CHAPTER 347

MODELING INLET SAND BYPASSING

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Abstract

Consideration of the magnitude and phasing of sand bypassing events with respect to incident wave conditions is necessary when modeling shoreline change adjacent to tidal inlets where sand bypassing occurs. Likewise, the effects of wave transformation over nearshore bathymetric features (i.e., ebb tidal shoals, bypassing bars, etc.) and the resulting variations in alongshore sand transport rates relative to bypass discharge locations should also be considered. This paper presents a method for developing time-dependent inlet sand bypassing data for use in predicting future shoreline change. The method includes developing a relationship between the local offshore wave climate, longshore sand transport regime and inlet sand bypassing utilizing coincident time series of (1) local wave climate and (2) sand bypassing. The proposed model is compared to two other typical sand bypassing models to demonstrate the importance of relating the wave climate and bypassing. The proposed method was used successfully to create a representative time series of both mechanical and natural sand bypassing data for a shoreline change study conducted for the downdrift shoreline of South Lake Worth Inlet, Florida.

Introduction

Shoreline change adjacent to inlets where sand bypassing occurs is directly related to the characteristics of bypassing conditions. Specifically, sand bypassing is responsible, in part, for the manner in which both the updrift and downdrift shorelines of an inlet respond to the offshore wave climate and longshore sand transport regime. That is, the rate at which sand is removed from an updrift shoreline or added to a downdrift shoreline relative to the magnitude of the longshore transport potential affects the rate of shoreline change. For example, if the bypassing rate is below average during

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above average transport conditions, the net effect would be an impoundment of sand along the updrift shoreline and erosion along the downdrift shoreline. Therefore, when modeling shoreline change adjacent to inlets where sand bypassing occurs, it is important to represent both longshore transport and bypassing conditions accurately. This requires that the magnitude and phasing of sand bypassing events with respect to incident wave conditions be considered.

Background

Shoreline change models are typically used to predict future response of shorelines where a beach fill or coastal structure may be constructed. The characteristics of the mechanisms which contribute to future shoreline change (i.e., the wave climate, longshore transport regime, updrift sand supply, bypassing, etc.), however, are generally not known *apriori*. Therefore, accurate prediction of future shoreline change requires assumptions regarding the future characteristics of mechanisms which contribute to shoreline change. Typically, the assumption is made that future conditions can be represented by average historical conditions.

In the instance where a time-dependent model is used, annual and seasonal variations in the shoreline change mechanisms are also represented. Time-dependent shoreline change models often require a time series of input conditions to represent the annual and seasonal variations in shoreline change. For example, a shoreline change model may require a wave time series to represent wave conditions. In predicting future shoreline change, wave conditions may be representative of historical average annual and seasonal conditions.

When modeling shoreline change for a shoreline adjacent to a tidal inlet where sand bypassing occurs, the time dependent nature of bypassing events and the relationship of sand bypassing to incident wave climate and transport regime must also be considered. It is known that inlet sand bypassing events, both mechanical and natural, are related to the incident wave climate and the resulting longshore sand transport regime. Considering this relationship, a *sand bypassing time series* which is correlated to the incident wave climate and resulting longshore sand transport regime is required to represent bypassing conditions accurately.

In instances where it is known that shoreline change adjacent to an inlet is directly affected by bypassing activities, bypassing data must be developed which are representative of the magnitude of bypassing quantities and a function of the incident wave climate. Developing representative wave and bypassing data, without consideration of their interdependence, may not produce an accurate representation of the mechanisms which contribute to shoreline change. A method for the development of this data is presented in the following.

Method

The purpose of the proposed method is to determine the relationship between wave conditions, longshore transport conditions, and sand bypassing. The method is therefore based upon the assumption that sand bypassing around an inlet is a function of both the incident wave climate and the resulting longshore sand transport regime. That is, it is assumed that sand bypassing occurs only when the wave and longshore transport conditions are such that a sufficient volume of material is transported toward an inlet which is mechanical or natural bypassing.

