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GenCade Version 1 Model Theory and User's Guide

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Final report

Abstract

This is the first report to describe the new shoreline change and sand transport model, GenCade. GenCade is based on the synthesis of GENESIS (Hanson and Kraus 1989), a project-scale, engineering design-level model, and Cascade (Larson et al. 2003), a regional-scale, planning-level model. This report describes GenCade model theory, model validation and benchmark cases. The first model validation was performed with data from an experiment conducted in the CHL Large-Scale Sediment Transport Facility while the second focuses on the Jucar River in Spain. A series of simple idealized cases was developed to demonstrate GenCade model capabilities and verify results against the established legacy model, GENESIS. Additionally, this report includes a user's guide that describes the process of setting up and running GenCade. This section should include enough detail for a user with no previous GenCade experience to run a simple GenCade case. The report also describes a GenCade model application on the south shore of Long Island, New York. This report should give a new user enough information to understand the theory behind the model and create a grid and run a GenCade simulation.

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Preface

This study was performed by the Coastal Inlets Research Program (CIRP), which is funded by the Operation and Maintenance (O&M) Navigation business line of the Headquarters, U.S. Army Corps of Engineers (HQUSACE). The CIRP is administered for Headquarters by the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), Vicksburg, MS, under the Navigation Program of HQUSACE. James E. Walker is HQUSACE Navigation Business Line Manager overseeing the CIRP. W. Jeff Lillycrop, CHL, is the ERDC Technical Director for Navigation. Dr. Julie Rosati, CHL, is the CIRP Program Manager.

Unless otherwise noted, the following are associated with ERDC-CHL, Vicksburg, MS. This report was prepared by Ashley E. Frey and Robert C. Thomas of the Coastal Engineering Branch; Kenneth J. Connell, Golder Associates, Inc.; Dr. Hans Hanson and Dr. Magnus Larson, Lund University; Sophie Munger, Blue Science Consultants, LLC and sponsored by Texas A&M University Corpus Christi; and Alan Zundel, Aquaveo, LLC. The work was performed by the Coastal Engineering Branch (HN-C) of the Navigation Division (HN), U.S. Army Engineer Research and Development Center – Coastal and Hydraulics Laboratory (ERDC-CHL). At the time of publication, Dr. Jeffery P. Waters was chief of Coastal Engineering Branch and Dr. Rose M. Kress was chief of Navigation Division. Dr. Julie Rosati, Mark Gravens, and Dr. David King, Jr. reviewed this report. Jose Sanchez and Dr. William D. Martin were the Deputy Director and Director of CHL, respectively, during the study and preparation of this report.

COL Kevin J. Wilson was ERDC Commander. Dr. Jeffery P. Holland was ERDC Director.

Unit Conversion Factors

Multiply	By	To Obtain
cubic yards	0.7645549	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
miles (nautical)	1,852	meters
miles (U.S. statute)	1,609.347	meters
miles per hour	0.44704	meters per second
square feet	0.09290304	square meters
square miles	2.589998 E+06	square meters
square yards	0.8361274	square meters
yards	0.9144	meters

List of Symbols and Abbreviations

a_1, a_2	Non-dimensional parameters
A	Scale parameter
BC	Bypassing coefficient
BYP	Sand bypassing factor
C_g	Wave group speed
CERC	Coastal Engineering Research Center
CIRP	Coastal Inlets Research Program
d_b	Breaker depth
D	Water depth
D_B	Berm elevation
D_C	Closure depth
D_G	Depth at seaward tip of structure on updrift side
D_{LT}	Depth to which longshore sand transport occurs
d_{50}	Median grain size
DBW	Detached breakwater
DT	Time step
D_X	Cell size
E	Wave energy density
ERDC	Engineer Research and Development Center
F	Total fraction of sand passing over, around, or through a shore-connected structure
FIMP	Fire Island to Montauk Point
g	Acceleration due to gravity
GUI	Graphical User Interface
H	Wave height
H_b	Breaking wave height
H_{ref}	Wave height at the offshore reference depth or nearshore reference line
H_s	Significant wave height
I_l	Transport rate in terms of immersed weight
IRM	Inlet Reservoir Model
ISMOOTH	Wave transformation contour smoothing window
K_1, K_2	Longshore sand transport calibration coefficients
K_D	Diffraction coefficient
K_R	Refraction coefficient
K_S	Shoaling coefficient

K_t	Transmission coefficient
L	Wavelength
LSTF	Large-Scale Sediment Transport Facility
MLLW	Mean Lower Low Water
MSL	Mean Sea Level
NX	Number of cells in domain
p	Porosity of sand
PERM	Permeability factor
Q	Longshore sand transport rate
q	Sand source or sink
Q_{lst}	Transport rate
q_o	Rate of sand source or sink from offshore side
q_s	Rate of sand source or sink from shoreward side
R_s	Stability parameter
RSM	Regional Sediment Management
SMS	Surface-water Modeling System
T	Wave period
$\tan\beta$	Average bottom slope from shoreline to maximum depth of longshore transport
u_m	Maximum wave-induced near-bottom horizontal velocity at wave breaking
$\bar{v}_b$	Wave generated current
$\bar{v}_l$	Average longshore current in surf zone
V_x	Sand volume
V_{xq}	Sand equilibrium volume
w_s	Fall velocity
WIS	Wave Information Study
x	Distance alongshore
y	Shoreline position
Y_{gro}	Length of the groin
Y_{nxt}	Shoreline location just next to the structure
Y_{vir}	Virtual shoreline location
y_{RC}	Constant rate of change
α_b	Angle of breaking waves to shoreline
α_{bs}	Angle of breaking waves to local shoreline orientation
γ	Breaker index
$\Delta Q \Delta t$	Net volume change
Δt	Time step
Δx	Length of the shoreline segment
Δy	Change in shoreline position

ε_1, ε_2	Diffusion coefficients
θ	Direction of waves
ρ	Density of water
ρ_s	Density of sand

1 Introduction

This report is the first to describe the model GenCade. It includes an introduction to the model, a brief background of Cascade and GENESIS, a description of the model theory, and user's guide, and benchmark and validation cases.

1.1 Overview

Predictive technology for coastal Regional Sediment Management (RSM) applications must efficiently simulate governing sediment transport and morphologic evolution processes at regional scales, and over many decades. Regional spatial scales may encompass a single littoral cell or numerous littoral cells, yet sufficient spatial resolution must be maintained such that natural and engineered coastal features, which have potential to alter transport and coastal processes significantly, are represented accurately. Tools developed to support sediment management planning and engineering decisions must consider temporal scales encompassing decades to centuries. However, these tools should also resolve processes that occur at the scale of individual storms and tidal cycles to calculate episodic shifts in coastal evolution accurately to avoid gross over- or under-estimation of cumulative impacts at regional spatial scales and over long periods of time. Some of the relevant processes and engineering activities that contribute to coastal sediment management decisions are illustrated in Figure 1.

CIRP has developed GenCade, a 1-D numerical model that combines the capabilities of regional-scale, planning-level calculations of Cascade and the project-scale, engineering design-level calculations of GENESIS. GenCade calculates shoreline change and wave-induced longshore sand transport. GenCade is run within the Surface-Water Modeling System versions 11.1 and higher (SMS).

1.2 GenCade

GenCade is a newly developed model for calculating sediment transport and morphology change along coastal regions, and volumetric evolution of shoals and sand bypassing at inlets and engineered structures. Based on the synthesis of the GENESIS model (Hanson and Kraus 1989) and the

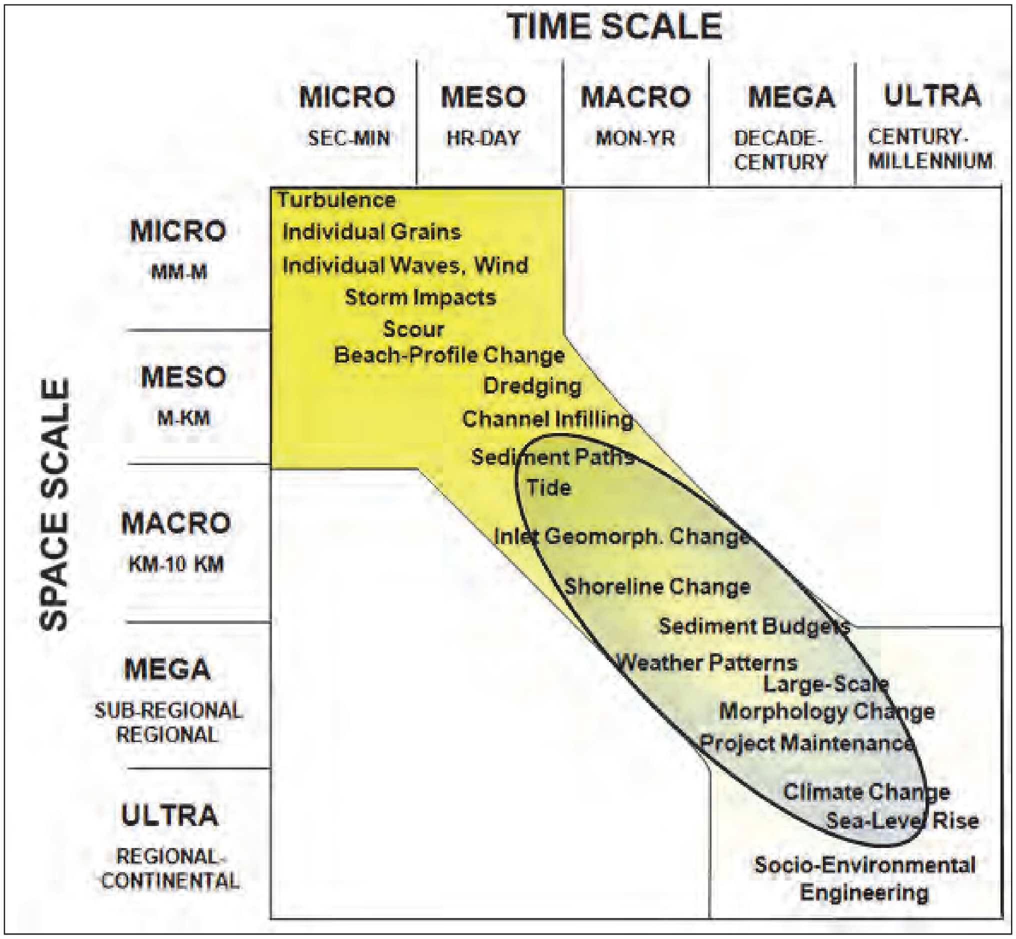


Figure 1. Spatial and temporal scales of influence over coastal evolution processes; ellipse represents the conceptual process scales encompassed by GenCade.

Cascade model (Larson et al. 2003), GenCade combines project-scale, engineering design-level calculations with regional-scale, planning-level calculations to analyze and accurately resolve both local modifications and regional cumulative effects of coastal projects and inlets. GenCade was developed as a unified framework and comprehensive solution to calculating first-order coastal processes over spatial and temporal scales ranging from the macro scale processes to the smaller ultra scale processes as shown in Figure 1. GenCade is developed and maintained by the U.S. Army Engineer Research and Development Center (USACE-ERDC), Coastal and Hydraulics Laboratory (CHL) with support from the Coastal Inlets Research Program (CIRP) and the RSM program.

GenCade simulates local shoreline change due to the presence of gradients in potential longshore sediment transport as forced by breaking wave height and angle and as affected by coastal infrastructure and engineering activities. GenCade simulates these local shoreline changes within the context of the larger-scale regional morphologic constraints. The evolution of multiple interacting coastal projects and morphologic features and pathways, such as those associated with inlets and adjacent beaches may also be simulated. GenCade, Version 1 calculates wave-induced longshore sediment transport rates, shoreline change, tidal inlet shoal volume evolution, bypassing, and the fate of coastal restoration and stabilization projects. It is intended for project-scale and regional-scale applications, engineering decision support, and medium-term (e.g., annual) through long-term (e.g., centurial) morphology response to physical and anthropogenic forcing. GenCade facilitates:

- Integrating both planning level and engineering design studies;
- Calculating on time scales ranging from one year to centuries;
- Preserving regional trends and converging to equilibrium conditions;
- Incorporating inlets through bypassing and shoal evolution;
- Resolving and differentiating engineered elements;
- Representing cumulative impacts through interaction of local projects on a regional scale.

GenCade Model functionality and capabilities include:

- Variable resolution grids;
- Inlet bypassing;
- Inlet Reservoir Model for calculation of shoal and inlet feature sediment balance;
- Representation of regional morphologic trends;
- Representation of coastal structures: groins, jetties, seawalls, t-head groins, breakwaters, etc.;
- Calculation of salients and tombolos behind breakwaters;
- Time-dependent detached breakwater transmission;
- Efficient calculation of breaking wave properties in an internal wave model.

A GenCade Graphical User Interface (GUI) has been developed in parallel with the GenCade numerical model and integrated into the Surface-water Modeling System (SMS) software package. The SMS enhances the user experience by providing graphical and geospatial tools for model grid and input forcing development, simulation execution, data post-processing, and seamless integration with other model and data applications working in real-world coordinate systems. The SMS GenCade GUI benefits include:

- Intuitive interface for project: conception to completion;
- Data synthesis;
- GenCade grid and input development;
- GenCade simulations;
- Post-processing, analysis, and figure generation ;
- World coordinates – everything georeferenced;
- Datum reprojection and transformation;
- Georeferenced aerial photograph support;
- GIS functions and connections to ArcGIS® and Google Earth™ ;
- CAD display and conversion support for AutoCAD® & Microstation®;
- Improved graphics;
- Potential to connect to other USACE numerical models supported within the SMS.

1.3 Background on GENESIS

GenCade was developed as a means to combine and extend the capabilities of two legacy shoreline change models: GENESIS (Hanson 1987; Hanson and Kraus 1989; Gravens et al. 1991; Hanson et al. 2006) and Cascade (Larson et al. 2003; Larson and Kraus 2003; Larson et al. 2006; Connell and Kraus 2006; Larson et al. 2007). The model name, GenCade, is a portmanteau word derived from blending the names GENESIS and Cascade; thereby inferring it is a generalized model for calculating coastal processes at simultaneously cascading spatial-temporal scales. GENESIS (GENEralized model for SImulating Shoreline change) provides the bulk of the foundation for GenCade since it has been developed over a long period and has incorporated a wide range of processes for coastal engineering design applications. The capabilities in Cascade for regional, large scale processes and inlet bypassing and shoal evolution were incorporated into the GENESIS modules as the basis for GenCade; GenCade development commenced from this foundation.

GENESIS is a one-line model designed to simulate long-term planform evolution of the beach in response to wave forcing on coastal structures and other engineering activities (e.g., beach nourishment). Hanson and Kraus (1989) presents a thorough description of the model theory and capabilities. Gravens et al. (1991) presents a user guide for development of input and solution files for guidance on coastal engineering applications.

1.4 Background on Cascade

The Cascade model simulates longshore sand transport and coastal evolution at the regional and local scale for regional sediment management and coastal planning applications. The model can efficiently calculate for time scales ranging from years to centuries. A typical coastal setting to which Cascade may be applied is a chain of barrier islands separated by inlets where the sediment is transferred or bypassed around the inlets through the inlet-shoal complex. One module within Cascade is the capability to model sediment storage and transfer at inlet morphologic shoal features (e.g., ebb tidal delta, bypass shoal, etc.) with a simplified version of the Inlet Reservoir Model (IRM) (Kraus 2002). The IRM has also been incorporated into GenCade and has been developed further to become more robust and similar to the stand-alone IRM. In past applications, Cascade could serve as a means of supplying regional sediment transport data and planning-level sediment budget information as boundary conditions for input into GENESIS engineering design applications. The development of GenCade facilitates this process by automating transfer of calculated regional transport, inlet bypassing, and inlet shoal evolution between the cascading time and space scales for seamless simulation of coastal projects at a regional scale.

1.5 Objectives

The CIRP's mission is to conduct applied research to improve the USACE's capabilities to manage federally maintained coastal navigation inlets, which are present on all coasts of the United States including the Atlantic Ocean, Gulf of Mexico, Pacific Ocean, Great Lakes, and U.S. territories. The objectives of the CIRP are to advance knowledge and provide quantitative predictive tools to (a) support the management of federal coastal inlet navigation projects to facilitate more effective design, maintenance, and operation of channels and jetties to reduce the cost of dredging, and (b) preserve the adjacent beaches and estuary in a systems approach that treats the inlet, beaches, and estuary as sediment-sharing components. To achieve these objectives, the CIRP is organized in research work units conducting a wide range of applied Research and Development (R&D) related to waves, hydrodynamics, and sediment transport and morphology change modeling specifically for estuaries, navigation and inlet structures, laboratory and field investigations, and technology transfer.

1.6 Report organization

This report is divided into six chapters. Chapter 1 provides an introduction and overview of GenCade and gives background on GENESIS and Cascade. Chapter 2 describes GenCade model theory. Chapter 3 describes model validation and several benchmark cases. Chapter 4 provides in-depth details of how to create a GenCade grid and run GenCade in the SMS. Chapter 5 discusses an application at Long Island, NY. Chapter 6 summarizes the report.

2 GenCade Version 1 Model Theory

2.1 Basic assumptions

Because GenCade is a one-line model, it is constrained by the standard assumptions upon which this type of model is based:

- The beach profile shape remains constant;
- The shoreward and seaward depth limits of the profile are constant;
- Sand is transported alongshore by the action of breaking waves and longshore currents;
- The detailed structure of the nearshore circulation is ignored;
- There is a long-term trend in shoreline evolution.

The first assumption presumes that the beach profile maintains an average shape that is characteristic of the particular coast, apart from times of extreme change as produced by storms. For example, steep beaches remain steep and gently sloping beaches remain gentle in a comparative sense and in the long term. Although seasonal changes in wave climate cause the position of the shoreline to move shoreward and seaward in a cyclical manner, with corresponding change in shape and average slope of the profile, the deviation from an average beach slope over the total active profile is relatively small.

A second geometrical-type assumption is that sand is transported alongshore between two well-defined limiting elevations on the profile. The shoreward limit is located at the top of the active berm, and the seaward limit is located where no significant depth changes occur, the so-called depth of closure. Restriction of profile movement between these two limits provides the simplest way to specify the perimeter of a beach cross-sectional area which changes in volume, from which shoreline change can be computed.

The model also requires predictive expressions for the total longshore sand transport rate. For open-coast beaches, the transport rate is a function of the breaking wave height and direction with respect to the local shoreline orientation. Since the transport rate is parameterized in terms of breaking wave quantities, the detailed structure of the nearshore current pattern does not directly enter. As an extension of the original formulation, GenCade may also represent sediment transport resulting from tide or wind, but only in the presence of the breaking waves.

Finally, it is assumed that there is a clear long-term trend in shoreline behavior. This must be the case to predict a steady signal of shoreline change from among the “noise” in the beach system produced by storms, seasonal changes in waves, tidal fluctuations, and other cyclical and random events. In essence, the assumption of a clear trend implies that the wave action producing longshore sand transport and boundary conditions are the major factors controlling long-term beach change. This assumption is usually well satisfied at engineering projects involving groins, jetties, and detached breakwaters, which introduce gradients in the transport rate and, in some cases, unambiguous boundary conditions along the neighboring open coast. Furthermore, stable beaches with no long-term trend in shoreline behavior are typically not locations where engineering studies are required. However, some beaches dominated by cross-shore transport may exhibit significant variability with no clear trend and yet may experience substantial erosion problems requiring engineering studies.

As described below, GenCade can account for the vertical and cross-shore distributions of longshore sand transport at groins and jetties in an empirical fashion. It does not, however, account for the full vertical and horizontal water and sand circulation, making it incapable, for example, of describing transport by rip currents, undertow, or other three-dimensional fluid and transport processes.

GenCade incorporates the Inlet Reservoir Model (Kraus 2000) to describe sediment storage and transfer at coastal inlets. The user provides each morphological unit (shoal) initial and equilibrium volumes for fixed hydrodynamic and sediment conditions.

Through its generalized interface, GenCade has the possibility to represent a large variety of coastal processes and engineering activities such as:

- Sand transport due to oblique wave incidence and longshore gradient in height;
- Representation of several barrier islands separated by inlets at which sediment is transferred through tidal shoal complexes and dredging and placement;

- Sand transport due to wind or tide induced longshore currents;
- Representation of sediment sources and sinks;
- Beach fills and dredged material placement;
- Offshore or nearshore input waves of arbitrary height, period, and direction (external wave models will be added in GenCade Version 2)
- Compound structures such as T-shaped, Y-shaped, and spur groins;
- Bypassing of sand around and transmission through groins and jetties;
- Wave diffraction at detached breakwaters, jetties, and groins;
- Water level dependent wave transmission at detached breakwaters.

Groins, jetties, detached breakwaters, beach fills, and seawalls may be represented in almost arbitrary numbers and combinations.

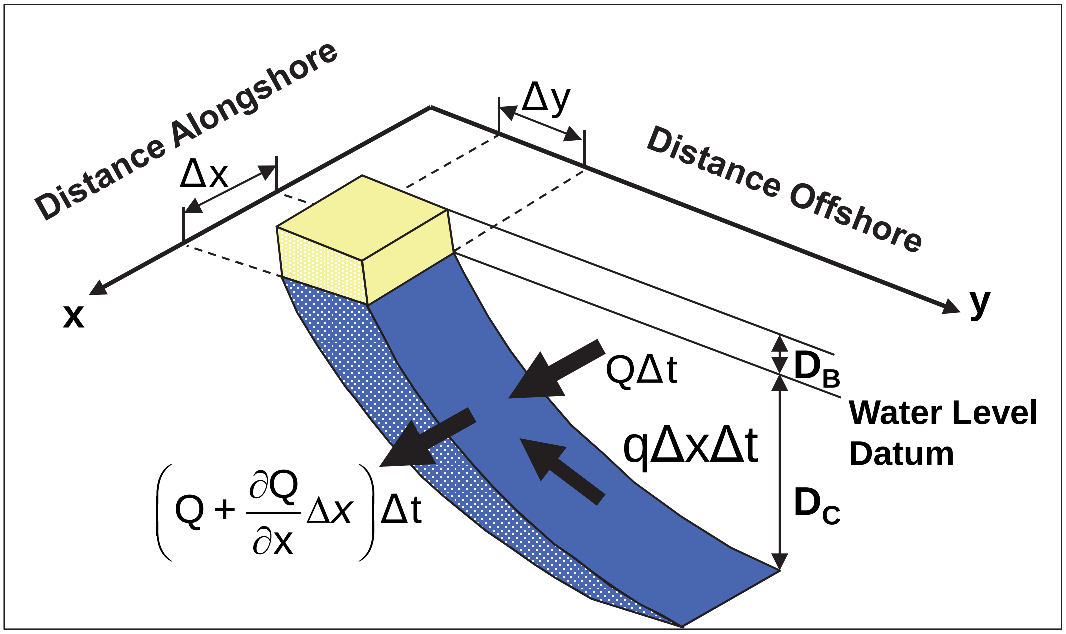
Limitations on structures in GenCade include those typical of this class of model:

- No wave reflection from structures;
- Minor restrictions on placement, shape, and orientation of structures;
- No direct provision for changing tide level for transport and shoreline change (though options are available for accounting for water level in breakwater transmission calculations);
- Basic limitations of shoreline change modeling theory.

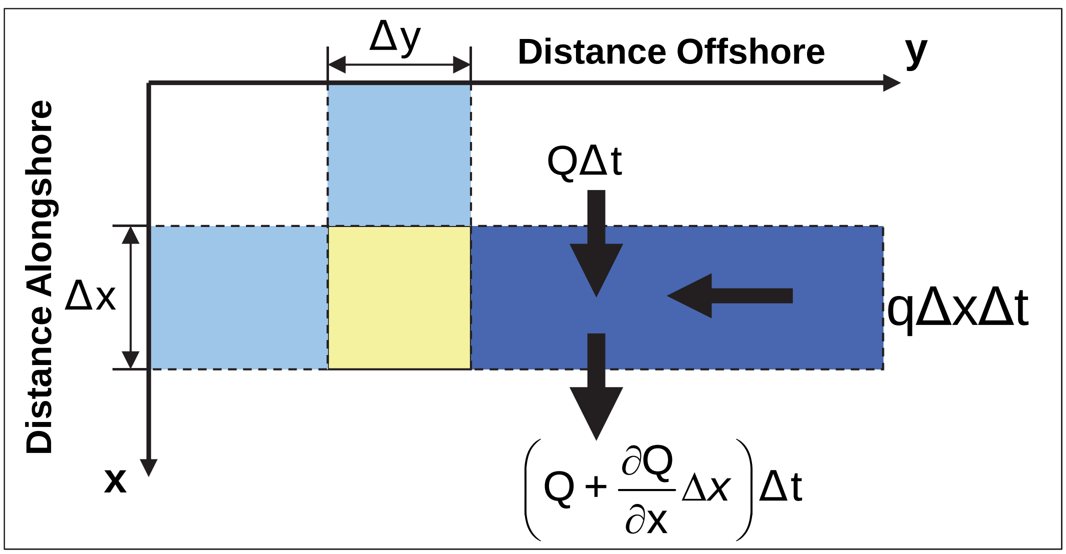
2.2 Governing equation

The equation governing shoreline change is formulated by conservation of sand volume. Consider a right-handed Cartesian coordinate system in which the y-axis points offshore and the x-axis is oriented parallel to the trend of the coast (Figures 2a and 2b). The quantity y thus denotes shoreline position, and x denotes distance alongshore. It is assumed that the beach profile translates seaward or shoreward along a section of coast without changing shape when a net amount of sand enters or leaves the section during a time interval Δt. The change in shoreline position is Δy , the length of the shoreline segment is Δx , and the profile moves within a vertical extent defined by the berm elevation D_B and the closure depth D_C , both measured from the vertical datum (for example, MSL or MLLW).

The change in volume of the section is $\Delta V = \Delta x \Delta y(D_B + D_C)$ and is determined by the net amount of sand that entered or exited the section from its four sides. If there is a difference in the longshore sand transport rate Q (m^3/sec) at the lateral sides of the cells, the volume changes. This



a. Cross-sectional view.



b. Plan view.

Figure 2. Definition sketch for shoreline change calculation.

net volume change is $\Delta Q \Delta t = (\Delta Q/\Delta x)\, \Delta x \Delta t$. Another contribution can come from a line source or sink of sand $q = q_s + q_o$, which adds or removes a volume of sand per unit width of beach from either from the shoreward side at the rate of q_s or from the offshore side at the rate of q_o. These produce a volume change of $q\Delta x\Delta t$. Addition of the contributions and equating them to the volume change gives $\Delta V = \Delta x \Delta y(D_B + D_C) = (\Delta Q/\Delta x)\, \Delta x \Delta t + q\Delta x \Delta t$. Re-arrangement of terms and taking the limit as $\Delta t \rightarrow 0$ yields the governing equation for the rate of change of shoreline position:

$$\frac{\partial y}{\partial t}+\frac{1}{\left(D_B+D_C\right)}\left(\frac{\partial Q}{\partial x}-q\right)=0 \tag{1}$$

To solve Equation (1), the initial shoreline position over the full reach to be modeled, boundary conditions on each end of the beach, and values for Q, q, D_B, and D_C must be given.

2.3 Sand transport rates

The classical 'CERC'-equation for calculating the longshore sediment transport rate Q (m^3/sec) is formulated as (Komar 1969):

$$Q=\left(H^2 C_g\right)_b a_1 \sin 2\alpha_b \tag{2}$$

where H is wave height (m), C_g is wave group speed (m/sec), α_b is angle of the breaking waves to the shoreline, subscript b denotes the wave breaker position, and a_1 is a non-dimensional parameter given by:

$$a_1=\frac{K_1}{16\left(\frac{\rho_s}{\rho}-1\right)(1-p)1.416^{5/2}} \tag{3}$$

where K_1 is an empirical coefficient with nominal value equal to 0.77, ρ_s (ρ) is the density of sand (water) (kg/m^3), and p is the porosity of sand. Later, the GENESIS model (Hanson 1987) used an extended version of this relation (Kraus and Harikai 1983):

$$Q=\left(H^2 C_g\right)_b\left(a_1 \sin 2\alpha_b-a_2 \cos\alpha_b \frac{\partial H_b}{\partial x}\right) \tag{4}$$

where a_2 is a non-dimensional parameter given by:

$$a_2=\frac{K_2}{8\left(\frac{\rho_s}{\rho}-1\right)(1-p)\tan\beta\, 1.416^{5/2}} \tag{5}$$

where $\tan\beta$ is the average bottom slope from the shoreline to the "maximum depth of longshore transport" (see Equation 23). The 'nominal' value of K_1 is 0.39 if waves are specified in terms of rms wave heights

(Komar 1976) and 0.77 when using significant wave heights. As a rule of thumb, based on modeling experience, Hanson and Kraus (1989) recommend 0.5 $K_1 < K_2 < 1.5$ K_1.

The second term in Equation (4) accounts for the longshore current and associated sediment transport induced by a gradient in wave height (Ozasa and Brampton 1980) as produced, for example, by diffraction behind a detached breakwater. In the calibration and verification procedure, values of K_1 and K_2 are determined by reproducing changes in shoreline position measured over a certain time interval. Figure 3 shows a schematic of the effect of this second term on shoreline evolution behind a detached breakwater and adjacent to a groin. As seen, the incorporation of the a_2-term results in a more realistic evolution down-drift of groins and jetties and a more pronounced evolution in the lee of detached breakwaters. In general, a variation of K_1 will affect the entire modeling domain whereas a variation of K_2 will only affect the evolution in areas influenced by wave diffraction near structures. In Figure 3 this would be in the leeward shadow of the detached breakwater and on the down-drift (right) side of the groin. Therefore, in a calibration process, it is generally recommended to first adjust the K_1 value to get a reasonable agreement with respect to annual transport rates and overall shoreline evolution. Thereafter, the K_2 value may be altered to improve predicted shoreline response near structures. (It should be noted that shoreline response near structures is also dependent on structural properties such as groin or detached breakwater permeability, length, location, etc. These properties are discussed in respective sections below).

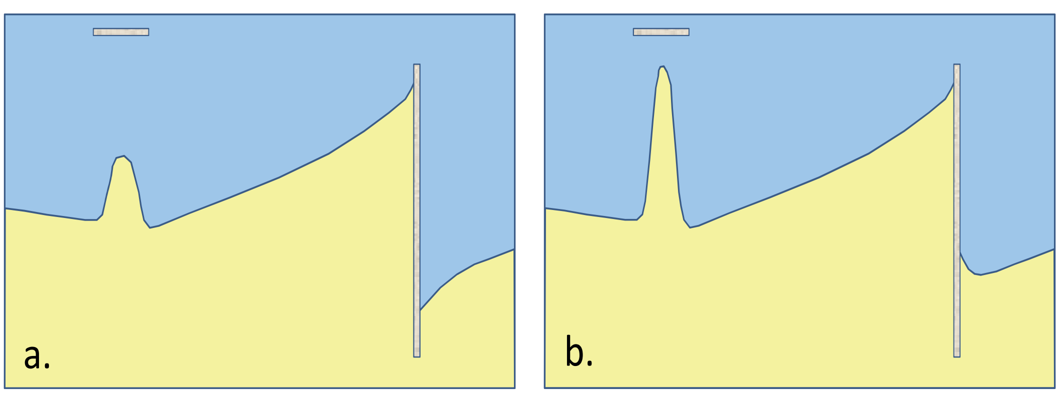


Figure 3. Schematic qualitative illustration of shoreline evolution adjacent to a detached breakwater and a groin when a) a_2 term in Equation (4) is NOT included and b) a_2 term in Equation (4) IS included.

By writing the transport rate in terms of immersed weight, I_l (N/sec), Equation (4) may be expressed as:

$$I_l = \left(EC_g\right)_b \left(K_1 \sin\alpha_b \cos\alpha_b - K_2 \frac{\cos\alpha_b}{\tan\beta} \frac{\partial H_b}{\partial x}\right) \tag{6}$$

where E is the wave energy density (J/m^2). Following the formula proposed by Bagnold (1963), the first term of Equation (6) can be modified to explicitly represent a longshore current as:

$$I_l = K_3 (EC_g)_b \cos\alpha_b \frac{\overline{v}_l}{u_m} \tag{7}$$

where K_3 is a dimensionless coefficient, $\overline{v}_l$ (m/sec) is the average longshore current in the surf zone, and u_m (m/sec) is the maximum wave-induced near-bottom horizontal velocity at wave breaking which may be written as:

$$u_m = \left(\frac{2E_b}{\rho d_b}\right)^{1/2} = \left(\frac{\gamma g H_b}{4}\right)^{1/2} \tag{8}$$

where d_b is the breaker depth (m), γ is the breaker index, and g is the acceleration due to gravity (m/sec^2). By using Equation (7), the longshore sediment transport rate is no longer restricted to being generated exclusively by breaking waves; the longshore current may originate from other mechanisms as discussed further by Komar and Inman (1970) and Kraus et al. (1982), for example, as generated by the tide or the wind.

If the longshore current $\overline{v}_l$ comprised of a wave generated current $\overline{v}_b$ alone, it may be calculated as (Longuet-Higgins 1970; Komar and Inman 1970):

$$\overline{v}_l = \overline{v}_b = K_4\, u_m \sin\alpha_b \tag{9}$$

where K_4 is an empirical coefficient for which Komar and Inman (1970) suggested K_4 = 2.7. By combining Equations. (7), (8) and (9), we obtain $K_3 = K_1/K_4$. Thus, with only wave generated currents taken into account, Equations (7) and (9) together are compatible with the 'CERC' equation but are still able to account for currents of different origin. Along the same lines, GenCade is using a generalized version of Equation (9) which includes the effect of longshore gradients as:

$$\overline{v_b} = K_4 u_m \sin\alpha_b - K_5 \frac{4}{\gamma g} u_m \frac{\partial (u_m^2)}{\partial x} \frac{1}{\tan\beta} \tag{10}$$

where K_5 is an empirical coefficient (= K_2/K_3). It can easily be shown that Equation (10) inserted into Equation (7) reduces back to Equation (6). Thus, the relationship expressed in Equation (10), which is used in GenCade, is equivalent to the 'original' transport relationship used in GENESIS when only wave-generated transport is considered. With the new formulation, GenCade can also take tidal or other currents into account.

If a mean current ($\overline{v}_t$) is linearly added to the wave-generated current $\overline{v}_l$, Equation (6) becomes:

$$I_l = \left(EC_g\right)_b \left(K_1 \sin\alpha_b \cos\alpha_b + K_3 \cos\alpha_b \frac{\overline{v}_t}{u_m} - K_2 \frac{\cos\alpha_b}{\tan\beta} \frac{\partial H_b}{\partial x} \right) \tag{11}$$

where K_3 is the dimensionless coefficient in Equation (7). Reverting back from immersed weight transport rate to volumetric transport rate, Equation (4) may be expressed as:

$$Q = \left(H^2 C_g\right)_b \left(a_1 \sin 2\alpha_b + \left(a_3 \frac{\overline{v}_t}{u_m} - a_2 \frac{\partial H_b}{\partial x} \right) \cos\alpha_b \right) \tag{12}$$

where a_3 is a non-dimensional parameter given by:

$$a_3 = \frac{K_3}{8\left(\frac{\rho_s}{\rho} - 1\right)(1-p)\, 1.416^{5/2}} \tag{13}$$

In GenCade, the calculated breaking wave condition at each grid point is converted to a wave-driven longshore current velocity from which the associated longshore sediment transport rate is calculated. A tidal or wind-driven current (or both) are read from files and linearly added to the wave-generated current before calculating the transport rate. GenCade at present does not calculate the current produced from the tide or the wind. These currents should be represented by an average through the surf zone and must be obtained from an external source, such as from a model or measurements. For further guidance on modeling wind-driven surf zone currents, see Kraus and Larson (1991) and Long and Hubertz (1988). Values of the external current are stored in a file that provides tide and wind currents at each calculation cell wall. These currents then serve as input for continued transport calculations.

2.4 Grid system

As discussed above, a right-hand coordinate system is laid out with the x-axis following the main trend of the shoreline and the y-axis perpendicular to it and pointing offshore (Figure 4). The shoreline grid along the x-axis consists of N cells defined by N+l cell walls. The user may specify a maximum of 4000 cells to define a domain. The cell resolution may be distributed uniformly or variably alongshore. In GenCade, calculated quantities along the shoreline are discretized on a staggered grid in which shoreline positions y_i are defined at the center of the grid cells ("y-points") and transport rates Q_i at the cell walls ("Q-points"), as shown in Figure 4. The left boundary is located at grid cell 1, and the right boundary is at cell N. In total there are N values of the shoreline position. Similarly, there are N+l values of the longshore sand transport rate since N+l cell walls enclose the N cells; values of the transport rate must be specified at the boundaries, Q_1 and Q_{N+1} , and the remainder of the Q_i and all y_i will be calculated. Since the Q_i-rates are a function of the wave conditions, all wave quantities are calculated at Q-points. The tips of groins and detached breakwaters are likewise located at Q-points. Seawalls, beach fills, river discharges, and other sand sources and sinks are located at y-points. For further information on the placement of structures, see Sections "*Placement of groins, jetties, and detached breakwaters*", "*Seawalls*" and "*Beach fills*" below.

2.5 Recommended resolution

GenCade allows the use of irregular grid spacing, as illustrated in Figure 5. Figure 5a displays the shoreline response by a 100-m long detached breakwater located 100 m offshore of the initially straight shoreline (note the break in the vertical axis for better display). The system was exposed to constant waves with H = 1 m, T = 5 sec, and θ = -5 deg for three months. The grid spacing was held constant at dx = 10 m for all 200 cells. Figure 5b

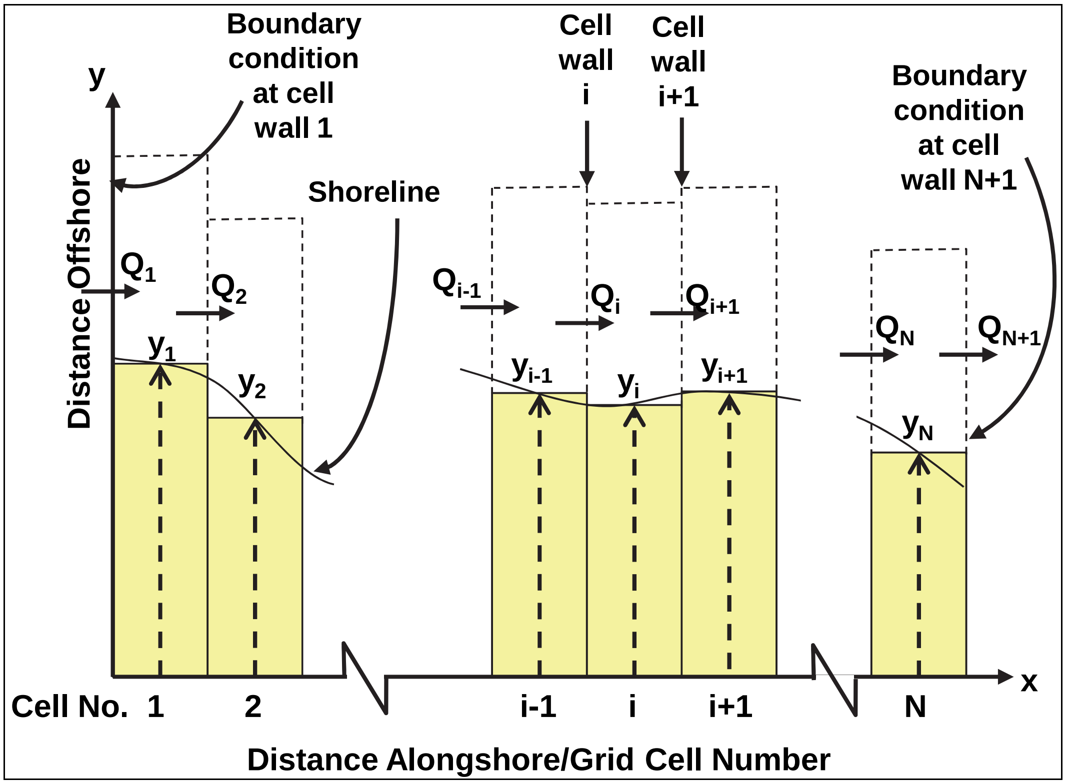


Figure 4. Finite difference staggered grid.

shows the same application with an irregular grid. The higher resolution of dx_{min} = 10 m was now only used in the immediate vicinity of the structure and the grid cell size was gradually increased to dx_{max} = 100 m further away from the breakwater. The resulting response from the simulation with the higher resolution is shown by a red line, whereas the corresponding result using the variable grid resolution is shown by a black line. As seen in Figure 5b, the two results are almost identical even though (a) used five times as much computation effort as (b). Thus, by using higher resolution only in areas with greater variation in processes and using lower resolution elsewhere, significant execution effort may be saved.

For detailed analysis, it is recommended that at least nine grid points (eight cells) be placed behind detached breakwaters and between adjacent groins. In a scoping mode application or if a wide coastal extent is being covered for which detail at any one structure is not vital, it is recommended that at least four cells be used. Grid spacing in the modeling system should be selected through a balance of the following four conditions:

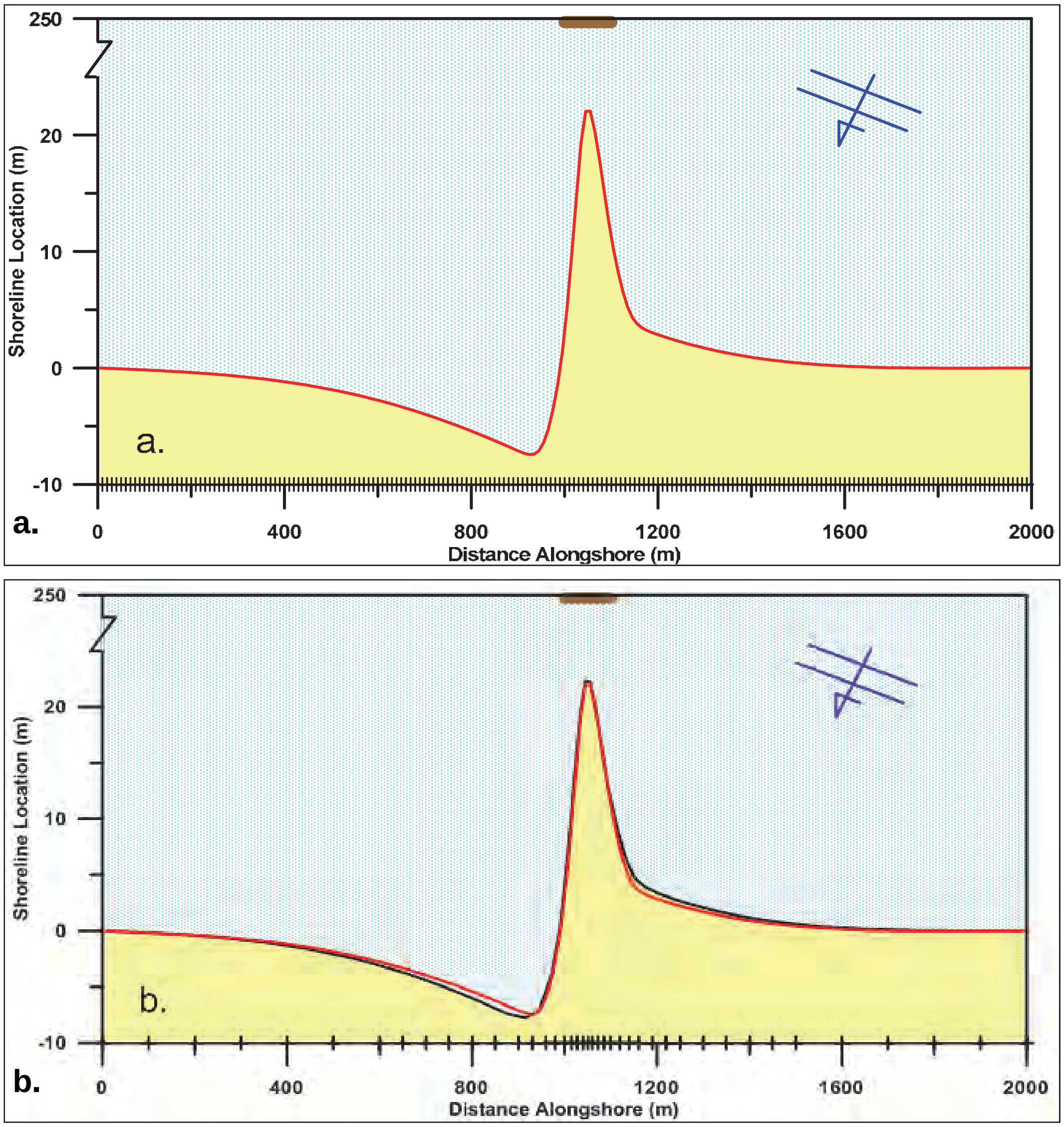


Figure 5. Simulation three months. H = 1 m, T = 5 sec, θ = -5 deg. Detached breakwater length = 250 m, length = 100 m. a.) 200 cells, dx = 10 m, red line. b.) 40 cells, dx_{min} = 10 m, dx_{max}= 100 m, black line.

- Resolution desired;
- Numerical stability;
- Accuracy of measured shoreline positions and other data;
- Expected reliability of the prediction (which mainly depends on the verification and quality of input wave data);
- Computer execution time (which depends on the time step, number of cells on the grid, and the simulation interval).

It should be remembered that execution time increases substantially as the number of diffracting structures increases. As stated above, by using the variable grid capability in GenCade, higher grid resolution can be applied behind detached breakwaters and between adjacent groins, while a lower resolution is used along open sections of the model domain. The variable grid capability can reduce execution time while allowing sufficient resolution in the vicinity of diffracting structures.

2.6 Boundary conditions

GenCade presently has three options for boundary conditions: *pinned*, *moving*, and *gated*. A boundary condition specified as pinned means that the boundary will not move from the initial shoreline position over the calculation interval. This is the default boundary condition. If a moving boundary condition is selected, the boundary will move a specified distance over a certain time period (specified by the user). The pinned and moving beach boundary conditions should be located far away from the project to assure that the conditions in the vicinity of the boundary are unaffected by changes that take place in the project. A gated boundary condition is bounded with a groin. Figure 6 shows plotted shorelines at Anaheim Beach, CA, where location (a) displays a pinned beach behavior (because all shorelines fall on top of each other here), location (b) represents the moving beach boundary because of the constant rate of accretion (noticed because there is a near-equal distance between consecutive shorelines) and location (c) could be specified as a gated beach (because of the presence of a groin/jetty).

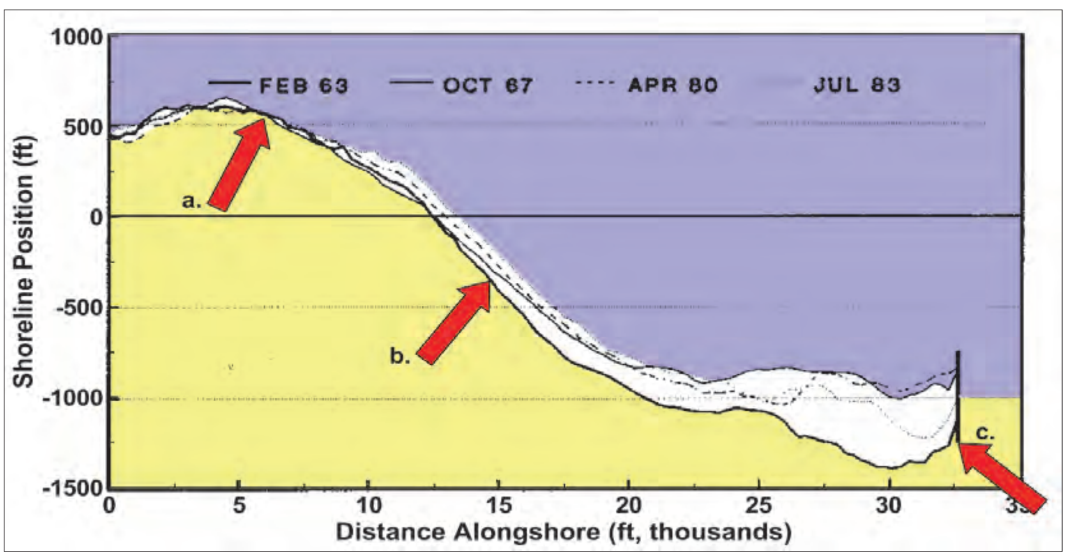


Figure 6. Measured shorelines at Anaheim Beach, CA, where the arrows indicate locations of possible boundary conditions. a. pinned beach (because all shorelines fall on top of each other here), b. beach moving at constant rate (because there is a near-equal distance between consecutive shorelines), and c. gated beach (because of the presence of a groin/jetty).

2.6.1 Pinned beach

It is helpful to draw all available measured shoreline position surveys on the same plot to determine locations along a beach that might be used as model boundaries. In doing so, it is sometimes possible to find a portion of the beach distant from the project that does not move appreciably in time, as shown in Figure 6 for a sandy beach or for regions with a hardened shoreline. By locating the model boundary at such a section, the modeled lateral boundary shoreline coordinate can be said to be ‘pinned’. Expressed in terms of the transport rate, this means:

$$Q_1 = Q_2 \quad \text{or} \quad Q_{N+1} = Q_N \tag{14}$$

depending on which end of the calculation grid is considered. These relations can be readily understood by reference to Equation (1); if $\partial Q / \partial x = 0$ at the boundary, then $\partial y / \partial t = 0$ meaning that y does not change over time.

