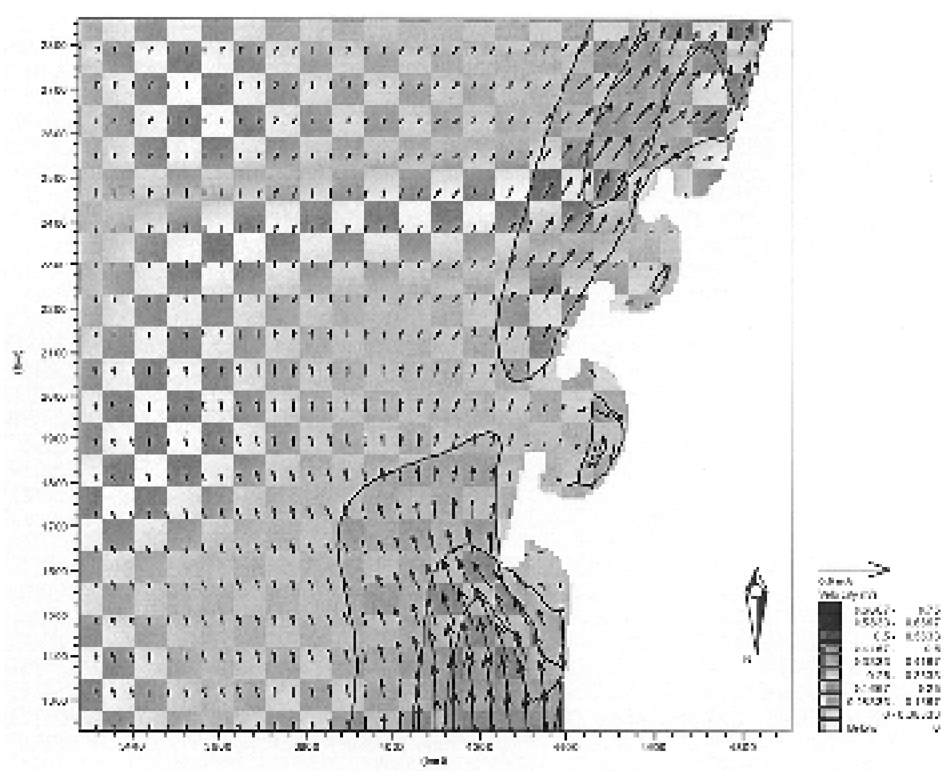

FIGURE 8 : Results of Current Model-Optimized Configuration