The method requires that coincident time series of historical wave and bypassing data are available. The wave data times series can be either from measured or hindcast sources. Bypassing data may be available from bypass plant records or other measurement efforts. Application of the method results in a correlation expression which describes the relationship between the magnitude and occurrence of bypassing events relative to that of wave and longshore sand transport events. This relationship can then be used along with an assumed representative wave data to formulate bypassing data for use in predicting future shoreline change.

Application of the method includes computing longshore transport conditions from offshore wave time series which correspond to the period for which sand bypassing data area available. Simplistically, the transport conditions may be computed with a longshore sand transport equation such as the CERC formula (Shore Protection Manual, 1984). The general CERC formula can be expresses as

$$Q = K\, H_b^{\frac{5}{2}} \sin 2\theta_b \tag{1}$$

where Q is the longshore sand transport rate, H_b is the incipient breaking wave height, θ_b is the local breaking wave angle relative to shore normal and K is a calibration coefficient. Incipient breaking wave heights can be computed from the offshore wave data assuming the wave climate is linear and monochromatic and the offshore bathymetric contours are straight and parallel. A time series of longshore transport data can then be compiled to correspond to the period and frequency of the bypassing data. The resulting longshore sand transport time series can be calibrated with the coefficient, K, to produce average annual transport conditions equivalent to known quantities for the region.

To determine the relationship between the transport and bypassing, the data are plotted and a best-fit expression is derived. This resulting expression implicitly describes the phasing and magnitude of bypassing relative to the offshore wave data.

Alternate Method. In instances where historical bypassing records are not available, an inlet sediment budget may be utilized along with the assumption that bypassing is proportionately related to the local longshore sand transport potential. Although this method does not strictly include the relationship between actual wave and bypassing data, it generally describes annual and seasonal variations in the wave climate and bypassing for modeling purposes. The technique simply describes bypassing as a fraction of longshore sand transport.

Once the relationship between transport and bypassing is determined, the wave time series may be applied to the expression to develop a corresponding bypassing time series which represents future bypassing conditions. This technique was applied for a shoreline change investigation described below.

Application

The proposed method was applied during a shoreline change model study conducted for South Lake Worth Inlet in South Florida. The intent of model study was to simulate shoreline change along approximately 12,000 feet of shoreline immediately downdrift of the inlet for purposes of formulating a Federal Shore Protection Project for the Town of Ocean Ridge, Florida ("Palm" 1996). Analysis of historical shoreline change data, as well as the general morphology and littoral transport patterns, suggested that sand bypassing across the inlet, both mechanical and natural, strongly influenced the downdrift shoreline. The shoreline change model GENESIS, developed by Hanson (1987) and Hanson and Kraus (1989), was used for the investigation. GENESIS is a one-line shoreline change model which computes time-dependent shoreline change using a time series of input wave and sand bypassing conditions. Realizing the importance of sand bypassing to the study shoreline, both mechanical and natural sand bypassing which occur at the inlet were modeled as input to the updrift boundary condition.

Background. South Lake Worth Inlet is located in southern Palm Beach County on the southeastern coast of Florida (Figure 1). The inlet was mechanically cut through the sandy barrier which separates the Atlantic Ocean and Lake Worth in 1927. The inlet is stabilized by two jetties; the north jetty extends about 122 meters farther seaward than the south jetty and is curved towards the southeast. In 1967, the inlet was modified to its current configuration in an attempt to improve its bypassing capacity and reduce interior shoaling. The regional net sand transport in the vicinity of the inlet is from north to south, with approximately eighty-five percent of the gross transport being southerly directed.