2.6.2 Moving beach

If a section of beach cannot be found to be represented by the pinned beach boundary condition, it might be possible to locate a section where the shoreline is moving with a constant rate of change y_{RC}. In such a case, the boundary condition can be expressed as:

$$y_N^{t+1} = y_N^t + y_{RC} \tag{15}$$

where the superscripts denote the relative time. In GenCade, the boundary condition is expressed in terms of transport rates. Again, with reference to Equation (1), the boundary condition may be formulated as:

$$Q_{N+1}^t = Q_N^t - \frac{y_{RC} - (D_B + D_C)q_N^t}{2B} \tag{16}$$

where $B = \Delta t / \left(2\left(D_B + D_C\right)\Delta x\right)$ and q is a line source/sink.

2.6.3 Gated boundary

Groins, jetties, shore-connected breakwaters, and headlands that interrupt, partially or completely, the movement of sand alongshore may be incorporated as a boundary condition if one is located on an end of the calculation grid. If located on the internal domain of the grid, these objects will act to constrain the transport rate and shoreline change that is automatically calculated by GenCade. The representation is the same for both cases, although it occurs in different places in the numerical solution scheme.

The effect of a groin, headland, or similar object located on the boundary is formulated in terms of the amount of sand that can pass the structure. Consideration must be given to sand entering and leaving the grid. For example, at a jetty located next to an inlet with a deeply dredged navigation channel, sand might move offshore of the jetty during times of high waves; in contrast, in the absence of shoals that might feed the beach, no sand is expected to cross the navigation channel and jetty to come onto the grid. The jetty/channel thus acts as a selective "gate," allowing sand to move off but not onto the grid.

As stated in Section 'Structures in GenCade' below, bypassing around groins and jetties is controlled by the ratio D_G/D_{LT}, where D_{LT} (m) is the depth out to which longshore sediment transport occurs and D_G (m) is the depth at the seaward tip of the structure on the updrift side. This depth is, in turn, controlled by the distance from the structure tip to the shoreline. Also, to calculate transport at the groin/jetty location the shoreline orientation is needed, which depends on the shoreline locations on either sides of the structure. One problem with groins and jetties adjacent to inlets is that there is no shoreline on one side of the structure. For groins/jetties located on the lateral model boundary, the shoreline location outside the grid is not known. Similarly, for jetties adjacent to inlets there is no shoreline on the inlet side of the structure. So, the user needs instead to specify a bypass coefficient that will control the bypassing around this structure. The bypass coefficient BC is defined as (Figure 7):

$$BC = \left(Y_{gro} - Y_{vir}\right) / \left(Y_{gro} - Y_{nxt}\right) \tag{17}$$

where Y_{gro} is the length of the groin, Y_{vir} is the virtual shoreline location (inside the inlet channel or just off the model grid), and Y_{nxt} is the shoreline location just next to the structure. The default value of BC is 1, but may be manually set to any value ≥ 0. If BC is set to <1, less sediment will go into the inlet channel (if next to an inlet) or out of the model area (if next to the model boundary). In both situations the accumulation against the structure (Y_{nxt}) will increase. For $BC > 1$, the opposite will happen. Thus, a constructive strategy could be to start with the default value *BC* = 1 and then increase or decrease *BC* depending on whether more or less accumulation is desired against the structure.

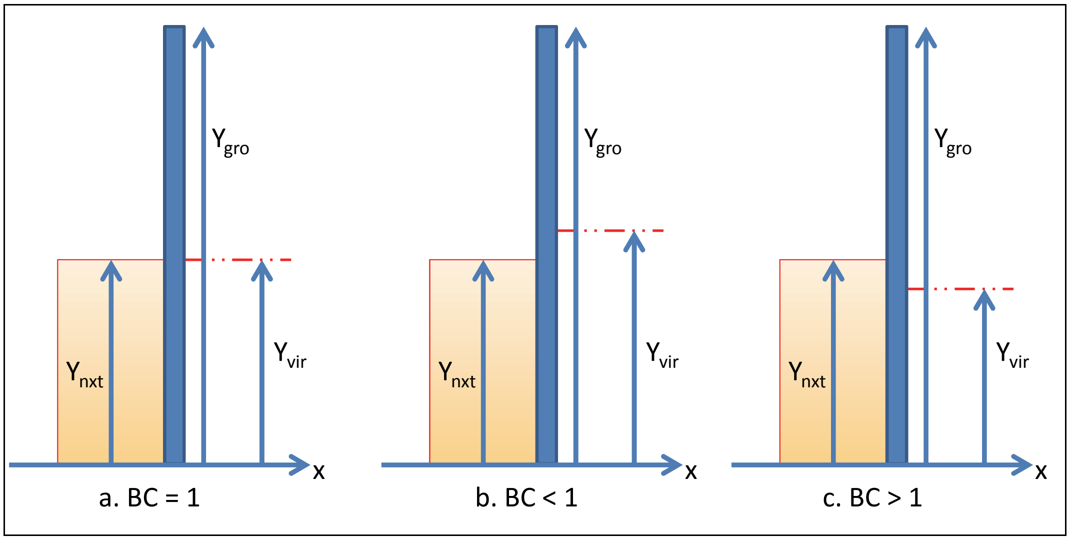


Figure 7. Schematics illustrating the meaning of the Bypass Coefficient *BC* depending on its value.

2.7 Numerical stability

The GenCade model utilizes an explicit solution scheme. The main advantages of this scheme are: easy programming, simple (and sometimes the only possible) expressions of boundary conditions, and shorter computer run-time as compared to an implicit scheme (for a single time increment). A major disadvantage is, however, the stability of the solution. This means that smaller time steps are often needed, and thus a larger number, when using an explicit scheme as compared to using an implicit scheme. As a consequence, simulations using explicit schemes often require a longer total computation time. To minimize the computational effort, the longest time step that may be used for a specific calculation must be determined. Under certain idealized conditions, Equation (2) can be reduced to a simpler form to examine the dependence of the solution on the time and space steps. First, rewrite Equation (2) in the form:

$$Q = Q_o \left[a_1 \sin 2\alpha_{bs} - a_2 \cos \alpha_{bs} \frac{\partial H_b}{\partial x} \right] \tag{18}$$

where $Q_o = H_b^2 C_{gb}$ (m³/sec). A useful approximate stability criterion can be obtained by linearizing Equation (1) with respect to y. The linearization is made by assuming small breaking wave and shoreline angles, which leads to $\sin 2\alpha_{bs} \approx 2\alpha_{bs}$ and $\alpha_{bs} = \alpha_b - \operatorname{atan}(\partial y / \partial x) \approx \alpha_b - \partial y / \partial x$ where α_{bs} = angle of breaking waves to the local shoreline orientation, α_b = angle of breaking waves to the x-axis, and $\partial y / \partial x$ is the local shoreline orientation. Assuming $\partial q / \partial x \approx 0$, Equation (1) becomes (Kraus and Harikai 1983):

$$\frac{\partial y}{\partial t} = (\varepsilon_1 + \varepsilon_2)\frac{\partial^2 y}{\partial x^2} \tag{19}$$

where

$$\varepsilon_1 = \frac{2Q_o a_1}{D_B + D_C}$$

and

$$\varepsilon_2 = \frac{Q_o a_2 sin\alpha_b}{D_B + D_C}\frac{\partial H_b}{\partial x}$$

In the presence of an external current not generated by breaking waves, the second diffusion coefficient in Equation (19) will change to:

$$\varepsilon_2 = \frac{Q_o \sin \alpha_b}{D_B + D_C}\left(a_2 \frac{\partial H_b}{\partial x} - a_3 \frac{\overline{v}_t}{u_m}\right)$$

As Equation (19) is a diffusion-type equation, its stability properties are well known. The numerical stability of the calculation scheme is governed by:

$$R_s = \frac{\Delta t(\varepsilon_1 + \varepsilon_2)}{(\Delta x)^2} \tag{20}$$

where the quantity R_s is known as the Courant number in numerical methods; here it is called the stability parameter. The finite difference form of Equation (19) shows that $\Delta y \sim \Delta t/(\Delta x)^2$ which means that if Δx is reduced by a factor of two, the time step will need to be reduced by a factor of four to maintain the same stability of the calculation scheme.

As stated above, if Equation (19) is solved using an explicit scheme (as done in GenCade), preservation of stability of the solution imposes a severe constraint on the longest possible calculation time step for given values on model constants and parameters. If an explicit solution scheme is used to solve the diffusion equation, the following condition must be satisfied (Crank 1975):

$$R_s \leq 0.5 \tag{21}$$

If the value of R_s exceeds 0.5 at any point on the grid, the calculated shoreline will show an unphysical oscillation that will grow in time if R_s remains above 0.5, alternating in direction at each grid point. The quantities ε_1 and ε_2 can change greatly alongshore since they depend on the local wave conditions. Assuming that the grid cell spacing is fixed by engineering requirements, a large wave height would necessitate a small value of Δt. The GenCade model will issue a warning if the stability requirement is violated at any point in the scheme. If such a warning is issued, either the time step Δt or the spatial resolution 1/Δx (or both) will need to be reduced. Thus, it is necessary to increase Δt and/or decrease Δx.

2.8 Empirical parameters

2.8.1 Depth of longshore transport

The width of the profile over which longshore transport takes place under a given set of wave conditions is needed to estimate the amount of sand (percentage of total) bypassing occurring at groins and jetties. Since the major portion of alongshore sand movement takes place in the surf zone, this distance is approximately equal to the width of the surf zone, which depends on the incident waves, principally the breaking wave height.

In GenCade, the sand bypassing algorithm requires a depth of active longshore transport, which is directly related to the width of the surf zone under the assumption that the profile is a monotonically increasing function of distance offshore. This depth of active longshore transport, D_{LT} (m), is defined and set equal to the depth of breaking of the highest one-tenth waves at the updrift side of the structure. Under standard assumptions, this depth is related to the significant wave height H_s (m) used throughout GenCade by:

$$D_{LT} = \frac{1.27}{\gamma} H_b \tag{22}$$

in which 1.27 is the conversion factor between the one-tenth highest wave height and significant wave height. The depth defining the seaward extent of the zone of active longshore transport D_{LT} is typically much less than the depth of closure D_C, except under extremely high wave conditions.

GenCade uses another characteristic depth, termed the maximum depth of longshore transport, D_{LTo}, to calculate the average beach slope $\tan\beta$ appearing in Equations. (5, 6, and 10), as described in the next section. The quantity D_{LTo} is calculated as:

$$D_{LTo} = 2.28H_o - 10.9H_o^2 / L_o \tag{23}$$

in which, H_o is significant wave height in deep water (m), L_o is wavelength in deep water (m).

The deepwater wavelength is calculated from linear wave theory as $L_o = gT^2/(2\pi)$, in which g is the acceleration due to gravity, and T is the wave period. If spectral wave information is given, T is taken as the peak spectral wave period; otherwise, it is the period associated with the significant waves. Equation (23) was introduced by Hallermeier (1983) to estimate an approximate annual limit depth of the littoral zone under extreme waves. In the framework of GenCade, D_{LTo} is calculated at each time step from the deepwater wave data and is assumed to be valid over the entire longshore extent of the modeled reach. Since wave characteristics vary seasonally, this definition of the maximum depth of longshore transport will reflect changes in average profile shape and beach slope, as described next.

2.8.2 Average profile shape and slope

The shoreline change equation does not require specification of the shape of the bottom profile since it is assumed that the profile moves parallel to itself. However, to determine the location of the breaking waves alongshore and calculate the average nearshore bottom slope used in the longshore transport equation, a profile shape must be specified. For this purpose, the equilibrium profile shape deduced by Bruun (1954) and Dean

(1977) is used. They demonstrated that the average profile shape for a wide variety of beaches can be described by the simple mathematical function:

$$D = Ay^{2/3} \tag{24}$$

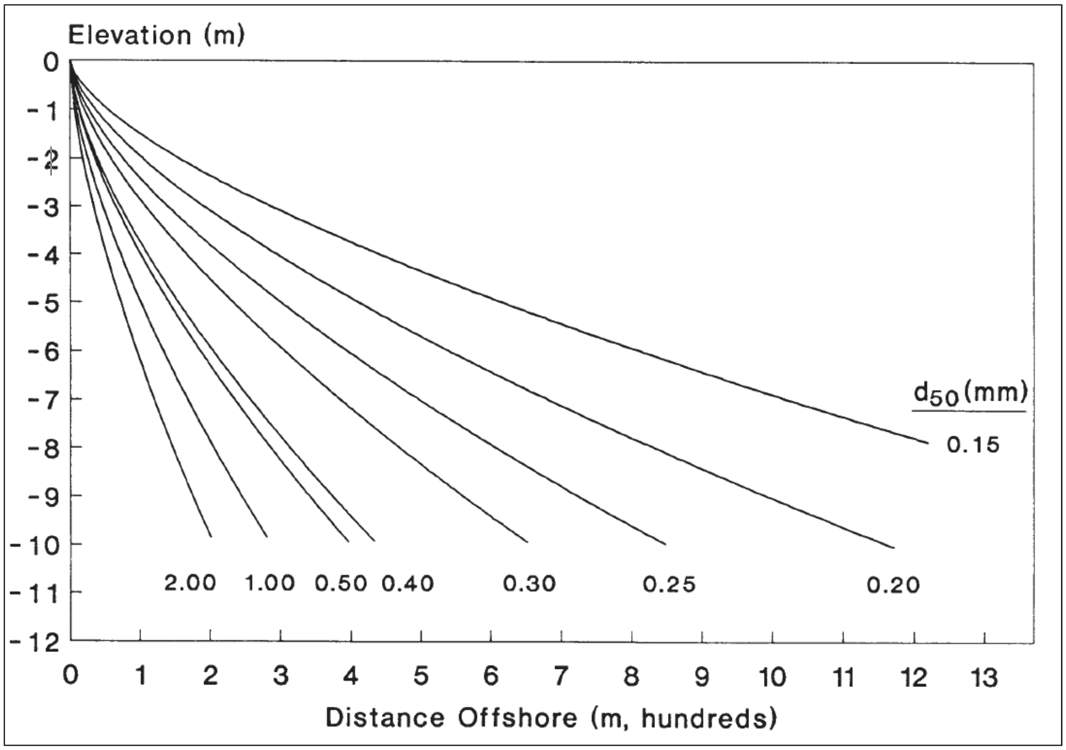
in which D is water depth (m), and y = distance from the shoreline (m). The scale parameter A ($m^{1/3}$) has been shown by Moore (1982) to depend on the median beach grain size d_{50} (mm), which in turn affects the fall velocity w_s (m/sec) as $A = 2.25\left(w_s^2 / g\right)^{1/3}$ (Kriebel et al. 1991). If beach survey profiles for the target beach are available, it is recommended that the modeler use the curves in Figure 8 (8a for metric units or 8b for American customary units) as templates to determine an '*effective*' median grain size. The '*effective*' grain size, if supplied to GenCade, will produce an A-value that will give the most representative profile shape. If profile survey data are lacking, the median grain size of the surf zone sand should be used. Table 1 is based on the methodology proposed in Moore 1982 and shows a summary of recommended A-values for grain size diameters.

The average nearshore slope $\tan\beta$ for the equilibrium profile defined by Equation (24) is calculated as the average value of the integral of the slope $\partial D / \partial y$ from 0 to y_{LT}, resulting in $\tan\beta = A\left(y_{LT}\right)^{-1/3}$, in which y_{LT} is the width of the littoral zone (m), extending seaward to the depth D_{LTo}. Since by definition, $y_{LT} = \left(D_{LTo} / A\right)^{3/2}$, the average nearshore slope is calculated to be:

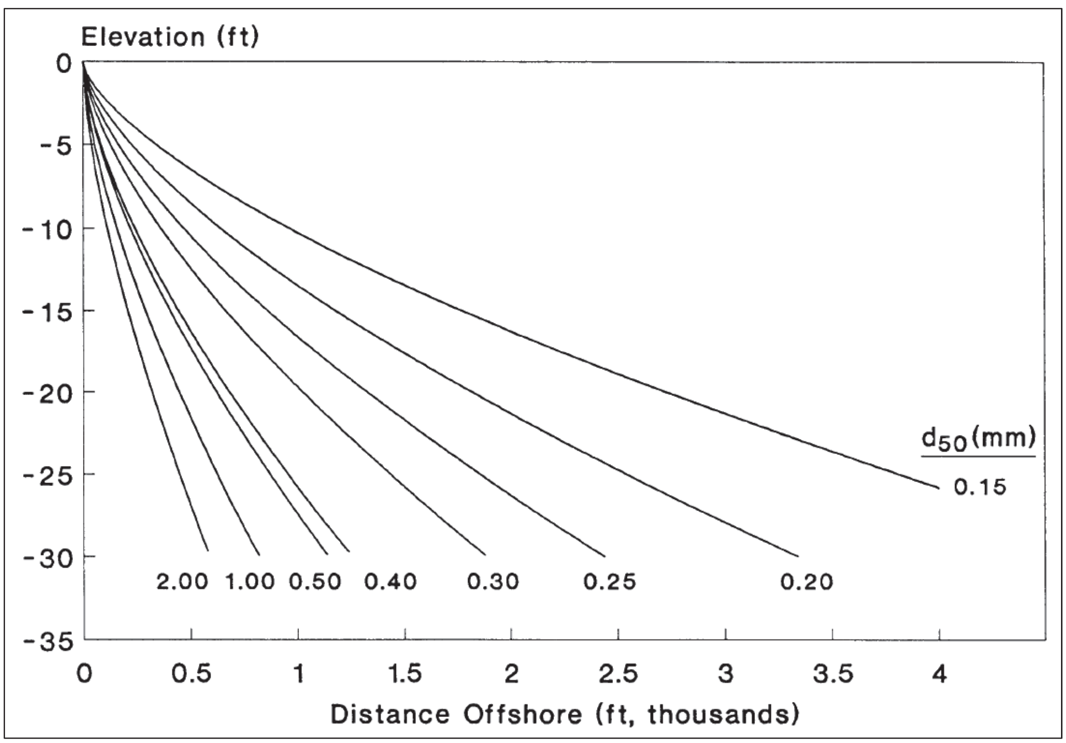
$$\tan\beta = \left(\frac{A^3}{D_{LTo}}\right)^{1/2} \tag{25}$$

2.8.1 Depth of closure

The depth of closure, D_C, the seaward limit beyond which the profile does not exhibit significant change in depth, must be specified by the user. Empirically, the location of the closure depth, D_C, cannot be identified with confidence, as small bathymetric change in deeper water is extremely difficult to measure. This situation usually results in a depth of closure located somewhere in a wide range of values, requiring judgment to be exercised to specify a single value. Often profile surveys are not available to a sufficient depth and with sufficient vertical and horizontal control to



a. Metric units.



b. American customary units.

Figure 8. Template to determine the 'effective' grain size.

Table 1. Summary of recommended A-values ($m^{1/3}$) for diameters from 0.10 to 1.09 mm (From Moore 1982).

d (mm)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.1	0.0471	0.0515	0.0559	0.0602	0.0646	0.0689	0.0732	0.0775	0.0818	0.0861
0.2	0.0903	0.0946	0.0988	0.1030	0.1072	0.1114	0.1156	0.1197	0.1239	0.1281
0.3	0.1322	0.1364	0.1405	0.1446	0.1487	0.1528	0.1569	0.1610	0.1651	0.1692
0.4	0.1715	0.1729	0.1742	0.1756	0.1769	0.1781	0.1794	0.1806	0.1819	0.1831
0.5	0.1842	0.1854	0.1866	0.1877	0.1888	0.1900	0.1911	0.1921	0.1932	0.1943
0.6	0.1953	0.1964	0.1974	0.1984	0.1994	0.2004	0.2014	0.2023	0.2033	0.2042
0.7	0.2052	0.2061	0.2070	0.2080	0.2089	0.2098	0.2107	0.2115	0.2124	0.2133
0.8	0.2141	0.2150	0.2158	0.2167	0.2175	0.2183	0.2192	0.2200	0.2208	0.2216
0.9	0.2224	0.2232	0.2239	0.2247	0.2255	0.2263	0.2270	0.2278	0.2285	0.2293
1.0	0.2300	0.2307	0.2315	0.2322	0.2329	0.2336	0.2343	0.2350	0.2357	0.2364

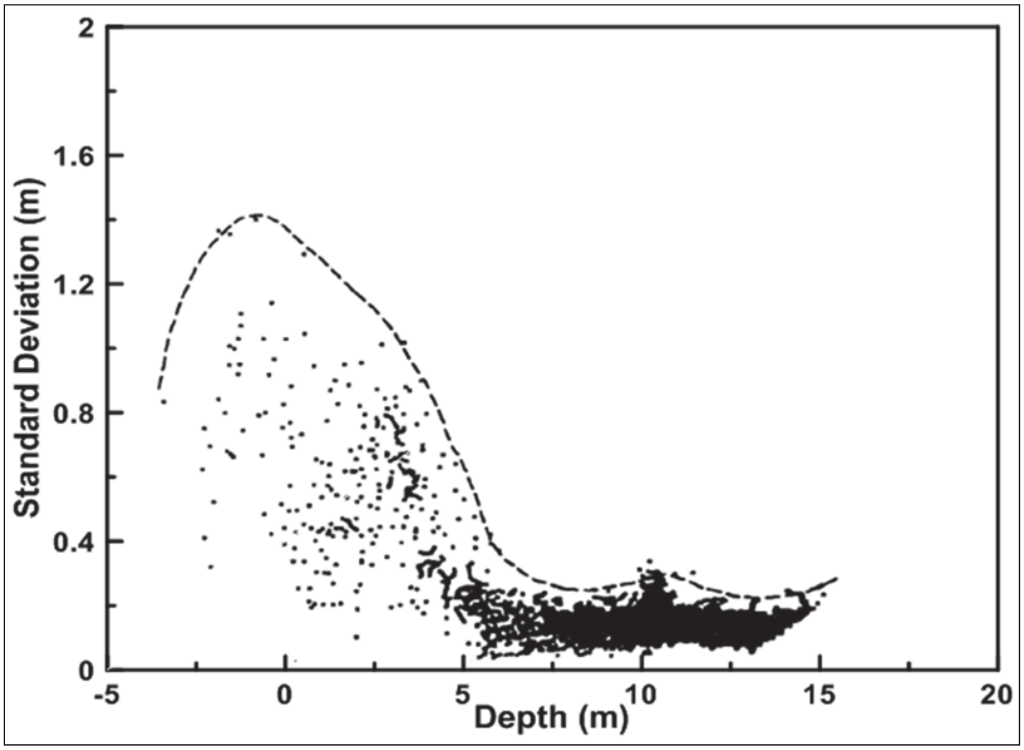
allow comparisons of profiles to be made. Figure 9a shows the standard deviation of depth values from five wide-scale bathymetric surveys plotted as a function of mean depth for Oarai, a Pacific Ocean beach in Japan (Kraus and Harikai 1983). Figure 9b shows a similar plot composed of data from multiple profile surveys made over a 4-year period along 9 transects at Oceanside, California.

Changes in the profile are minimal at a depth of about 6 m for the case of Oarai and at about 30 ft (9 m) for the case of Oceanside. These values were used as the depths of closure D_C in the respective shoreline response model configurations.

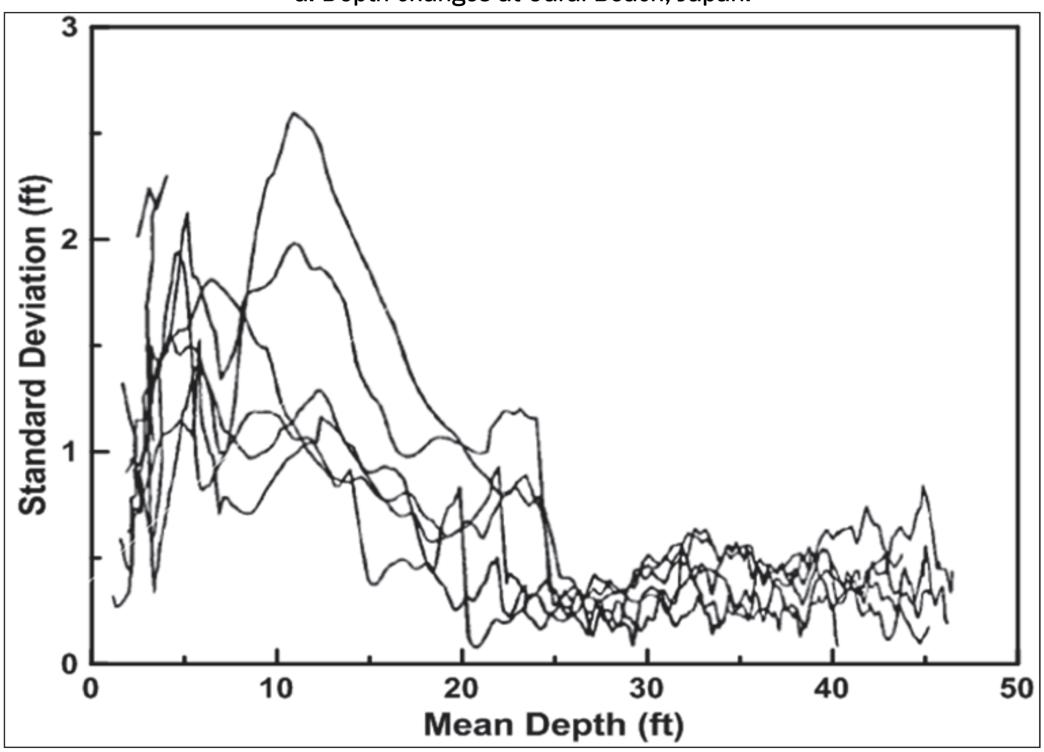
2.9 Wave calculation

Offshore wave information can be obtained from either “numerical” gages, *i.e.*, from a hindcast calculation, or from actual wave gages. Wave data are input to the model at a fixed time interval, typically in the range of 3-24 hr.

One submodel in GenCade is a wave model which calculates breaking wave height and angle alongshore as determined from wave information given at a reference depth offshore, under simplified conditions. This submodel is called the *internal wave model*. If the *internal wave model* cannot be used, a completely independent, *external wave model*, may be used to supply nearshore wave information to GenCade.



a. Depth changes at Oarai Beach, Japan.



b. Depth changes at Oceanside, California.

Figure 9. Empirical determination of the depth of closure, D_C.

Use of the internal and external wave models is depicted in Figure 10. The internal model is applicable to a sea bottom with approximately straight and parallel contours, and breaker height and angle are calculated at grid points alongshore starting from the reference depth of the offshore wave input (Figure 10a). If an external wave model is used (Figure 10b), it calculates wave transformation over the actual (irregular) bathymetry starting at the offshore reference depth. Resultant values of wave height and direction at depths alongshore for which wave breaking has not yet occurred are placed in a file (by the modeler) for input to the internal wave model. These depths, taken, for example, as the depths in each wave calculation cell immediately outside the 6-m (20-ft) contour, define a “nearshore reference line,” from which the internal wave model in GenCade takes over grid cell by grid cell to bring the waves to the breaking point. If structures which produce diffraction are located in the modeling reach, the internal model will automatically include the effect of diffraction in the process of determining breaking wave characteristics.

2.10 Internal wave transformation model

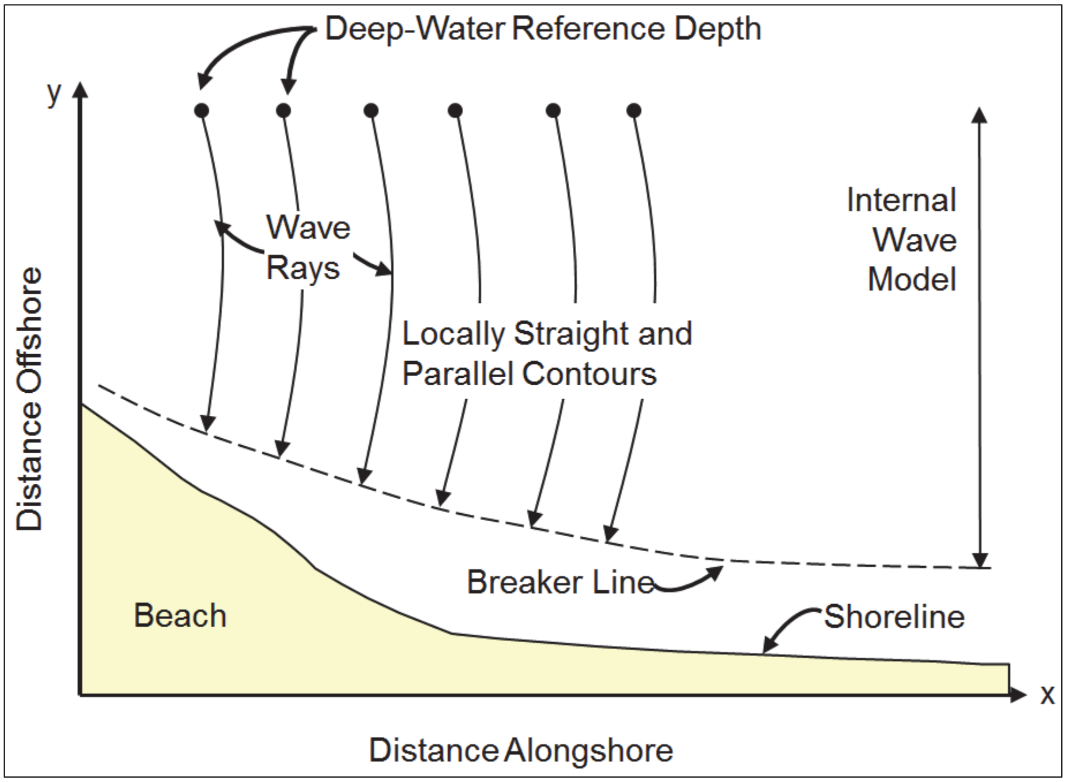
2.10.1 Breaking waves

Wave transformation from the deepwater reference depth or the nearshore reference line (depending on whether or not the external wave model is used) is initially conducted without accounting for diffraction from structures located in the model reach. The solution strategy is to obtain a first approximation of breaking wave conditions without including diffraction and then modify the result by accounting for changes to the wave field by each diffraction source.

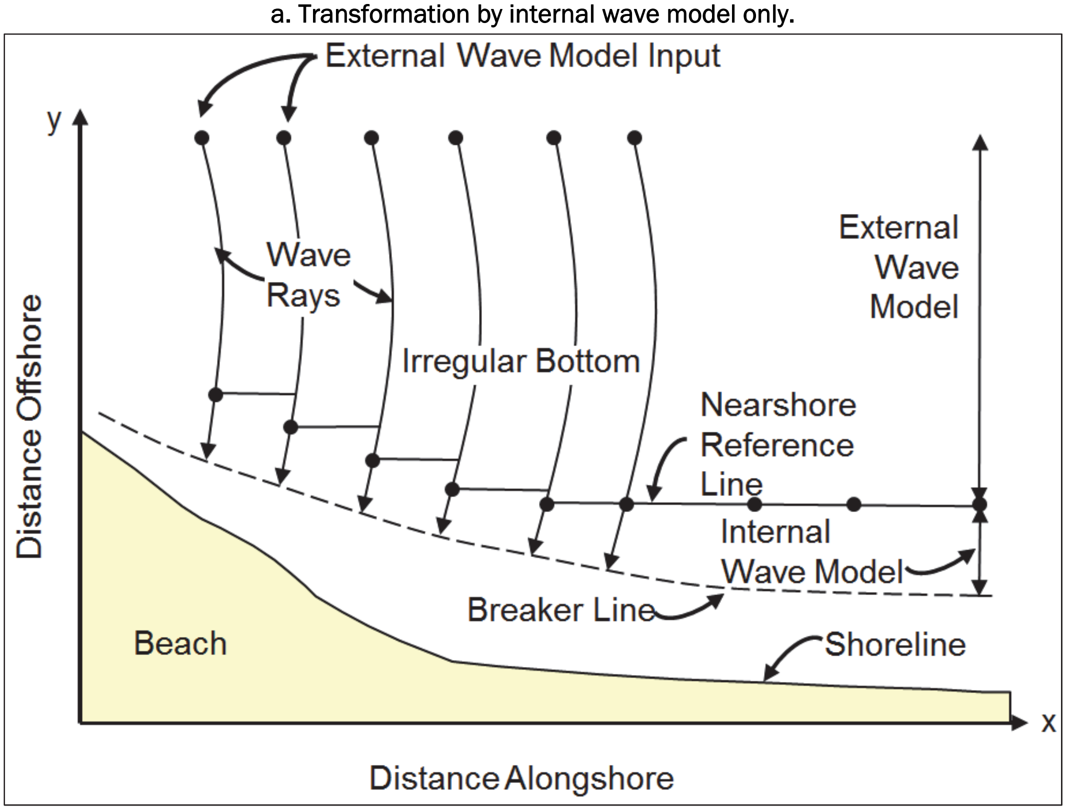
Omitting diffraction, there are three unknowns in the breaking wave calculation: the wave height, angle, and the depth at breaking. Three equations are needed to obtain these quantities, which are introduced below. These are the equation for the breaking wave height based on reference wave data (Equation 26); a depth-limited breaking criterion (Equation 28); and a wave refraction equation (Snell’s law).

Equation (26) is used to calculate the height of breaking waves which have been transformed by refraction and shoaling:

$$H_b = K_R K_S H_{ref} \tag{26}$$



a. Transformation by internal wave model only.



b. Transformation by external and internal wave models.

Figure 10. Operation of wave transformation models.

where H_b = breaking wave height at an arbitrary point alongshore, K_R = refraction coefficient, K_S = shoaling coefficient, H_{ref} = wave height at the offshore reference depth or the nearshore reference line depending on which wave model is used. The refraction coefficient K_R and the shoaling coefficient K_S are calculated in the classical way as:

$$K_R = \sqrt{\frac{\cos\theta_1}{\cos\theta_2}} \quad \text{and} \quad K_S = \sqrt{\frac{C_{g1}}{C_{g2}}} \tag{27}$$

where θ_1 is the starting angle of the ray and θ_2 the angle of arrival at P_2, the location of which is determined by the breaking depth, and C_{g1} and C_{g2} are the group velocities at respective depths (m/sec). The equation for depth-limited wave breaking is given by:

$$H_b = \gamma d_b \tag{28}$$

in which γ is taken to be 0.78.

If there are no structures to produce diffraction, the undiffracted wave characteristics are used as input to the sediment transport relation (Equation 4). If such obstacles are present, breaking wave heights and directions are recalculated, as described next.

2.10.2 Breaking waves affected by structures

Structures such as detached breakwaters, jetties, and groins which extend well seaward of the surf zone intercept the incident waves prior to breaking. Headlands and islands (specified as structures in GenCade) may also intercept waves. In the following discussion, all such objects are referred to as structures. Each tip of a structure will produce a near-circular wave pattern, and this distortion of the wave field is a significant factor controlling the response of the shoreline in the lee of the structure. Sand typically accumulates in the diffraction shadow of a structure, being transported from one or both sides by the oblique wave angles in the circular wave pattern and the decrease in wave height alongshore with penetration into the shadow region. Accurate and efficient calculation of waves transforming under combined diffraction, refraction, and shoaling to break is required to obtain realistic predictions of shoreline change in such situations.

Figure 11 is a definition sketch of the calculation procedure for the breaking wave height and angle behind a structure (Kraus 1981, 1982, 1984). Conceptually, the area of interest is separated into a shadow region and an illuminated region by a wave ray directed toward the beach from the tip of the structure at the same angle as the incident waves arriving at the tip. To determine the breaking wave height, a diffraction coefficient must be calculated in both regions because the diffraction effect can extend far into the illuminated region. To determine the breaking wave angle inside the shadow region, wave rays are assumed to proceed radially from the tip of the structure P_1 at an angle θ_1 to arrive at some point P_2 with an angle θ_2, where they break.

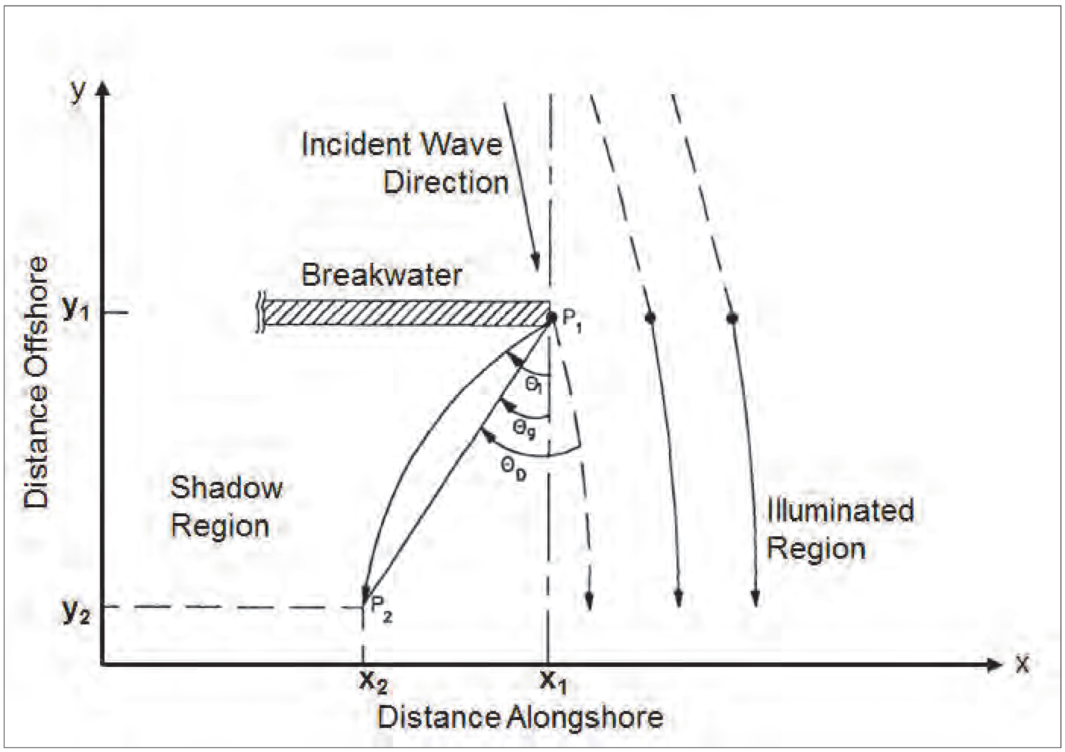


Figure 11. Definition sketch for wave diffraction calculation.

The angle θ_1 at which a wave ray must start to arrive at P_2 inside the shadow region is not known a priori since it is a function of the breaking criterion as well as the distance alongshore defining the location of grid cells in the numerical calculation. A ray shooting technique can be used to determine θ_1 (Kraus 1982, 1984), but this procedure is complex and requires considerable execution time. As a first approximation, the geometric angle θ_g defined by the straight line between P_1 and P_2 is used.

Due to the impact of diffraction, the wave height is reduced and, thus, the wave is not breaking. An iterative procedure is used to find the location where the wave, which has been transformed by diffraction, refraction, and shoaling, is breaking. At breaking, the wave fulfills the two conditions:

$$H_b = K_D\left(\theta_D\right)H_b^{'} \quad \text{and} \quad H_b = \gamma d_b \tag{29}$$

where K_D is a diffraction coefficient, θ_D is the angle between incident wave ray at P_1 and a straight line between P_1 and P_2, if P_2 is in the shadow region, H'_b is the breaking wave height at the same cell without diffraction.

For waves that are inside two overlapping shadow zones, an average θ_g is calculated together with a composite K_D coefficient for the two diffracting systems. Then, the same iteration procedure as the one used inside one diffraction system is used. In the illuminated region a similar procedure is used, where a composite K_D is used, but instead of a θ_g, the undiffracted wave direction is used.

Because GenCade was developed to simulate waves and shoreline change in the field, the procedure of Goda et al. (1978) (see also, Goda (1984)) was adapted. Details of application of the method to calculate wave breaking produced by combined diffraction, refraction, and shoaling as used in GenCade are given by Kraus (1981, 1982, 1984, 1988). For given wave conditions at the diffracting tip, the diffraction coefficient is only a function of θ_D. In GenCade, it is assumed that the method is valid for relatively short structures such as detached breakwaters.

2.10.3 Smoothed nearshore contour - ISMOOTH

A basic assumption in the formulation of the shoreline change model is that the profile moves parallel to itself. As a consequence, bottom contours would move parallel to the shoreline. If this assumption is applied directly in the internal wave model, unrealistic wave transformation can result in regions where the shoreline position changes relatively abruptly, possibly leading to numerical instability. The use of the smoothed contour recognizes that the shoreline evolution feeds back on the nearshore bathymetry without having to be a direct replica of the shoreline.

GenCade uses a smoothed bottom contour in performing the internal wave calculation, as illustrated in Figure 12. In this figure, the shore-parallel contour shown changes radically at the groin. The smoothed contour is expected to better represent the offshore bathymetry. The smoothed contour shape is calculated as a running average using a window size containing the number of cells as specified by the input parameter ISMOOTH. A larger value of ISMOOTH will result in an offshore contour that has less curvature. An extreme case of ISMOOTH = 1 would result in an offshore contour that would be parallel to the shoreline (as the dash-dotted line in Figure 12) whereas ISMOOTH = N would result in a straight contour line parallel to the *x*-axis. ISMOOTH must always be a positive, odd number. If an even number is entered for ISMOOTH, the model automatically resets the value of ISMOOTH to equal ISMOOTH-1 (and therefore an odd number). If a negative value is entered for ISMOOTH, the model automatically resets the value of ISMOOTH to equal 1. At the lateral boundaries (i.e., X=1 and X=N), the moving average calculates values less than: [(ISMOOTH -1)/2] by interpolation from the boundary value to the first smoothed value. The calculated contour is assumed to be representative for all contour lines between the input wave depth and the undiffracted wave breaking depth. The shape of the representative offshore contour is recalculated continuously using the shoreline position at that time. It is recommended that the user vary the ISMOOTH value to obtain a more realistic shoreline evolution. Too small values often lead to large angles between the waves and the shoreline which may produce unrealistic transport directions.

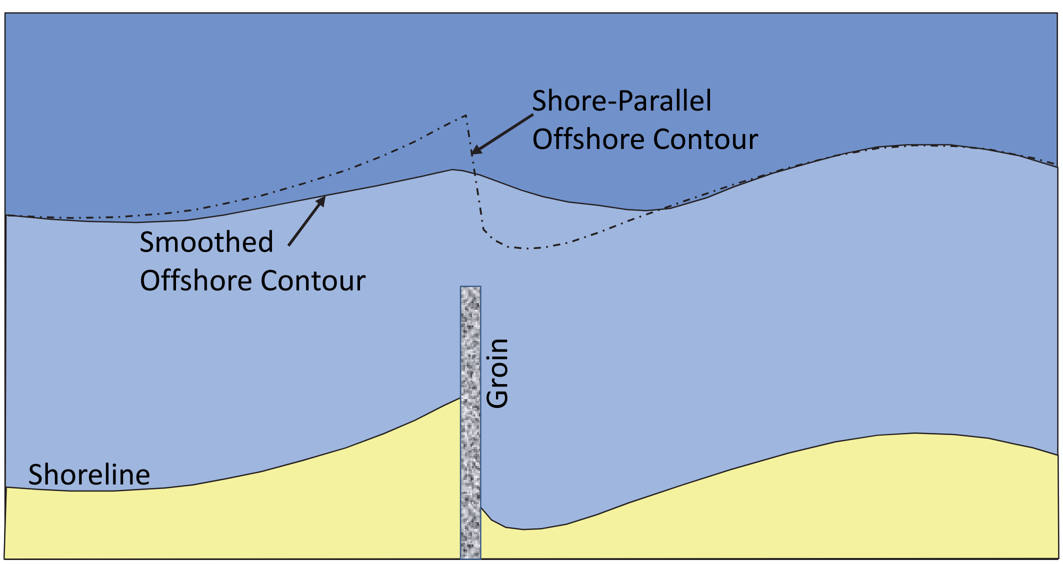


Figure 12.Example of smoothed offshore bottom contour.

2.10.4 Pre-specified regional contour

In GenCade, all waves are transformed with respect to the bottom contour orientation, upon which the incoming waves are refracted. This bottom contour orientation (i.e., the offshore contour) is calculated as a smoothed rendering of the shoreline orientation using ISMOOTH as discussed in the previous section. This is to ensure that the incident breaking waves are realistically described while preserving some feedback from the shoreline change to the transformation of the waves (Kraus and Harikai 1983). However, this methodology has two limitations: 1) dominant local or regional bathymetric features are not well represented, and 2) an open coast without structures or sources or sinks of sediment will evolve to a straight line if the model is run for a sufficiently long duration. If a 2-D external wave model is employed to transform waves from the offshore, the GenCade internal transformation is still applied, but only from the depth of the 2-D external wave model output point to the breaking point.

These limitations can be remedied by specifying a fixed representative regional contour (Larson et al. 2003) that is appended to the nearshore contour calculated based on ISMOOTH. Correctly specified, GenCade will maintain a desired overall shoreline curvature, *e.g.* preserving a bay shape without the presence of structures, even if the model is run for very long time periods. As a result, the shoreline will, on an open coast without structures, gradually evolve into the shape of the regional contour rather than into a straight line. Figure 13 illustrates the impact of the regional contour on the long-term evolution of a concave embayment with open lateral boundaries, but without any structures. Without the regional contour (Figure 13a) the embayment will gradually fill, and the shoreline will evolve into a straight line. However, with the regional contour (Figure 13b), the shoreline evolution will be guided by the contour. Gradually, the shoreline will become parallel to the regional contour rather than to a straight line.

Adding a regional contour represents a simplified method to describe the effects on the shoreline evolution of processes acting at longer time scales than what is simulated in GenCade (*i.e.*, hundreds of years). At the time scales characteristic for GenCade simulations, the influence of these processes is included through the constraints controlling shoreline response provided by the regional contour. Thus, the regional contour should incorporate large-scale trends in shoreline shape, and not small-scale features that are expected to change at time scales modeled by

GenCade. Typically the regional contour is kept constant during a simulation, since changes in the contour shape would occur over time scales not described by GenCade.

Mathematically, adding the regional contour in the wave transformation and longshore sediment transport calculations has the same effect as introducing a small modification to the breaking wave angle alongshore that forces the shoreline to maintain the large-scale shape specified by the contour. Thus, the processes described by GenCade, for example, the influence of structures, inlets, sources, and sinks, produce shoreline changes as perturbations on the contour. It should be stressed that the alongshore spatial gradient in the regional contour is small and locally the curvature may not be easily discerned, but to achieve satisfactory modeling results it may be important to include the contour, if a straightening of the shoreline occurs that is not in agreement with observations.

It may not be an easy task to specify the shape of the regional contour. Typically a limited set of historic shorelines are available and only from recent times (*e.g*., within the latest hundred years). However, if there are shorelines available over a longer time period, they may provide a basis for deriving the shape of the regional contour. Several consecutively measured shorelines may indicate persistent large-scale spatial features that are suitable to describe through the regional contour. To extract those features, different types of techniques for filtering or pattern extraction could be employed, including moving-average methods and principal component analysis. A single shoreline may also be used to derive the regional contour, if something subsequently occurs that markedly disturbs the coastal system, for example an inlet or the introduction of an engineering structure or activity. In such cases, the measured shoreline, characterizing the undisturbed state, could be employed to determine the regional shoreline. Again, it is important to point out that the regional contour should reflect large-scale shapes that are results of processes acting at time scales longer than what is described in GenCade, and the contour should not be used to calibrate shoreline features that originate from processes within time scales simulated by GenCade.

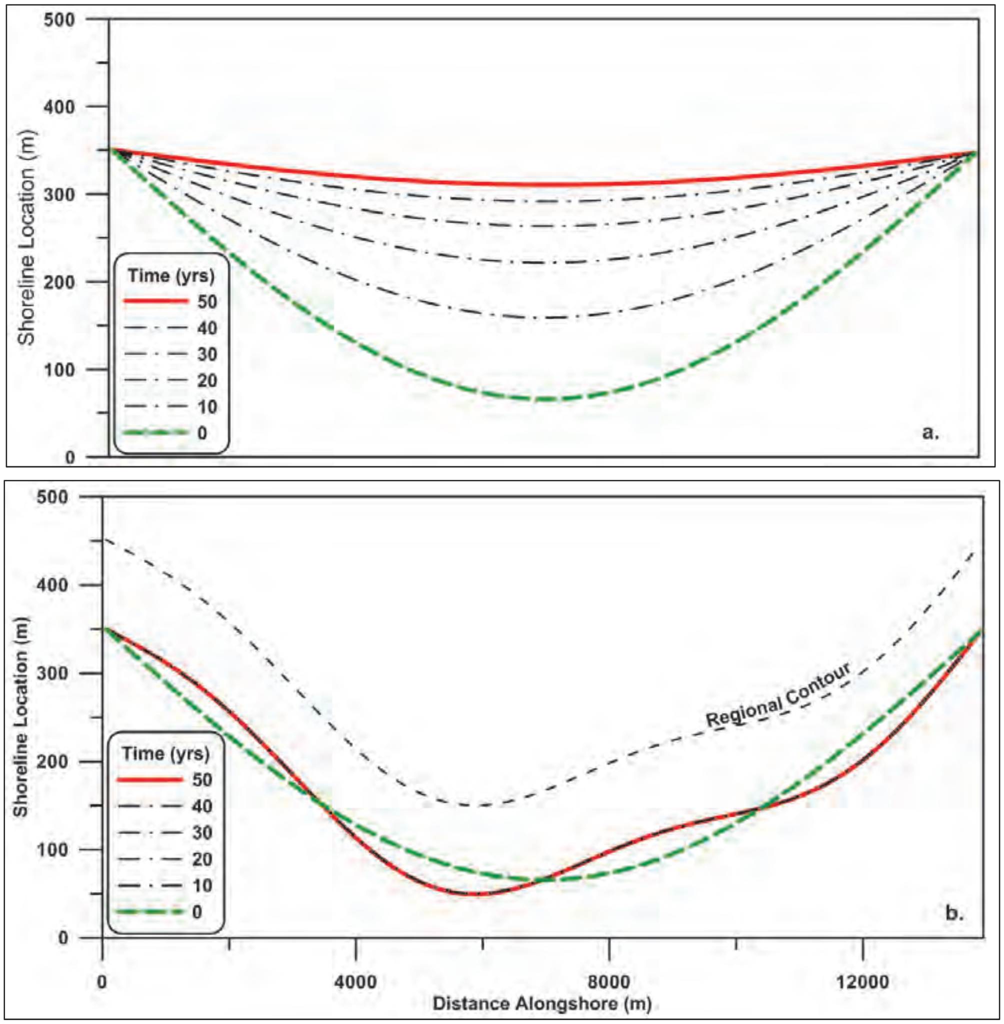


Figure 13. Long-term (50 years) simulations of concave embayment with open lateral boundaries with free influx of sediment. (a) illustrates a situation without regional contour; (b) illustrates a situation with regional contour. Without the regional contour the embayment will gradually fill in totally, if the simulation is long enough. With a regional contour, this will determine the long-term shape of the embayment.