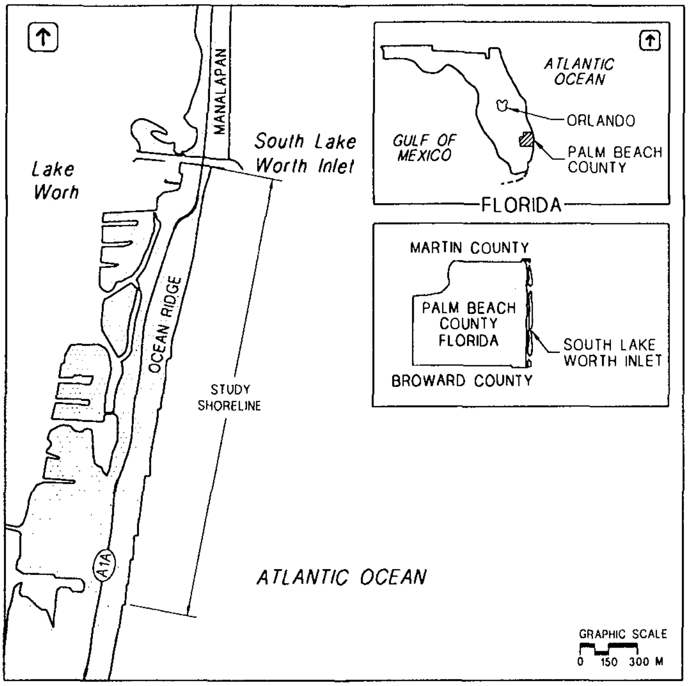

Figure 1: Location of South Lake Worth Inlet, Florida.

Despite natural and mechanical sand bypassing, the inlet acts as a partial littoral barrier to the net southerly drift of sand along Florida's southeast coast. Sand which drifts towards the inlet from the north is intercepted by the inlet's north jetty or diverted to the inlet's ebb and flood tidal shoals. Sand intercepted by the inlet's north jetty is impounded either in the fillet along the northern shoreline or mechanically bypassed to the southern shoreline. Sand diverted to the ebb shoal is stored either in the shoal platform, transported to the flood shoal and sand trap, or naturally bypassed to the southern shoreline. It is estimated that approximately 18 percent of the net southerly drift is intercepted and lost to the inlet system, resulting in a net sediment deficit along the downdrift shoreline. The net southerly sand transport in the vicinity of the inlet may vary between 134,000 and 172,000 cubic meters per year.

Sediment Budget. To quantify sand transport in the vicinity of South Lake Worth Inlet, Olsen Associates, Inc. (1990) developed a detailed nine-componcnt sediment budget which quantitatively described sediment transport paths at South Lake Worth Inlet. The sediment transport components of the sediment budget are highlighted in Figure 2. Six of the nine sediment transport components of the sediment budget were developed from available data. Using these values and the governing equations of the sediment budget, estimates of the natural bar bypassing and the net drift rate south of the inlet were calculated for a range of net littoral drift rates north of the inlet.

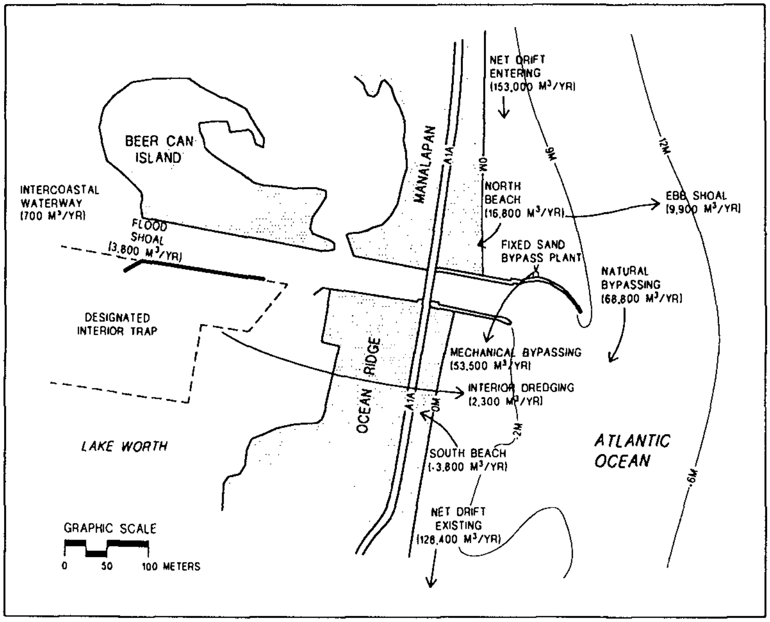

Figure 2: Sediment transport components for South Lake Worth Inlet, Florida.

Data collected since the 1967 modifications suggest that approximately 45 percent of the southerly net drift is bypassed across the ebb tidal shoal and bypassing bar. An additional 35 percent of the net southerly drift is bypassed by the fixed sand transfer plant.