2.11 Representation of inlets

Morphology change at inlets and their interaction with adjacent beaches is of great importance for many coastal areas. GenCade employs the Inlet Reservoir Model (IRM) as first presented in Kraus (2000) and further developed by Larson et al. (2003, 2006). Each inlet is represented by six morphological elements (shoals and bars) plus the inlet channel (Figure 14). Each morphological element is, in turn, represented by an actual sand volume V_x and an equilibrium volume V_{xq}, where the subscript x is a placeholder for subscripts a (attachment bars), b (bypass bars), e (ebb shoal), or f (flood shoal). Each morphological element is assumed to have a certain equilibrium volume for fixed hydrodynamic and sediment conditions. The flux of sediment out of each morphological element is given by:

$$Q_{ox} = Q_{ix} \frac{V_x}{V_{xq}} \tag{30}$$

where Q_{ox} represents the flux out of the element x and Q_{ix} the flux into the element. The attachment and bypass bars also have a third index, l or b, in front of the other two, where index l stands for the left side of the inlet and index r stands for the right side when looking seaward from land. When the sediment transport goes from left to right, the attachment and bypass bars on the left-hand side of the inlet are not active, as the sediment is assumed to be transferred from the beach on the left-hand side onto the ebb shoal without passing through the attachment and bypass bars on that side. The corresponding situation occurs as sediment is moving from right to left.

In Figure 14, the transport goes from left to right. A transport rate Q_{lst} is moving alongshore towards the inlet, which may or may not be stabilized by a jetty. If there is a jetty, a portion of this sediment Q_j will be trapped by the jetty (thus, when no jetty, Q_j=0) whereas the remaining part Q_{in} will enter into the inlet system. A part of this rate may go to the ebb shoal, Q_{ie}, depending on how full the ebb and flood shoals are with respect to the equilibrium volume, while the other portion, Q_{ic} , will go into the inlet channel. This will, in turn, feed the ebb and flood shoals in proportion to their relative volumes. In mathematical terms, this may be expressed as:

$$Q_{ie} = \delta Q_{in}, \quad Q_{ic} = (1-\delta) Q_{in}, \quad \delta = \frac{V_e + V_f}{V_{eq} + V_{fq}} \tag{31}$$

and

$$Q_{ce} = \beta Q_{ic}, \quad Q_{cf} = (1-\beta) Q_{ic}, \quad \beta = \frac{1 - V_e / V_{eq}}{2 - V_e / V_{eq} - V_f / V_{fq}} \tag{32}$$

Unless the system is completely full at equilibrium, only a portion Q_{out} of the incoming rate Q_{in} will leave the inlet system and be transported further along the beach. Initial and equilibrium volumes of the respective morphological elements are specified as input values to the model as are the respective locations of the attachment bars.

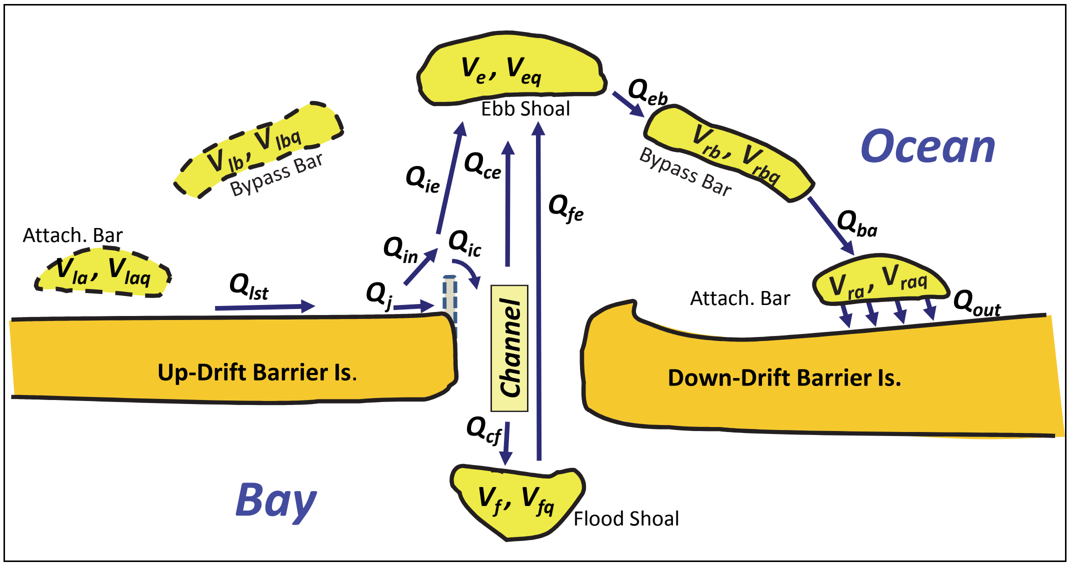


Figure 14. Schematic of the interaction between the morphological elements in an inlet.

Walton and Adams (1976) derived empirical equations for the equilibrium ebb shoal volume based on field data from 43 United States inlets. Walton and Adams' definition of the ebb shoal approximately corresponds to the sum of the IRM's volumes of the ebb shoal and bypass bars. To employ these equations for computing V_{xq} of the different morphologic units, some assumptions must be made concerning the size relationship among them. Historical aerial photographs or bathymetric surveys can be employed to determine the relative proportions of the morphological elements.

To represent an inlet that does not have ANY impact on adjacent beaches the inlet needs to fulfill ALL the three conditions below:

- Have no jetties on either side of the channel;
- Have all morphological units completely full where the initial volume of the morphological elements is equal to the equilibrium volume;
- Q_{out} on either side is released only to the first cell adjacent to the inlet.

As an illustration of the use of the inlet module in GenCade, an example from Ocean City, MD, will be briefly presented. Beaches south of Ocean City Inlet have experienced long-term shoreline recession caused by impoundment of southerly-directed longshore transport by the north jetty and capture of additional sand by the ebb tidal shoal complex. The sediment trapping capacity of the north jetty has effectively reached its maximum, with most of the sediment transported southward bypassing the jetty (Stauble et al. 1993). This sediment deposits in the entrance channel of the inlet, settles on the ebb-tidal shoal, or bypasses the inlet and supplies Assateague Island south of the inlet with material.

Since the Ocean City Inlet opened in 1933, the evolution and migration of the ebb-tidal shoal, the bypass bar, and the attachment bar have been monitored. In this particular study, only the volumetric evolution was considered to validate the IRM.

The net sediment transport Q_{lst} at the site is estimated at some 150,000 m^3/yr from north to south (Stauble et al. 1993). Equilibrium volumes of the morphological units at the inlet are estimated to be 3 Mm^3 for the ebb-tidal shoal, 7 Mm^3 for the bypass bar, and 0.5 Mm^3 for the attachment bar.

Based on these numbers, the GenCade model was run for the period from 1933 to 2013 over which period the volumetric evolution of the morphological units at the inlet were calculated (Figure 15). The symbols represent measured volumes and the lines calculated volumes. The model reproduces the measured values quite well. Based on the same numbers, it is now possible to calculate other quantities such as bypassing rates. Figure 16 (upper, dashed 'No Mining' lines) plots the values relative to the incoming longshore net transport rate. As the ebb-tidal shoal is reaching its equilibrium volume around year 2000, the relative bypass rate accordingly reaches unity. Similarly, as the attachment bar reaches its equilibrium volume around the same time, the transport rate out of that morphological unit equals the rate coming in, i.e., the rate bypassed from the bypass bar. Because the bypass is still not near its equilibrium volume, its relative bypass rate is far from unity.

With the inlet bypass representation in the GenCade model being verified, it is possible to use the model to evaluate alternatives for mining the different morphological elements of the inlet system. This capability is illustrated by a schematic example.

The example involves mining 1.5 Mm^3 of the bypass bar in 1980 (Figure 16, lower, solid and dash-dotted 'After Mining' lines). Because the bypass bar is down-drift of the ebb-tidal shoal, this latter unit will not be affected by the operation. On the other hand, the operation has immediate effect on the relative transport rates from the bypass bar and the attachment bar,

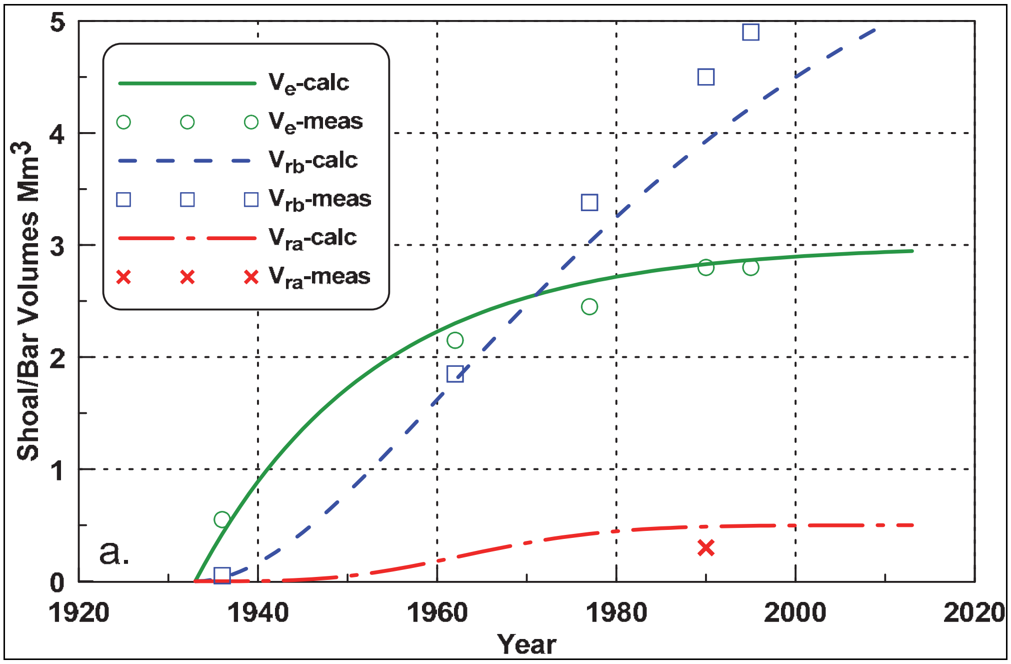


Figure 15. Calculated vs. measured volumetric evolution of morphological elements in Ocean City Inlet.

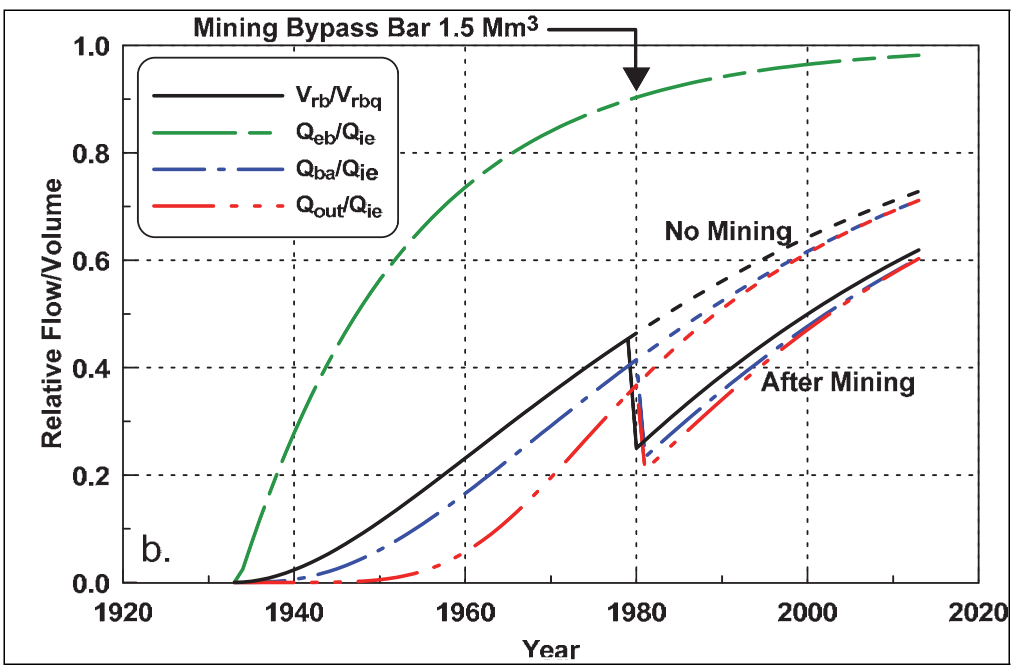


Figure 16. Impact of mining the bypass bar on volumetric evolution and relative bypassing rates. Dashed black, blue, and red lines correspond to no mining. Solid and dash-dotted lines correspond to mining of the bypass bar.

respectively. As seen in Figure 16, the volumetric development of the bypassing bar was set back 20 years. At the same time, the bypassing rate was set back 17 years for the same feature. Due to the reduced influx to the attachment bar, the bypassing rate from this feature, which is the rate that is transported to the down-drift beach, was set back 12 years. Thus, the bypassing rate to the down-drift beach was initially reduced to 54 percent of the undisturbed value. After 33 years, this number has increased to 85 percent. For this scenario, the volumetric situation in the inlet system is back to normal after about 15 years after which, in principle, the dredging operation could be repeated. This presumes, of course, that the impact on the down-drift beach is either acceptable or remedied.

2.12 Structures in GenCade

2.12.1 Types of structures

GenCade simulates the effects of common coastal structures on the shoreline position. Generic types of structures that can be represented are groins, jetties, harbor breakwaters (with respect to their functioning as a jetty or groin), detached breakwaters, seawalls, and the “soft structure” or beach fill. Considerable flexibility is allowed in combining these basic structures to produce more complex configurations, e.g., T-shaped groins, Y-shaped and half-Y groins, and jetties with spurs. Combinations of these types of structures are also possible.

In shoreline change modeling, structures exert two direct effects:

- Structures that extend into the surf zone block a portion or all of the sand moving alongshore on their updrift sides and reduce the sand supply on their downdrift sides. These structures, referred to as ‘non-diffracting’ groins or jetties, only affect the sediment transport through direct blocking and have no effect on the waves.
- Groins/jetties with seaward ends extending well beyond the surf zone, referred to as ‘diffracting groins/jetties’, and detached breakwaters, produce wave diffraction. This causes the local wave height and direction to change, altering the longshore sand transport rate. In addition to this, the diffracting groins and jetties also block the sediment transport directly.

In reality, all groins and jetties are ‘diffracting’ to some degree. As diffracting structures require substantial computational effort, the user has been given the option to classify short groins and jetties as being 'non-diffracting', to save computational time. It is up to the user to determine for which groins and jetties wave diffraction may be ignored. Preferably, comparative simulations should be run, where short groins and jetties are represented as 'diffracting' and 'non-diffracting', respectively. Comparisons of simulation results may indicate the groins and jetties for which diffraction may be ignored. Only groins and jetties may be regarded as 'non-diffracting'. Detached breakwaters are always regarded as diffracting as are groins and jetties that are combined with detached breakwaters or each other to form composite structures such as Y-groins.

2.12.2 Placement of groins, jetties, and detached breakwaters

This section describes capabilities and limitations in placing structures in GenCade. Idealized examples of plan views of various configurations are given for reference. It is noted that structures are represented as infinitesimally thin objects in the model. For example, a groin or jetty is located at the wall of a single cell and cannot occupy the position of more than one wall. In the figures below, structures are drawn thick for visibility only.

Three basic rules governing placement of groins, jetties, and detached breakwaters are:

- The position of a structure is defined by the location of its tip(s), and these positions are located at cell walls;
- There must be at least two cells between groins and jetties. As an important special case, a groin cannot be placed in the cell next to a lateral boundary;
- The locations of the tips of diffracting structures can coincide (be located at the same cell wall), but they cannot overlap.

Figures 17 and 18 give schematic examples of structure placements in GenCade. Structures that affect the waves (detached breakwaters and diffracting groins and jetties) are denoted as 'diffracting structures' and indicated by a ')))' symbol in the figures.

Figure 17 gives examples of ***allowable*** placement of structures. Non-diffracting groins/jetties may be placed behind a diffracting breakwater (but diffracting groins/jetties cannot) (upper left sketch). The other three sketches in this figure show situations involving the tips of two structures sharing the same grid cell. The tip of a detached breakwater and a diffracting groin/jetty can be at the same longshore grid cell, as can the tips of two detached breakwaters. Two or three diffracting tips may be put together to form an angled structure such as a spur groin/jetty (lower right sketch), Y-groin, angled groin, etc. In such a case, the attaching points ***must*** be located in the same cell, at the same distance offshore, and having the same depth (see text below).

Figure 18 illustrates the major ***restrictions*** on placement of structures. Groins/jetties must be placed at least two grid cells apart (upper left sketch). This is not a serious limitation, since groins in the field are typically placed one to two groin lengths apart. A groin/jetty cannot be placed in the cell adjacent to a boundary cell, whether the boundary is gated by a groin/jetty or being an open beach (upper right sketch). Diffracting structures of any type cannot overlap (lower left and lower right) (except having their tips at the same cell wall; Figure 17).

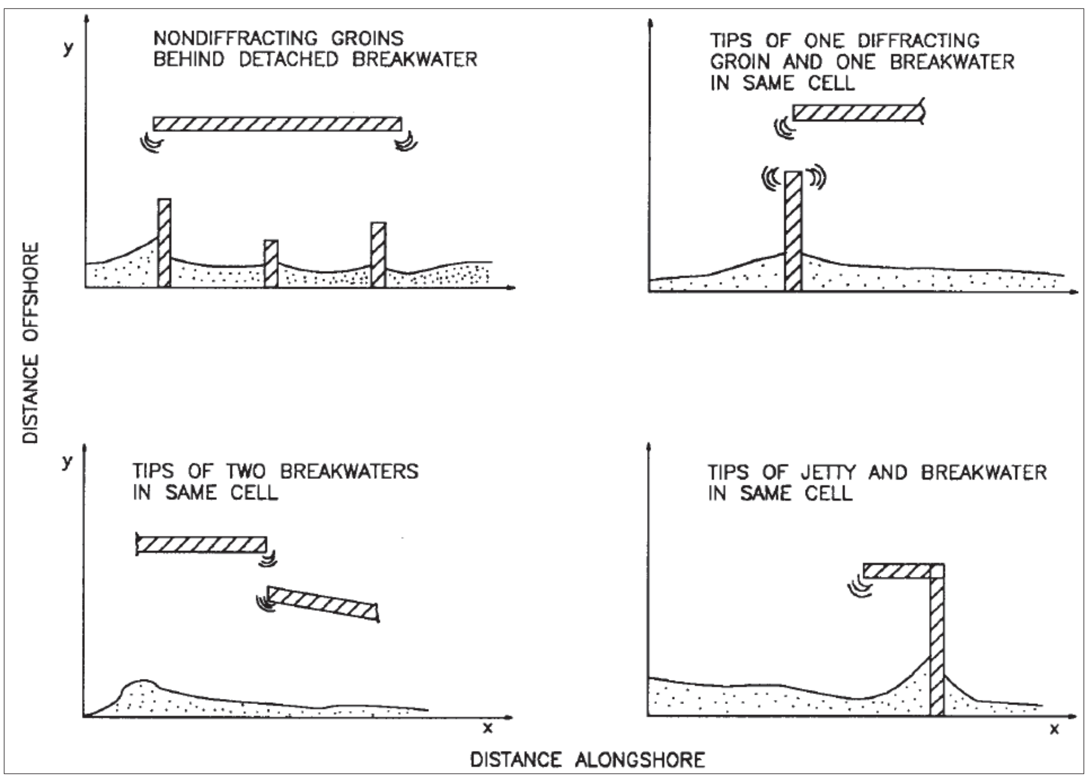


Figure 17. Examples of allowable placements.

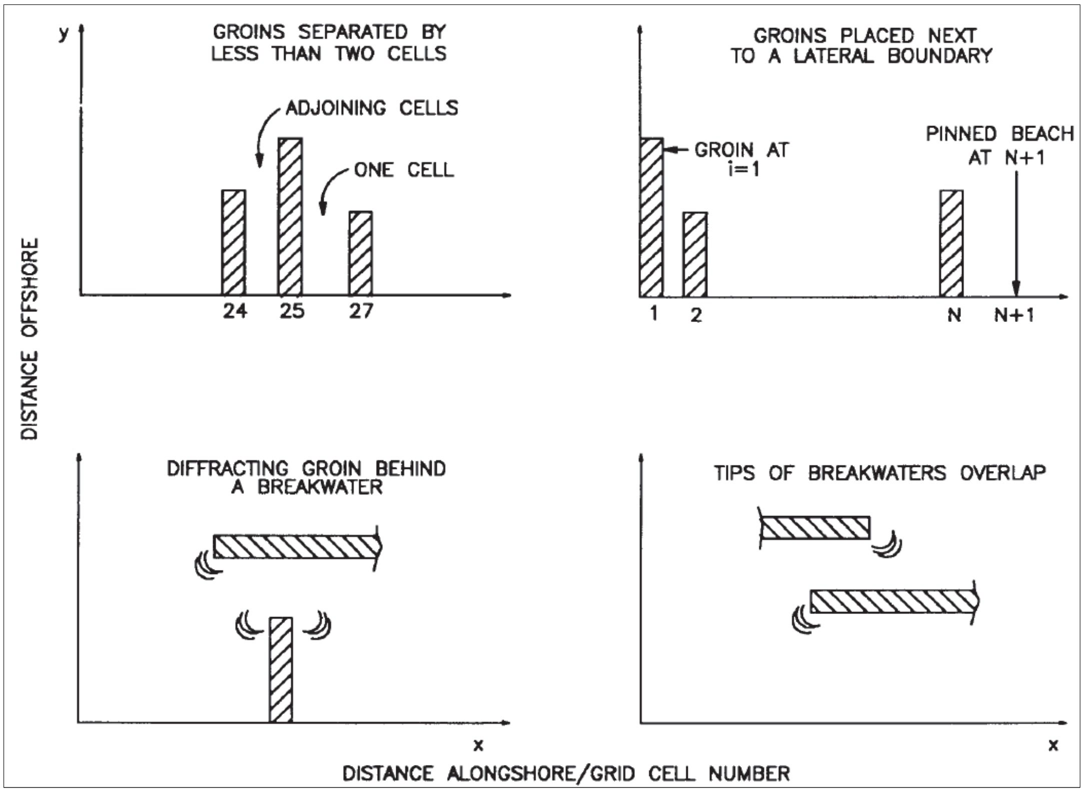


Figure 18. Examples of non-viable placements.

Figure 19 illustrates detached breakwater parameters that may be varied. Detached breakwaters are defined in the modeling system by specifying pairs of ends or tips of the structures. Wave transmission coefficients must also be given. As a summary, as long as detached breakwaters do not overlap (except for two tips sharing the same grid cell wall), the modeler is free to vary the length, transmission coefficient, orientation, distance offshore, and, in the case of segmented breakwaters, the gap width between structures.

Figure 20 illustrates various representations of groins/jetties. Simple groins/jetties can have arbitrary lengths and are aligned parallel to the *y*-axis by GenCade; *i.e.*, angled groins/jetties cannot be directly modeled. A groin/jetty cannot be flanked on its landward end; *i.e.*, it cannot be isolated in the surf zone. However, groins/jetties can be covered by sand, as may occur during a beach fill, and will then be inactive. If uncovered by wave action, they will resume functioning.

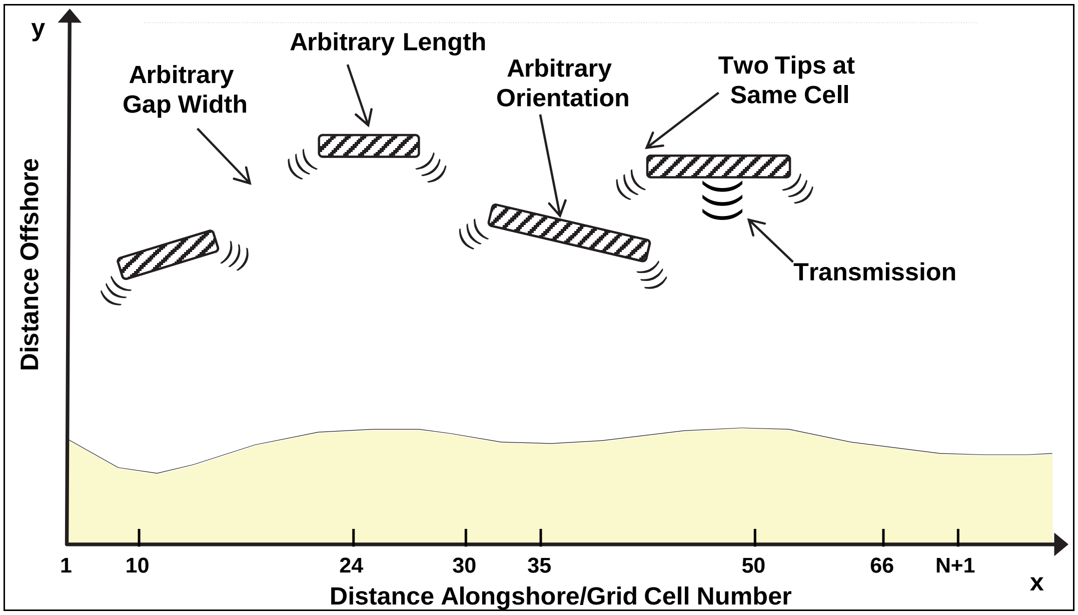


Figure 19. Parameters associated with detached breakwaters.

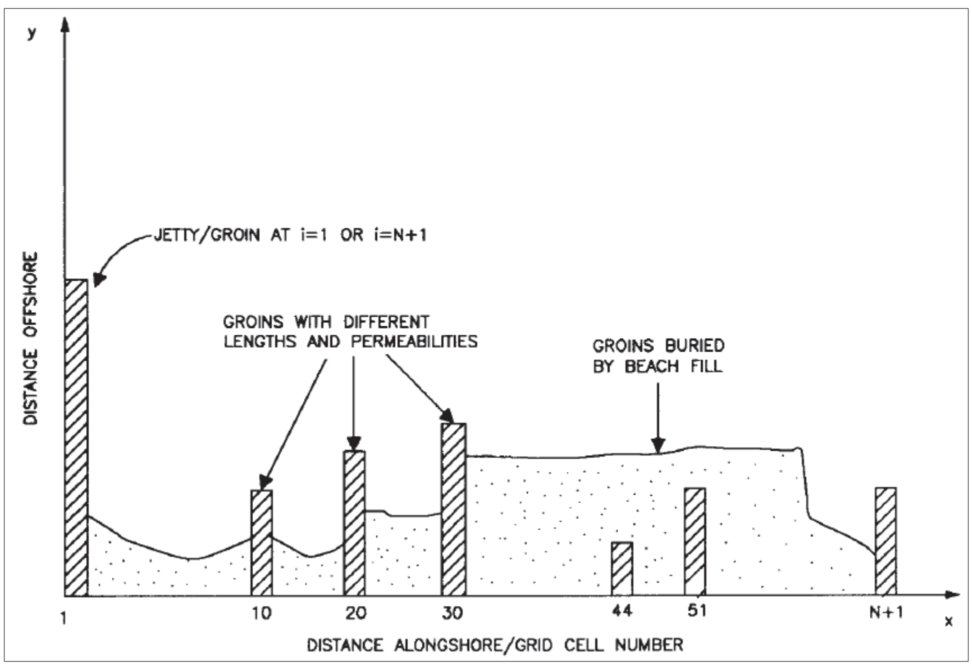


Figure 20. Allowable placements of simple groins.

Complex groin or jetty configurations, such as Y-groins, T-groins, and spur jetties, can be represented by placing tips of diffracting groins and detached breakwaters together. Figure 21 shows examples of complex structure configurations that may be represented, and Table 2 shows the corresponding values defining these configurations.

Table 2. Input variables for complex configurations in Figure 21.

Variable	Spur groin a.	T-groin b.	Angled jetty c.	Diffracting groin with spur d.
IDG	1	1	1	1
NDG	1	1	1	1
IXDG(I)	1	50	100	25
YDG(I)	350	135	410	225
DDG(I)	3.1	2.0	3.5	1.7
YG1	120	-	-	-
YGN	-	-	630	-
IDB	1	1	1	1
NDB	1	2	1	1
IXDB(I)	1, 12	45, 50, 50, 56	97, 100	25, 31
YDB(I)	350, 400	135, 135, 135, 135	410, 410	225, 135
DDB(I)	3.1, 3.5	1.8, 2.0, 2.0, 2.3	3.7, 3.5	1.7, 1.3

Several features in the examples in Figure 21 deserve attention:

- At locations where structures are attached, they ***must*** be located in the same cell, at the same distance offshore, and having the same depth. If not, GenCade will not recognize the structures as being connected;
- The top of the “T” forming a T-groin (such as in example c) must be represented by two structures, each attaching to the diffracting groin. Otherwise, the configuration would be illegal (overlap of diffracting structures) as shown in Figure 18;
- The connection between two attaching detached breakwaters must be at the exact same point in all specifications (as in example b).
- All groins/jetties attaching to detached breakwaters must be represented as diffracting.

2.12.3 Impact of groins and jetties

In GenCade, two types of sand movement past a groin or jetty are simulated. One type of movement is around the seaward end of the structure, called bypassing, and the other is through and over the structure, called transmission. Bypassing is assumed to take place if the water depth at the tip of the structure D_G is less than the depth of active longshore transport D_{LT} (see Equation 22). Since the shape of the bottom profile is known (Equation 24), D_G is determined from knowledge of the

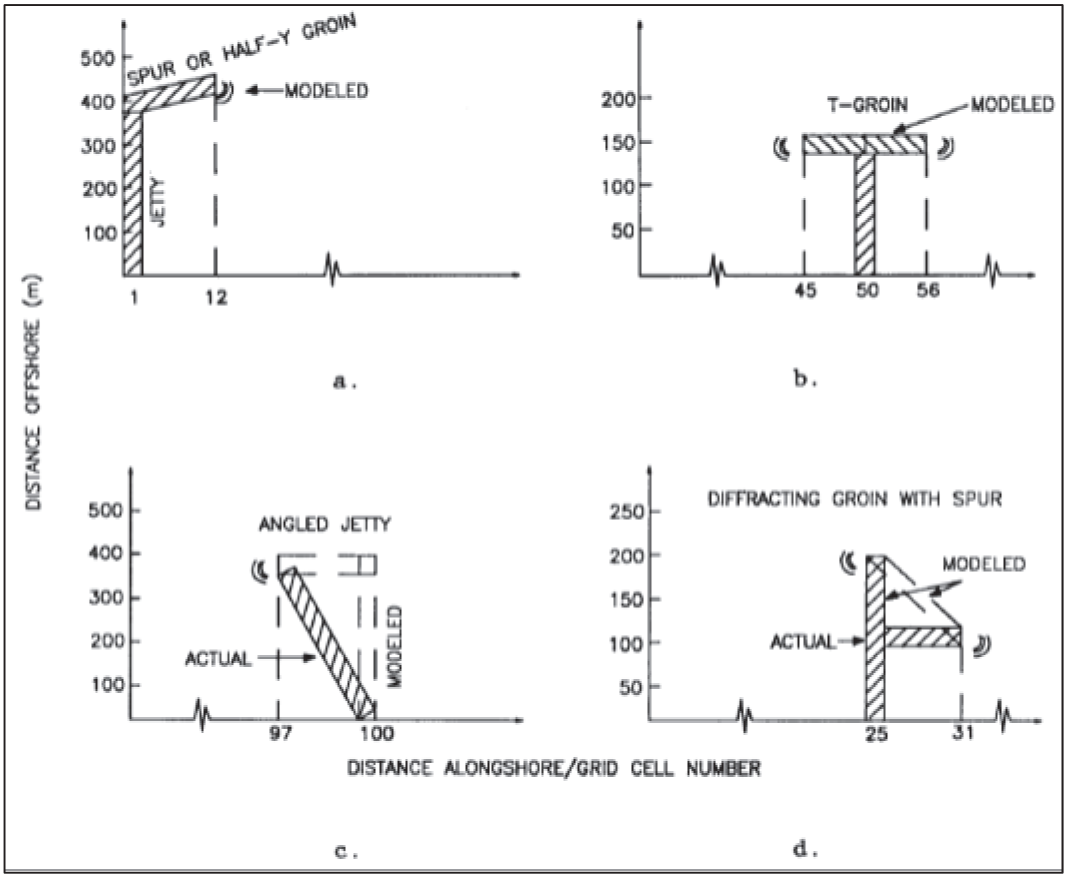


Figure 21. Examples of complex groin and jetty configurations.

distance between the tip of the structure and the location of the shoreline. However, because groins/jetties are located at grid cell walls between two calculated shoreline positions, this depth is not unique. In GenCade, the updrift depth is used. To represent sand bypassing, a bypassing factor BYP is introduced and defined as:

$$BYP = 1 - \frac{D_G}{D_{LT}}, \quad D_G \leq D_{LT} \tag{33}$$

which is calculated at each time step.

Analogously, a permeability factor $PERM$ is introduced to describe sand transmission over, through, and landward of a shore-connected structure such as a groin. A high (in relation to the mean water level), structurally tight groin that extends far landward so as to prevent landward sand bypassing is assigned $PERM$ = 0, whereas a completely "transparent" structure is assigned the value $PERM$ = 1. Values of $PERM$ thus lie in the range of $0 \leq PERM \leq 1$ and must be specified through judgment of the modeler based upon, for example, the structural characteristics of the groin (jetty, breakwater), its elevation, the tidal range at the site, or an on-site inspection of the structure. Aerial photographs are often helpful in estimating a structure's amount of void space (hence *PERM*) in relation to other structures on the model grid. The optimal value of *PERM* for each structure must then be determined in the process of model calibration.

With the values of *BYP* and *PERM* determined, GenCade calculates the total fraction *F* of sand passing over, around, or through a shore-connected structure as (Hanson 1987):

$$F = PERM\,(1 - BYP) + BYP \tag{34}$$

This fraction is calculated at every time step for each shore-connected (groin-type) structure defined along the model grid.

2.12.4 Impact of detached breakwaters

The response of the shoreline to placement of a detached breakwater (DBW) must be considered in the design process. The transmission coefficient is a leading parameter in controlling beach response to DBWs (Hanson and Kraus 1990). GENESIS (Hanson and Kraus 1989) was applied to model shoreline change both in the field and in movable-bed physical model experiments based on its capability of representing combined wave diffraction, refraction, and transmission at multiple DBWs (*e.g.*, Hanson and Kraus 1989, 1990, 1991a, 1991b; Hanson et al. 1989; Rosati et al. 1992; Gravens and Rosati 1994; Herbich et al. 1996). Initially, the GENESIS model only represented a constant transmission coefficient (K_t) for DBWs. To describe wave transmission in the modeling system, a value of a transmission coefficient K_t was provided for each DBW as an input parameter. The transmission coefficient, defined as the ratio of the height of the incident waves directly shoreward of the breakwater to the height directly seaward of the breakwater, has the range $0 \le K_t \le 1$, for which a value of 0 implies no transmission and 1 implies complete transmission. Figure 22 shows the result of simulations with GenCade for a single DBW for different values of the wave transmission coefficient K_t, which has the range of $0 \le K_t \le 1$. As expected, greater wave transmission results in a smaller salient or seaward growth of the shoreline.

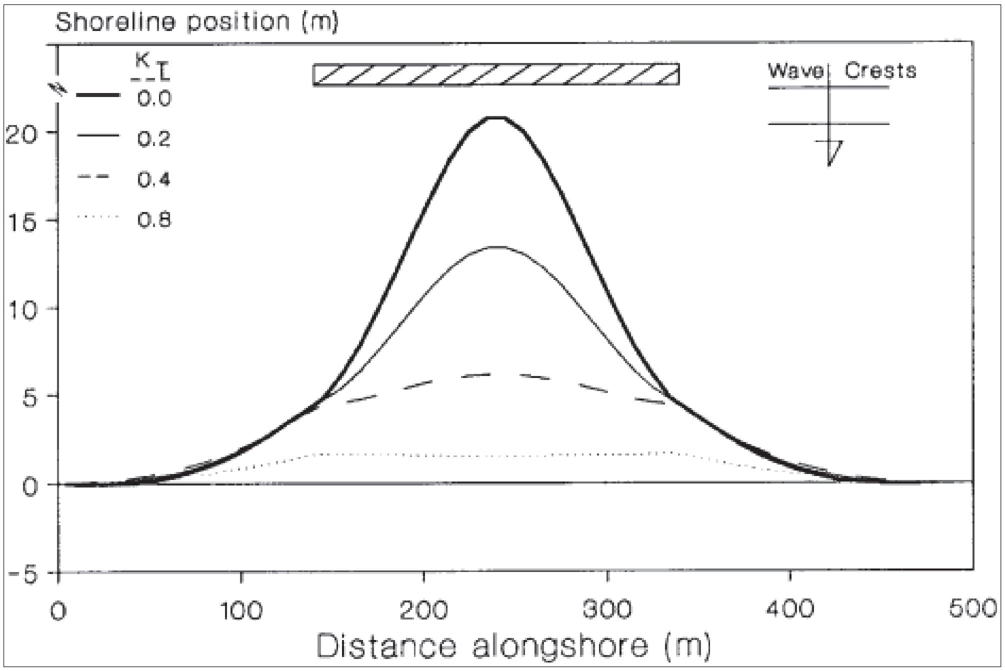


Figure 22. Shoreline response inside of a detached breakwater as a function of wave transmission (From Hanson and Kraus 1989).

Later, it was found desirable to have the capability of predicting shoreline response to DBWs for a wide range of engineering conditions. To improve the predictive capability, several published empirical formulas for the wave transmission coefficient were evaluated (Wamsley and Hanson 2002; Wamsley et al. 2002, 2003). Sensitivity tests were performed to determine the most suitable predictive formula for a given structure configuration and properties, water level, and wave condition. In GenCade, the user may choose either a constant value of K_t for each structure or allow the model to calculate appropriate values based on time-varying water level and wave height, and structure characteristics. If the variable-K_t option is selected, water level is read from an input file at a specified input time interval. For each structure, the user specifies geometric properties (crest height and width, slopes on seaward and landward sides, and median rock size) and can select between the calculation methods of Ahrens (2001), Seabrook and Hall (1998), and d'Angremond et al. (1996). The method selected should be based upon structure type and configuration.

The Seabrook and Hall formula appears to best capture transmission processes associated with submerged structures (Wamsley and Hanson 2002; Wamsley et al. 2002, 2003). Their work (Seabrook and Hall 1998) specifically concerned submerged structures and should not be transferred to surface-piercing structures. The d'Angremond et al. (1996) equation can be applied to rubble mounds and solid structures, and it appears to work well for structures with relative submergence between about -0.75 and 0.5. For deeply submerged and relatively high structures, the d'Angremond formulation is not recommended. Both the Seabrook and Hall and d'Angremond formulations were developed primarily with conventional structure data and, therefore, care should be taken in applying them to reef structures. The most promising work from a general predictive equation prospective appears to be the Ahrens (2001) dominant-mode approach. The Ahrens equation was the only one to render an S-curve in plotting K_t versus R/H_o (in agreement with laboratory data from Tanaka (1976)) and to give reasonable results for high structures. Also, the Ahrens equation does not impose applicability limits. The Ahrens equation, however, was developed based primarily upon reef breakwater data and may over-predict transmission for a conventional structure. Additionally, the Ahrens equation for submerged structures may not adequately account for the influence of relative crest width.

Figure 22 above showed the development of a salient inside a DBW. Under certain conditions the salient will continue to grow until it reaches the DBW and will then form a tombolo. The boundary condition for representing tombolo formation at T-head groins and DBWs is formulated analogously to that of a seawall in GENESIS as discussed in Hanson and Kraus (1986) and in Kraus and Hanson (1995). However, implementation of the tombolo constraint is more complex because it includes wave diffraction, blocking of previously open calculation cells, and transport of sediment on both the landward and the seaward sides of the structure. The tombolo concept implies that the beach can reach the structure, but no further. As a calculation cell makes contact with the structure, the transport rate into that cell is adjusted to allow the excess sediment to remain in updrift cells. The procedure to do this conserves sediment volume and preserves the direction of its transport.

The procedure is illustrated in Figure 23, a plan view of an idealized beach protected by a T-head groin. As usual, a net influx (gain) into a cell produces beach accretion and a net out flux (loss) produces erosion. In this particular example a tombolo has developed in Cells i+1 though i+4 during previous time steps.

At the updrift (left-hand) structure tip, a portion of the longshore transport will take place inside the tip and the rest will pass on the outside (Figure 23a). The routine to calculate this is identical to the one applied at regular, straight groins. The sand on the inside of the shore-parallel structure will be transported behind the structure by the diffracted waves (Figure 23b). In this case, this transport would cause the shoreline to move beyond the structure in Cell *i*. As this is not possible, the initially calculated transport Q_i into Cell *i* will have to be adjusted to a value Q_i^* (Figure 23c) that will cause the shoreline y_i to advance up to the DBW but no further, resulting in $y_i^* = yb_i$, where yb_i is the structure location in Cell *i*. With the new transport Q_i^* now leaving Cell *i*-1, the shoreline location in this cell will be adjusted from y_{i-1} to y_{i-1}^*. In this particular case, because y_{i-1}^* did not exceed yb_i, only two cells had to be recalculated. In a general situation, the correction may be carried through any number of cells until the criterion that the shoreline cannot advance beyond the structure is satisfied in all cells. The adjustment is made to preserve sediment volume and direction of sediment transport.

The portion of the longshore transport that passes outside of the structure tip at the updrift side will be transferred to the other end of the structure (Figure 23d) and released to the cells closest to the structure on the down-drift side. In this process, the sediment is assumed to be distributed over a distance equal to the distance from the down-drift tip to the shoreline.

2.12.5 Seawalls

Effective sections of seawalls may be defined anywhere on the grid. It is noted that the seawall does not need to be straight but may form a “curve” to follow the trend of the beach contours. The seawall may be placed at the shoreline or behind it. However, a seawall cannot be placed seaward of the shoreline.

A seawall or, in general, any shore-parallel non-erodible barrier such as a rocky cliff, imposes a constraint on the position of the shoreline because the shoreline cannot move landward of the wall. Hanson and Kraus (1985, 1986) developed a procedure for calculating the position of the shoreline constrained by a seawall. The procedure is consistent with shoreline response modeling theory and has the following three properties:

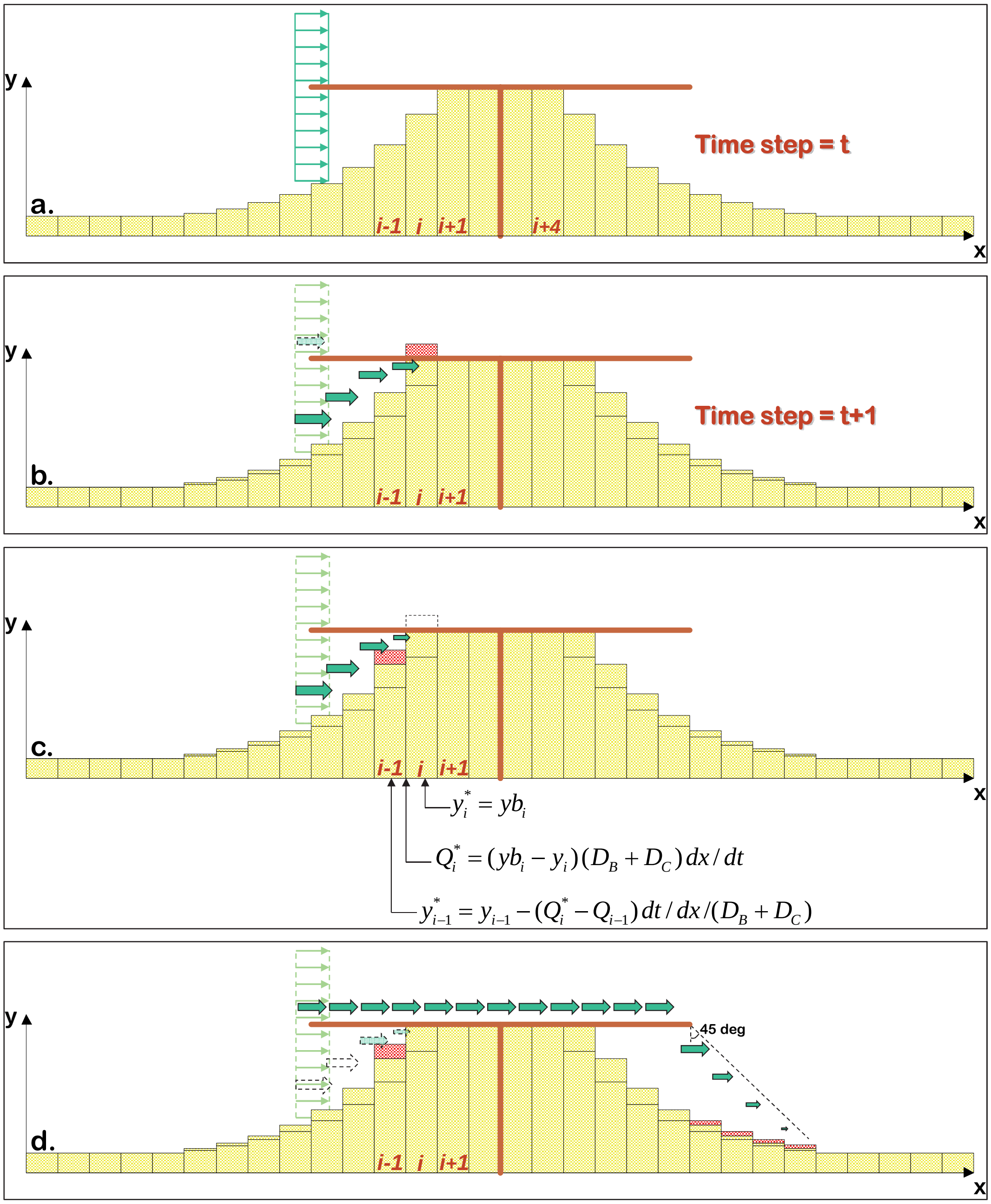


Figure 23. Schematic of the procedure in GenCade for the development of a tombolo inside of a detached breakwater. (a) General planform outline of schematic tombolo example. (b) Transport rate at updrift (left-hand) structure tip is separated into one part inside of the structure and one part outside. Transport inside of structure causes excessive shoreline advance in Cell *i*. (c) Chain of corrections to make sure shoreline location y_i does not move beyond structure and that sediment volume is conserved. (d) Bypassing of sediment outside of the structure and its deposition on the downdrift side.

- The shoreline in front of a seawall cannot recede landward of the wall;
- Sand volume is conserved;
- The direction of longshore sand transport at the wall is the same as that of the potential local transport.

GenCade first calculates longshore sand transport rates along the beach based on the assumption that the calculated amount of sand is available for transport (the potential transport rate). At grid cells where the seawall constraint is violated, the shoreline position and the transport rate are adjusted in a way similar to the breakwater routine described above. The quantities in neighboring cells are also adjusted, as necessary, to preserve sand volume and the direction of transport. The calculation procedure is complex, and the reader is referred to Hanson and Kraus (1986) for full details. Flanking of the seawall is not possible since it would lead to a double-valued shoreline position at the same grid cell. As opposed to groins, jetties, and detached breakwaters that are placed at cell walls, seawalls are placed at cell centers. The reason is that seawalls do not affect the waves, located at cell walls, but only the shoreline location, defined at cell centers. In the schematic example shown in Figure 24, the seawall would extend from cell 23 to cell 34.