Mechanical bypassing at the inlet is achieved with the inlet's sand transfer plant, which transports sand from the northern shoreline to a location between 60 and 150 meters south of the inlet. The plant is located atop the north jetty and bypasses sand from the northern to southern shoreline at a typical rate of about 53,500 cubic meters per year. Natural sand bypassing occurs along the inlet's ebb tidal shoal and bypassing bar platform. The bypassing bar attaches to the southern shoreline about 600 to 900 meters south of the inlet.

Because approximately 80 percent of the net transport is bypassed across the inlet, it was essential that this input to the study shoreline be included in model simulations.

Therefore, both mechanical and natural sand bypassing data (which were assumed to represent future bypassing conditions) were developed with the method described herein.

Mechanical Sand Bypassing Data. The relationship used to develop mechanical sand bypassing data representative of future conditions was determined from comparison of longshore sand transport data -- computed from offshore wave hindcast data -- and historical sand bypassing records. Mechanical bypassing records are available for the South Lake Worth Inlet sand transfer plant for the period from 1967 to the present. The bypassing rates are compiled from operation records and measured bypassing rates at the plant. WIS hindcast data are available for the area offshore of South Lake Worth Inlet for the period from 1956 to 1995. A time series of longshore sand transport was computed using these WIS hindcast wave data. The period for which the two databases overlap and are most reliable is 1970 to 1990. Therefore, it is this twenty year period for which longshore sand transport and mechanical sand bypassing data were compared.

The sand bypassing data were compared to both the net and southerly longshore transport components. This comparison revealed that mechanical bypassing is more closely correlated to the southerly transport component than the local net transport rate. (In fact, the mechanical sand bypassing plant operates only during periods of southerly directed transport.) The computed southerly transport data are plotted against the measured bypassing data in Figure 3. These data represent the twenty year period from 1970 to 1990. Inspection of the figure suggests a general trend in the data, where the magnitude of bypassing is related to the magnitude of southerly directed sand transport. The best-fit curve is of the form:

$$MB = aQ^{b} \tag{2}$$

where Q is the computed southerly transport rate from Eq. 1 (with K=1.0), MB is the reported mechanical bypassing rate, each in units of cubic meters per month, and a and b are coefficients. In this instance, the coefficients a and b were 29.0 and 0.54, respectively.

To demonstrate the effectiveness of this expression to represent actual mechanical sand bypassing data, a 9-year time series of southerly sand transport was applied to the expression to create a predicted 9-year time series of mechanical bypassing. The actual and predicted bypassing data for this period are presented in Figure 4. It is noted that areas of disagreement between actual and predicted bypassing records (such as the predicted spike in the latter part of 1974) may result from operational limitations of the sand bypass plant. Nonetheless, the comparison suggests that the mechanical sand bypassing at the inlet is correlated reasonably well with the incident wave climate.