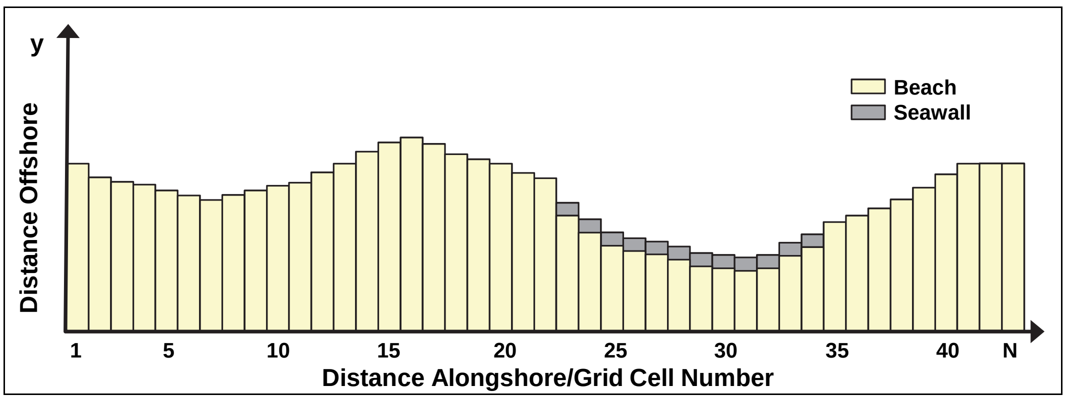


Figure 24. Schematic illustration of the placement of a seawall.

Figure 25 demonstrates a hypothetical case where a divergence point of sand transport is located half-way between two groins. A seawall is initially located a small distance landward of the shoreline at this location. As a result of the divergence, the beach initially erodes, gradually exposing the seawall. As the shoreline reaches the seawall, it cannot recede further. Thus, the potential erosion of an exposed cell is transferred to the adjacent cell in the direction of transport, i.e., away from the divergence point. If the entire seawall is exposed, erosion occurs in the cells just adjacent to the structure on either side. The example shows that the constraint provides realistic shoreline evolution in front of as well as adjacent to a seawall.

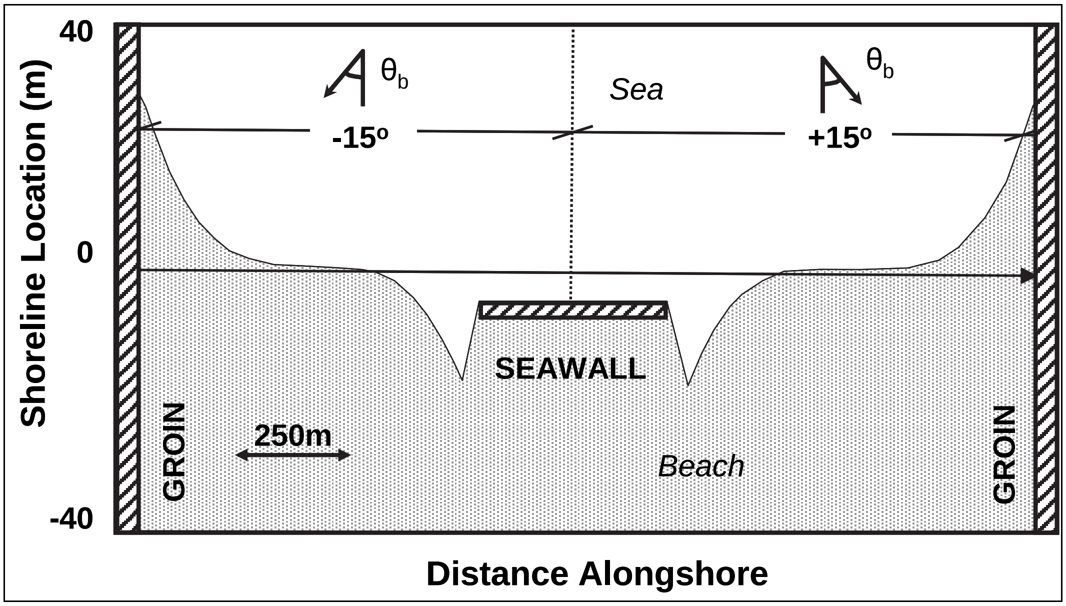


Figure 25. Hypothetical example of effect of seawall in the GenCade model. (Modified from Hanson and Kraus 1985).

2.12.6 Beach fills

Beach fills may be placed anywhere on the beach and can overlap in time and position. The beach is advanced an equal amount daily at each cell where a given fill has been defined. Beach fills can cover groins, and, if the beach erodes, the groins will become uncovered and begin functioning.

GenCade is capable of representing the behavior of fills under the following assumptions:

- The fill has the same median grain size as the native sand;
- The profile of the fill represented in the model has the equilibrium shape corresponding to its grain size;
- The berm height of the nourished beach is the same as the natural beach.

The second point means that the beach fill width that is specified as input to the model is NOT the width corresponding to the fill template but the width that is expected to develop as the filled beach has been equilibrated by waves and currents.

Figure 26 illustrates a simple, schematic beach fill. In GenCade, this fill would need to be represented by a number of individual fills, each with a constant width alongshore. Thus, the beach fill would be represented by three fills: one covering cells 1 through 30, with a width of 20 m, starting on 01 Jan 89 and ending on 28 Feb 89; a second fill covering cells 10 through 20, with a width of 5 m, starting on 01 Jan 89 and ending on 28 Feb 89; a third covering cells 20 through 60, with a width of 5 m, starting on 15 Jun 89 and ending on 15 Jul 89.

As an alternative, the first two fills may be represented by three attaching fills: one covering cells 1 through 10, with a width of 20 m; a second fill covering cells 10 through 20, with a width of 25 m; a third covering cells 20 through 30, with a width of 20 m, all fills starting on 01 Jan 89 and ending on 28 Feb 89. In addition, there would be a fourth fill corresponding to the third fill in the previous configuration.

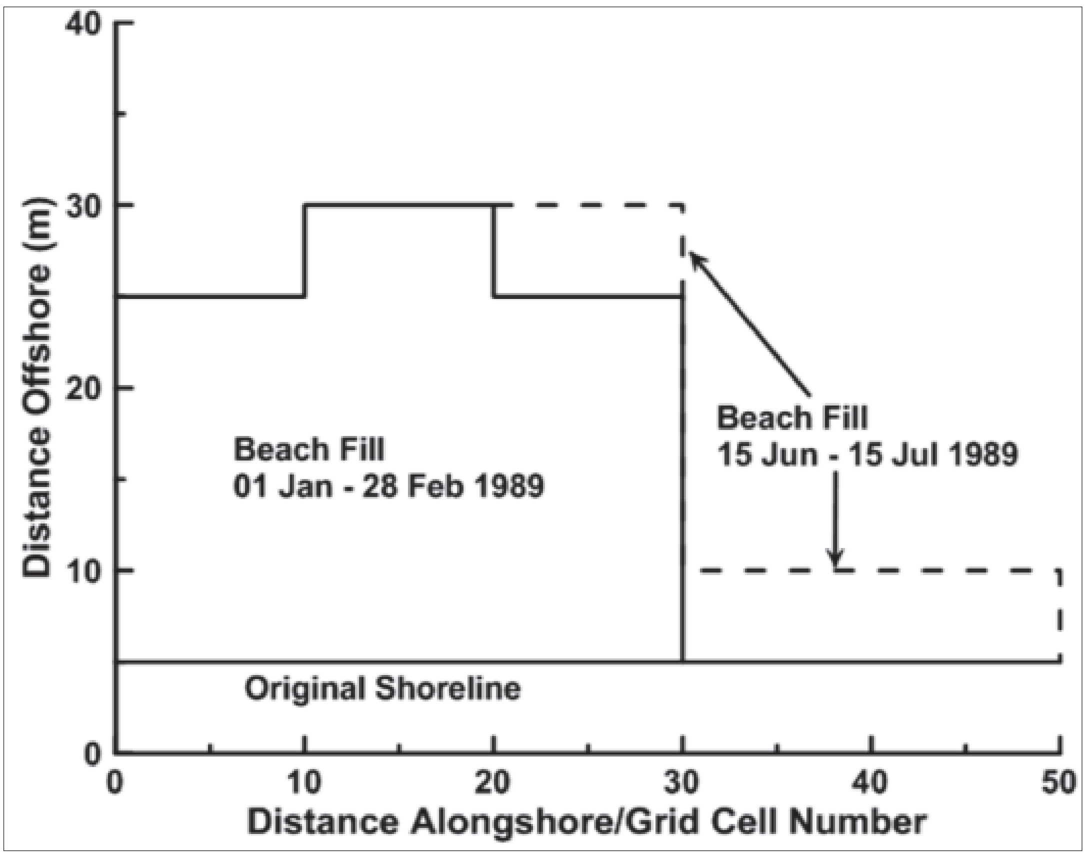


Figure 26. Example illustrating a simple beach fill configuration.

2.12.7 Sources and sinks

In GenCade, sediment may be added or taken away from the coastal area through sources or sinks, respectively, creating a shoreline response. In the GenCade interface this feature will appear under *Bypass Event*. Common sediment sources are erosion of cliffs, bluffs, and dunes; beach nourishment, including placement of dredged material; wind-blown sand; river-transported sediment; and onshore transport of material from deeper water. Common sediment sinks are wind-blown sand; dredging; barrier-island overwash; and offshore transport of material to deeper water. Thus, certain processes may act both as a source and a sink for the coast, depending on the particular conditions. In GenCade, an arbitrary number of sources and sinks may be specified having varying locations in space, different magnitudes and associated timing.

An example of an application where a sediment source term could be applied as an input to GenCade is for a coastal engineering application where there is a dedicated fixed sediment bypassing facility that is pumping sediment across an inlet at approximately a constant rate. In this case, a bypassing term would be input as a constant rate (m^3/hr or CY/hr) over the duration of the simulation. This would function similar to a beach fill, but is input differently than a beach fill because beach fills are input as an increase in berm width.

3 GenCade Model Validation and Standard Benchmark Cases

This chapter focuses on GenCade model validation and standardized benchmark cases. The first section describes a verification case for GenCade using laboratory results at the USACE-ERDC-CHL Large-Scale Sediment Transport Facility (LSTF). Several standardized benchmark cases were tested and are explained in the second section. The third section compares GenCade results to previous GENESIS simulations for the Jucar River in Spain.

3.1 Model validation – LSTF laboratory cases

A model validation of shoreline evolution in a laboratory setting was performed for GenCade following a similar case presented in Hanson et al. (2006). The laboratory experiment was conducted in the USACE-ERDC-CHL Large-Scale Sediment Transport Facility (LSTF) (Hamilton et al. 2001) and the methodology and results are described in Gravens and Wang (2007). The validation experiment analyzes the capability of the GenCade model to calculate shoreline and salient evolution and tombolo formation in the lee of a detached breakwater in a controlled laboratory environment. It should be noted that Hanson et al. (2006) performed the GENESIS validation with a research version of GENESIS, which employed a different sediment transport formulation from what is employed in the release version of GENESIS-T (i.e., the version included with the CEDAS interface package) (Hanson and Kraus 1989) and in the current release of GenCade. Therefore, the results presented herein may be used to compare agreement between the measured results of the laboratory experiment and the calculated results from a different sediment transport formulation.

3.1.1 GenCade model setup and parameters

3.1.1.1 Model domain

The GenCade model domain was developed to represent the LSTF lab experiment test case 1. The model grid was 60 m long with a 4 m long detached breakwater positioned in the center of the domain 4 m offshore of the initial shoreline position with both diffracting tips at a depth of 0.17 m. Model grid cell resolution was set to a constant 0.1 m (600 cells total). The model experiment was simulated for 24 hours as was the case in the laboratory case. GenCade lateral boundaries were selected as pinned beach boundaries. The median grain size (d_{50}) was set at 0.15 mm as represented in the LSTF experiments. The berm height was set to 0.35 m and the depth of closure was set to 0.5 m. Figure 27 shows the LSTF domain. Additional model parameters are described in section 3.1.1.3 below.

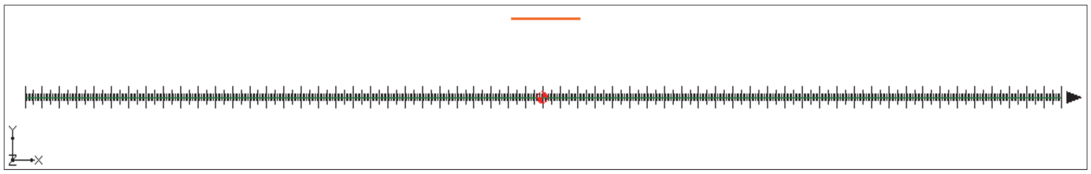


Figure 27. GenCade LSTF domain, with detached breakwater in orange.

3.1.1.2 Model forcing: waves

Wave forcing applied to the GenCade simulations was held constant throughout the simulation such that breaking wave heights were H=0.26 m, T = 1.5 sec, and D_{ir}=6.5-deg as measured in the LSTF experiment. Wave inputs were supplied at the 0.9 m depth contour.

3.1.1.3 Model parameters

GenCade calibration parameters were adjusted to calibrate the model to measured transport rates and salient shape. First calibration was conducted with the K1 parameter to obtain average longshore transport rates in agreement with the measured average longshore transport rates. The measured average longshore transport rates were reported at 2,194 m^3/yr (Hanson et al. 2006) and GenCade simulations resulted in average longshore transport rate of 1,991 m^3/yr, and within 10 percent of measured rates with K1 set to 0.18. Next, K2 and ISMOOTH parameters were adjusted to improve calculated salient shape. Table 3 lists the best fit values obtained.

Table 3. Model parameters.

Parameter	Value
K1	0.18
K2	0.06
ISMOOTH, # Cells in smoothing window	1

3.1.2 GenCade model results and discussion

Figure 28 presents the GenCade results compared to results obtained from the LSTF experiment (Gravens and Wang 2007) and the GENESIS-T validation (Hanson et al. 2006) for shorelines after 24 hours. This figure shows that GenCade calculated tombolo formation after 24 hours. The GenCade calculated shoreline and shape of the tombolo and salient show excellent agreement with the measured shoreline at the center of the tombolo. However, the transitions immediately updrift and immediately downdrift of the breakwater are not as well represented and appear to transition more abruptly in the GenCade calculations than is observed in the measurements and the GENESIS (Hanson et al. 2006) results. This may indicate an area for future improvement of sediment transport formulation or diffraction routines.

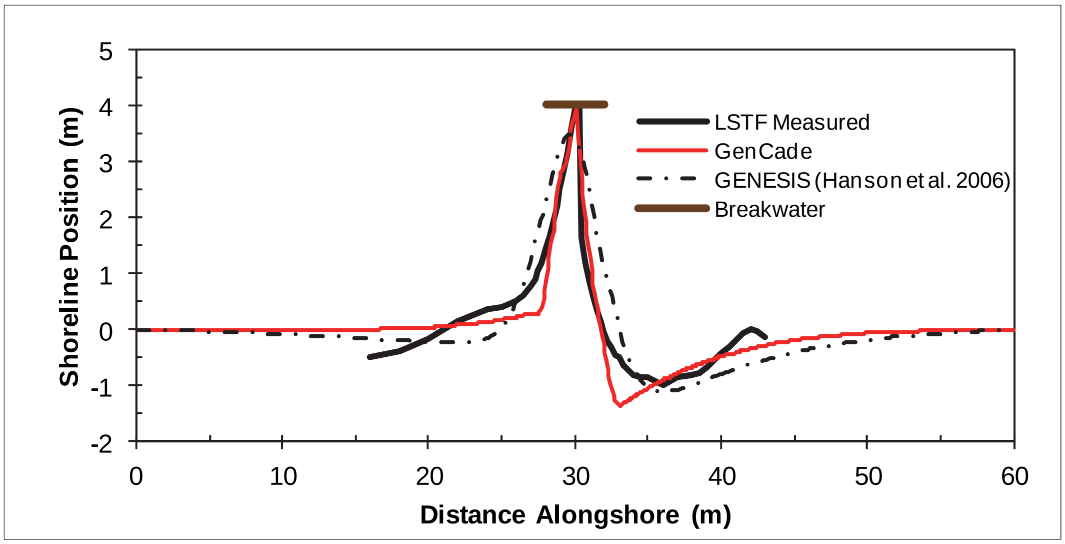


Figure 28. Calculated vs. measured shoreline position in the LSTF.

3.2 Standardized benchmark cases

A series of standardized test cases was developed to demonstrate isolated GenCade model capabilities and verify results against established legacy models (e.g., GENESIS). Simple idealized cases focusing on each of the primary model processes and coastal structures were evaluated separately. Isolation of individual modeled components is an effective means of examining the fundamental skill of a model and can be a practical tool for identifying potential errors, oversights, or omissions when investigating individual components of the model under simple idealized cases.

The standardized benchmark cases developed here are separated into the primary coastal structures and project components that are frequently applied in GenCade. Each of the cases is presented with a range in wave forcing to test symmetry of process calculation. GENESIS simulations were also developed following corresponding test cases to evaluate how GenCade results agree with the well-validated legacy model and to support user-confidence for the transfer and migration from GENESIS.

3.2.1 GenCade model setup

3.2.1.1 Model domain

Two categories of idealized model domains were developed for the standardized benchmark cases: straight shoreline domains and concave embayment domains. The purpose of the straight shoreline domains is to provide an uncomplicated foundation to test the most fundamental processes and the impact of coastal structures within the GenCade model. The purpose of the concave embayment domains is to examine the effects wave forcing and structures have on a continuous and uniform alongshore shoreline angle gradient and examine regional contour capabilities.

Figures 29 through 35 show each of the seven domains in the straight shoreline category. Figure 29 represents the simplest case with a straight shoreline and no structures or project features within the domain. Figures 30 through 35 build upon this domain with the addition of individual coastal structures or project components. These structures or components include: a single groin (Figure 30), a detached breakwater (Figure 31), a T-head groin (Figure 32), a seawall with a groin to force shoreline erosion to the seawall (Figure 33), a beach fill project (Figure 34), and an inlet with jetties (Figure 35).

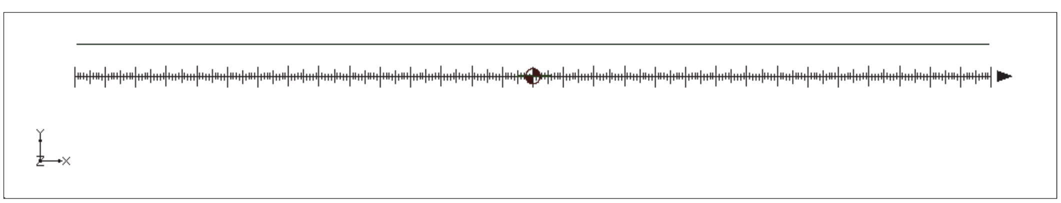


Figure 29. GenCade straight shoreline with no structures domain.

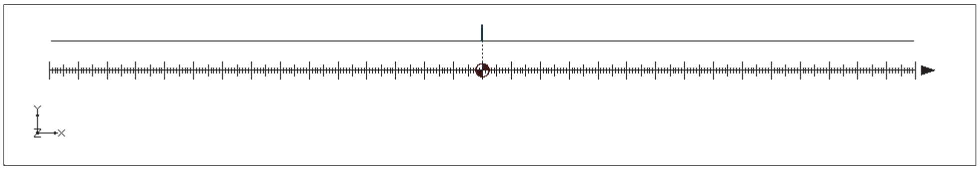


Figure 30. GenCade straight shoreline with single groin domain.

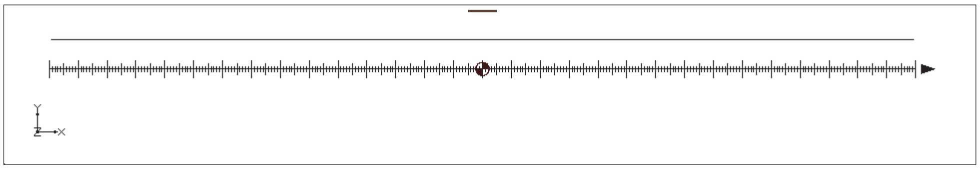


Figure 31. GenCade straight shoreline with detached breakwater domain.

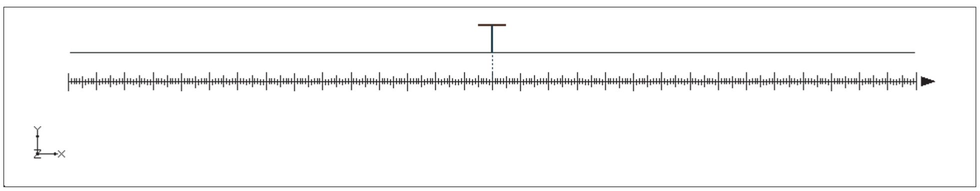


Figure 32. GenCade straight shoreline with T-head groin domain.

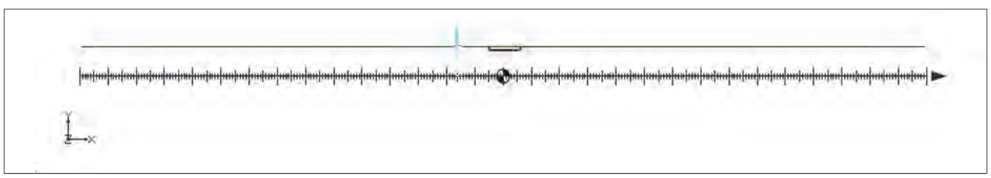


Figure 33. GenCade straight shoreline with seawall domain.

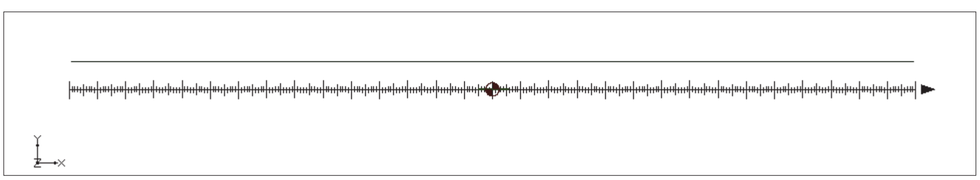


Figure 34. GenCade straight shoreline with beachfill domain.

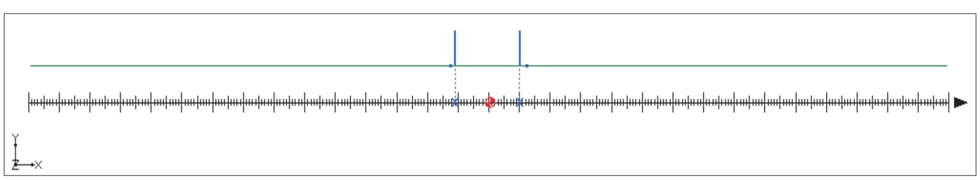


Figure 35. GenCade straight shoreline with structured inlet domain.

Figures 36 and 37 show the two domains in the concave shoreline category. The concave shorelines were developed using a simple quadratic formula to maintain symmetry. The quadratic function employed for these concave shorelines was:

$$y = ax^2, \tag{35}$$

where $a = 10^{-4}$. Figure 36 represents a simple case with a concave shoreline and no structures or project features within the domain. Figure 37 builds upon this domain with the addition of two groins.

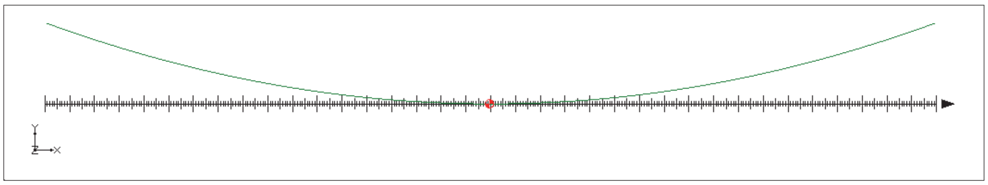


Figure 36. GenCade concave shoreline with no structures.

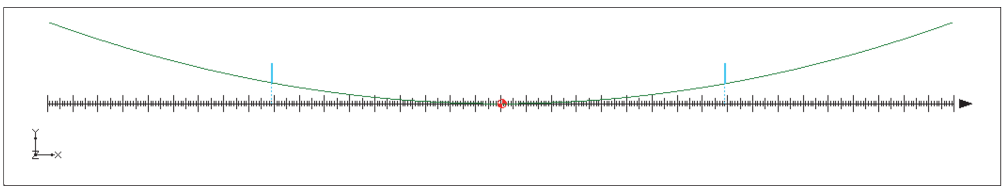


Figure 37. GenCade concave shoreline with two groins.

3.2.1.2 Model forcing: waves

Simulations of the standardized benchmark cases were conducted under various wave forcing. Constant wave forcing over the entire length of the simulation was initially examined for general investigation purposes. First constant waves with 0.75 m offshore wave height and 8 sec period were applied as forcing for both positive wave angles at +15-deg and negative wave angles at -15-deg. Wave forcing simulations were also conducted for constant zero-deg (i.e., shore normal) angles and simulations for all angles between +85-deg and -85-deg in 5-deg increments, but since the net shoreline change for these simulations results in zero change, they are not presented here. For all cases, wave inputs were supplied at the 50 m depth contour.

3.2.1.3 Model parameters

Wherever possible, the model parameters were held constant between each of the simulations in each domain category for purposes of consistency of comparison between simulations. Table 4 presents the model parameters common to all the standardized benchmark cases in the straight shoreline domains.

Table 4. Model parameters common to all benchmark cases.

Parameter	Value
DX, m	10
NX	300 (straight domain) 360 (concave domain)
DT, hrs.	0.5
K1	0.50
K2	0.25
# Cells in smoothing window	3
Non-jetty boundary condition, m/year	Pinned

3.2.2 GenCade model results and discussion

3.2.2.1 No structures

The simplest case of a straight shoreline without any coastal structures or coastal project components is presented first. Figure 38 shows the results after a 2-year simulation with constant +15-deg wave angle forcing. As one would expect, there is zero shoreline change since the alongshore gradients in transport are zero and transport is constant at approximately 200,000 m^3/yr. Figure 39 shows the results after a 2-year simulation with constant -15-deg wave angle forcing. Similar to the positive wave angle forcing case, there is zero shoreline change since the alongshore gradients in transport are zero. Figure 39(c) indicates that transport is constant at approximately -200,000 m^3/yr. Results for all simulations with no structures result in good agreement between GenCade results and GENESIS results.

3.2.2.2 Single groin

A case having a straight shoreline with a single groin 75 m long (175 m from the grid origin) at the center of the domain is presented next to examine shoreline response to the presence of a groin. Figure 40 shows the results after a 2-year simulation with constant +15-deg wave angle forcing. The groin presents an obstruction to longshore transport, which results in a reduction of transport rates as sediment is bypassed around the groin. This local transport reduction in the vicinity of the groin translates to a gradient in transport rates as transport transitions to and from background rates. This difference in sediment transport potential accounts for the accretion of sediment and resulting shoreline

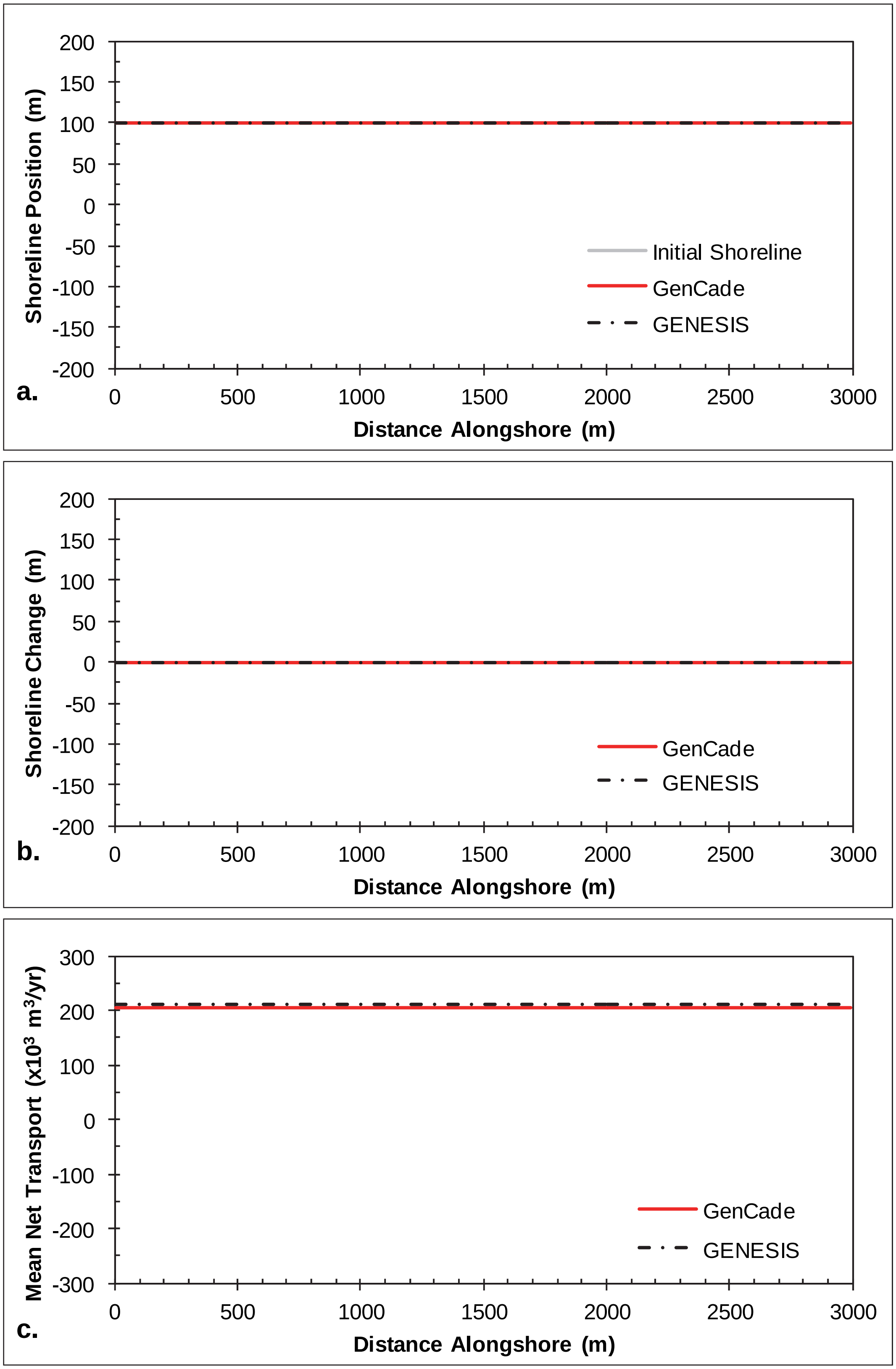


Figure 38. Calculated (a) shoreline position, (b) shoreline change, and (c) mean net transport for straight shoreline with no structures; H_0 = 0.75 m, T = 8 sec, θ_0 = +15-deg.

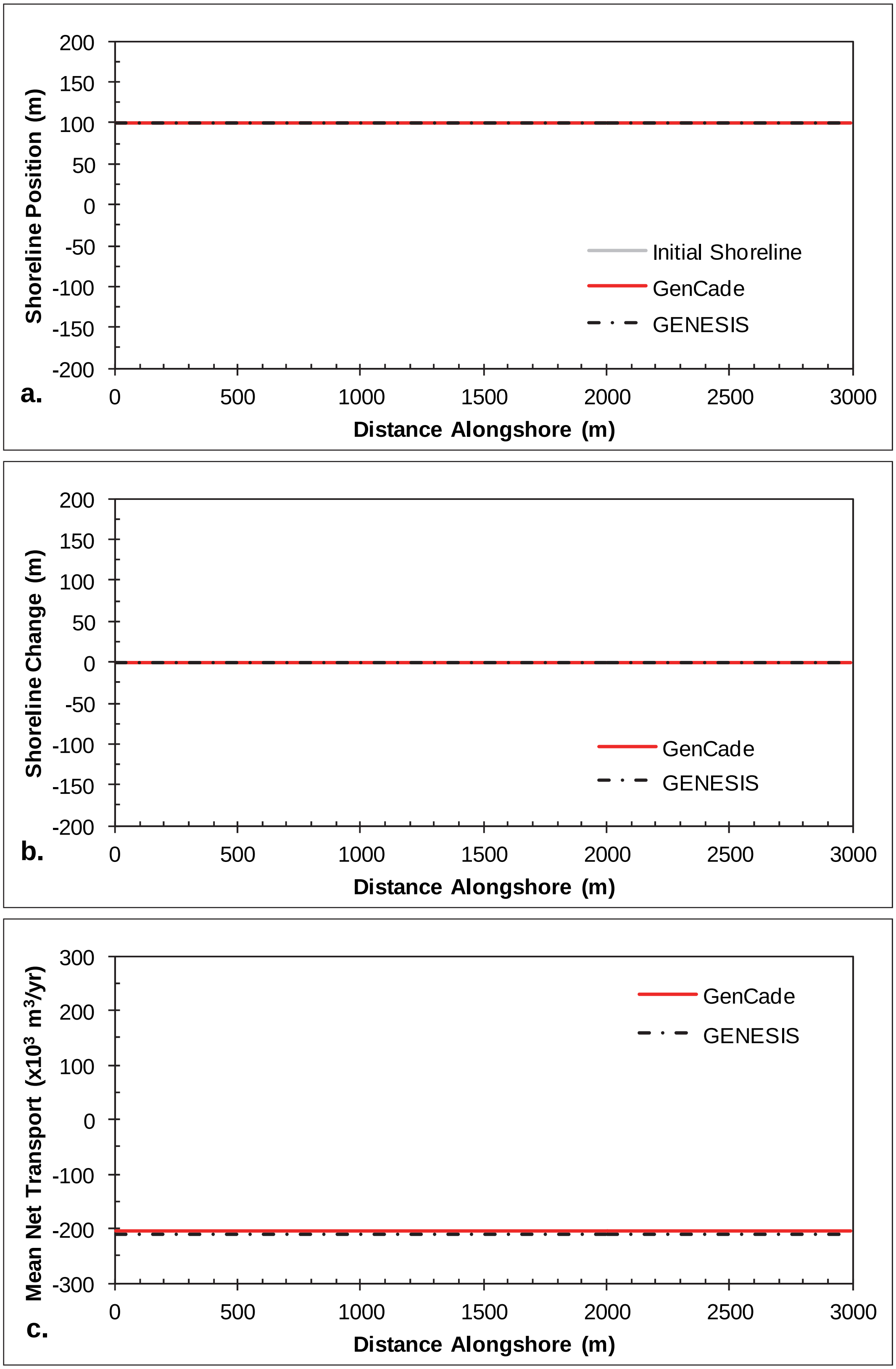


Figure 39. Calculated (a) shoreline position, (b) shoreline change, and (c) mean net transport for straight shoreline with no structures; H_0 = 0.75 m, T = 8 sec, θ_0 = -15-deg.

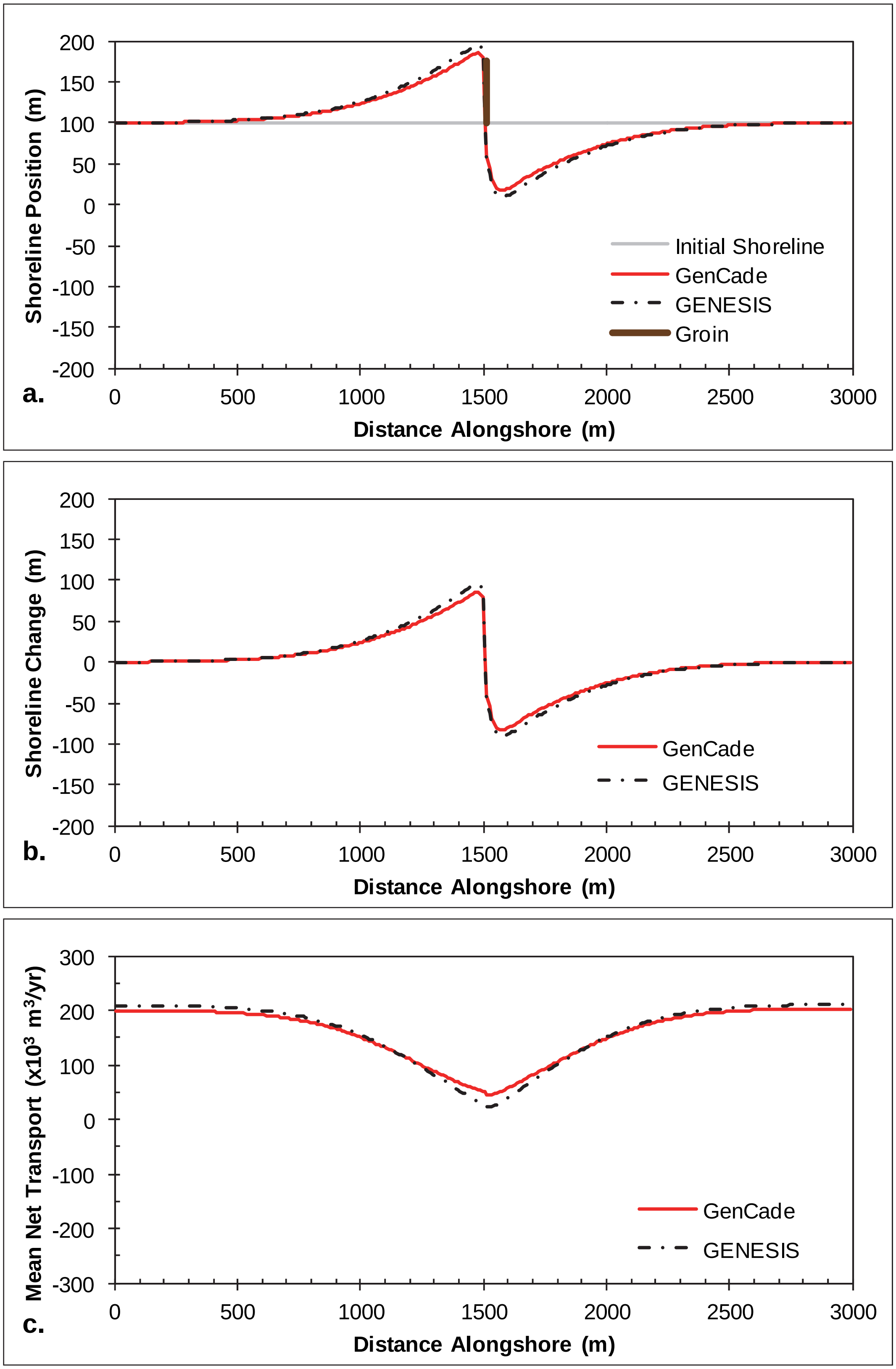


Figure 40. Calculated (a) shoreline position, (b) shoreline change, and (c) mean net transport for straight shoreline with single groin; H_0 = 0.75 m, T = 8 sec, θ_0 = +15-deg.

progradation seaward on the left (updrift) side of the groin as the transport rates decrease from 200,000 m^3/yr to approximately 50,000 m^3/yr at the groin. Conversely, as transport rates increase from 50,000 m^3/yr in the vicinity of the groin back to 200,000 m^3/yr outside of the region of groin influence, the expected downdrift shoreline erosion is observed.

Figure 41 presents the results after a 2-year simulation with constant -15-deg wave angle forcing. The opposite pattern is observed in this example because transport is forced by negative wave angles relative to shore normal. Figure 41(c) shows that an increase in transport occurs on the left (downdrift) side of the groin from -200,000 m^3/yr background transport rate to -50,000 m^3/yr in the vicinity of the groin. This positive gradient results in erosion while the negative gradient on the right (updrift) side of the groin results in accretion. Figures 40 and 41 clearly depict excellent agreement between GenCade results and GENESIS results for all simulations with a single groin as well as perfect symmetry between the positive and negative wave angle forcing.

3.2.2.3 Detached breakwater

A detached breakwater case is evaluated in this section with a 90 m long emergent breakwater at the center of the domain located 100 m offshore of the shoreline at a depth of 6 m. Although this case is similar in configuration to the LSTF experiment detailed in section 3.1, this case is simulated at full prototype (i.e., larger) scale and over a much longer time frame. Figure 42 shows the results after a 2-year simulation with constant +15-deg wave angle forcing. These simulations result in a nearly symmetric shoreline change response in the lee of the breakwater and the development of a large salient approximately 75 m at the apex. The transport rates decrease from a background rate of 200,000 m^3/yr to approximately 25,000 m^3/yr directly behind the breakwater structure.

Figure 43 presents the results after a 2-year simulation with constant -15-deg wave angle forcing. The opposite pattern is observed in this example because transport is forced by negative wave angles relative to shore normal. Figure 43(c) shows that an increase in transport occurs on the left (downdrift) side of the breakwater from -200,000 m^3/yr background transport rate to -25,000 m^3/yr in the lee of the breakwater. Again, the expected opposite shoreline response is observed here. Figures 42 and 43 show good overall agreement between GenCade results and GENESIS

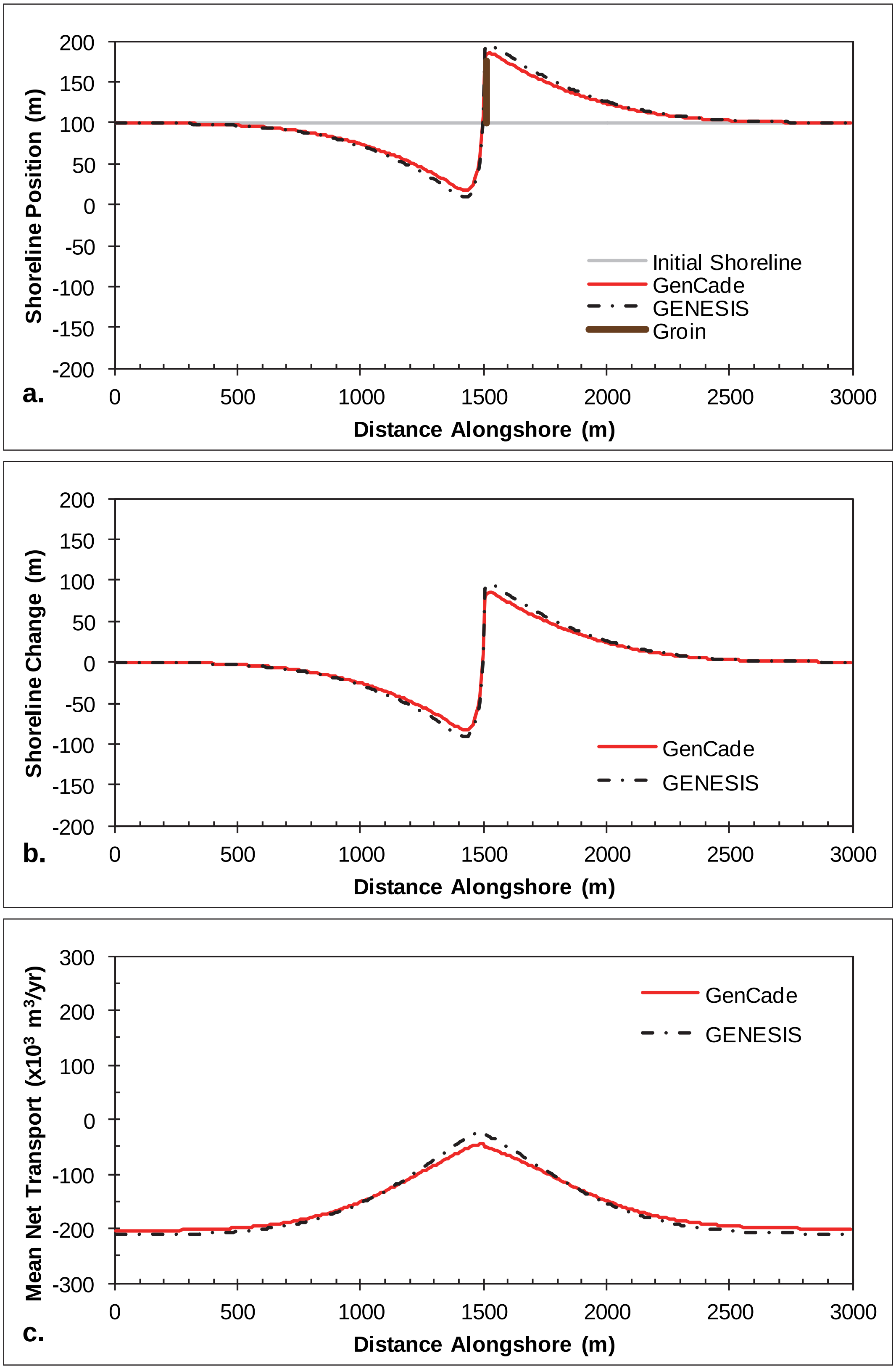


Figure 41. Calculated (a) shoreline position, (b) shoreline change, and (c) mean net transport for straight shoreline with single groin; H_0 = 0.75 m, T = 8 sec, θ_0 = -15-deg.

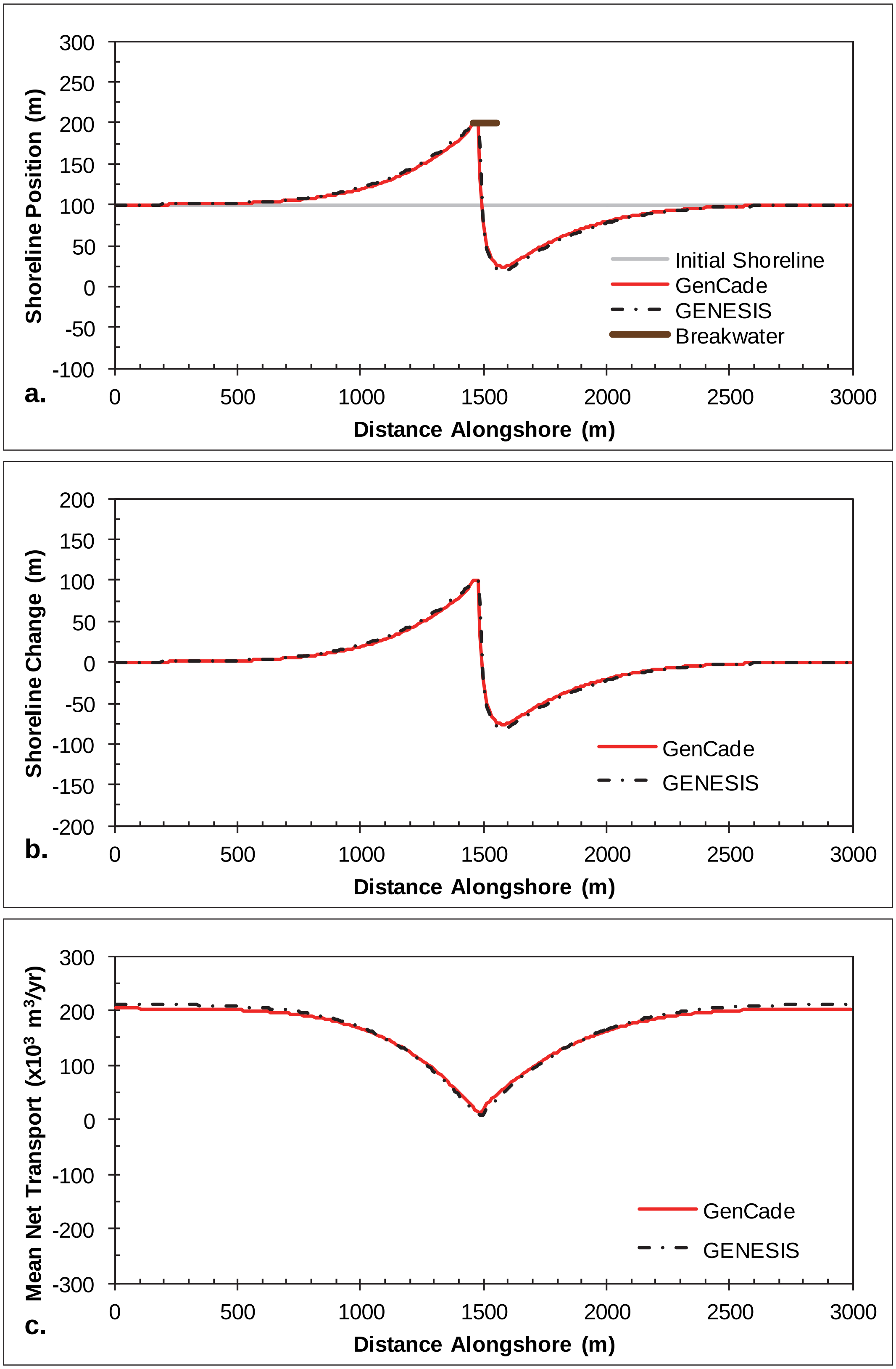


Figure 42. Calculated (a) shoreline position, (b) shoreline change, and (c) mean net transport for straight shoreline with detached breakwater; $H_0 = 0.75$ m, $T = 8$ sec, $\theta_0 = +15$-deg.

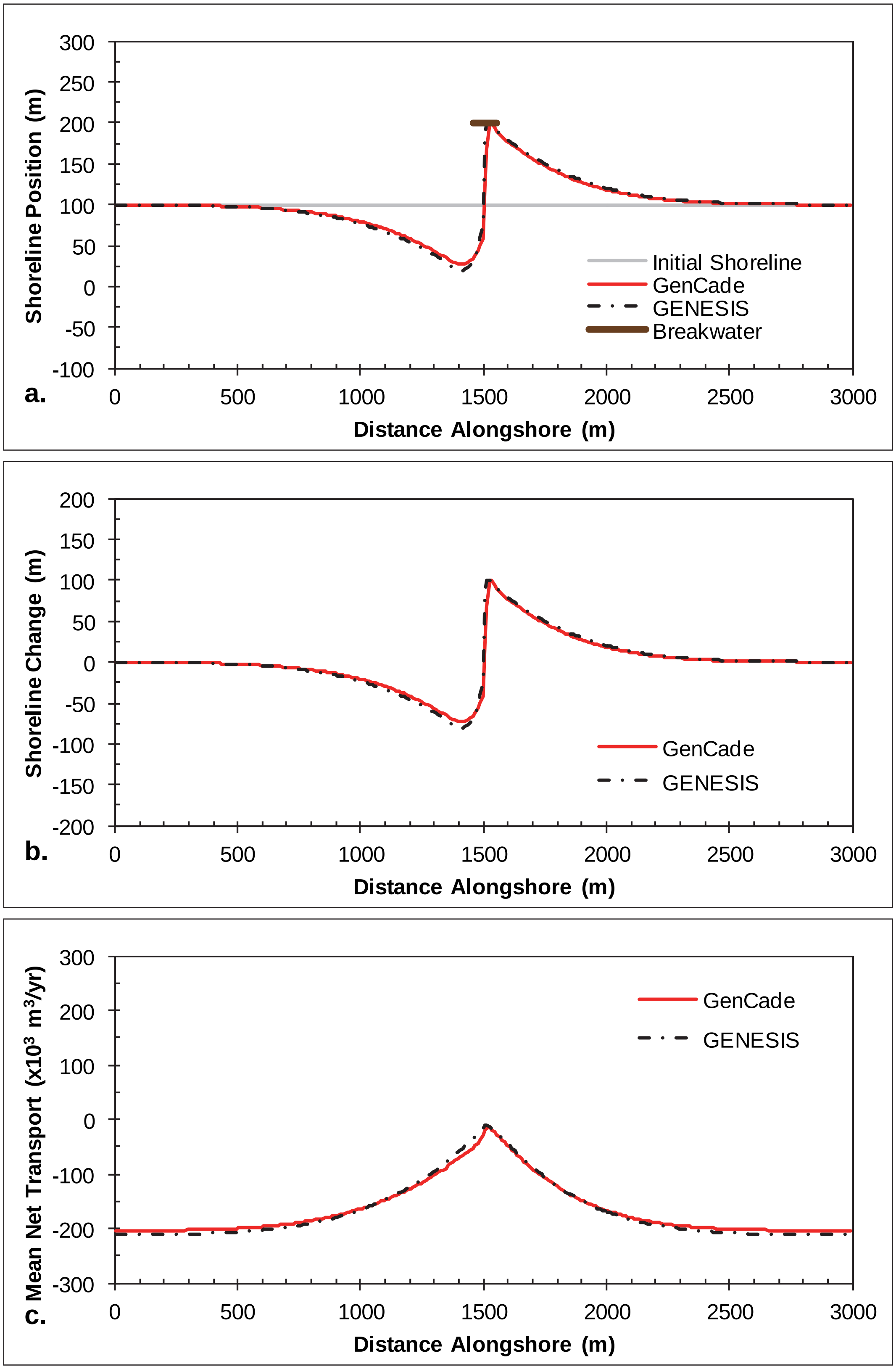


Figure 43. Calculated (a) shoreline position, (b) shoreline change, and (c) mean net transport for straight shoreline with detached breakwater; H_0 = 0.75 m, T = 8 sec, θ_0 = -15-deg.

results. There is some difference observed at the peaks of the salient and the downdrift erosional zones; however, this difference is small and accounts for only about two percent error (1.7 percent normalized mean absolute error and 2.3 percent normalized root-mean-square error). Differences in results could be because of differences in the wave transformation model.

3.2.2.4 T-groin

A T-groin case is demonstrated in this section with a 90 m long T-head groin at the center of the domain located 100 m offshore of the shoreline with all diffracting tips set to a depth of 6 m. Figure 44 shows the results after a 2-year simulation with constant +15-deg wave angle forcing. These simulations result in a nearly symmetric shoreline change response in the lee of the T-head and on either side of the groin and the accretion of shoreline out to the structure tip. The transport rates decrease from a background rate of 200,000 m^3/yr to zero directly adjacent to the groin structure.

Figure 45 presents the results after a 2-year simulation with constant -15-deg wave angle forcing. The opposite pattern is again observed in this example because transport is forced by negative wave angles relative to shore normal. Figure 45(c) shows that an increase in transport occurs on the left (downdrift) side of the groin from -200,000 m^3/yr background transport rate to zero directly adjacent to the groin structure. Figures 44 and 45 show good agreement between GenCade results and GENESIS results over the entire length of the domain.

3.2.2.5 Seawall

A seawall case is demonstrated next with a simple 100 m long seawall at the center of the domain located 10 m shoreward of (i.e., behind) the shoreline. Since a seawall that lies behind a straight shoreline with no other structures will never become exposed, a groin was added 100 m updrift of the seawall to force shoreline erosion in the vicinity of the seawall and expose the seawall to influence downdrift shoreline evolution. The groin follows the same dimensions of the single groin case in section 3.2.2.2. Figure 46 shows the results after a 2-year simulation with constant +15-deg wave angle forcing. The shoreline erodes to the right of the groin exposing the seawall. This halts erosion at the seawall, but accelerates erosion to the right (downdrift) of the seawall. Prior to the end of the simulation sediment accretes in front of the seawall resulting in the shoreline position observed in Figure 46(a).

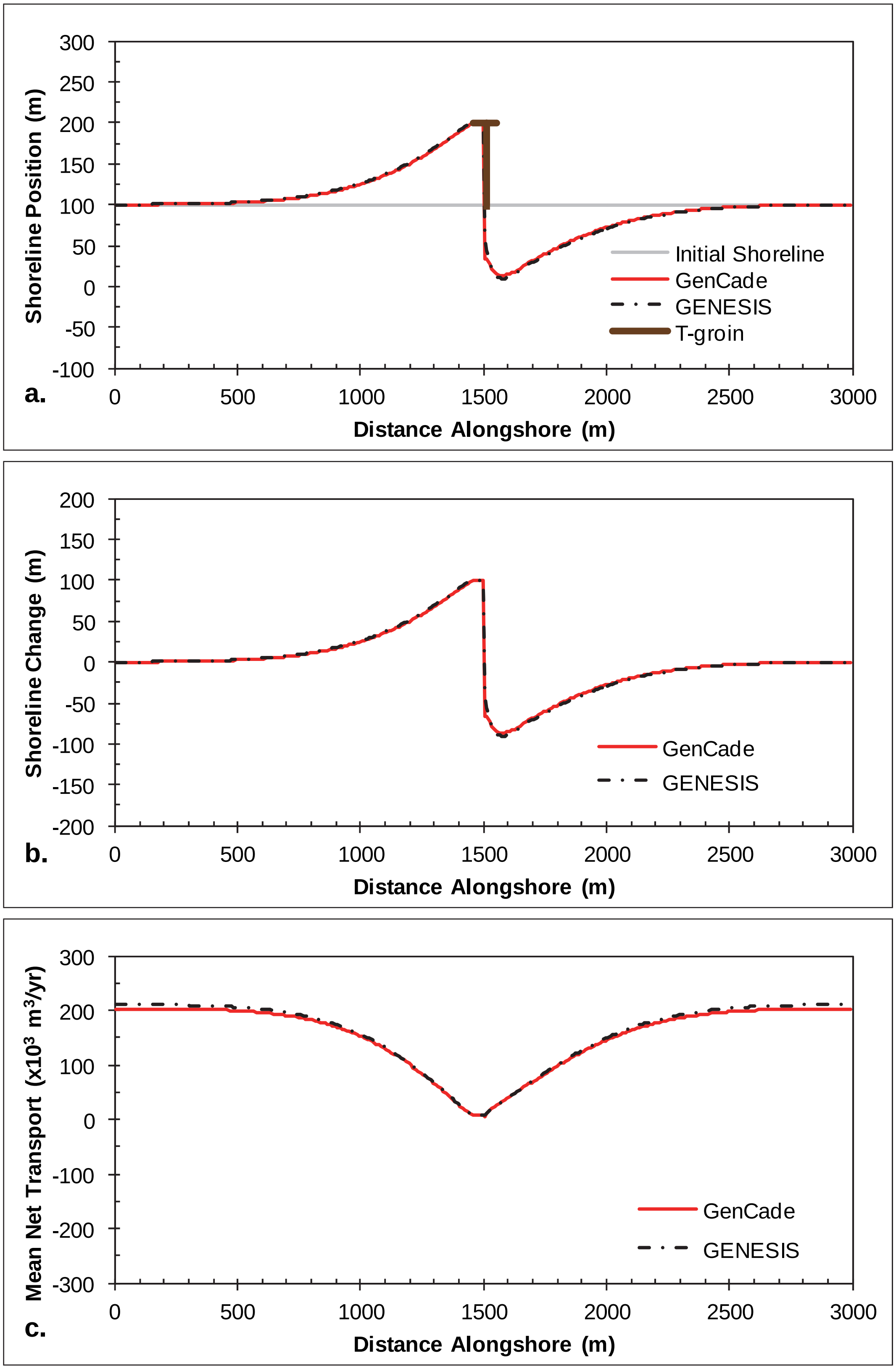


Figure 44. Calculated (a) shoreline position, (b) shoreline change, and (c) mean net transport for straight shoreline with T-head groin; H_0 = 0.75 m, T = 8 sec, θ_0 = +15-deg.

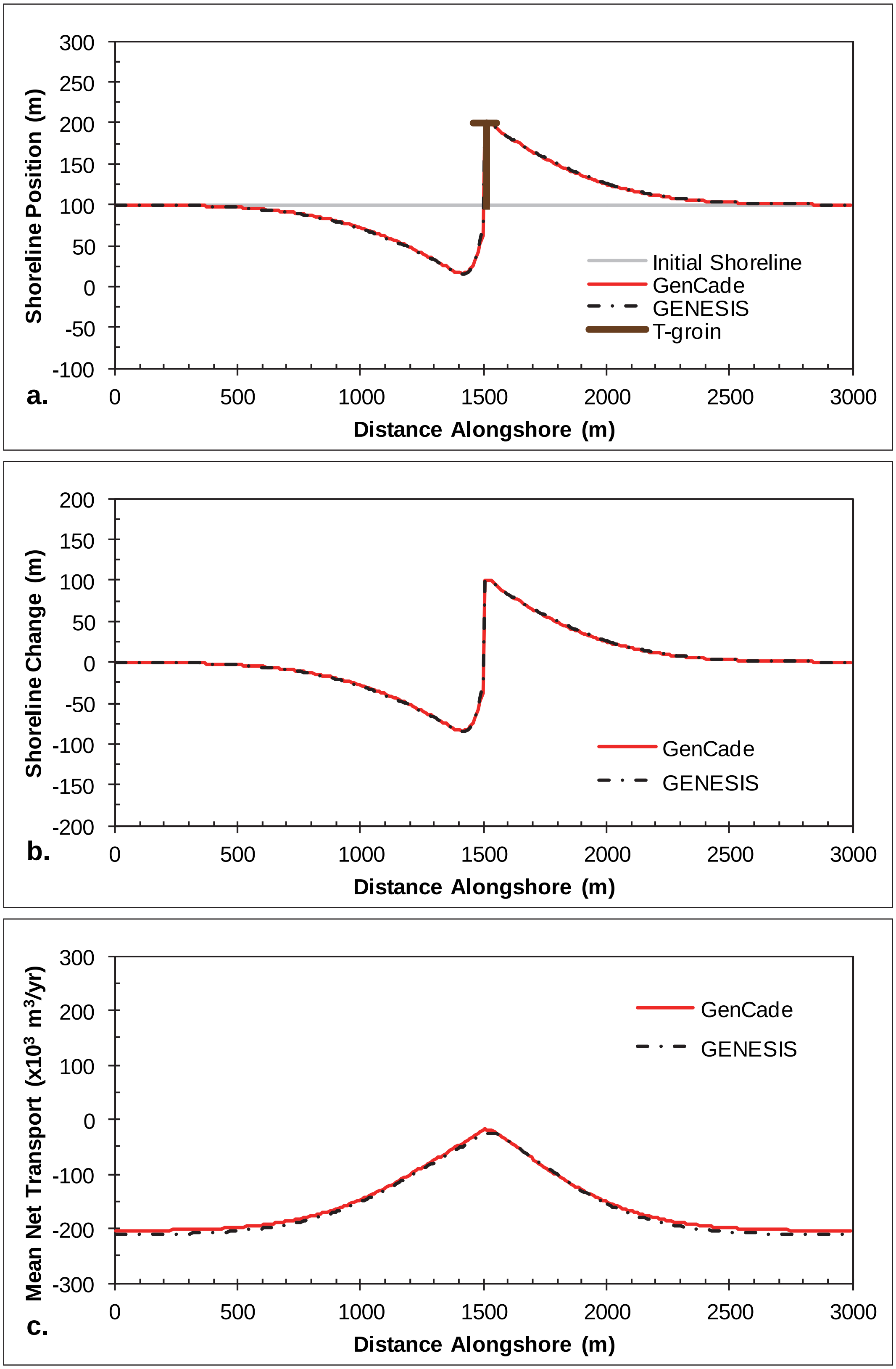


Figure 45. Calculated (a) shoreline position, (b) shoreline change, and (c) mean net transport for straight shoreline with T-head groin; H_0 = 0.75 m, T = 8 sec, θ_0 = -15-deg.

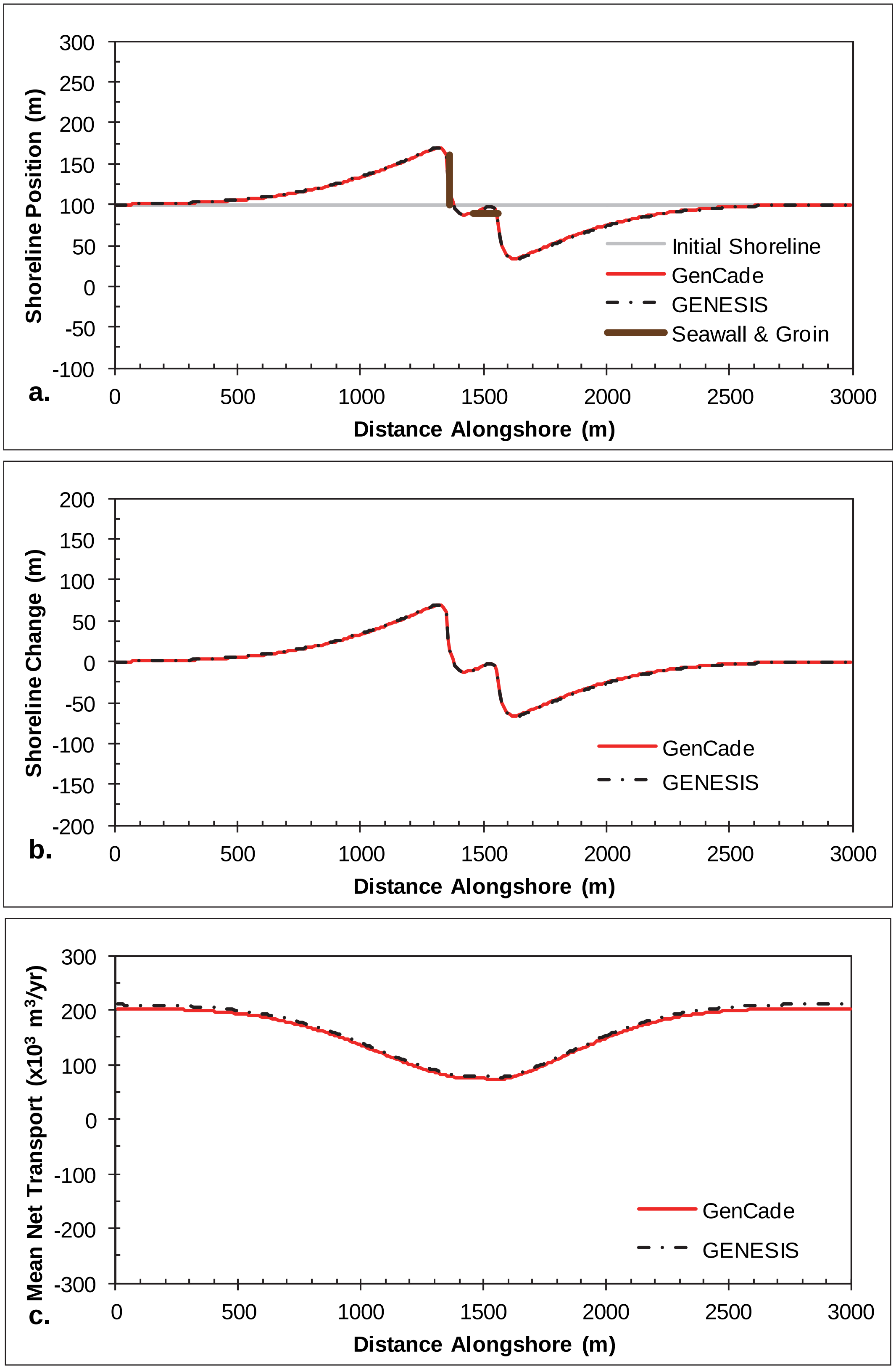


Figure 46. Calculated (a) shoreline position, (b) shoreline change, and (c) mean net transport for straight shoreline with seawall and groin; H_0 = 0.75 m, T = 8 sec, θ_0 = +15-deg.

Figure 47 presents the results after a 2-year simulation with constant -15-deg wave angle forcing. In this case the groin was again placed updrift of the seawall, but since the wave angle is reversed, the groin is now 10 m to the right (updrift) of the seawall. Figures 46 and 47 again show excellent agreement between GenCade results and GENESIS results over the entire length of the domain.

3.2.2.6 Beach fill

The simple case of a straight shoreline without any coastal structures is again presented in this section, but in this case a beach fill is added to evaluate shoreline progradation during the fill and the diffusion of the material and shoreline evolution after beach fill project completion. The beach fill project was initiated two months into the simulation and involved a construction duration of two months adding 50 m of berm width over an alongshore distance of 500 m. Upon beach fill completion (i.e., after two months of pumping fill onto the berm), no additional material was added.

Figure 48 shows the results after a two-year simulation with constant +15-deg wave angle forcing. Figure 48(a) shows the shoreline position immediately after the fill project as well as the shoreline position after two years (i.e., 20-months after completion of the fill project). This clearly shows the lateral diffusion of the beach fill material along the shoreline. Figure 48(c) shows the transport gradient around the beach fill berm feature with the greatest deviation from background transport rate occurring at the fill transition zones. Figure 49 shows the results after a two-year simulation with constant -15-deg wave angle forcing. As one should expect, the shoreline evolution is identical to that shown in Figure 48 and only the transport rates are inverted. Results for all simulations with beach fills result in close agreement between GenCade results and GENESIS results.

3.2.2.7 Inlet

A case with a single inlet centered along a straight shoreline is demonstrated with GenCade in this section. The idealized inlet is 200 m wide and is stabilized with two 200 m jetties with bypassing coefficients set to 1.0 permeability set to 0.0, and diffracting tip depth set to 7 m. All morphological elements are set to equilibrium. The attachment bars spread bypassing across five cells (50 m) starting immediately adjacent to

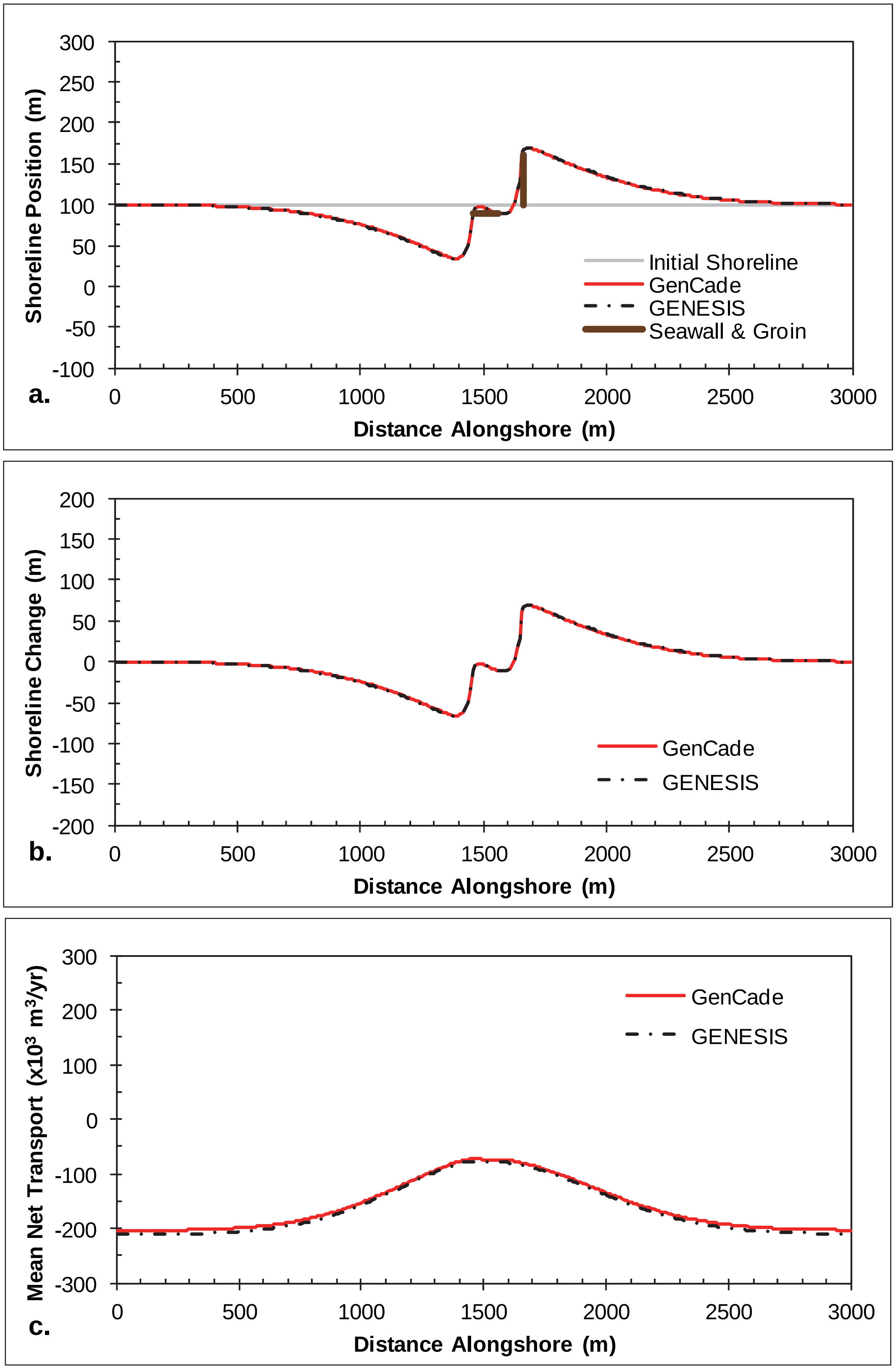


Figure 47. Calculated (a) shoreline position, (b) shoreline change, and (c) mean net transport for straight shoreline with seawall and groin; H_0 = 0.75 m, T = 8 sec, θ_0 = -15-deg.

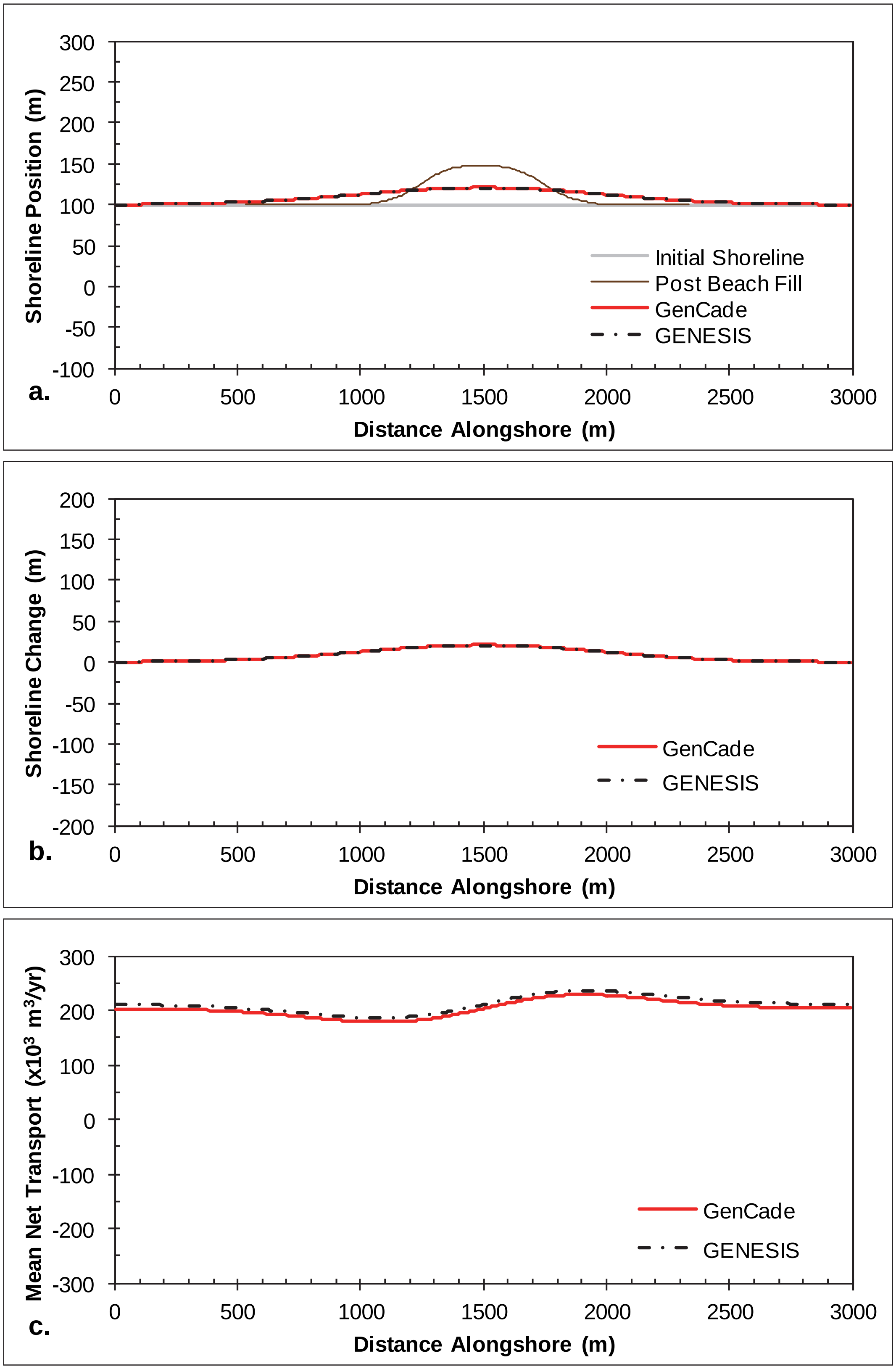


Figure 48. Calculated (a) shoreline position, (b) shoreline change, and (c) mean net transport for straight shoreline with a beach fill; H_0 = 0.75 m, T = 8 sec, θ_0 = +15-deg.

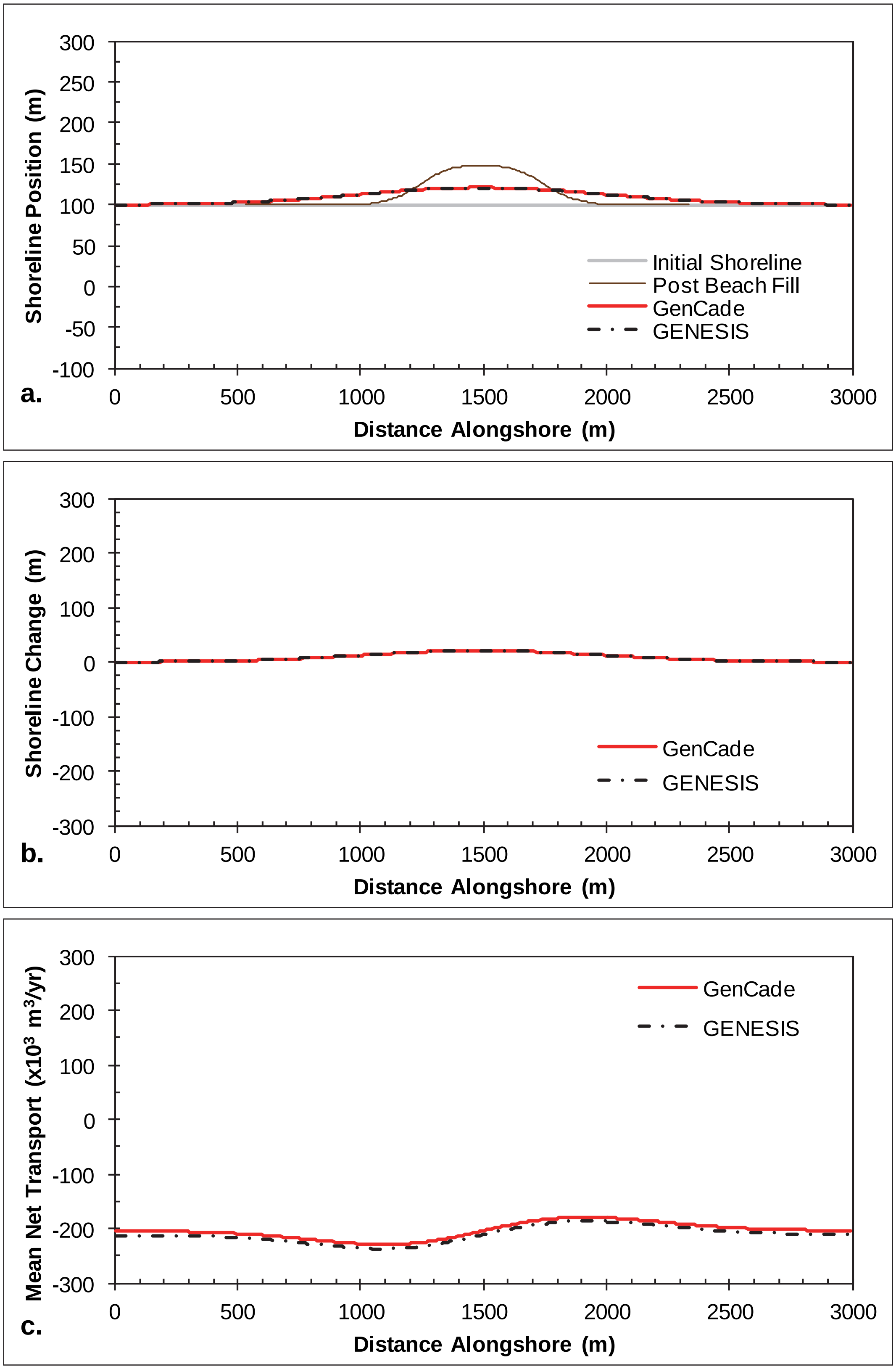


Figure 49. Calculated (a) shoreline position, (b) shoreline change, and (c) mean net transport for straight shoreline with a beach fill; H_0 = 0.75 m, T = 8 sec, θ_0 = -15-deg.

each of the jetties. Figure 50 shows the results after a two-year simulation with constant +15-deg wave angle forcing. This simulation results in an updrift offset inlet configuration that is typical of inlets associated with adequate updrift sediment supply and moderate transport rates. The development of an updrift fillet and downdrift erosion is observed in the shoreline response. The transport rates decrease from a background rate of 200,000 m^3/yr to approximately 100,000 m^3/yr adjacent to the jetty, then immediately drop to zero inside the inlet.

Figure 51 shows the results after a two-year simulation with constant -15-deg wave angle forcing. The opposite pattern is observed in this example because transport is forced by negative wave angles relative to shore normal. Figure 51(c) shows that the transport rates increase from a background rate of -200,000 m^3/yr to approximately -100,000 m^3/yr adjacent to the jetty, then immediately rise to zero inside the inlet. Again, the expected opposite shoreline response is observed here. No comparison was developed for GENESIS because inlets, shoal evolution, and bypassing are new capabilities only incorporated in GenCade.

Sediment transport and bypassing within the inlet are calculated within the inlet reservoir module of GenCade. Figure 52 shows the ebb and flood tidal delta evolution for these simulations compared to the shoal evolution in the same cases with 100,000 m^3/yr after 2.5 years, 200,000 m^3/yr after 5.5 years, and 50,000 m^3/yr after 9.5 years dredged from the ebb shoal and with 150,000 m^3/yr after seven years dredged from the flood shoal.

3.2.2.8 Concave shoreline in GenCade – no structures

A case having a simple concave shoreline without any coastal structures or coastal project components is presented in this section to examine long-term shoreline response with and without the constraint of the regional equilibrium trend applied. Figures 53-55 show the results of calculated shoreline position, shoreline change, and net sediment transport after a two-year simulation of a concave shoreline case similar to the straight shoreline benchmark applications presented in Figures 38-51 for comparison of the effects of a cuspate regional trend on the solution. The results are presented with and without the application of the regional equilibrium contour for improved understanding of the consequences of the large-scale regional alongshore gradients have over the simulation. The wave transformation contour smoothing window (ISMOOTH) was set to the number of cells in the domain to maintain constant wave angle

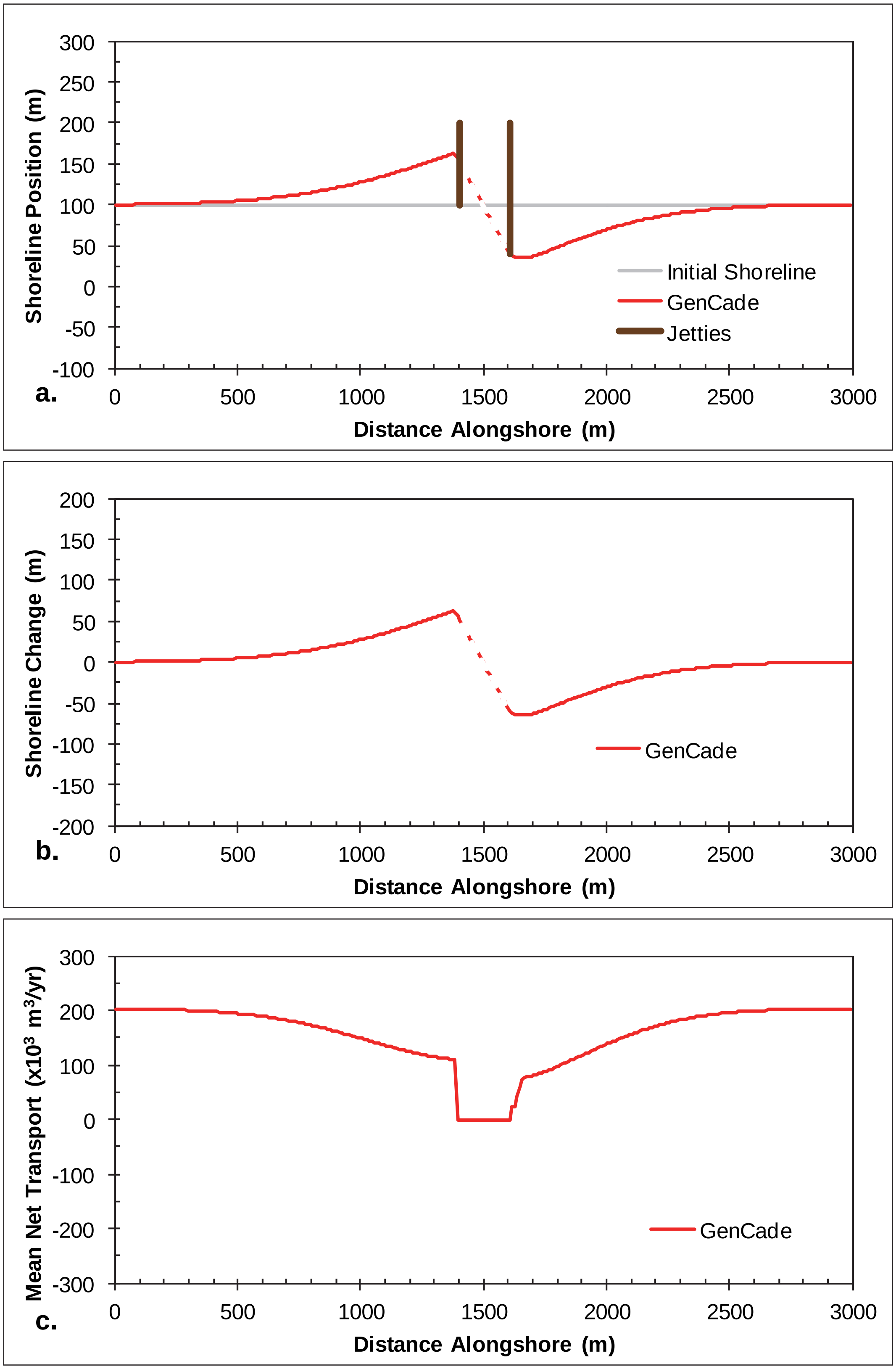


Figure 50. Calculated (a) shoreline position, (b) shoreline change, and (c) mean net transport for straight shoreline with an inlet; H_0 = 0.75 m, T = 8 sec, θ_0 = +15-deg.

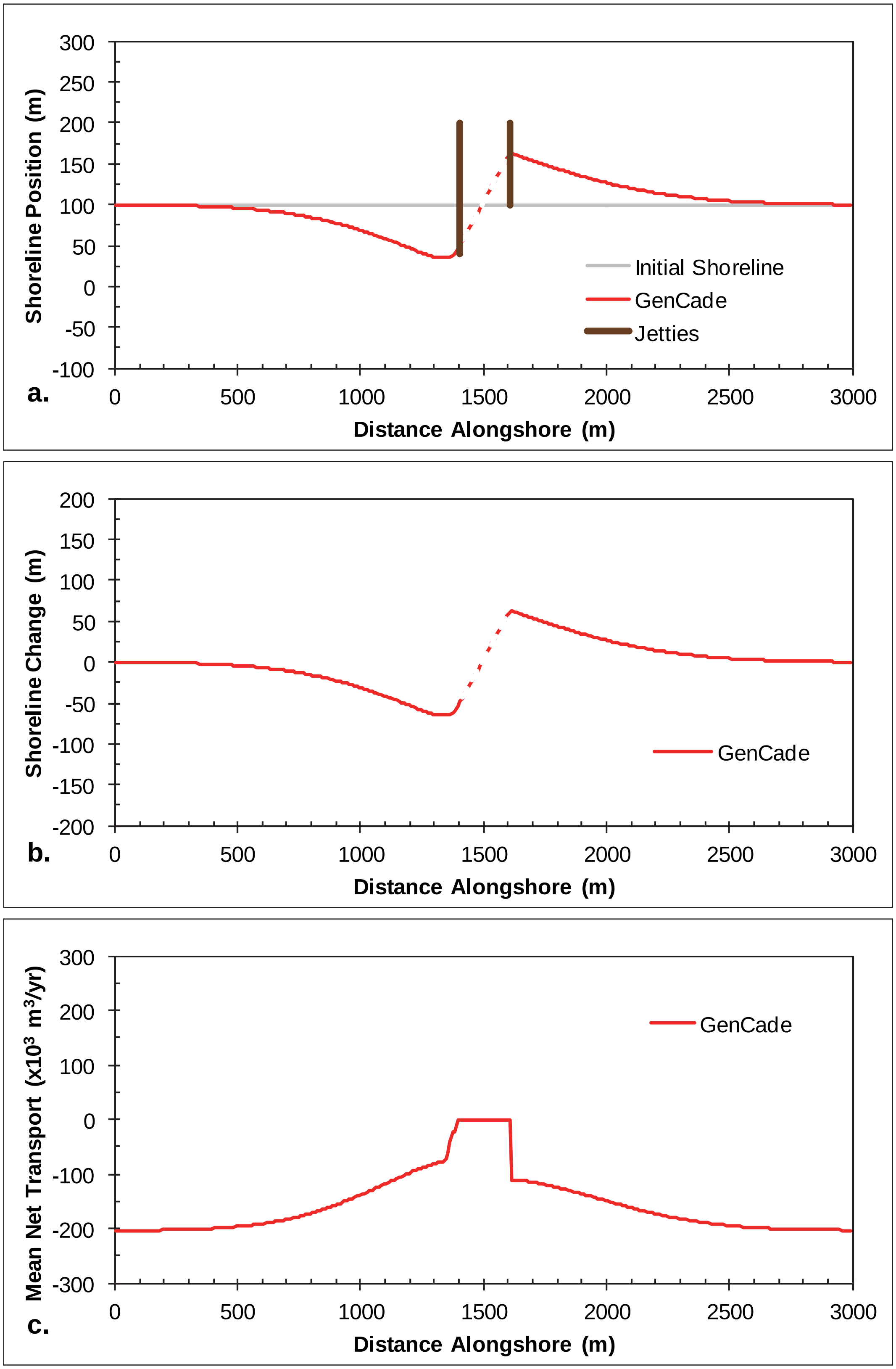


Figure 51. Calculated (a) shoreline position, (b) shoreline change, and (c) mean net transport for straight shoreline with an inlet; H_0 = 0.75 m, T = 8 sec, θ_0 = +15-deg.

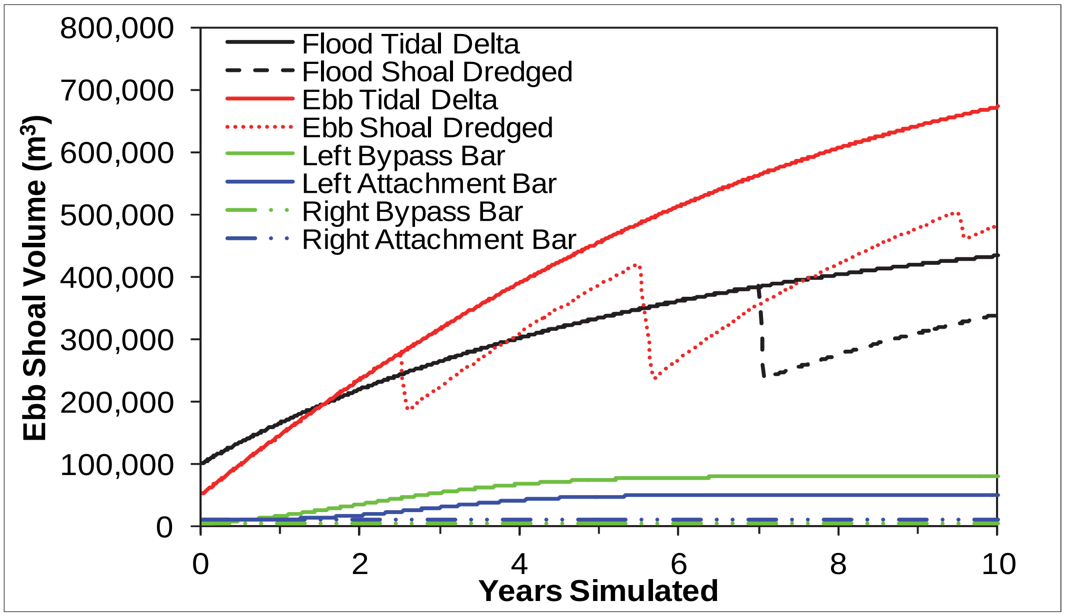


Figure 52. Calculated ebb and flood shoal evolution.

forcing. Figure 53 shows the results of a two-year regionally cuspate shoreline simulation with no structures forced by constant 0-deg. offshore wave angle. This figure demonstrates that the application of the regional trend forces the solution to maintain the regionally concave shape, while the results without the regional equilibrium contour begin to fill in and return to a straight shoreline due to the transport gradient across the domain. Figures 54 and 55 present similar results for +15-deg and -15-deg offshore wave angle, respectively.

Figure 56 shows the shoreline position results after a 30-year simulation with constant -15-deg wave angle forcing. Because of the alongshore gradients in the shoreline orientation angle relative to the breaking wave angle, the concave shoreline progrades seaward and eventually fills the concave embayment completely resulting in a straight shoreline. In many cases this long-term shoreline straightening is not representative of the long-term equilibrium observations. In many cases the underlying geology or other coastal bathymetric or shoreline features result in a shoreline maintaining a long-term equilibrium regional shape over which local variations in shoreline evolution occur. For this reason, it is sometimes advantageous to employ the GenCade regional contour to maintain a long-term equilibrium shape. Figure 56 (b) presents a demonstration of this regional contour capability. This figure shows that when the regional contour is employed, the regional contour is maintained over the entire 30-year period.

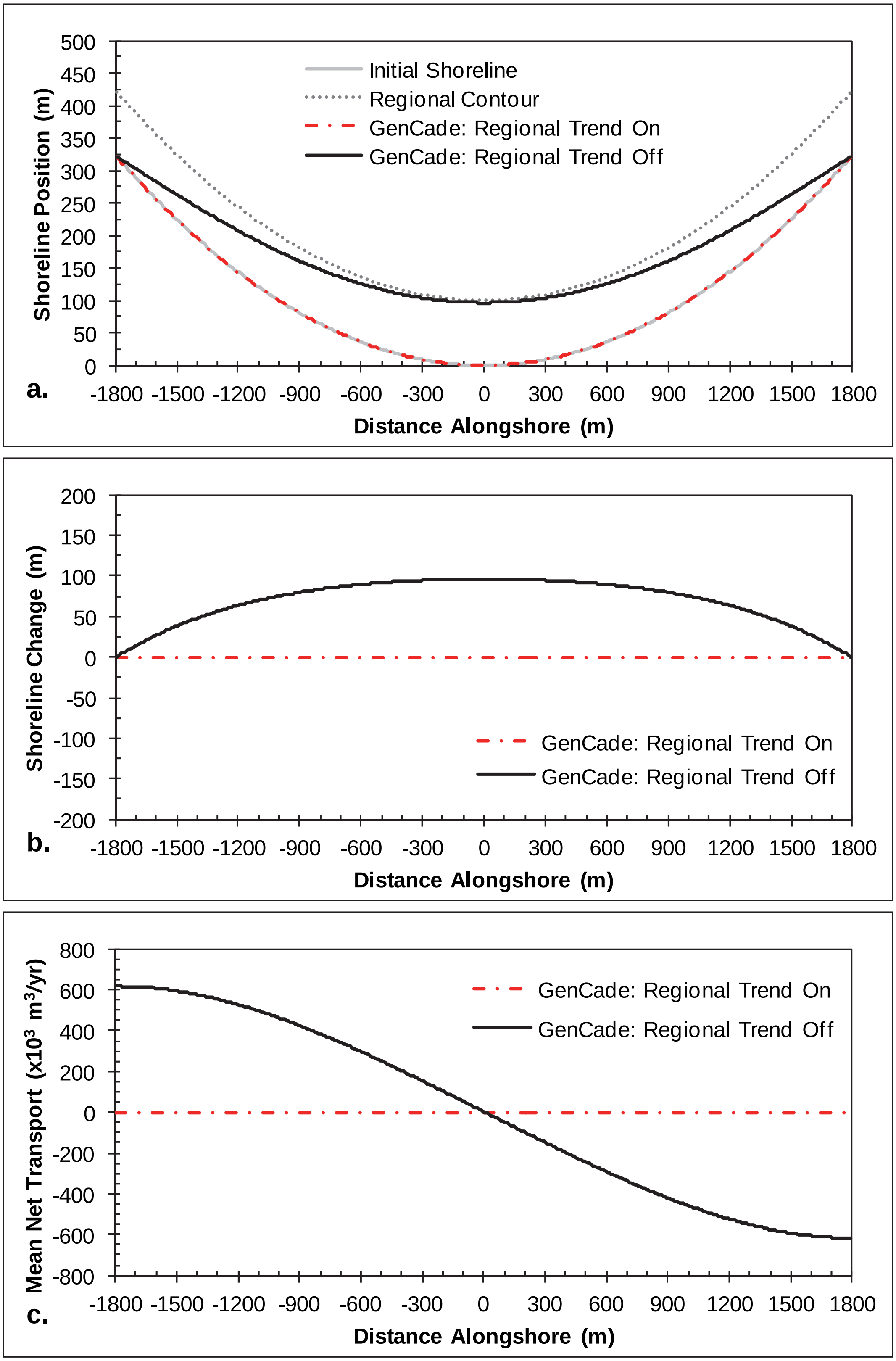


Figure 53. Calculated (a) shoreline position, (b) shoreline change, and (c) mean net transport for concave shoreline with no structures; $H_0 = 0.75$ m, $T = 8$ sec, $\theta_0 = 0$-deg.