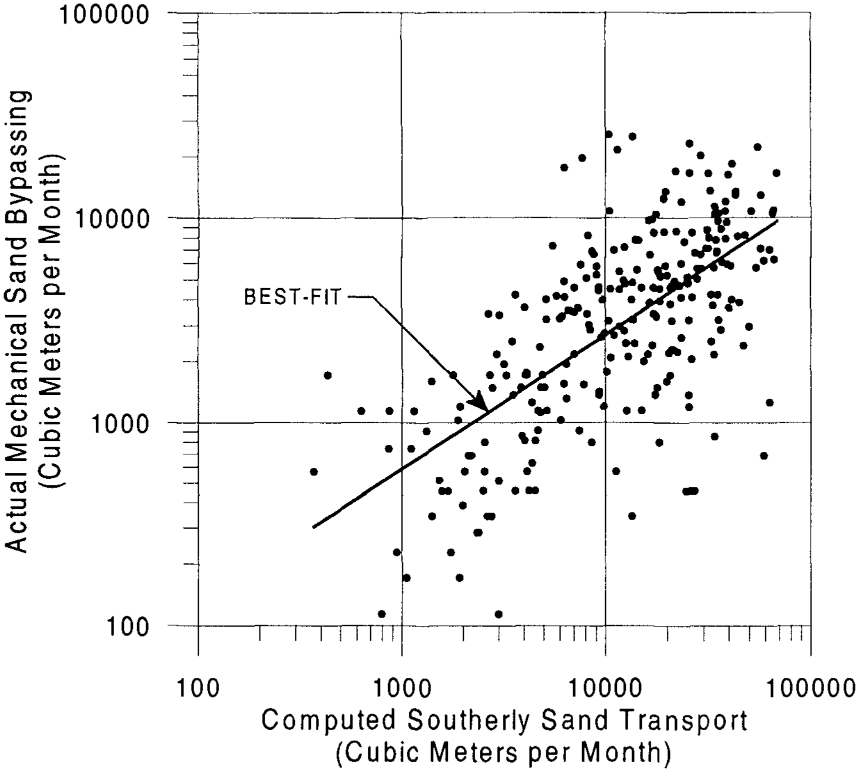

Figure 3: Correlation between actual mechanical sand bypassing (1967-1990) and computed southerly sand transport at South Lake Worth Inlet, Florida.

Natural Sand Bypassing Data. A time series of natural sand bypassing related to the longshore sand transport time series was also required as input to the shoreline change model. Actual measurements of the quantity and occurrence of natural bypassing, however, are not available at most inlets, including South Lake Worth Inlet. Therefore, the inlet's sediment budget and the assumption that natural bypassing occurs only during periods of southerly directed transport were used to formulate a natural bypassing time series. That is, the "natural bypassing" time series was developed by assuming that north to south sand transport across the bypassing bar is proportionately correlated to the southerly longshore sand transport component. This assumption was based, in part, upon the comparison of computed southerly sand transport and recorded mechanical sand bypassing. The proportionality constant for natural bypassing (0.45) was determined from the inlet's sediment budget (Figure 2); i.e.,

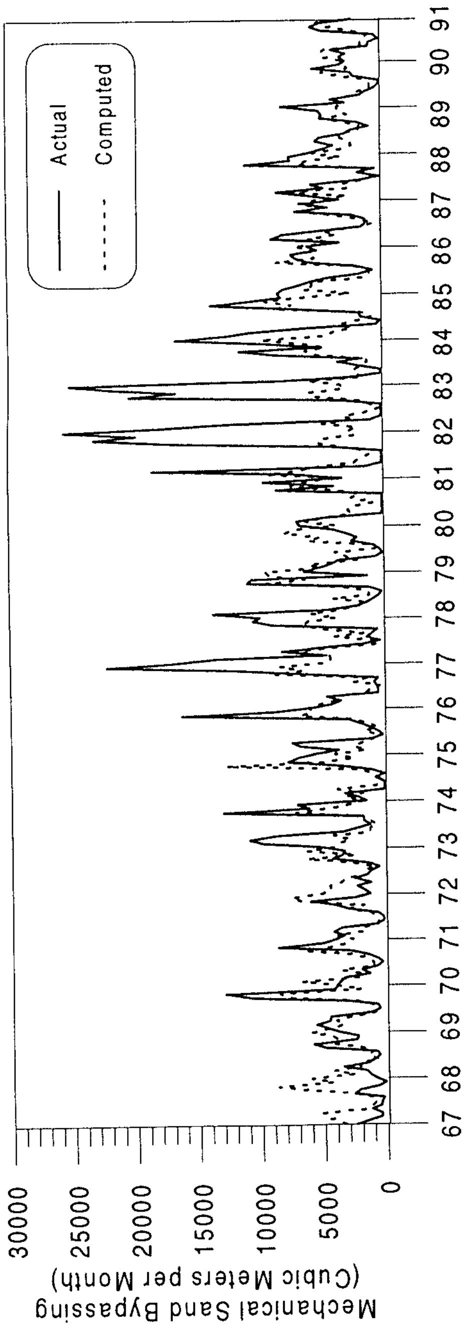

Figure 4: Time Series of actual and computed mechanical sand bypassing at South Lake Worth Inlet, Florida.

$$NB = 0.45Q \tag{3}$$

where NB is the rate of natural bypassing and Q is computed southerly transport rate from Eq. 1 (with K=1.0).