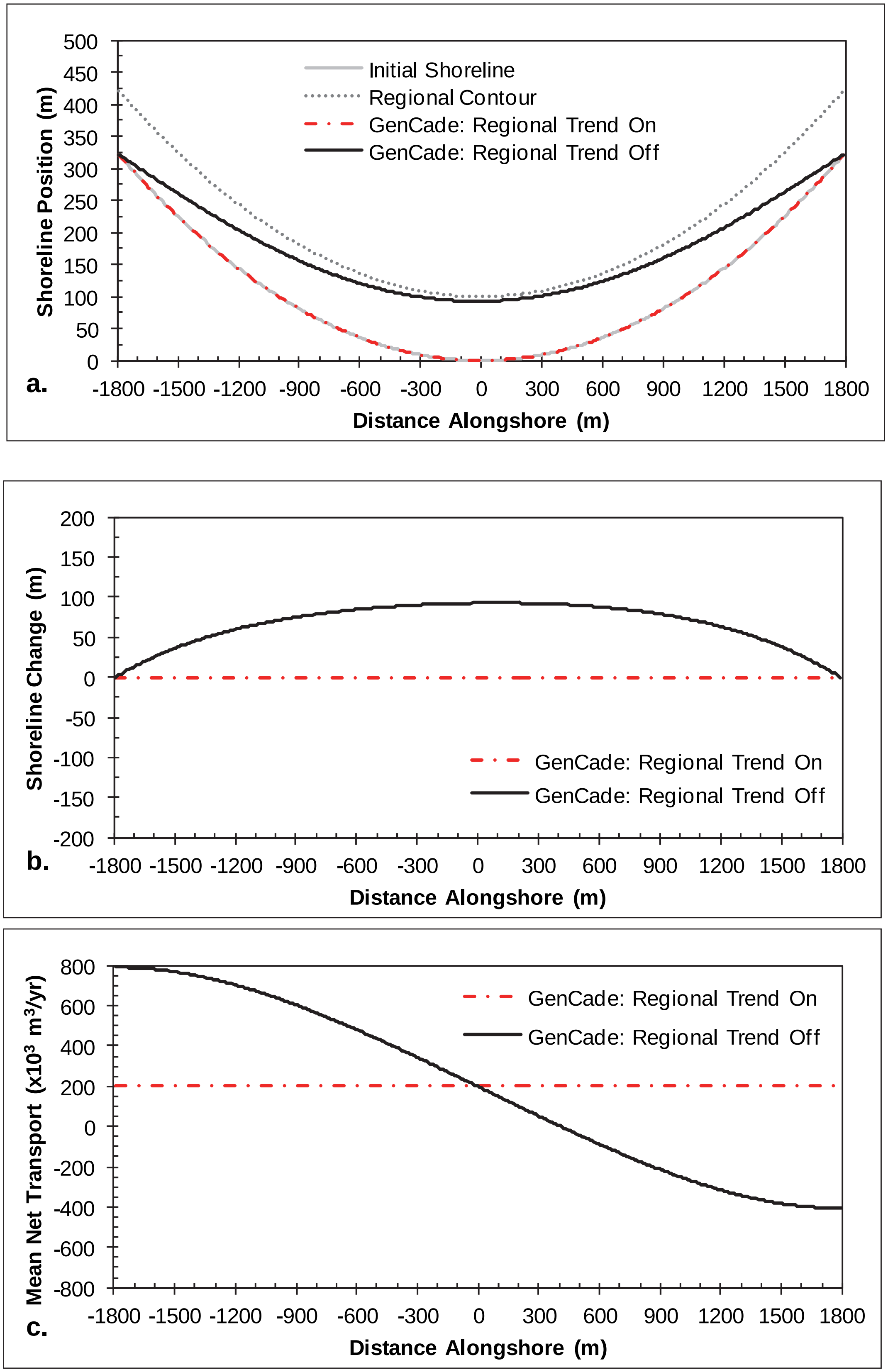


Figure 54. Calculated (a) shoreline position, (b) shoreline change, and (c) mean net transport for concave shoreline with no structures; $H_0 = 0.75$ m, $T = 8$ sec, $\theta_0 = +15$-deg.

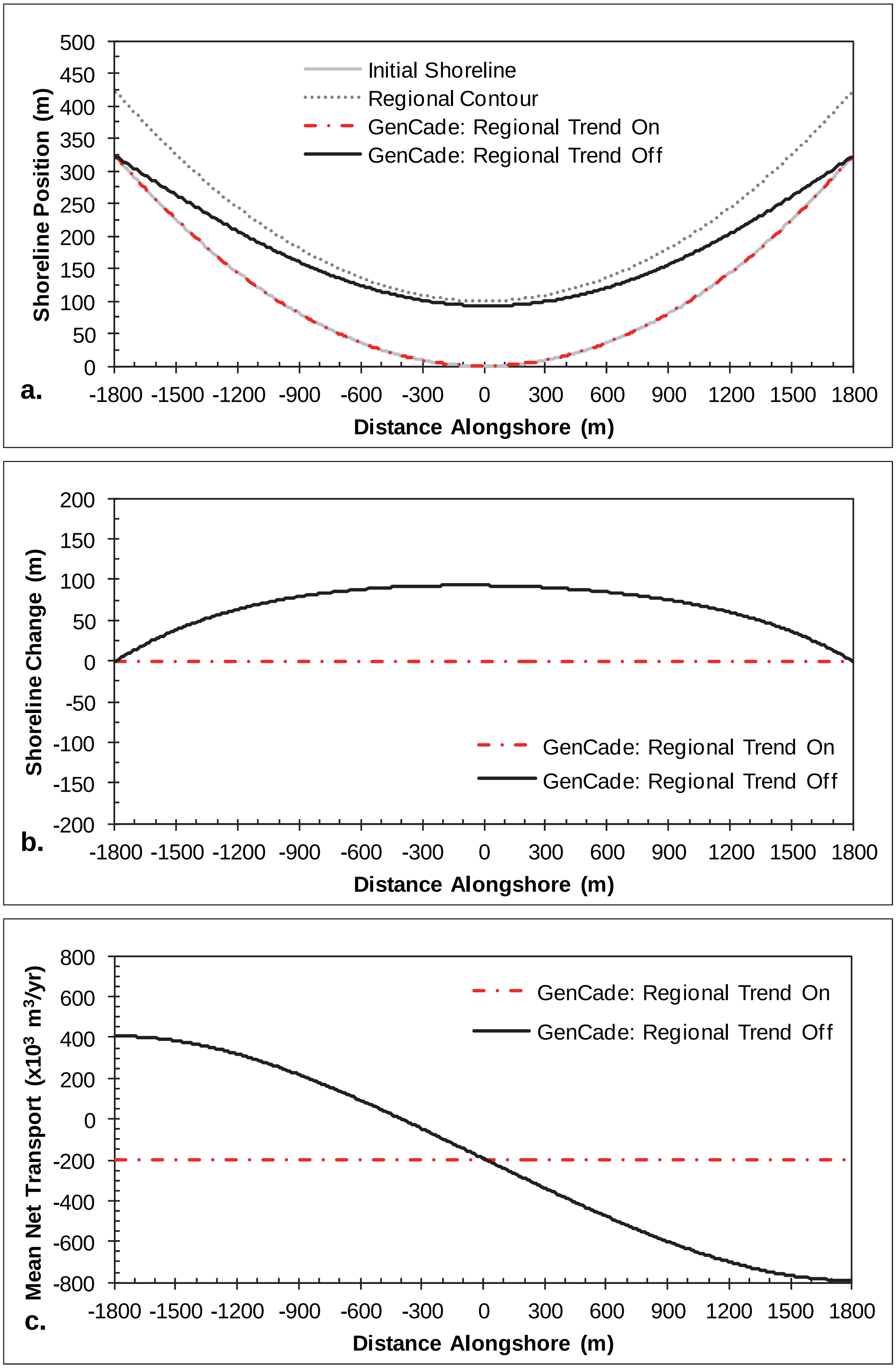


Figure 55. Calculated (a) shoreline position, (b) shoreline change, and (c) mean net transport for concave shoreline with no structures; H_0 = 0.75 m, T = 8 sec, θ_0 = -15-deg.

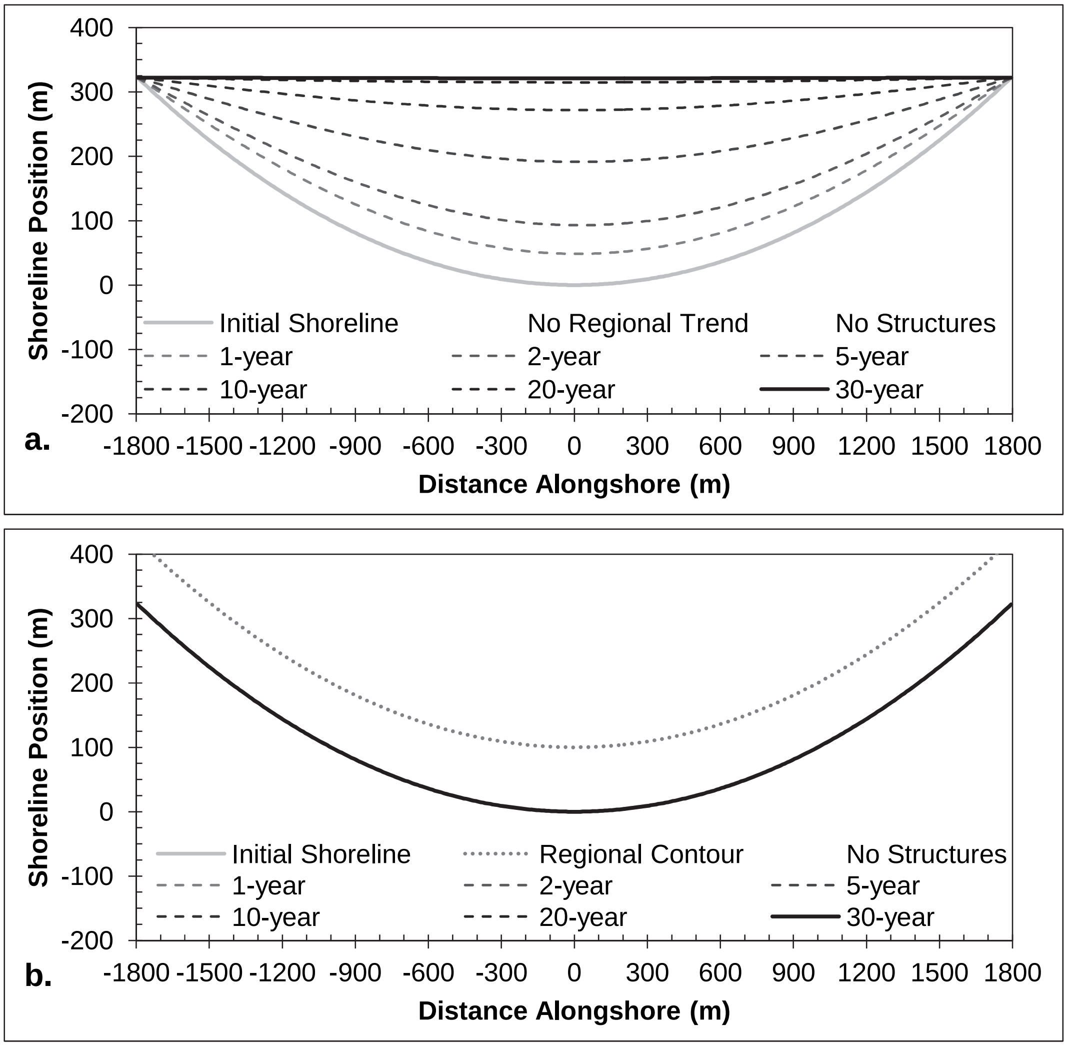


Figure 56. Calculated shoreline position (a) without regional contour and (b) with regional contour for concave shoreline no structures; H_0 = 0.75 m, T = 8 sec, θ_0 = -15-deg.

3.2.2.9 Concave shoreline in GenCade – two groins

A case having a simple concave shoreline with one groin on each side of the domain is presented in Figures 57-60 to examine long-term shoreline response with and without the regional equilibrium contour applied and the local shoreline response to structures with opposing transport directions due to the shoreline angle gradient relative to the breaking wave angles. Figures 57-59 present results similar to Figures 53-56 but with local shoreline changes around structures imposed upon the regional trend during oblique wave forcing (Figures 58 and 59).

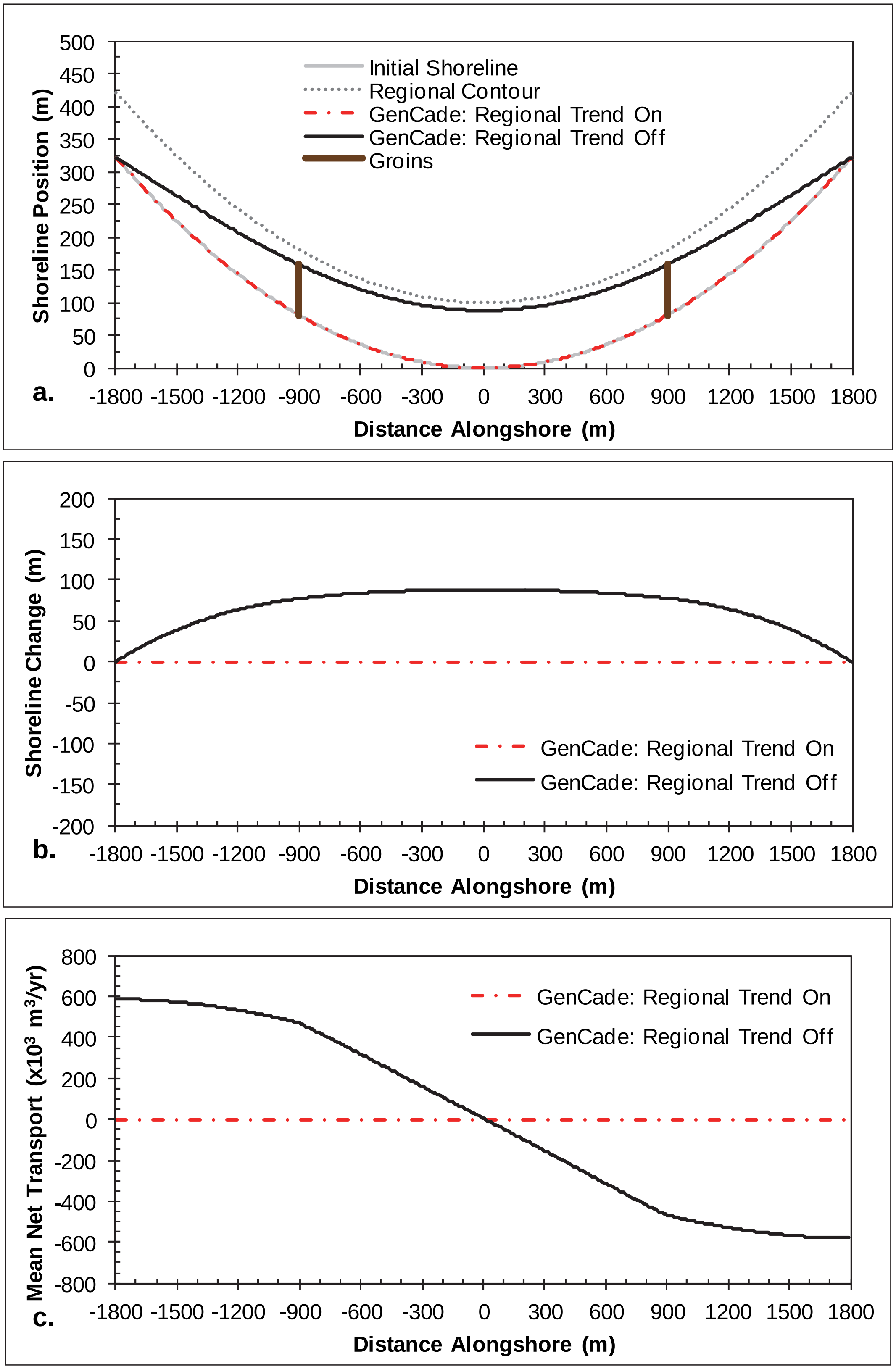


Figure 57. Calculated (a) shoreline position, (b) shoreline change, and (c) mean net transport for concave shoreline with two groins; H_0 = 0.75 m, T = 8 sec, θ_0 = 0-deg.

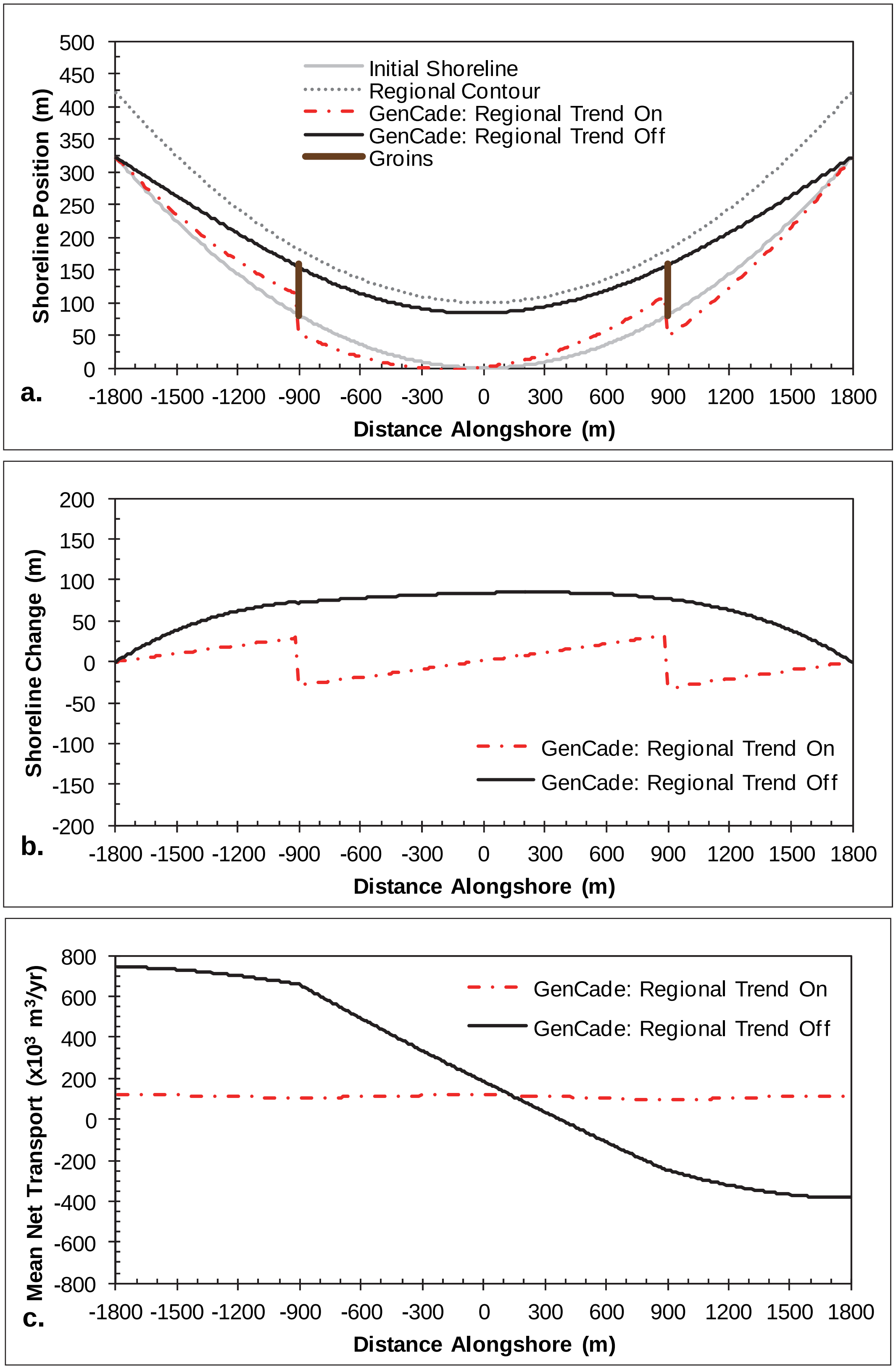


Figure 58. Calculated (a) shoreline position, (b) shoreline change, and (c) mean net transport for concave shoreline with two groins; H_0 = 0.75 m, T = 8 sec, θ_0 = +15-deg.

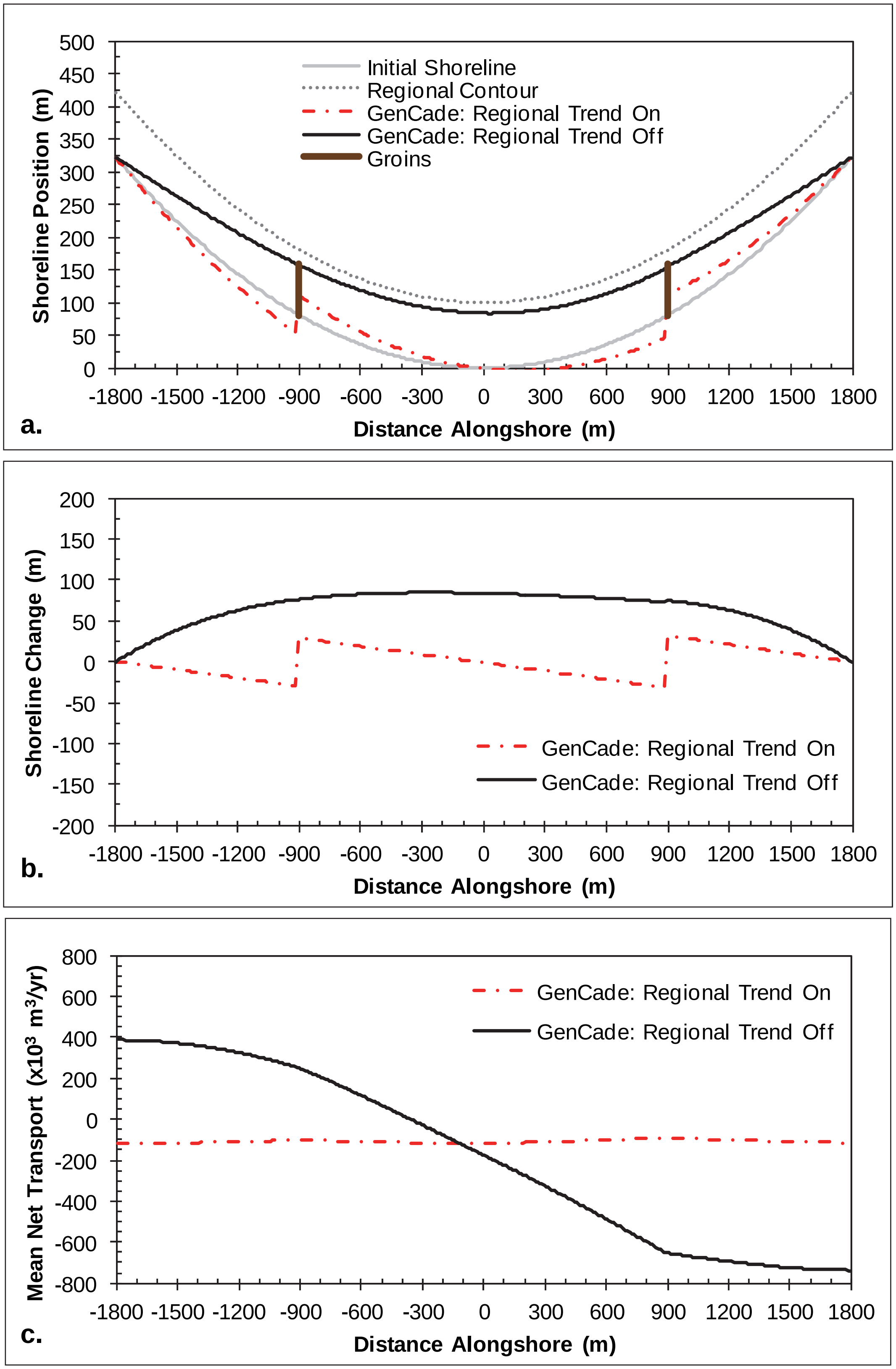


Figure 59. Calculated (a) shoreline position, (b) shoreline change, and (c) mean net transport for concave shoreline with two groins; H_0 = 0.75 m, T = 8 sec, θ_0 = -15-deg.

Figure 60 shows the shoreline position results after a 30-year simulation with constant -15-deg. wave angle forcing. Because of the alongshore gradients in the shoreline orientation angle relative to the breaking wave angle, the local updrift fillet develops on one side of each groin. A similar pattern to what is observed in Figure 56 is also observed in Figure 60 when comparing results of the simulations with and without the application of the regional equilibrium contour.

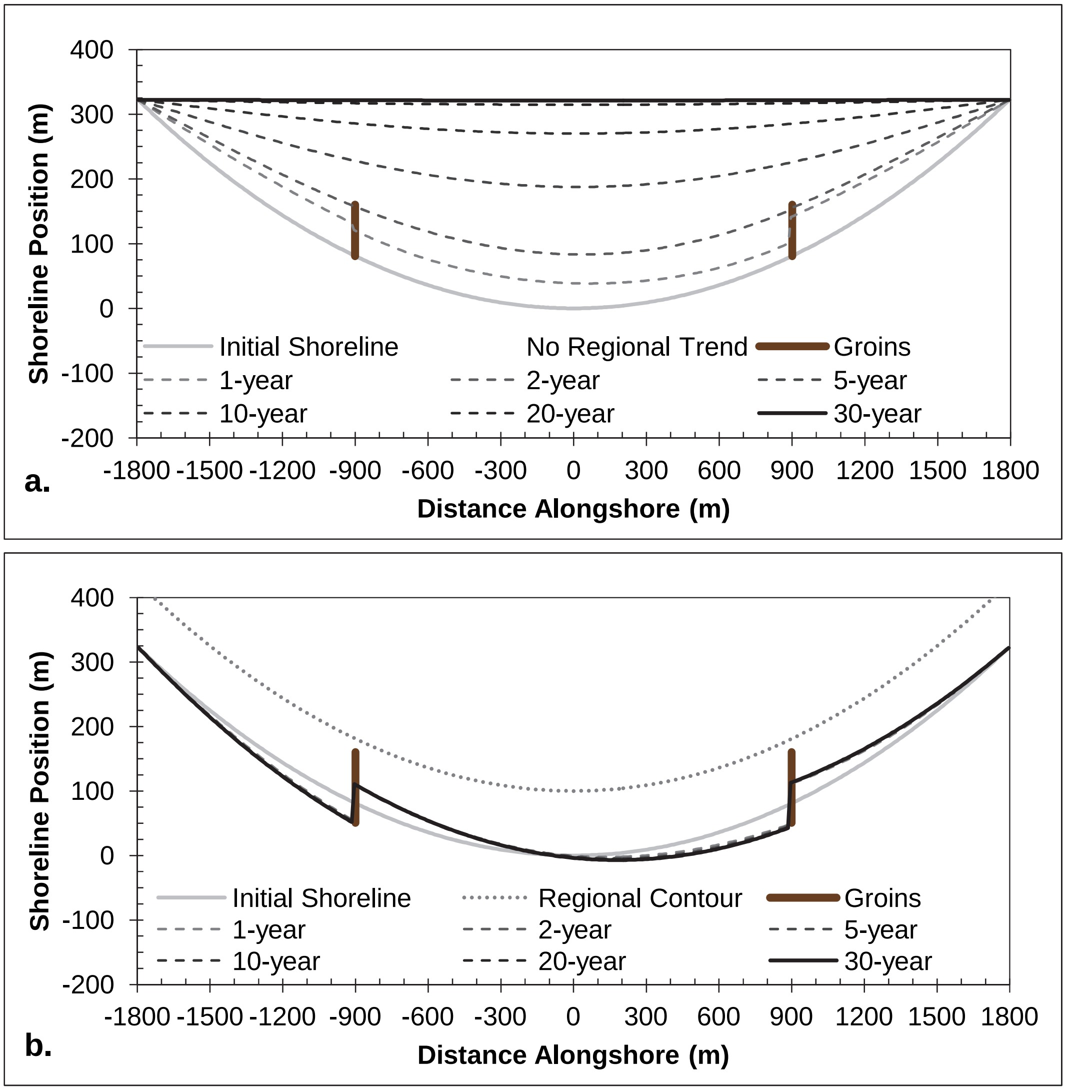


Figure 60. Calculated shoreline position (a) without regional contour and (b) with regional contour for concave shoreline with two groins; H_0 = 0.75 m, T = 8 sec, θ_0 = -15-deg.

3.2.2.10 Wave breaking sensitivity

A series of GenCade simulations were executed to evaluate the sensitivity to breaking wave parameters of the GenCade internal wave model.

Calculations were verified against linear wave theoretical estimates and results from CMS-Wave (Lin et al. 2008) simulations. The simplest case of a straight shoreline without any coastal structures or coastal project components (refer to section 3.2.2.1) was employed for this application. Offshore wave forcing was applied at a depth of 50 m and for all angles between +85-deg and -85-deg at 5-deg increments. Simulations were executed for three wave height and period combinations: 1) H_0 = 0.75 m and T_p = 8 sec; 2) H_0 = 1.50 m and T_p = 8 sec; and 3) H_0 = 3.00 m and T_p =12 sec.

A corresponding CMS-Wave model application was developed employing a grid 3.2 km in the cross-shore direction by 3.6 km wide in the alongshore direction with 5-m cell resolution (i.e., 640 x 720 = 460,800 cells). The bathymetric data was developed to represent an idealized equilibrium profile based on a medium sand median grain size of d_{50} = 0.25 mm (i.e., Dean A-parameter = 0.11139). Wave energy was supplied at the offshore boundary (depth = 50 m) as a TMA-type unidirectional spectrum for each wave condition consisting of 11 frequency bins (0.05 to 0.15 Hz at 0.01-Hz increment) and 35 direction bins (covering a half-plane with 5-deg spacing). Although CMS-Wave is a spectral phase-averaging wave model, breaking wave parameters were estimated by selecting the peak significant wave height output immediately offshore of the breaking wave index output flag. Figures 61-63 presents the results for each wave condition comparing breaking wave parameters for GenCade, CMS-Wave, and a third linear wave theoretical estimate method based on a planar beach with slope 1.5:100 (m = 0.015). GenCade results agree well with the linear theory with only slightly larger waves calculated by GenCade for the high energy case (H_0 = 3.00 m and T_p =12 sec). GenCade calculated breaking wave height results agree well with CMS-Wave calculated H_b results with an average root-mean-square error (RMSE) of 2 cm. Breaking wave directions do not agree quite as well, with an average RMSE of 2.2-deg, but the majority of the error is accounted for in the acutely oblique angles of the storm condition (H_0 = 3 m; T_p = 12 sec). Despite narrow spectrum input for CMS-Wave, directional spreading may account for much of the differences observed.

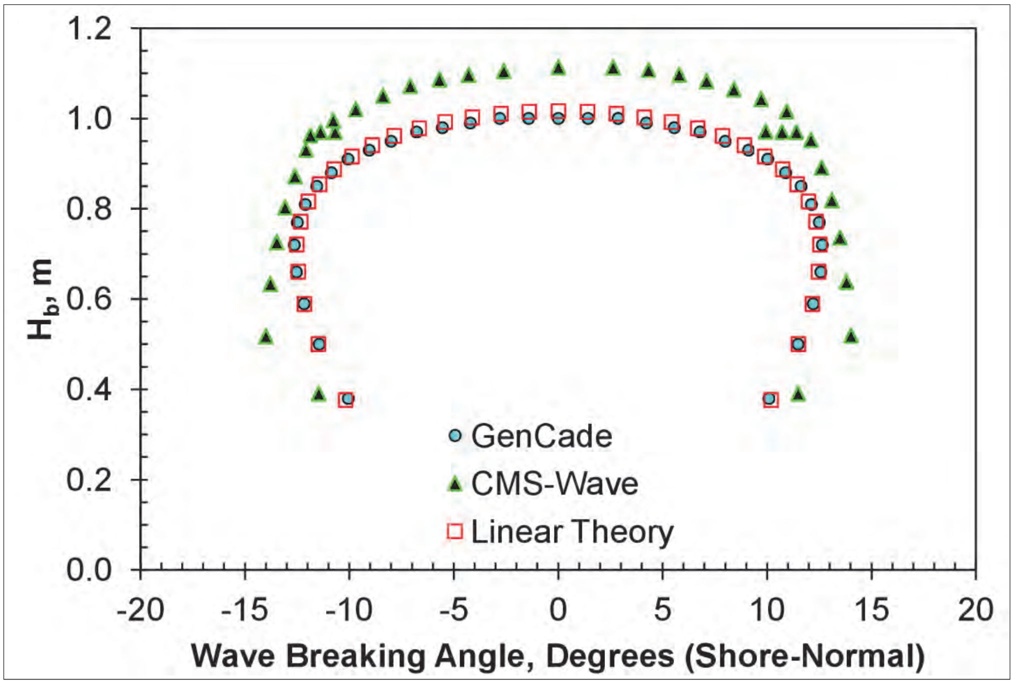


Figure 61. Calculated breaking wave height and direction; H_0 = 0.75 m, T = 8 sec, θ_0 = -85-deg. through +85-deg. at 5-deg. intervals.

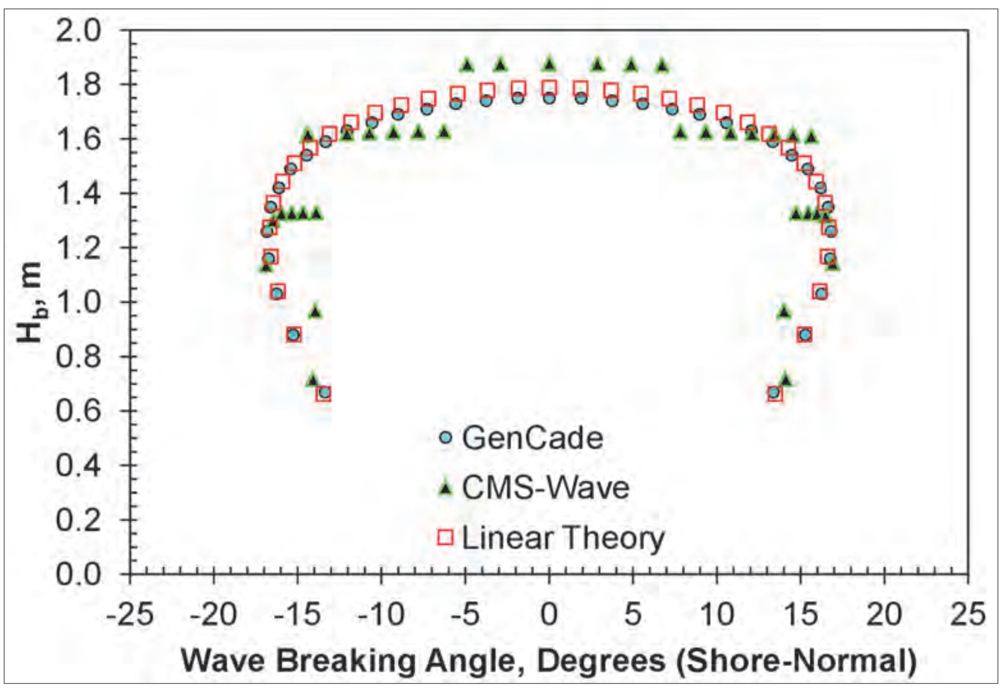


Figure 62. Calculated breaking wave height and direction; H_0 = 1.50 m, T = 8 sec, θ_0 = -85-deg. through +85-deg. at 5-deg. intervals.

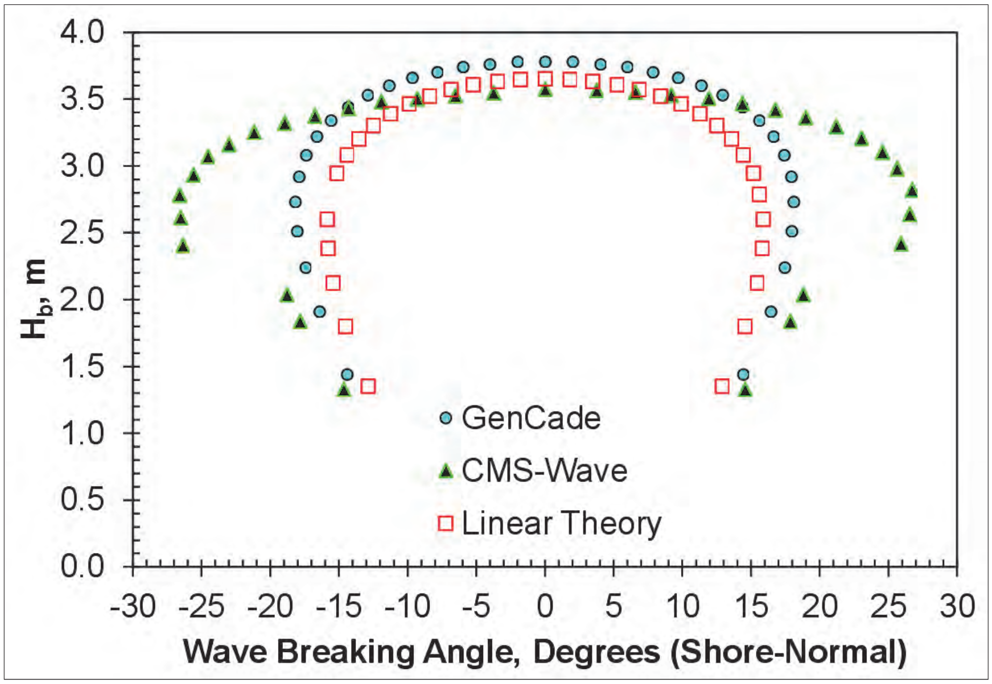


Figure 63. Calculated breaking wave height and direction; H_0 = 3.00 m, T = 12 sec, θ_0 = -85-deg. through +85-deg. at 5-deg. intervals.

3.3 Model validation – Jucar River; Cullera, Spain

Analysis of shoreline change along beaches adjacent the Jucar River in Spain was performed by Gravens (1997, 1998a, b) using the Generalized Model for Simulating Shoreline Change (GENESIS) model (Hanson 1987), a predecessor of the GenCade model. The Jucar River case was analyzed with GenCade to provide additional model validation for simple cases excluding the inlet within the model domain and to investigate potential differences between GenCade and GENESIS for one well documented case.

3.3.1 Background

Figure 64 shows a recent aerial of the Jucar River and beaches. Shoreline position data are available from 1957, 1965, 1972, 1977, 1981, and 1994 (shorelines plotted in Figures 65 and 66); however, shorelines do not cover both north and south sides of the inlet for most data sets. The data show persistence of a sandy beach to the north with shoreline advance adjacent the north jetty. Sand was extracted from the beach north of the jetties multiple times between 1982 and 1994. Beaches to the south experienced chronic erosion and were armored in the early 1970s to protect beach property.

Gravens (1997) applied a target sediment budget, developed based on a 1994 CEDEX report, along with measured shoreline change to help calibrate the models. Net sand transport along the beaches was reported to be approximately 65,000 m^3/year to the south with gross transport of 115,000 m^3/year.

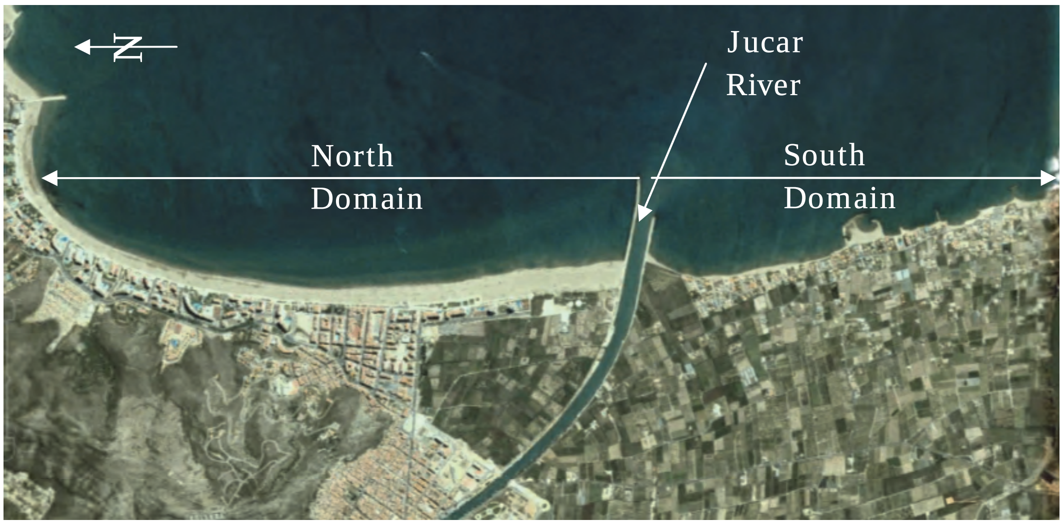


Figure 64. Recent aerial of Jucar River and adjacent beaches.

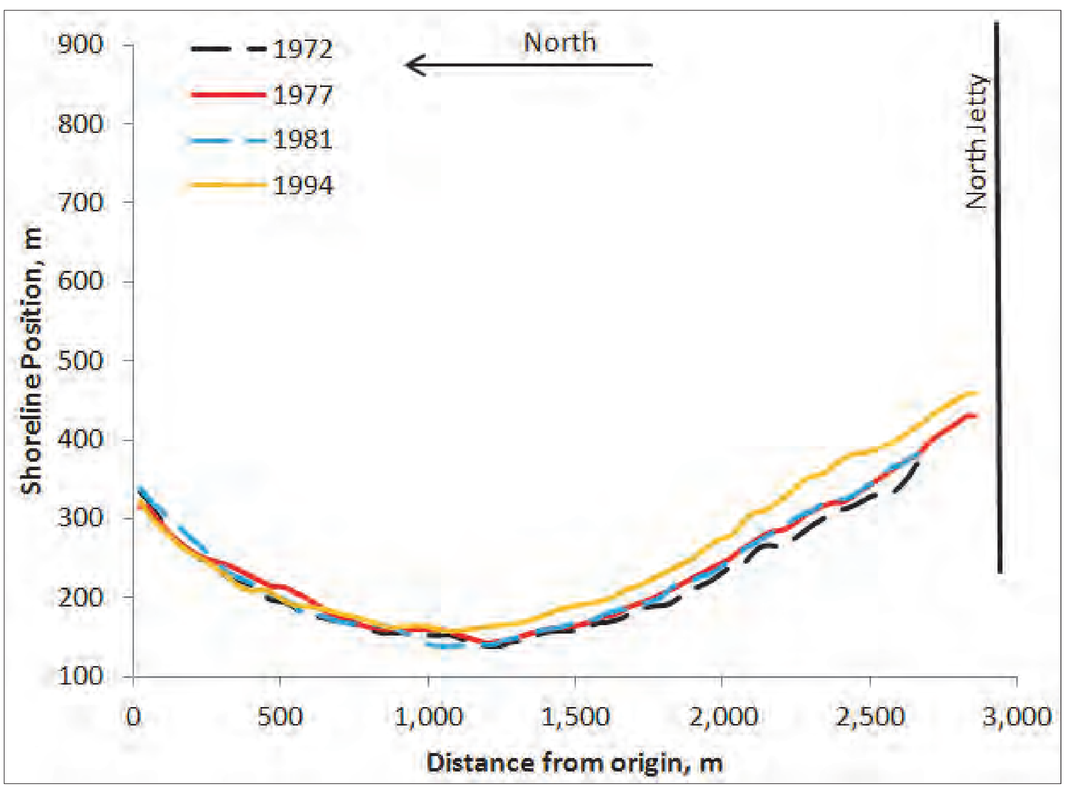


Figure 65. Measured shoreline change north of Jucar River jetties.

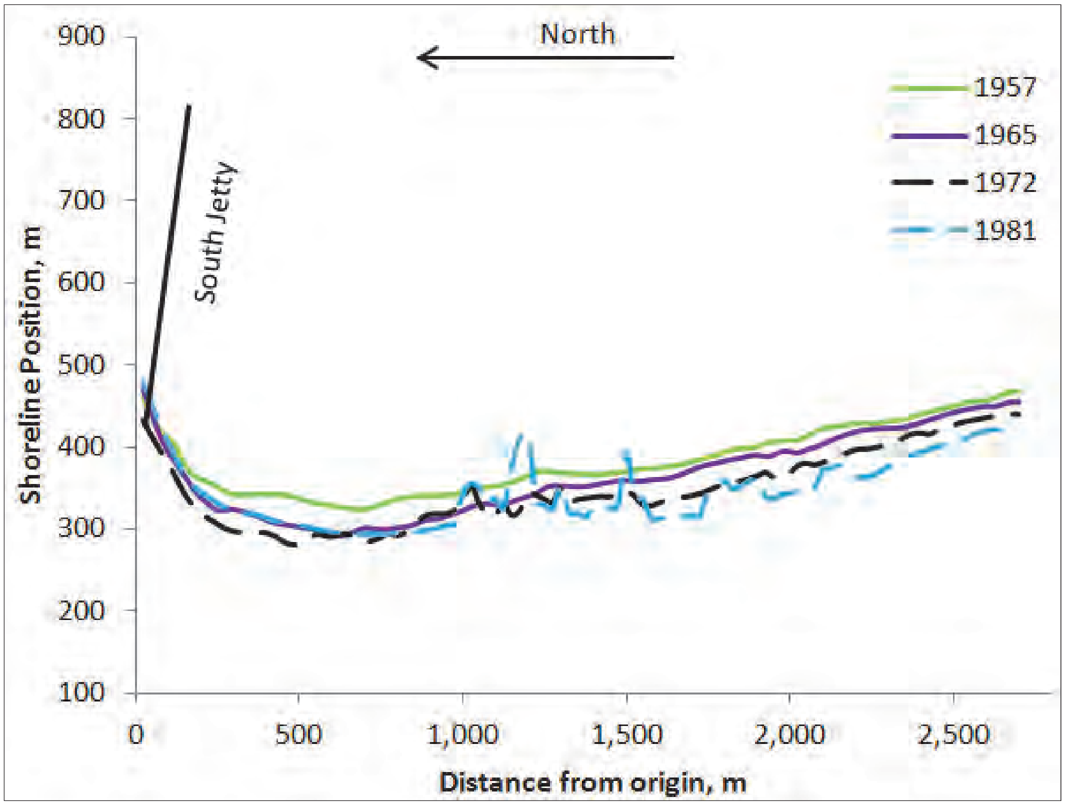


Figure 66. Measured shoreline change south of Jucar River jetties.

3.3.2 GENESIS results

GENESIS results, excerpted from Gravens (1997), are plotted in Figures 67 – 70 for comparison to GenCade. North domain model results (Figures 67 – 68) show shoreline advance except for a region about 2,000 m north of the jetty, following the general trends observed in the measured shorelines. GENESIS results fit observations less well for the southern domain (Figure 69). The model over predicts retreat near the jetty and predicts advance further south where the observed shoreline retreated. Observations available to verify model performance over the south domain include construction of groins and revetments, complicating shoreline response and modeling.

Calculated average net transport for the north domain during the calibration period was 61,900 m^3/year to the south with gross transport of 90,000 m^3/year. Calculated average net transport for the south domain during the calibration period was 59,300 m^3/year to the south with gross transport of 98,000 m^3/year. Calculated rates over both domains match the target budget well.

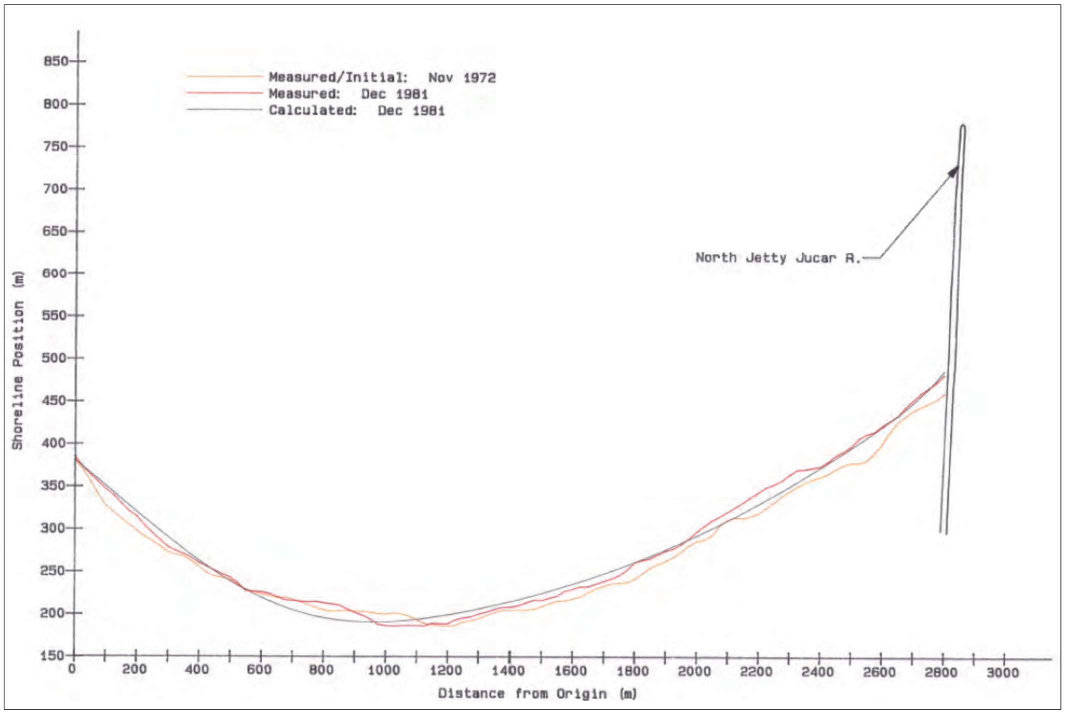


Figure 67. GENESIS calibration for north domain (Gravens 1997).

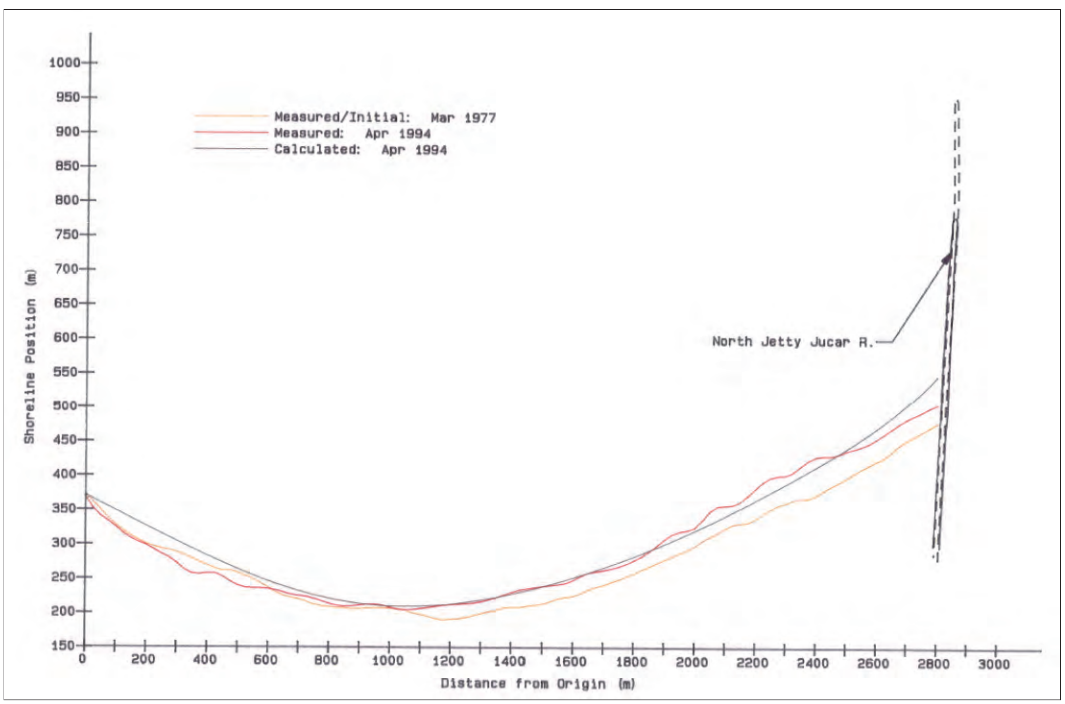


Figure 68. GENESIS verification for north domain (Gravens 1997).