Shoreline Change Simulations. For purposes of predicting future shoreline change, a representative four year wave time series was developed for input to the GENESIS model. This time series was selected from the entire 38 year WIS hindcast time database as being most representative of average annual and seasonal variations in wave conditions offshore of the study site. Using this representative wave time series, corresponding mechanical and natural bypassing time series were computed using Eqs. 2 and 3, respectively. Both the wave and bypassing time series were used as input to the GENESIS for model simulations.

Bypassing Locations. The locations along which bypassed sand is supplied to the shoreline were also considered in the shoreline change investigation. As noted above, the study shoreline is supplied with bypassed material along two general areas. The sand which is mechanically bypassed is supplied to the shoreline within 60 to 150 meters south of the inlet. The sand which is bypassed naturally is supplied to the shoreline at the point where the natural bypassing bar attaches to the shoreline. This attachment point is some 600 to 900 meters south of the inlet.

Consideration of the locations along which the sand is supplied to the study shoreline was necessary because the alongshore distribution of sand transport is characterized by extreme accelerations and decelerations due to the effects of the inlet's ebb tidal shoal and bypassing bar on the incident wave climate. Because of these variations, shoreline change is strongly influenced by the locations along which bypassed material is supplied to the shoreline. To accommodate this sensitivity, sand was added to the model at the locations representative of the mechanical sand bypass plant discharge points and the average location at which the natural bypassing bar attaches to the shoreline.

As configured, the GENESIS model does not consider changes to the wave climate caused by such shallow features at South Lake Worth Inlet's ebb tidal shoal and bypassing bar. Because these changes to the wave climate are important to shoreline change and the movement of bypassed sand, a method was developed by Bodge, et.al. (1996) to consider the effects of nearshore bathymetric features on the wave climate. Briefly, the method computes the breaking waves conditions through a grid-based refraction analysis for wave conditions which are representative of the offshore time series. The breaking wave information is then "back-refracted" to a nearshore wave reference line which the GENESIS model is designed to accept. This technique, therefore, includes the variations in breaking wave conditions created by nearshore bathymetric features (such as ebb tidal shoals and bypassing bars) in the wave data input to the GENESIS model. This provides for more accurate representation of the local transport conditions in the areas were sand is supplied to the shoreline through bypassing.

Comparison Bypass Model Comparison. To demonstrate the necessity of accurately representing the relationship between longshore sand transport and sand bypassing, two other representations of sand bypassing were developed. These include assuming that an annual equivalent volume of bypassing is supplied to the shoreline at a constant rate (*uniform*). The other assumes that an annual equivalent volume of bypass sand is supplied at the beginning of each year (*plug*). A graphical representation of these concepts is provided in Figure 5.

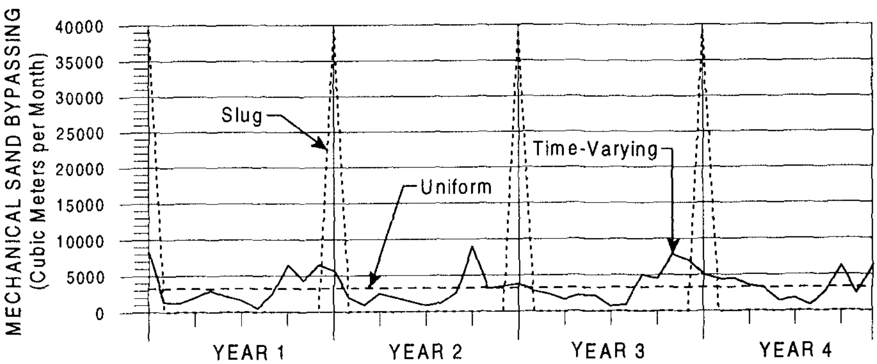

Figure 5: Concept of sand bypassing models.