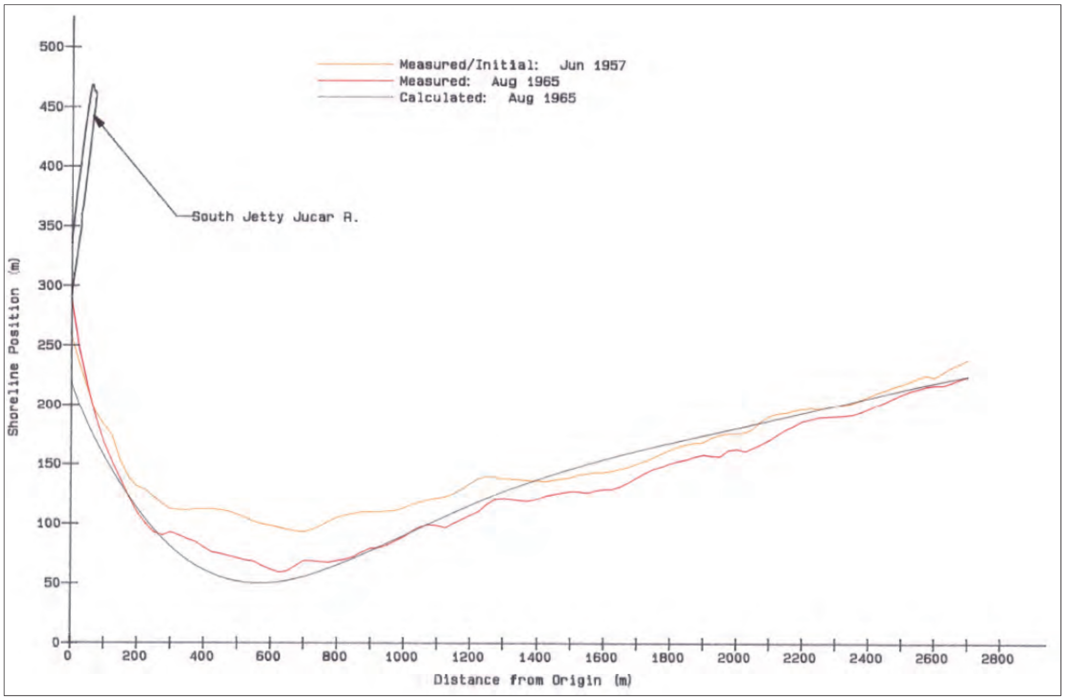


Figure 69. GENESIS calibration for south domain (Gravens 1997).

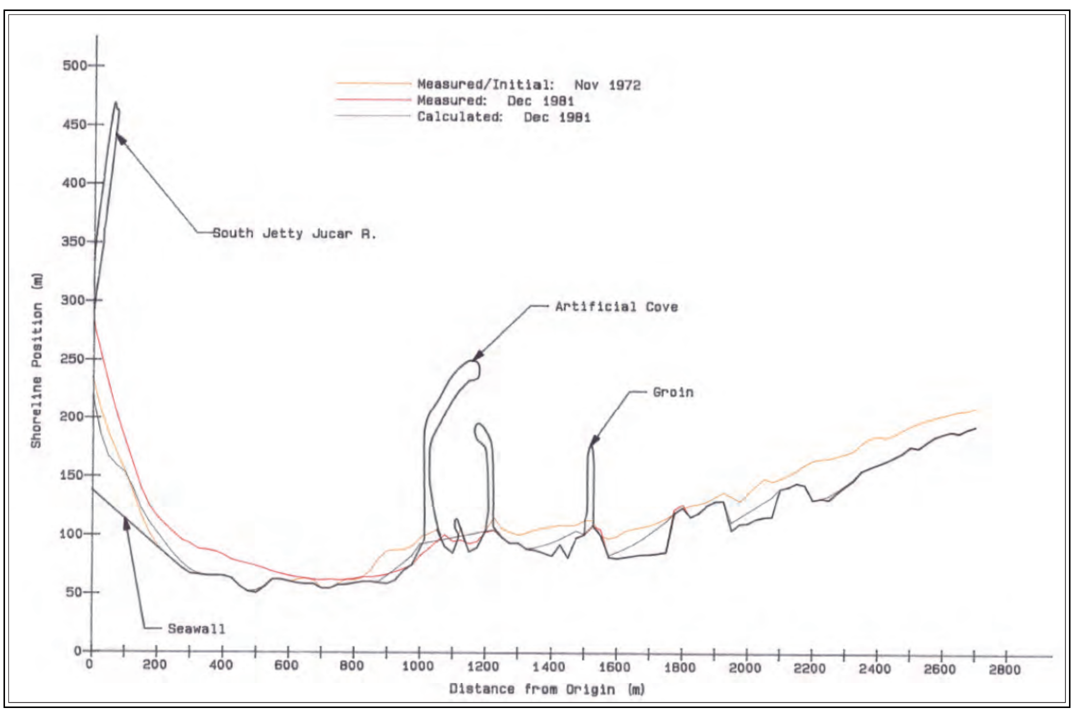


Figure 70. GENESIS verification for south domain (Gravens 1997).

3.3.3 GenCade model setup and parameters

3.3.3.1 Model domain

Two model domains were developed. The beaches to the north of the jetties at Jucar River, Playa de San Antonio and Playa del Reco, comprise the north domain. Playa del Marenyet and Playa de Estany beaches, south of the jetties, comprise the southern domain (domain locations labeled in Figure 64). Both domains used the jetties as one boundary. The northern end of the north domain was pinned and the southern end of the south domain was specified with measured shoreline change. A constant cell size of 25 m was applied. Figure 71 shows the northern domain. Figure 72 shows the southern domain. Table 5 lists common input data applied.

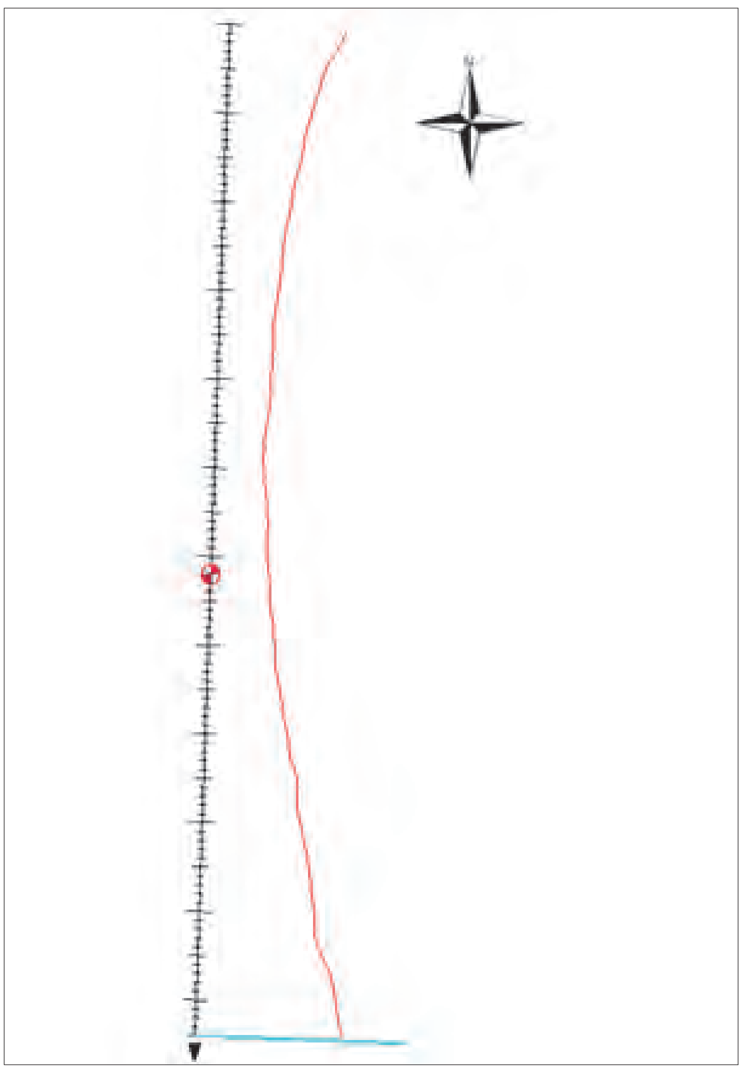


Figure 71. GenCade north domain, red line is the initial shoreline, blue line is the north jetty.

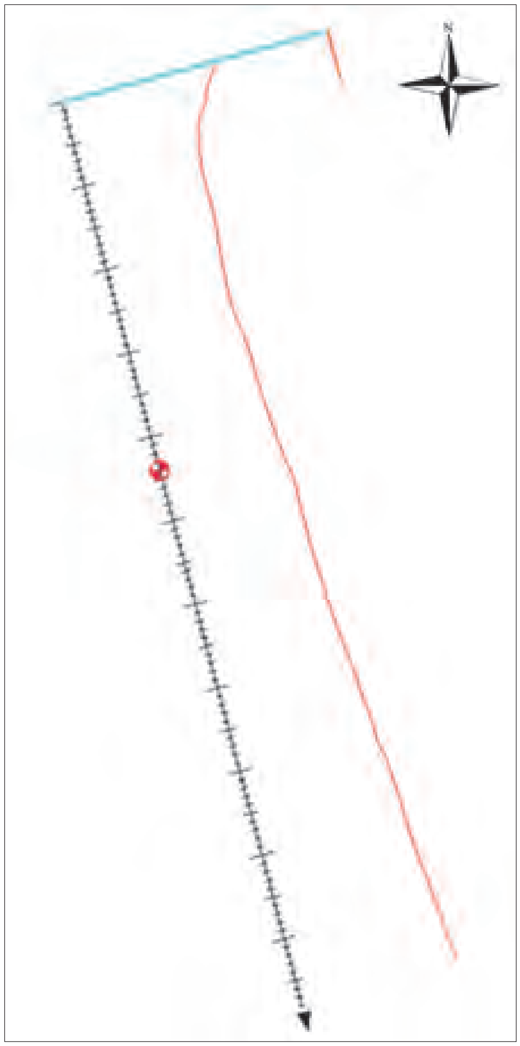


Figure 72. GenCade south domain, red line is the initial shoreline, blue and orange lines represent the composite south jetty.

Table 5. Model input.

	North Domain	South Domain
Effective Grain Size, mm	0.21	0.21
Average Berm Height, m	1.5	1.5
Depth of Closure, m	7.0	7.0

3.3.3.2 Model forcing: waves

Statistical wave data based on ship board observations analzyed by ALATEC S.A. in November 1996 were applied in Gravens (1997). The data were binned in seven heights and 16 directions and organized in 6-hour time steps to represent a typical year. Data applied in Gravens (1997) was applied in GenCade to enable consistent comparison between model results. Wave observations are assumed to be at the 20 m depth contour.

3.3.3.3 Model parameters

Various parameters were adjusted to calibrate GenCade. Table 6 lists the best fit values for each domain

Table 6. Model parameters.

	North Domain	South Domain
K1	0.15	0.13
K2	0.08	0.25
# Cells in smoothing window	40	11
Non-jetty boundary condition, m/year	Pinned	-1.79
Groin permeability	0.10	0.35

3.3.4 GenCade model results and discussion

3.3.4.1 North domain

K1 and K2 were initially varied to match the target sediment budget, and then modified to improve the shoreline change predictions. Table 7 shows the GenCade calculated transport rates. Similar values for K1 and K2 were required to match observed shoreline change observed. Calculated transport was higher than GENESIS calculated transport rates which were lower than estimated transport rates.

Table 7. GenCade north domain calculated average annual transport rates.

Time Period	Net Transport (southward), m^3/ year	Gross Transport, m^3/year
Calibration	102,000	129,500
Verification	102,600	131,000

Figure 73 plots the measured and GenCade calculated shoreline position from 1972 to 1981 over the north domain. GenCade matches the observed shoreline change well near the jetty and middle of the domain, but over predicts to the north.

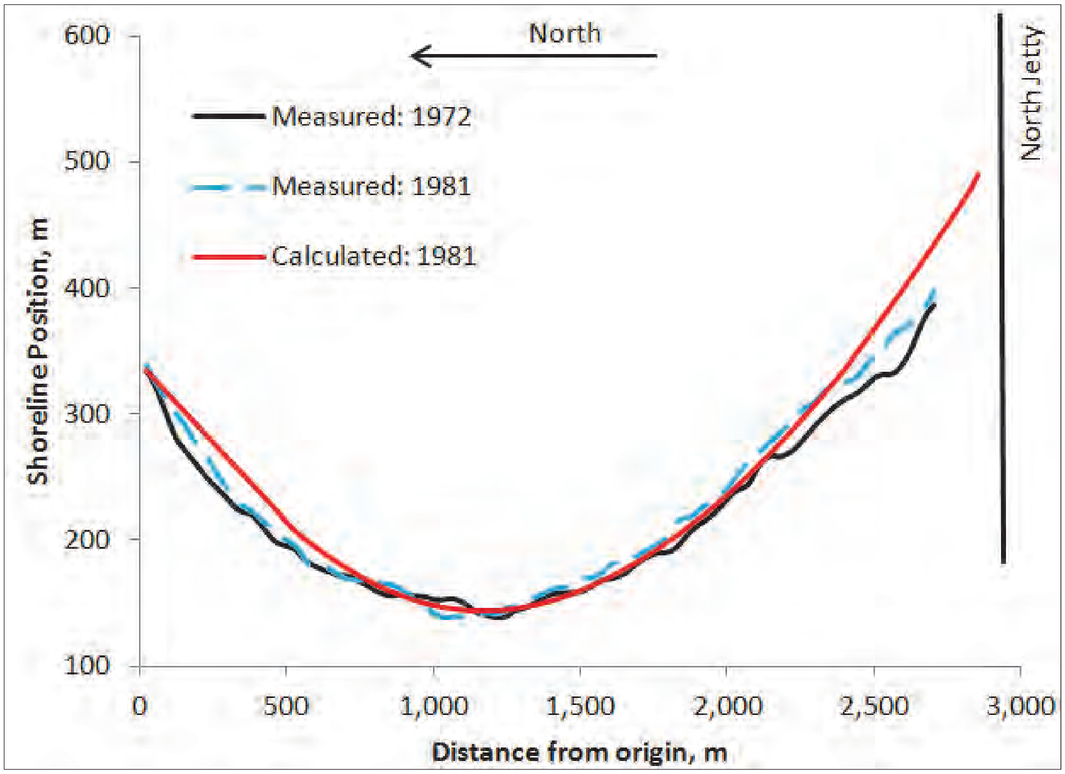


Figure 73. GenCade calibration for north domain.

Figure 74 plots the measured and GenCade calculated shoreline position from 1977 to 1994 over the north domain to verify the calibrated model setup. Over this time period, GenCade matches the observed shoreline change well near the jetty and tends to over-predict advance over the northward 1,000 m. GENESIS results in Figure 68 show the same general trend.

3.3.4.2 South domain

Table 8 shows the GenCade mean calculated transport rates. Net transport during the calibration period is slightly above the target, while the gross transport is about equivalent to the target budget. Calculated transport rate during the verification period is lower than the target, likely the result of shoreline armoring.

Figure 75 plots the measured and GenCade calculated shoreline position from 1957 to 1965 over the south domain. GenCade over-predicts retreat 500 m south of the jetty. Beyond about 1,500 m south of the jetty, GenCade predictions are seaward of the observations. GENESIS results in Figure 69 show the same general trend.

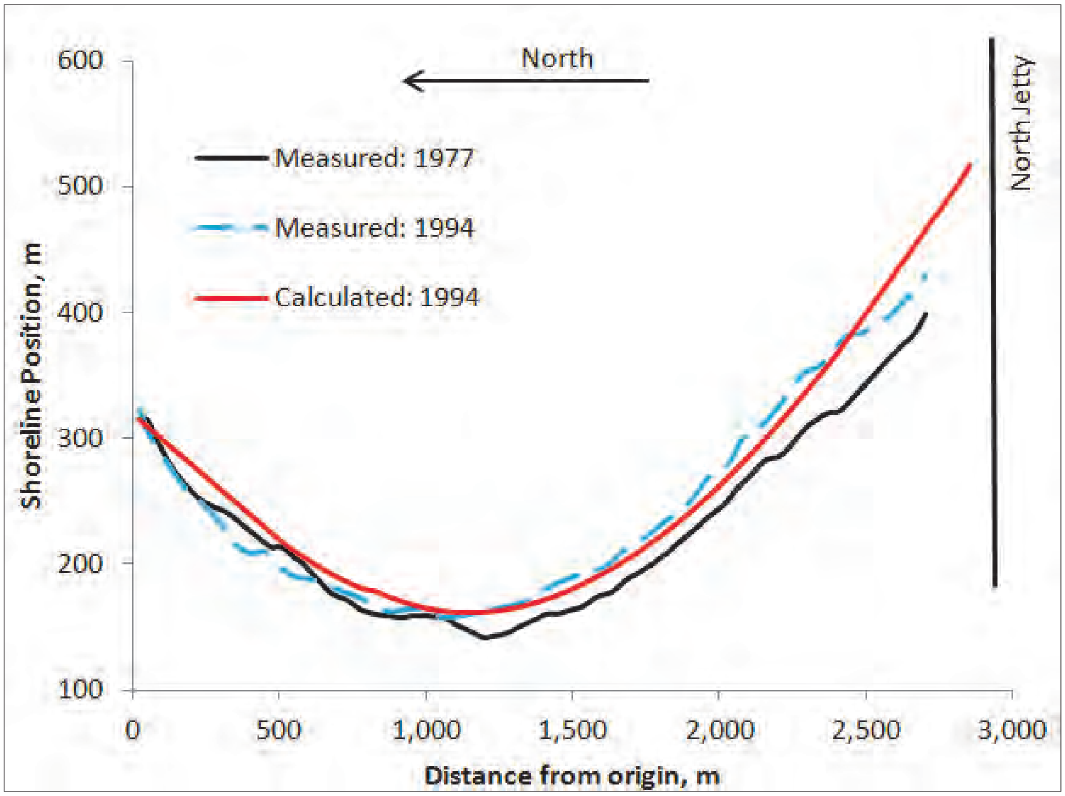


Figure 74. GenCade verification for north domain.

Table 8. GenCade south domain calculated annual transport rates.

Time Period	Net Transport, m3/year	Gross Transport, m3/year
Calibration	73,500	117,300
Verification	19,600	45,200

Figure 76 plots the measured and GenCade calculated shoreline position from 1972 to 1981 over the south domain to verify the calibrated model setup. The shoreline was heavily armored during this period, making it difficult to accurately verify the model. The verification does provide an opportunity to test the seawall function within GenCade. A seawall and multiple short groins were specified to represent the revetment and marina construction along the shoreline. The modeled shoreline retreats to the seawall with small pocket beaches forming between groins and in places where the revetment acts as a groin. These pocket beaches are evident in the modern aerial photo (Figure 64). The GENESIS model effort encountered the same difficulty and resulted in the same trends.

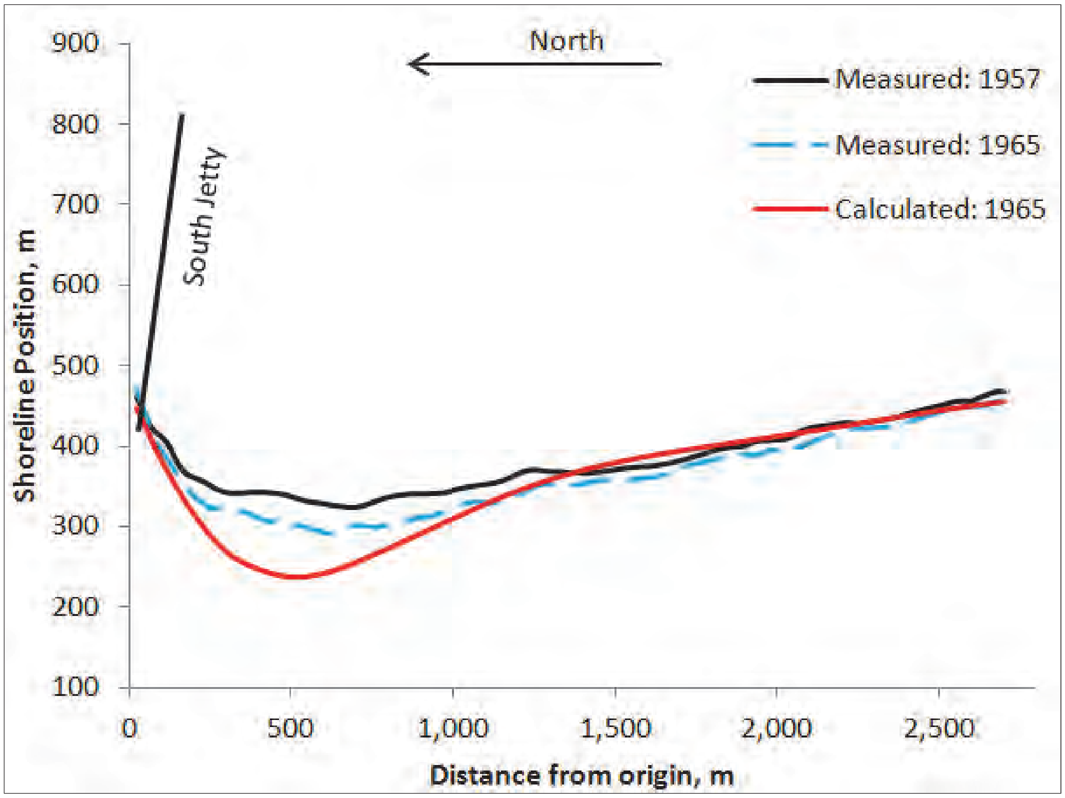


Figure 75. GenCade calibration for south domain.

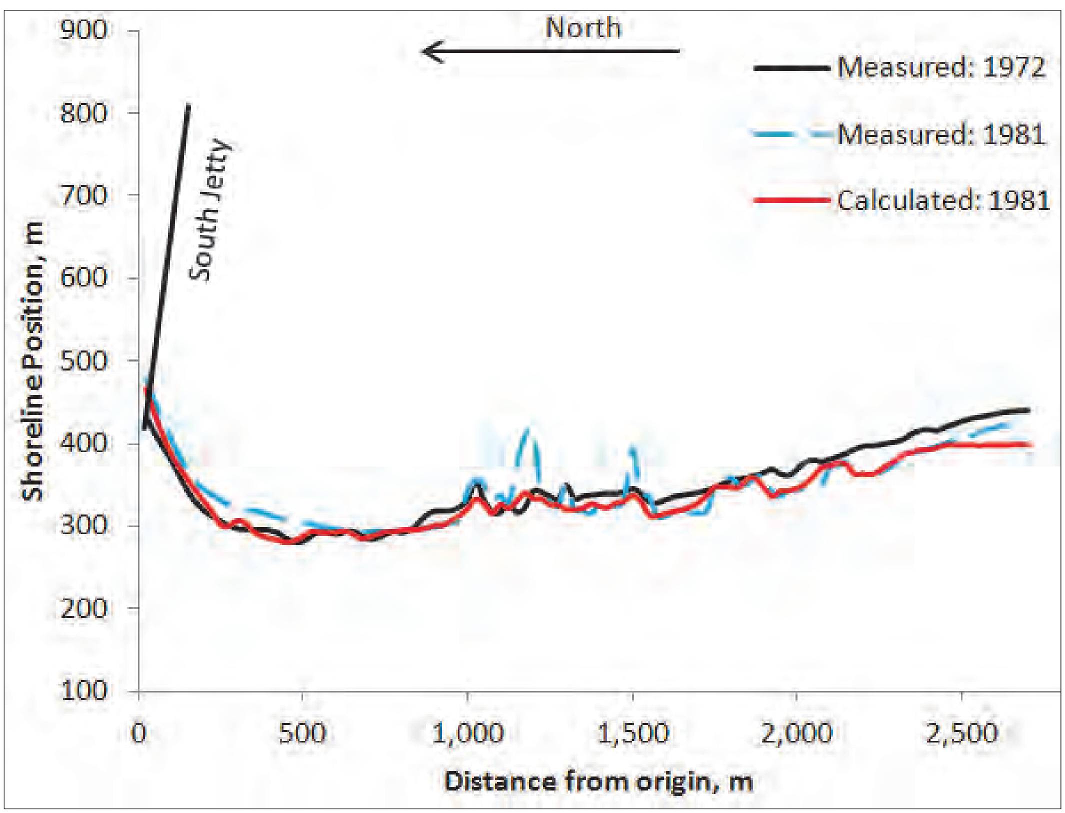


Figure 76. GenCade verification for south domain.

3.3.5 Conclusions

A GenCade model was developed for the beaches adjacent the Jucar River mouth near Cullera, Spain. The model demonstrates GenCade performance for sandy beaches adjacent a jettied river mouth and enables comparison to GENESIS. The following general conclusions are offered:

- GenCade reproduced shoreline change and transport as well as GENESIS for this case;
- GenCade calculated transport rates varied slightly from the target transport. The magnitude of the difference in GenCade was similar to the difference calculated in GENESIS.

4 GenCade Interface and User's Guide

GenCade has been implemented within the Surface-water Modeling System (SMS), a graphical user interface. There are two separate interfaces for GenCade. The first is the conceptual model where a user may develop a project in real world, geographical coordinates. Once the project is set up, the conceptual model is converted to a 1-D grid called the GenCade model. In the GenCade model, features are assigned cell numbers instead of real world coordinates. Due to the cell spacing specified by the user, the shape of the shoreline or structure may look slightly different in the GenCade model, but all other information defined in the conceptual model will be added to the GenCade model when converting to the 1-D grid. Several parameters related to the model, beach, and boundary conditions may only be defined in the GenCade model. GenCade is executed and results are visualized within the SMS. If the grid needs to be modified after running GenCade, the user may make changes in the conceptual model, convert to a new 1-D grid in the GenCade model, and re-run GenCade with the updated grid.

4.1 GenCade input and output files

There are three input files required to run GenCade. The GenCade control file (*.gen) lists all information related to the GenCade simulation. This file records the details for structures, inlets, dredging events, beach fills, boundary conditions, wave gauges, and the model setup. This file also defines the paths for each of the input files and one of the output files, the *.prt file. Although the *.gen file can be opened, it is recommended that the new users refrain from modifying the file. However, experienced users may find it easier to introduce minor modifications by directly editing the *.gen file outside of the SMS. The initial shoreline (*.shi) and wave file(s) (*.wave) are also necessary to run all GenCade simulations. A separate wave file is created for each wave gauge. The regional contour file (*.shr), water level file (*.wl), and variable resolution file (*.shdx) are only necessary in cases utilizing those capabilities. For example, the water level file is only created when time-dependent wave transmission is necessary while the regional contour file is only created when a regional contour is defined.

Following a GenCade simulation, at least seven output files will be created in the assigned directory. The print file (*.prt) saves all of the information related to the simulation including wave heights, shorelines, and transport rates. The shoreline position output file (*.slo) documents the shoreline position for each recorded time step for every cell in the grid. The net transport rate file (*.qtr) prints the net transport rate for each cell at every recorded time step. The inlet shoal volume file (*.irv) lists the volume for each inlet shoal for every time step in the simulation. A separate inlet shoal volume file is created for each inlet represented in the simulation. If the grid does not include an inlet, no *.irv file will be created. All of the files except the print file may be opened and viewed in the SMS. The aforementioned files contain the majority of the information a user would need to evaluate the results of a simulation. The mean annual net transport rate files (*.mqn [mean annual net transport rate], *.mql [mean annual transport rate to the left], and *.mqr [mean annual transport rate to the right]) list the transports for each cell for each year in the simulation. The offshore contour for each recorded time step for each cell is included in the offshore contour file (*.off). Descriptions of all required and optional input and output files are listed in Table 9.

Table 9. Input and output file names and descriptions.

File Name	Type	Description
*.shi	Input - required	x-y coordinates of initial shoreline relative to grid
*.gen	Input - required	GenCade control file
*.wave	Input - required	Wave height, period, and direction
*.shr	Input - optional	x-y coordinates of the regional contour relative to grid
*.shdx	Input - optional	Variable grid resolution
*.wl	Input - optional	Water levels
*.prt	Output	Print file (Shorelines, net annual transport)
*.slo	Output	Calculated shoreline for each time step for each cell
*.qtr	Output	Calculated net transport rate
*.irv	Output	Calculated inlet shoal volumes
*.mqn	Output	Calculated mean annual net transport rate
*.mql	Output	Calculated mean annual transport rate to left
*.mqr	Output	Calculated mean annual transport rate to right
*.off	Output	Calculated offshore contour

4.2 Conceptual model

GenCade is only operational within SMS 11.1 and later versions. Some capabilities of GenCade are available in SMS 11.0, but the interface is not fully functional. This section of the Technical Report will guide a user through the process to set up the conceptual model, convert to a 1-D grid, review the GenCade model, run GenCade, visualize results, and develop alternatives. It is assumed that the reader has no previous experience with GenCade. Additional information about general SMS functionality is supplied in the SMS help documentation or by visiting http://www.xmswiki.com/.

4.2.1 Set up GenCade in the SMS

First, the GenCade executable must be identified on the machine. The GenCade executable is named *GenCade_v1r1.exe*. This executable must be placed in the models folder under SMS 11.1. The folder containing SMS 11.1 will most likely be located in *Program Files*.

Once SMS 11.1 is open on the machine, it is necessary to specify the location of the GenCade executable. If this is specified incorrectly or not at all, GenCade will not run. To indicate the location of the executable, it is necessary to click on *Edit*, go to *Preferences*, and click on the tab labeled *File Locations*. The user should scroll down to *GenCade* under *Model Executables* and click on *BROWSE*. Once the GenCade executable is selected, the path for the executable should be listed under *Model Executables* next to *GenCade*. Figure 77 shows the *File Locations* window.

4.2.2 Set the projection

GenCade uses a real world coordinate system, so it is necessary to set up the current projection upon opening the SMS. GenCade projects may be set up in either U.S. customary units or SI units. The user may select the appropriate projection by clicking *Edit->Projection*. Once the *Current Projection* window is opened, the *Global projection* option under *Horizontal* should be selected. The *Select Projection* window will open. In this window, the user can define the projection, zone, datum, and planar units. The user should also define the *Vertical* projection, although this will not affect the units in GenCade. The steps to set up the projection are shown in Figure 78. This ensures all shorelines, structures, wave gauges, and other important features are mapped correctly. The user may also open aerial photographs to aid in completing the conceptual model. In many cases, the files representing shorelines and other features may be georeferenced correctly without defining the current projection; however, it is a good idea to define the projection before starting a GenCade project.

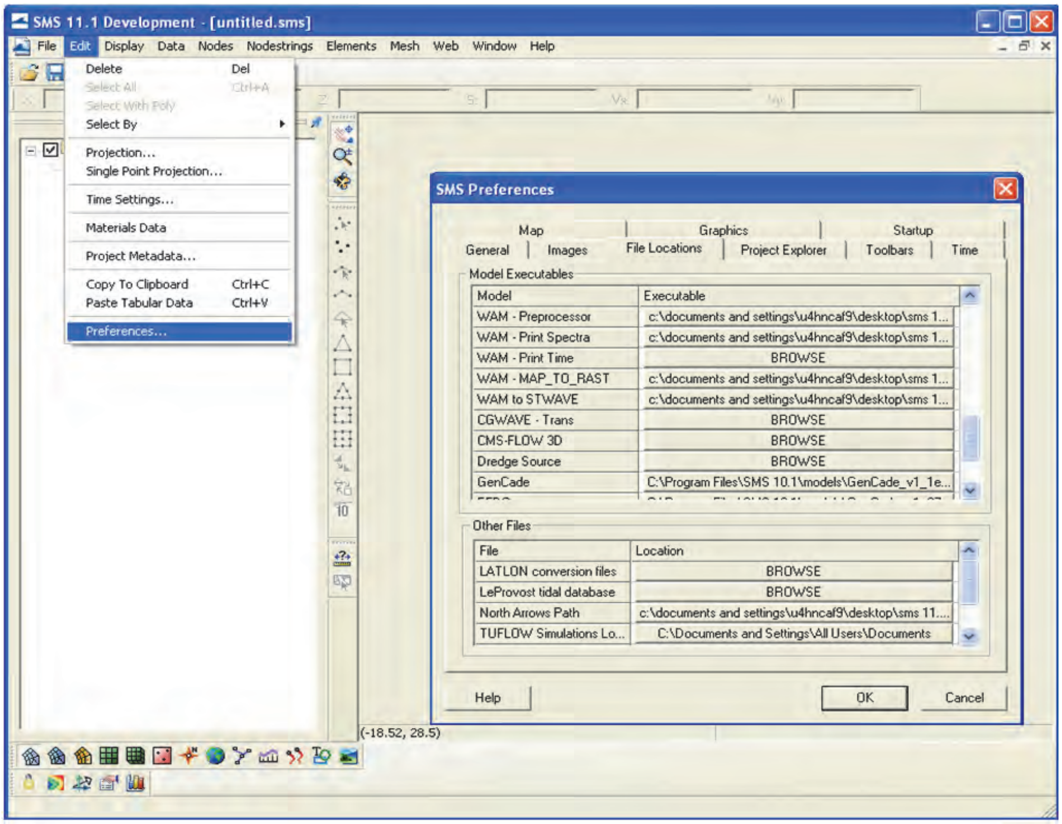


Figure 77. Define GenCade model executable.

4.2.3 Change the projection

In some cases, an aerial photograph may be defined in a different coordinate system than the shorelines. It may also be necessary to develop the conceptual model for the GenCade project in a different coordinate system than the shoreline or aerial photos. There are two ways to change the projection of the project. For a case where the user would like to convert the shoreline and the project to the same projection as the imported aerial photo, there are several steps to follow. First, go to *Edit->Project*, specify the projection used for the shoreline, and bring in the shoreline (more information on the format of shorelines is in section 4.2.4). Right click on the coverage including the shoreline under *Map Data* in the left panel and go to *Reproject*. A warning will pop up notifying the user that the command is non-reversible. After clicking *Yes*, the *Reproject Object* window will open. Check *Set* and change the new projection to the projection of the aerial photo (Figure 79). Go back to *Edit->Project* and change the projection to match the projection of the aerial photo (Figure 80). All of the units will match the projection of the aerial photo. Now the user can bring in the aerial photo and the shoreline will overlay the aerial photograph correctly (Figure 81).

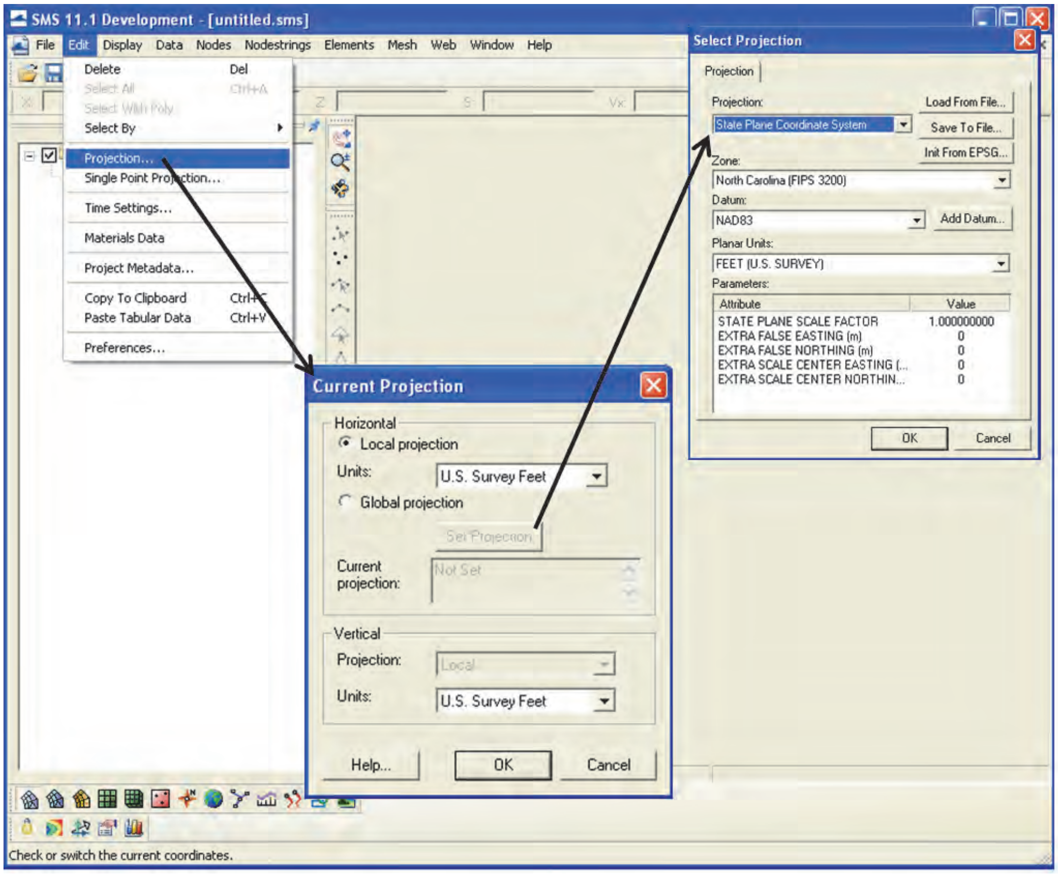


Figure 78. Specify projection.

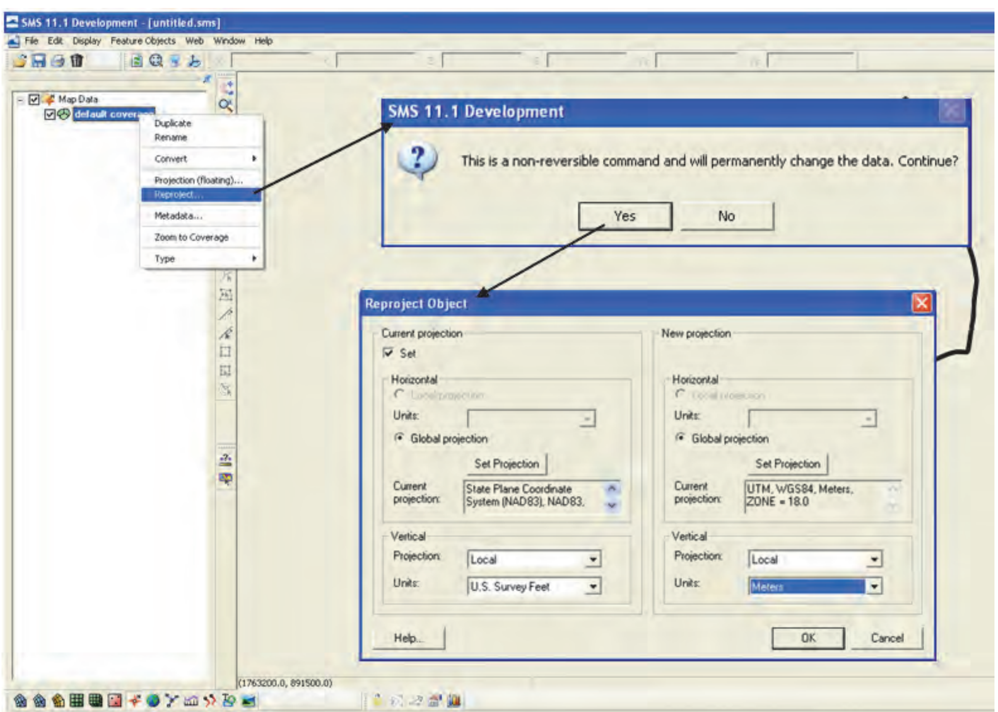


Figure 79. Reproject map data.

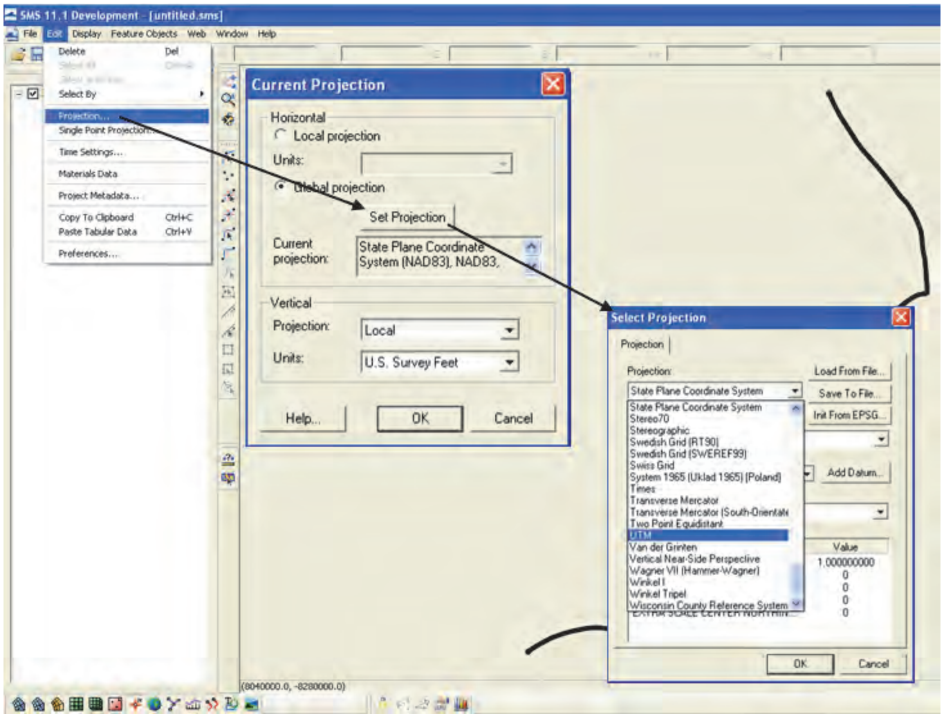


Figure 80. Change projection.

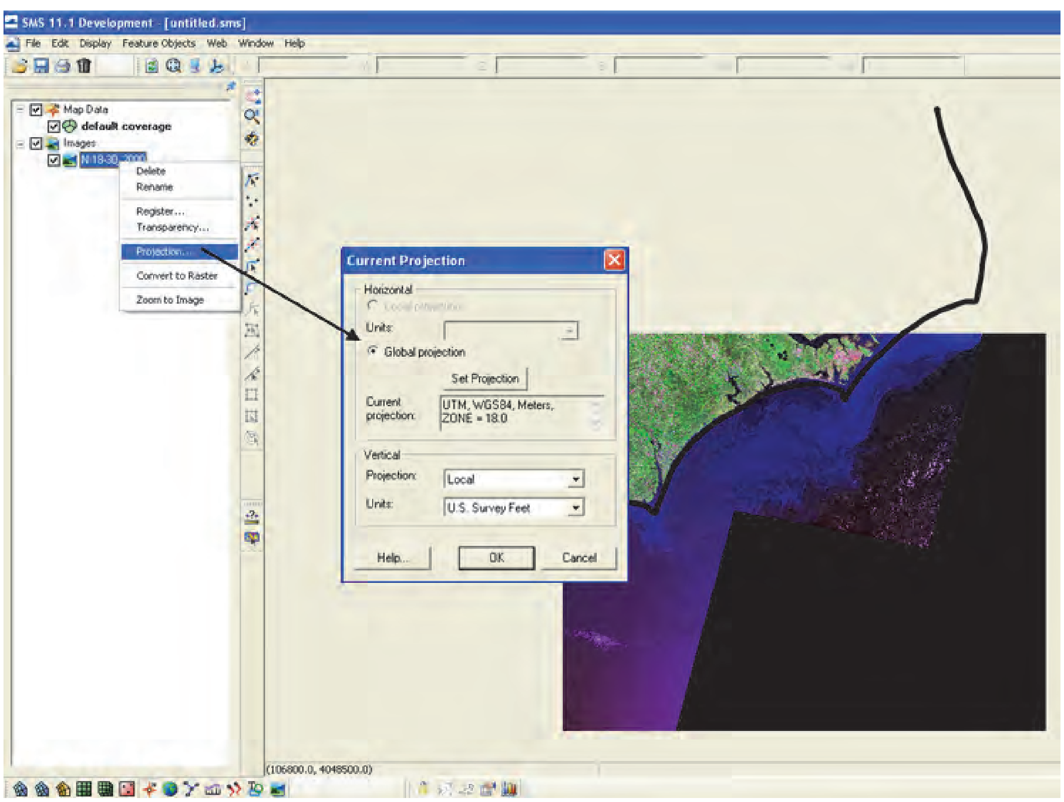


Figure 81. Confirmation of change in projection.

It is much simpler to use the units from the shoreline shapefile or text file for the project. In this case, the user needs to convert the aerial photo. First, go to *Edit->Project* and define the projection. Then open the shoreline, right click on the coverage, and go to *Projection (floating)* (Figure 82). The user should confirm that the object projection matches the projection defined under *Edit->Project*. When the user brings in the aerial photo, SMS will automatically convert the aerial photo to the correct projection so that the photo matches the shorelines (Figure 83).

4.2.4 Open and define initial shoreline

As mentioned previously, an initial shoreline is required to run GenCade. The model type must be defined as *GenCade* before opening any file in the SMS. This can be accomplished by selecting *Type->Models->GenCade* after right clicking on the default coverage under *Map Data* in the data tree (panel on left side of screen). If the user has a file with a list of shoreline points that is in the same projection as the project, the file may be opened in the SMS. Before the file is opened in the SMS, it is important to double-check the projection of coverage under *Map Data*. This can be done by right clicking on the coverage and clicking on *Projection (floating)*. If it is necessary to convert to a new projection for the shoreline, follow the steps outlined in 4.2.3. To read the file into the conceptual model correctly, the file must be in *.cst format. The *.cst format requires the *x* and *y* coordinates of every point along the shoreline. The *.cst file differs from an x-y scatter set in that the order in which the *x-y* points appear in the file is important. Points must be ordered in the same way they would appear if a person was to "walk" along the shoreline. Any misplaced point will create a zigzag pattern. An example of the format is shown in Figure 84. To modify a file with *x* and *y* coordinates for a shoreline, add the first three lines shown in Figure 84 to the existing text file. The formatting in the *.cst file has been carried over from GENESIS. The first number on the third line represents the total number of shoreline points listed in the file. This is the only number in the first three lines that will differ from the file shown in Figure 84.

There are many different ways to create an initial shoreline for GenCade in the SMS. If the shoreline is represented by points in a shapefile, these can be converted into a scatter set and saved as a text file. Then the text file can be modified to create the proper *.cst format and opened in the SMS.

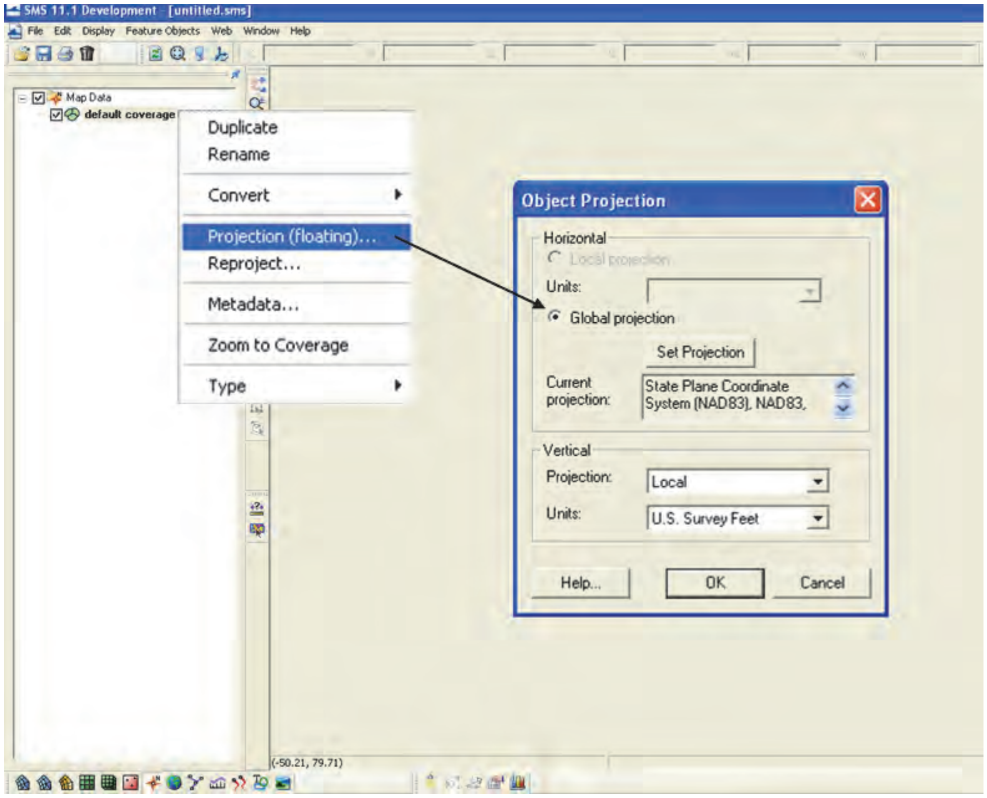


Figure 82. Reproject object projection.