These two bypassing models along with the bypassing model proposed herein (*time-varying*)were used to develop bypassing data for comparative model simulations. The representative four year wave time series described above was used to develop the bypassing data. Each representation of bypassing supplies an equivalent volume of sand to the model domain over the simulation period. For verification purposes, where both initial and final measured shorelines are available, model simulations were conducted for the 18 year period between 1975 and 1993. The results of the three comparative simulations are shown in Figure 6. In the figure, it is clear that the *time-varying* bypassing model provides a more accurate representation of measured shoreline change. The *uniform* and *slug* bypassing models fall short of the time-varying model by producing a significant build of sand along the northernmost section of the study shoreline. This is due to sand being supplied to the shoreline during periods of inactive longshore transport; thus allowing a build up of matcrial which is not transported away when transport becomes active. To more clearly demonstrate these results, the differences between measured and computed shorelines are provided in Figure 7.

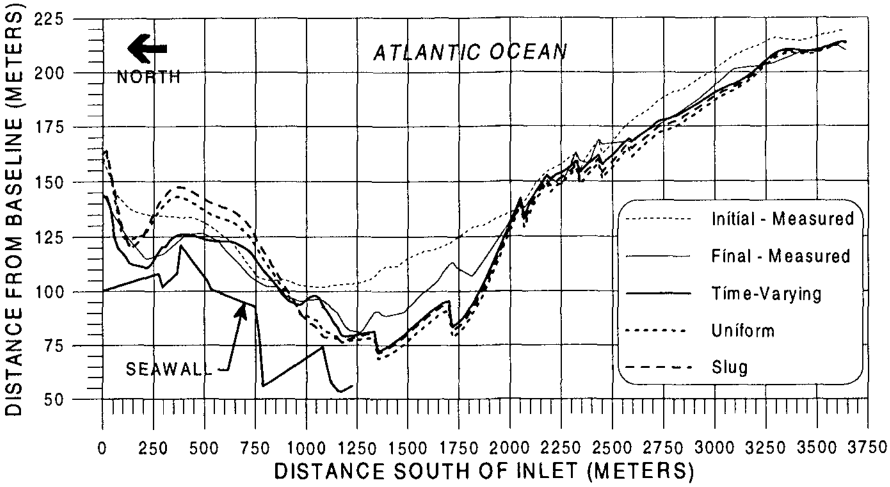

Figure 6: GENESIS shoreline change results using three sand bypassing models.

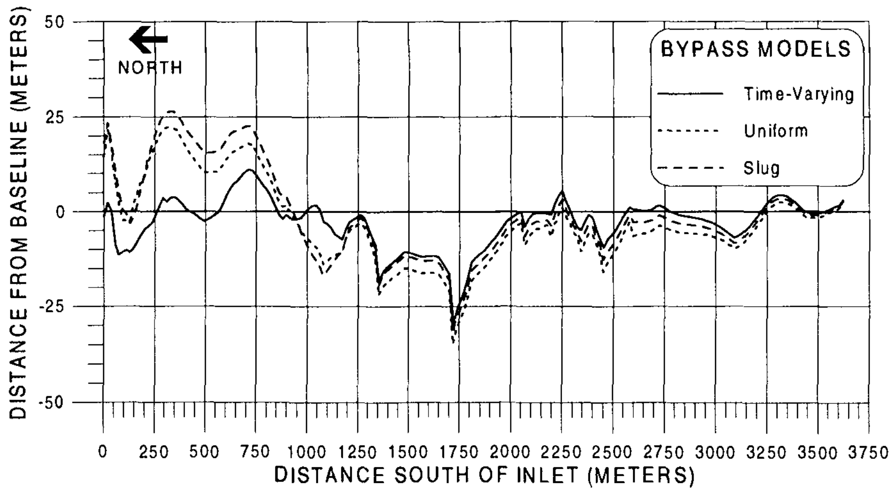

Figure 7: Difference between measured and computed shorelines.

Conclusions

A method is proposed to relate mechanical and natural inlet sand bypassing to the incident wave climate and develop a time series of bypassing for use as input to shoreline change models. Data requirements for the method include coincident times series of (1) local wave climate and (2) sand bypassing are required. Application of the model indicates that the magnitude and phasing of sand bypassing events with respect to incident wave conditions should be considered when modeling shoreline change adjacent to tidal inlets where sand bypassing occurs. The proposed method was used to successfully simulate shoreline change for the downdrift shoreline of South Lake Worth Inlet, Florida. U.S.A.

Acknowledgment

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