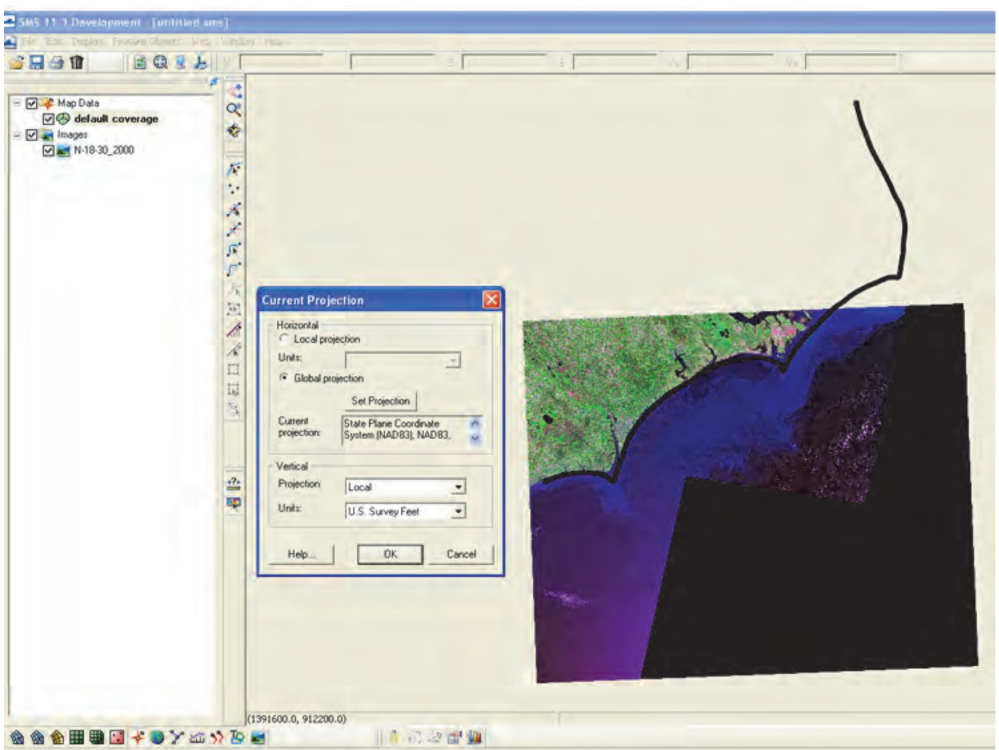
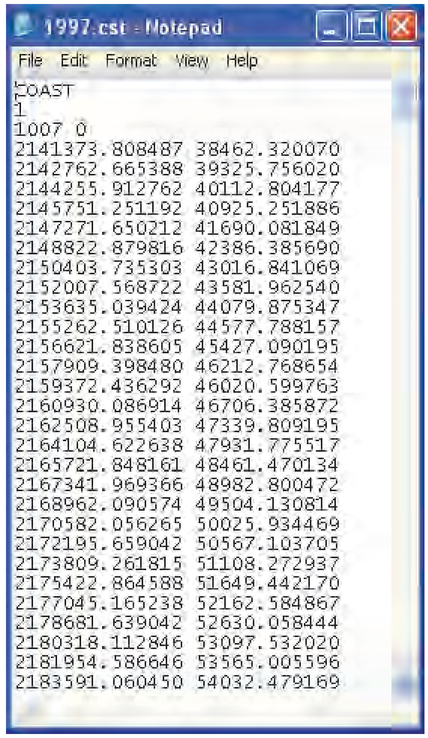


Figure 83. Reproject current projection.




```
COAST
1
1007 0
2141373.808487 38462.320070
2142762.665388 39325.756020
2144255.912762 40112.804177
2145751.251192 40925.251886
2147271.650212 41690.081849
2148822.879816 42386.385690
2150403.735303 43016.841069
2152007.568722 43581.962540
2153635.039424 44079.875347
2155262.510126 44577.788157
2156621.838605 45427.090195
2157909.398480 46212.768654
2159372.436292 46020.599763
2160930.086914 46706.385872
2162508.955403 47339.809195
2164104.622638 47931.775517
2165721.848161 48461.470134
2167341.969366 48982.800472
2168962.090574 49504.130814
2170582.056265 50025.934469
2172195.659042 50567.103705
2173809.261815 51108.272937
2175422.864588 51649.442170
2177045.165238 52162.584867
2178681.639042 52630.058444
2180318.112846 53097.532020
2181954.586646 53565.005596
2183591.060450 54032.479169
```

Figure 84. Example format of *.cst file.

A GenCade initial shoreline can also be created from a polyline shapefile. Once the shapefile is opened in the SMS, it is necessary to click on *Mapping* and select *Shapes->Feature Objects* (Figure 85). This will create a *Feature Arc*. After converting the *Map Data* to *GenCade*, the arc may be selected by clicking on the *Select Feature* Arc button and by double-clicking. If the shapefile was converted into multiple arcs, it is necessary to connect these segments to create one arc (Figure 86). Click on the *Create Feature Arc* button and draw an arc connecting the existing arcs. Click on the *Select Feature Point* button and select all of the nodes between the existing and the new arcs. To convert the nodes to vertices, go to *Feature Objects* and select *Vertices<->Nodes*. Once all of the nodes have been converted to vertices and the shoreline appears as one continuous arc, the shoreline is in the proper format for GenCade. When developing a shoreline in GenCade from a polyline shapefile, it is not necessary to create a *.cst file.

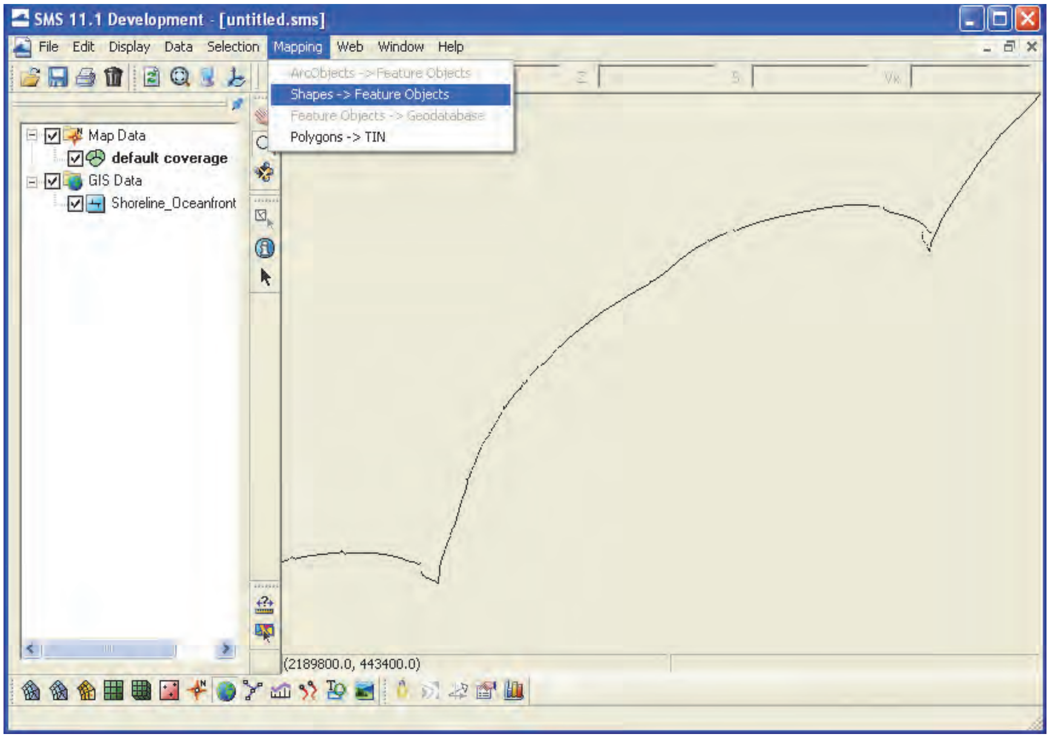


Figure 85. Convert shapefile to feature objects.

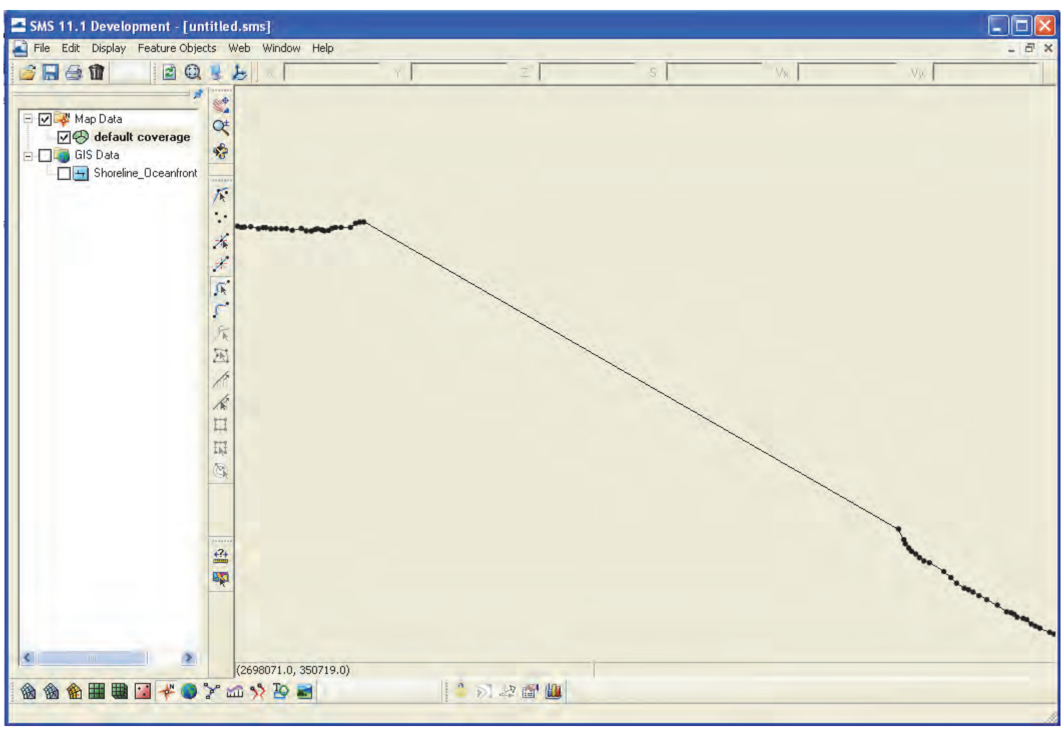


Figure 86. Connect segments to create one feature arc.

Regardless of whether or not the initial shoreline is opened as a *.cst file, the initial shoreline must be defined. To define the initial shoreline, *GenCade* must be selected as the model type for the coverage. The feature arc representing the shoreline should be double-clicked (or right-click and select *Attributes*) after clicking on the *Select Feature Arc* button. The *GenCade Arc Attributes* window will open. The *Initial Shoreline* option should be selected under *Arc Options*. These steps are shown in Figure 87.

Rigorous quality control is required to make sure the initial shoreline accurately represents the shoreline of interest. This process requires a detailed inspection of the shoreline. It is recommended to smooth out sudden changes in shoreline orientation especially near an inlet. The smoothing algorithm can be use for this purpose. To do so, select the shoreline arc, right click and select *Smooth Arcs* from the dropdown menu, and inspect the shoreline for accuracy.

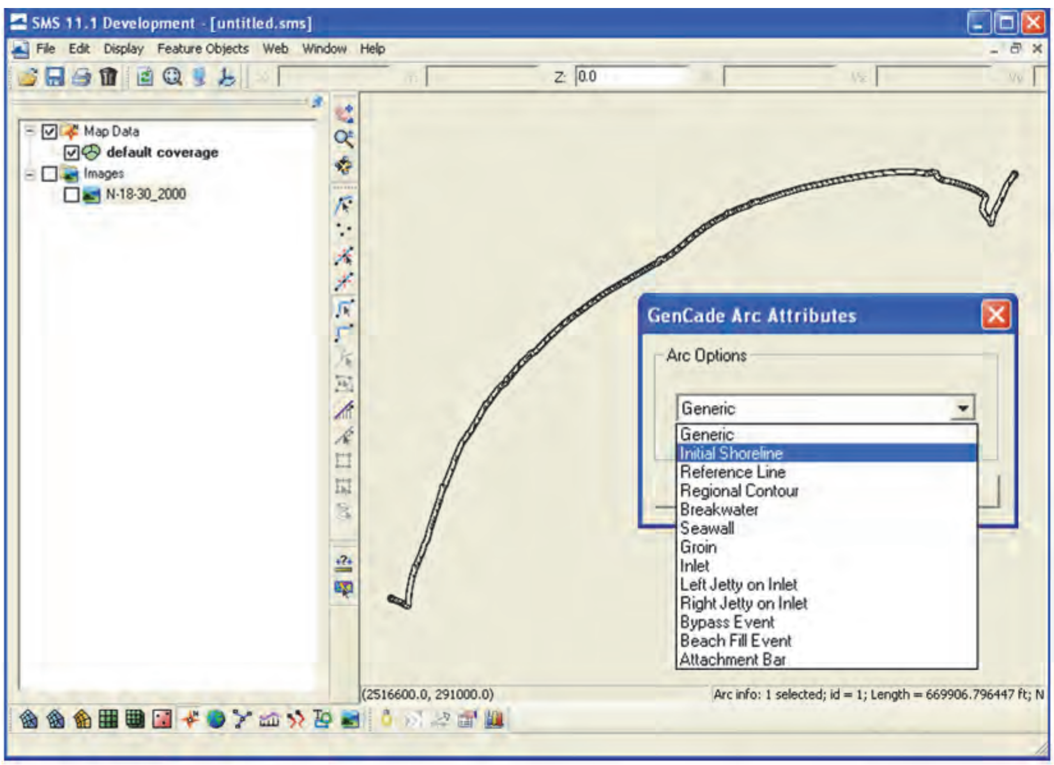


Figure 87. Define arc as initial shoreline.

4.2.5 Open and define regional contour or additional shorelines

In some cases, a regional contour or additional shorelines may need to be added to the conceptual model. To define a second feature arc, it is necessary to right-click on *Map Data* and select a *New Coverage*. This new coverage must also be defined as *GenCade*. The user can rename the new coverage, so that it can be easily identified. It is very important to open the new arc in a new coverage. If the arc is opened in the same coverage as the initial shoreline, the two arcs will most likely overlap, and the arcs will be split into many arcs. Once the regional contour is opened in the interface, define the arc as *Regional Contour* in the *GenCade Arc Attributes* window (Figure 88). A shoreline representing the final shoreline or an additional shoreline may be defined as a *Reference Line*.

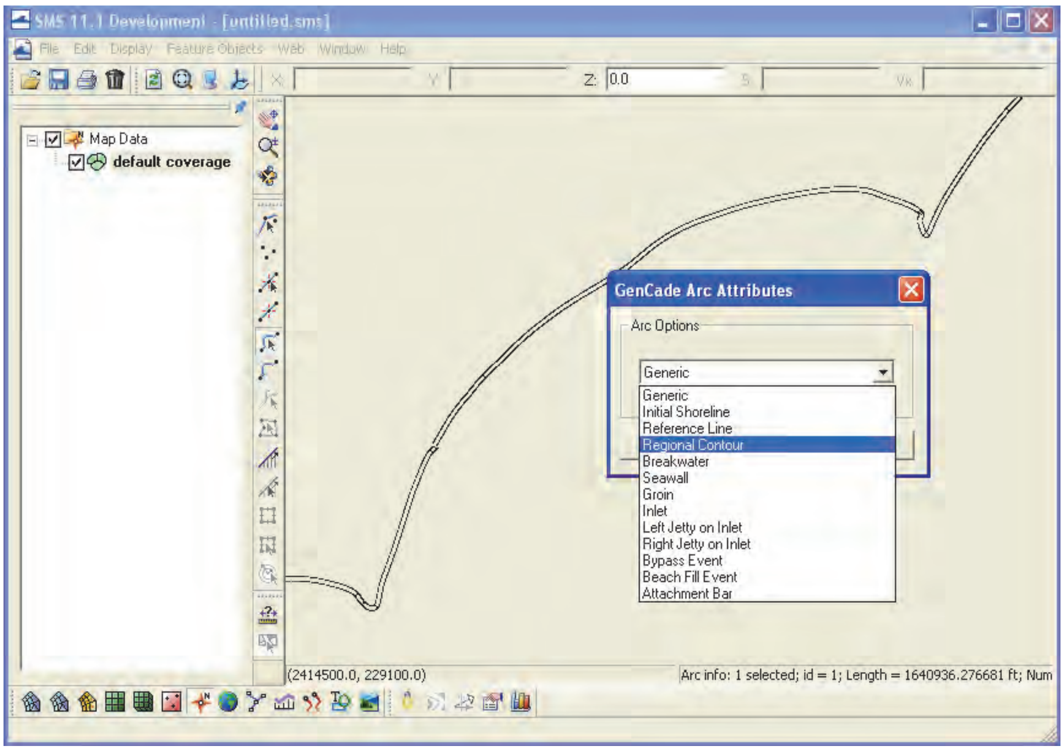


Figure 88. Define arc as regional contour.

4.2.6 Merge coverages

After the initial shoreline and regional contour have been loaded and defined in the SMS interface, it is necessary to merge the two arcs in a single coverage. All structures, inlets, wave gages, and other features will be created in this single coverage. Highlight both the default coverage (initial shoreline) and the new coverage (regional contour) from the data tree. This can be done by hitting *ctrl* on the keyboard and clicking on both coverages. After right-clicking, select *Merge Coverages*. A window will open asking if the user would like to delete the coverages used to make the merged coverage. If *No* is selected, the initial shoreline and regional contour coverages will remain in the interface. It is a good idea to keep these coverages in the interface. If a problem occurs with the merged coverage, the initial shoreline and regional contour may be merged again.

Figure 89 shows how coverages are merged while Figure 90 illustrates the initial shoreline and regional contour in the merged coverage.

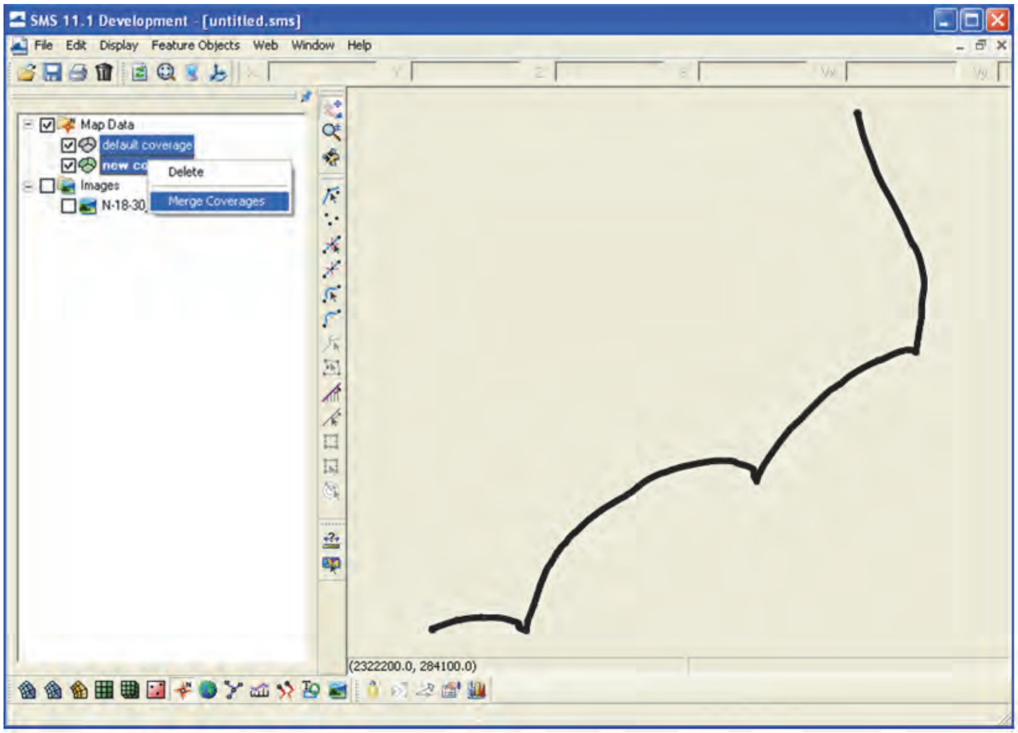


Figure 89. Merge initial shoreline and regional contour in a single coverage.

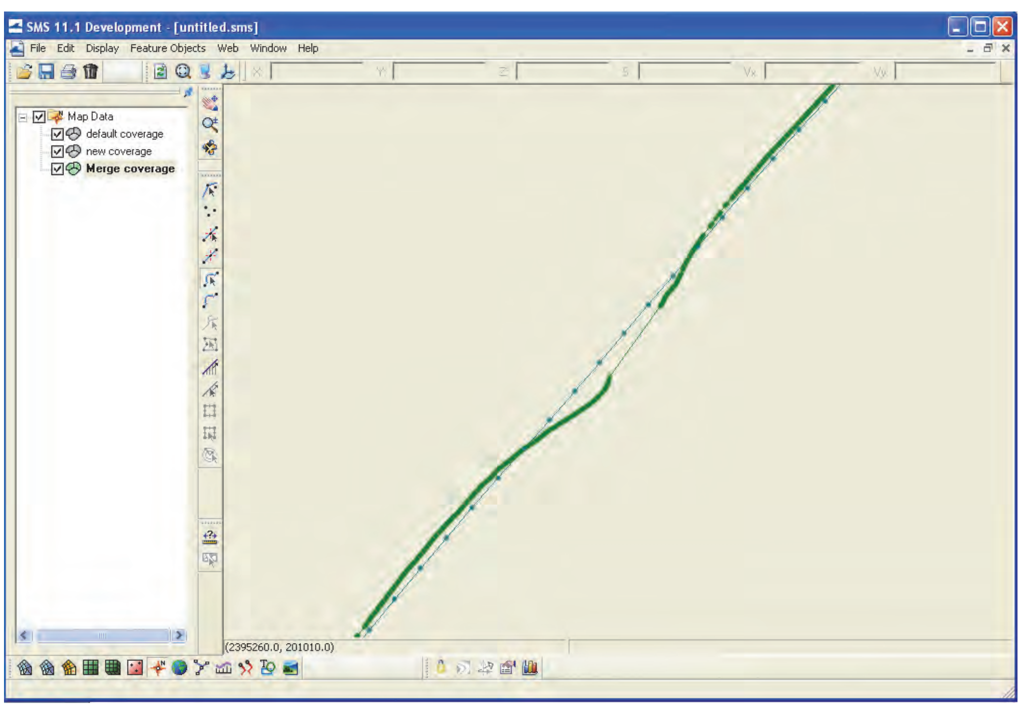


Figure 90. Initial shoreline and regional contour merged into a single coverage.

4.2.7 Create inlets, shoals, dredging events, and jetties

The inlet name, inlet shoal volumes, dredging events, and bypassing coefficients may be defined when an inlet is created. To do this, select the *Create Feature Arc* button and draw a line from one side of the inlet to the other. When creating inlets and other features, a high quality aerial photo is very helpful. After the inlet is created, click on the *Select Feature Arc* button and double-click on the arc representing the inlet. This can also be accomplished by a single click, followed by a right click on *Attributes*. The *GenCade Arc Attributes* window will open. Select *Inlet* and click on *Attributes*. The *Inlet Reservoir Model* window will open. The inlet can be named, shoal volume can be defined, and dredging events can be added. The initial and equilibrium shoal volumes for the ebb, flood, left bypass, left attachment, right bypass, and right attachment can be defined after clicking on the *Volume* button. Similarly, after clicking on *Dredging*, the *Dredging Events* window will open and the user can specify the beginning and ending date, the volume, and the shoal to be mined for each dredging event. The user also has the option to modify the left and right bypassing coefficients when jetties are present. Both the left and right bypassing coefficients have a default value of 1. This value will always be zero or greater. However, due to the measured distances included in the bypassing coefficient equation, it is highly unlikely that the bypassing coefficient will be larger than 100. More information about the equation for bypassing around jetties can be found in the model theory chapter. Inlets that do not have jetties will not have a bypassing coefficient. After the inlet information is specified, the arc representing the inlet will turn blue. All of the steps to create an inlet and add shoal volumes and dredging events are shown in Figure 91.

A jetty can be created at the inlet after selecting the *Create Feature Arc* button. The arc representing the jetty should not intersect with an arc representing the inlet, regional contour, or initial shoreline. If this occurs, either the arc representing the jetty or the other arc will be split into two separate arcs. To remedy the problem of splitting arcs; the user should delete the arc representing the jetty, convert the newly created node to a vertex, and redefine the formerly split arc.

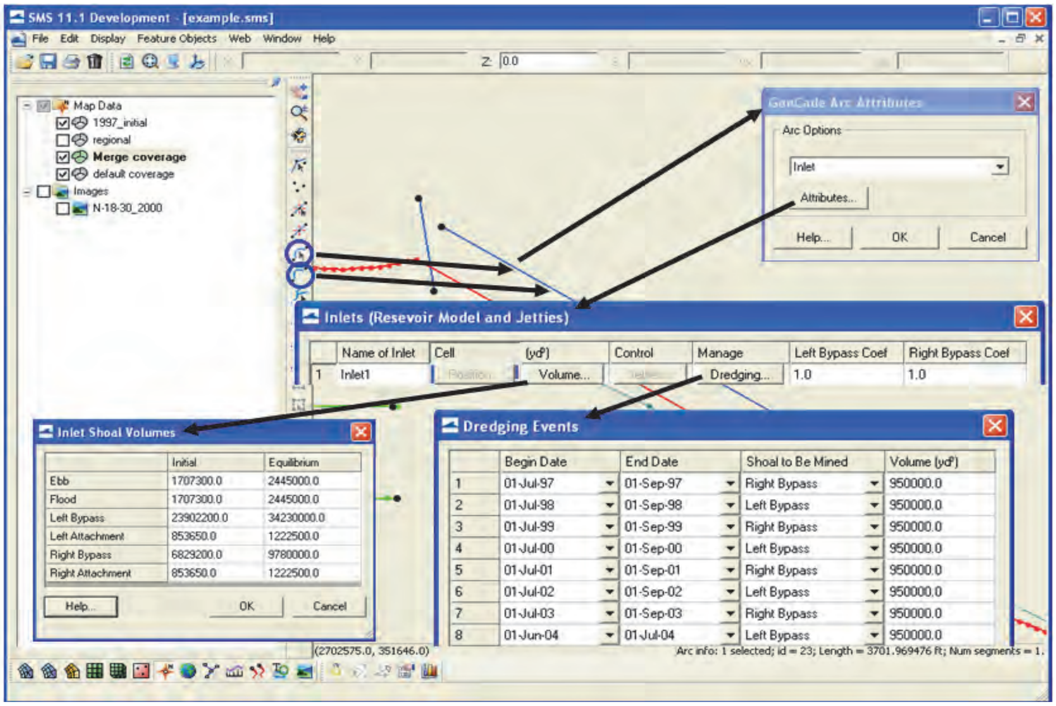


Figure 91. Create and define an inlet, shoal volumes, and dredging events.

After drawing the jetty, the user should click on the *Select Feature Arc* and double-click on the line representing the jetty. When the *GenCade Arc Attributes* window opens, the *Left Jetty on Inlet* or *Right Jetty on Inlet* should be selected. To determine if a jetty is consider *left* or *right*, the user should imagine standing on land, looking out at the ocean and the inlet. The *left jetty* would be to the left of a person standing in the location described. After *Attributes* is selected, a new window will open where the *Permeability* can be specified, *Diffracting* can be checked or unchecked, and a *Seaward Depth* can be added. The default value for *Permeability* is zero. Although *Diffracting* is unchecked as a default option, the user should check this box in most cases. The line representing a jetty will also turn blue once all of required jetty information is provided. Figure 92 shows how to create a jetty.

Once the grid is converted to GenCade, bypassing associated with an inlet is defaulted to the one cell immediately adjacent to either side of the inlet. However, the size and location may be defined in the conceptual model by selecting the *Create Feature* Arc button and drawing the arc. Double-click on the arc after creating to open the *GenCade Arc Attributes* window. The arc should be defined as an *Attachment Bar* (Figure 93). The attachment bar is also represented by a blue line. Aerial photographs are very helpful in determining the width of the attachment bar. This will determine the amount of cells the bypassing sediment flux (Q_{out}) is distributed over.

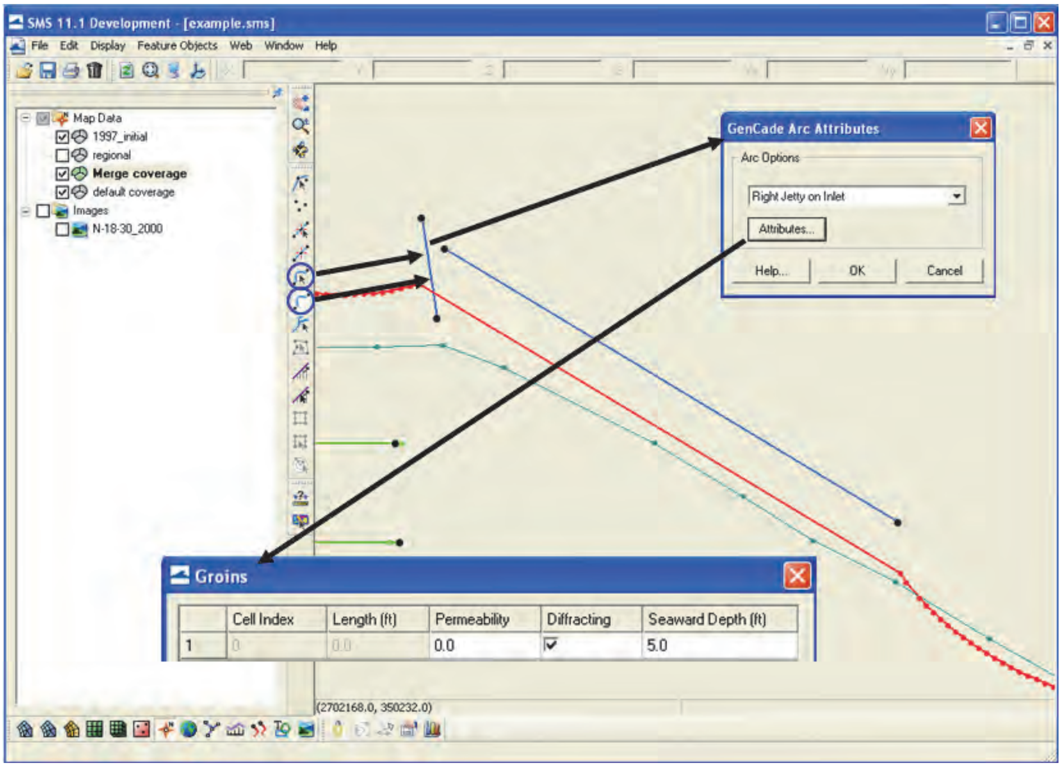


Figure 92. Create and define a jetty.

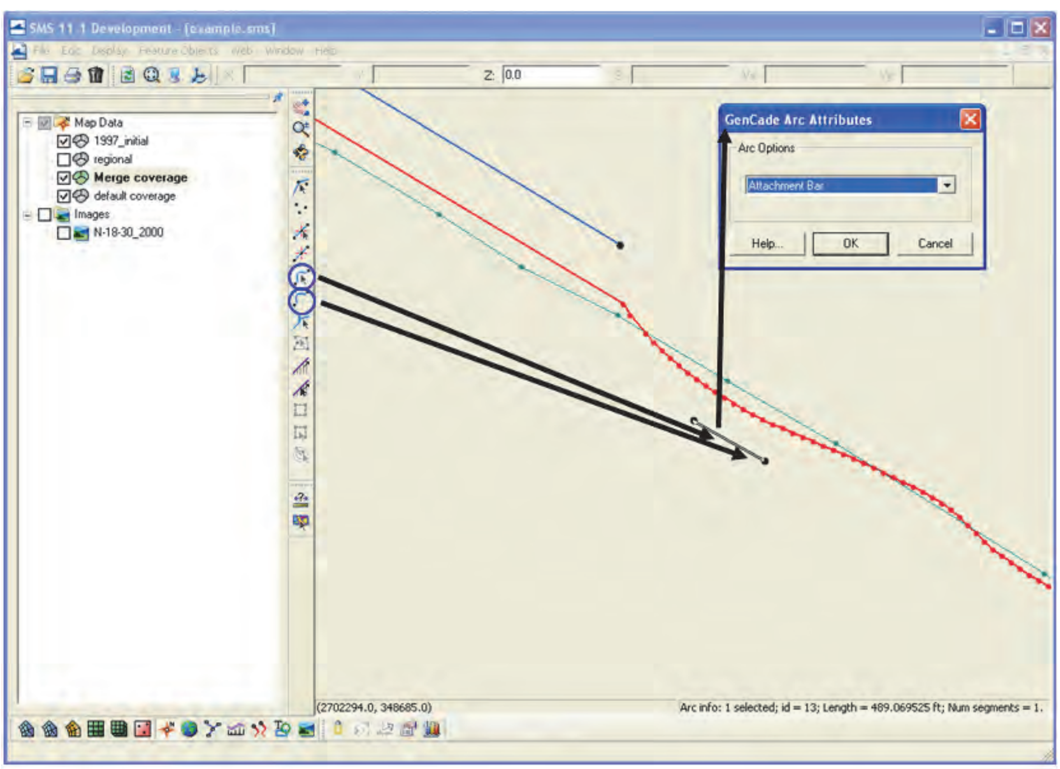


Figure 93. Create and define an attachment bar.

4.2.8 Seawalls

To draw a seawall, select the *Create Feature Arc* button and draw the seawall landward of the shoreline. If the user attempts to draw the seawall directly on top of the initial shoreline, an error will occur. The seawall drawn by the user should resemble the shape of the real seawall as closely as possible. If the user is not meticulous in drawing the seawall, the shape of the seawall in the GenCade model may not resemble the actual seawall. Additionally, since cell numbers are used in the GenCade model, the seawall shape may look different after converting from the conceptual model. After the seawall is drawn, the user should click on the *Select Feature Arc* button and click on the seawall. The *GenCade Arc Attributes* window will open. *Seawall* should be selected in *Arc Options*. The seawall will turn blue. When the model is converted to a 1-D grid, an error message indicating that GenCade will modify the cells defined for the seawall may pop up. This message should be ignored; GenCade will modify the cells defined for the seawall. The user should review the seawall in the GenCade model. If the seawall does not resemble the actual seawall, the user may need to decrease the size of the cells in the vicinity of the seawall. The process to create a seawall is shown in Figure 94.

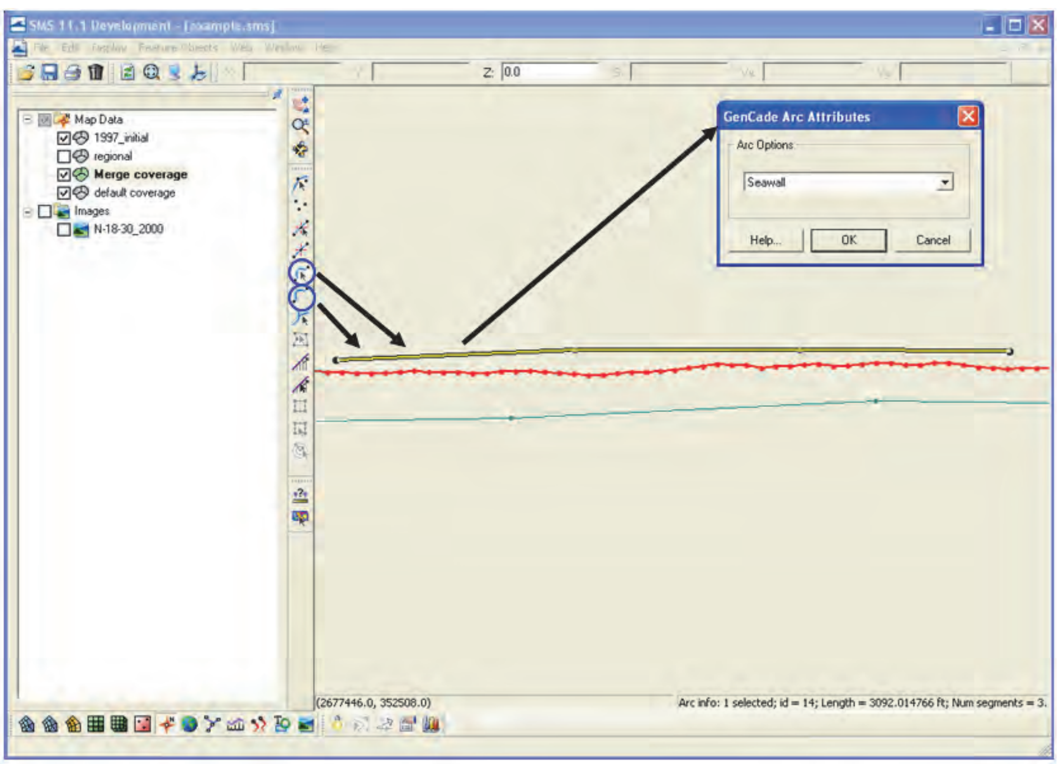


Figure 94. Create and define a seawall.

4.2.9 Beach fills

Beach fills can be created in the same way as inlets and seawalls. One should select the *Create Feature Arc* button to draw the beach fill. Beach fills may be drawn seaward or landward of the shoreline. If there are many beach fills in one location during the simulation, draw the beach fills carefully so that the arcs do not connect or intersect. After each beach fill is drawn, click on the *Select Feature Arc* and double-click on the line representing the beach fill. Select the *Beach Fill Event* after the *GenCade Arc Attributes* window opens. For each beach fill, add the *Begin Date* and *End Date* and the *Added Berm Width*. After selecting *OK* in the *GenCade Arc Attributes* window, the line representing the beach fill will turn green. Figure 95 demonstrates the steps to create and define beach fill events.

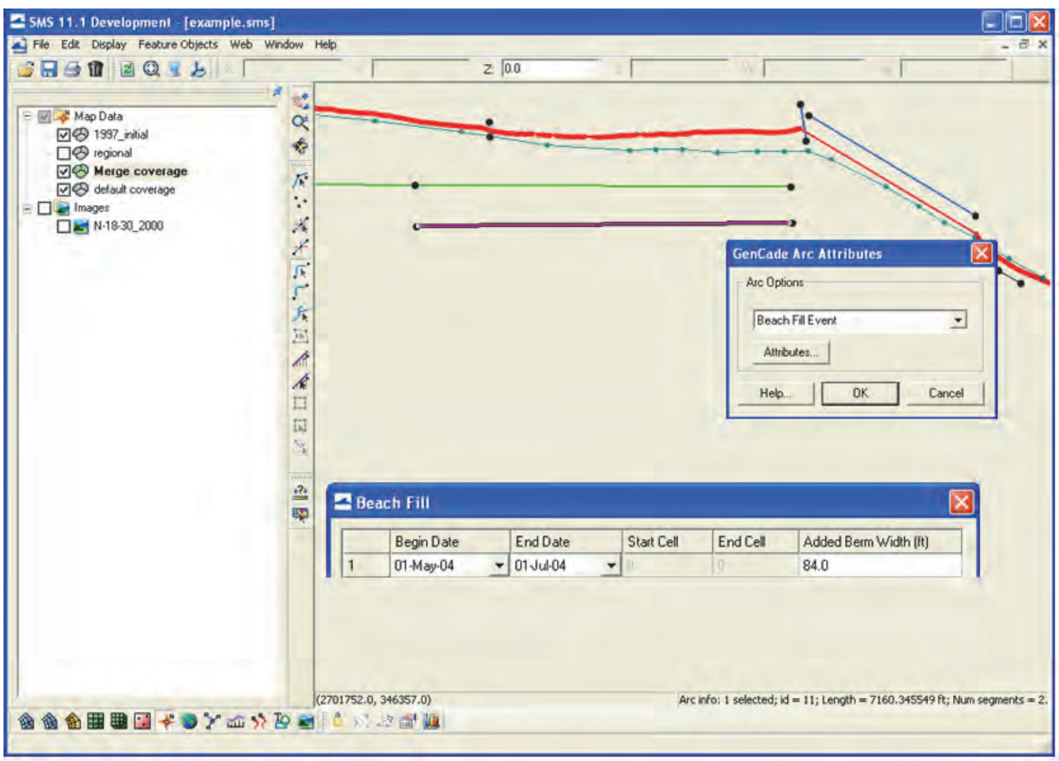


Figure 95. Create and define a beach fill.

4.2.10 Bypass event

Another option in GenCade is a bypass event. A bypass event can be used to represent other sand sources or sinks such as those discussed in section 2.12.7. The user should select the *Create Feature Arc* button and draw the bypass event in the desired location. After the event is created, the user should click on the *Select Feature Arc* button and double-click on the arc representing the bypass event. Once *Bypass Event* is selected in the *GenCade Arc Attributes* window, the *Bypassing* window will open. A *Begin Date*, *End Date*, and *Bypass Rate* can be specified. A positive rate will be interpreted as a source of sand and a negative rate as a sink. If the project projection is in U.S. Customary Units, the bypass rate is cubic yards per hour. Likewise, the bypass rate is cubic meters per hour when SI units are used. Figure 96 demonstrates the steps to create and define bypass events.

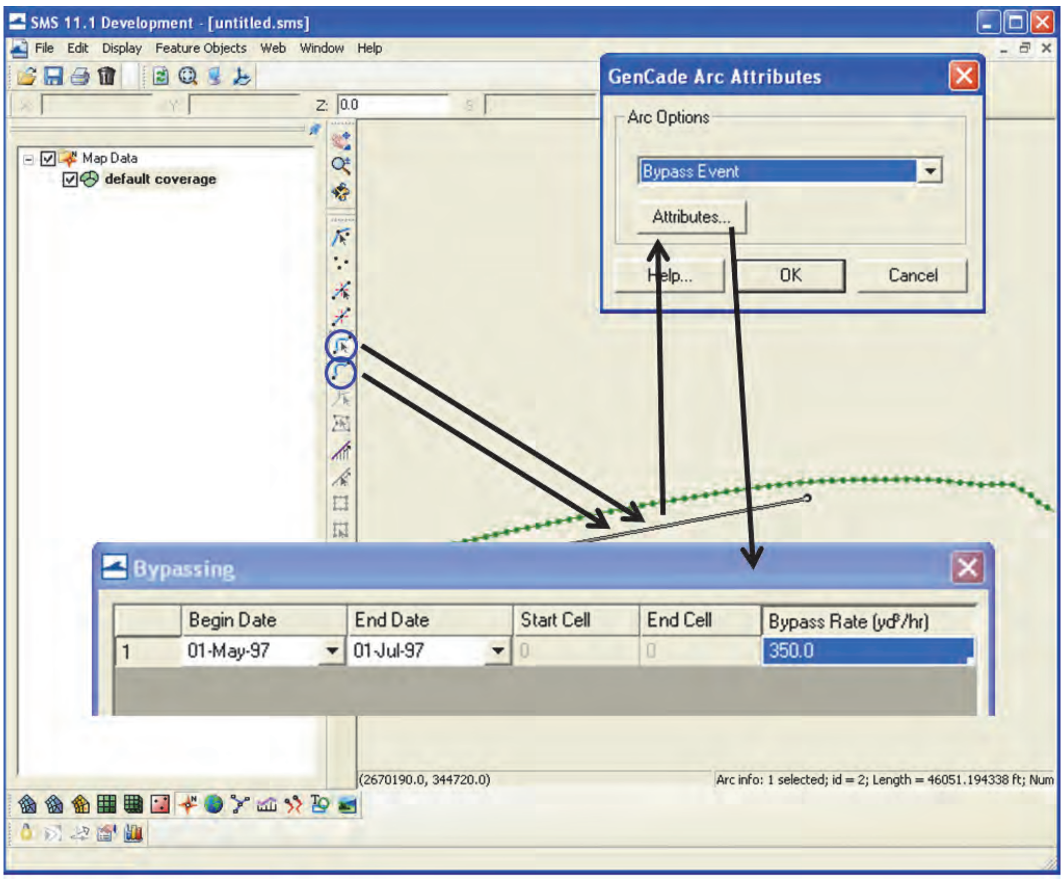


Figure 96. Create and define bypass event.

4.2.11 Detached breakwaters

A detached breakwater is created by selecting the *Create Feature Arc* button and drawing the arc representing the detached breakwater. The user should click on the *Select Feature Arc* button and double-click on the detached breakwater. The *GenCade Arc Attributes* window will open. Scroll down to *Breakwater* and click on *Attributes*. The depth at each end of the detached breakwater can be entered in the *Detached Breakwater* window. There is a pull-down window for wave transmission which includes constant transmission and three equations for time-dependent wave transmission: Ahrens (2001), Seabrook and Hall (1998), and d'Angremond et al (1996).

4.2.12 Constant transmission

Under the *Transmission* bar, select *Constant*. The last column in the detached breakwaters window is *Coeff/Perm/Atts*. For constant transmission, this last column represents the transmission coefficient of the detached breakwater. Once all necessary information is entered, click *OK*. The detached breakwater will turn orange. A detached breakwater with constant transmission is shown in Figure 97.

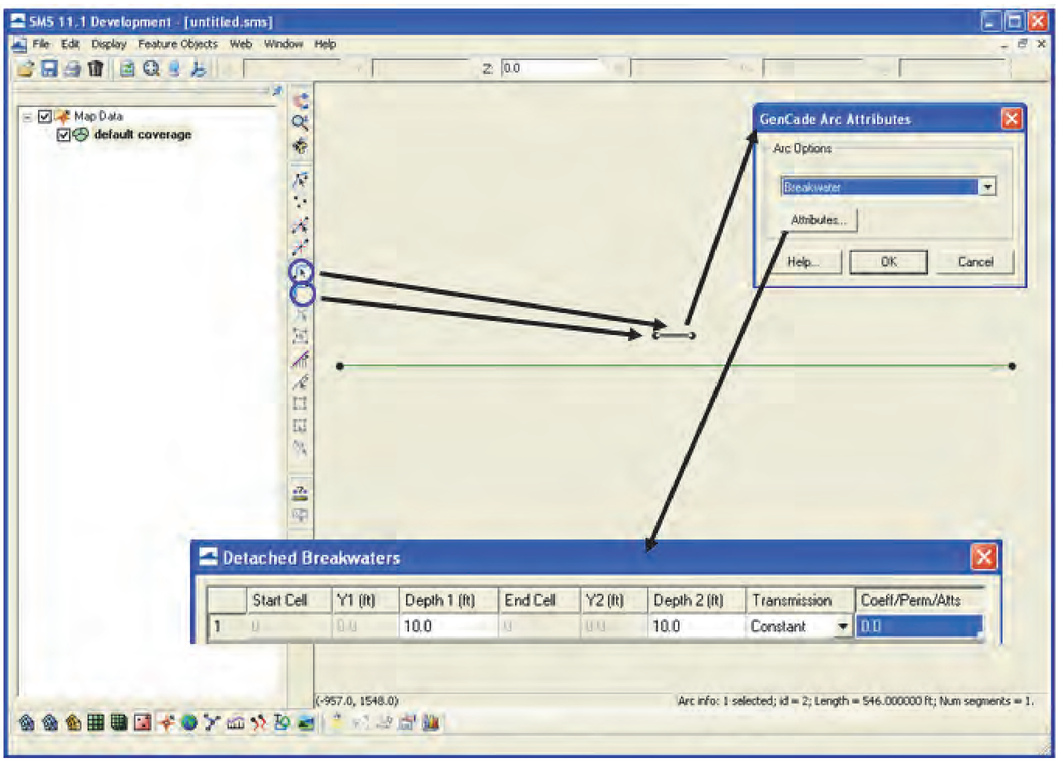


Figure 97. Create and define a breakwater with constant transmission.

4.2.13 Time-dependent wave transmission

4.2.13.1 Ahrens

After selecting *Ahrens* under *Transmission* in the *Detached Breakwater* window, the final column (*Coeff/Perm/Atts*) can be selected. Clicking this box will open the *Breakwater Attributes* window. For Ahrens, the required values include freeboard to MSL, width, seaward side slope, shoreward side slope, and the d50 of the armor stone (Figure 98). Click *OK*, and the detached breakwater should turn orange.

4.2.13.2 d'Angremond

Another equation that can be used for time-dependent wave transmission is d'Angremond. Similarly to the option for *Ahrens*, click on the final column of the *Detached Breakwaters* window which should now say *Atts*. For d'Angremond, the freeboard to MSL, width, seaward side slope, shoreward side slope, and permeability are required (Figure 99).

4.2.13.3 Seabrook and Hall

Seabrook and Hall can also be used for time-dependent wave transmission. After selecting Seabrook and Hall in the *Detached Breakwaters* window, click on *Atts* in the final column. The *Breakwater Attributes* window will open, and the freeboard to MSL, width, seaward side slope, shoreward side slope, and d_{50} of the armor stone can be entered (Figure 100).

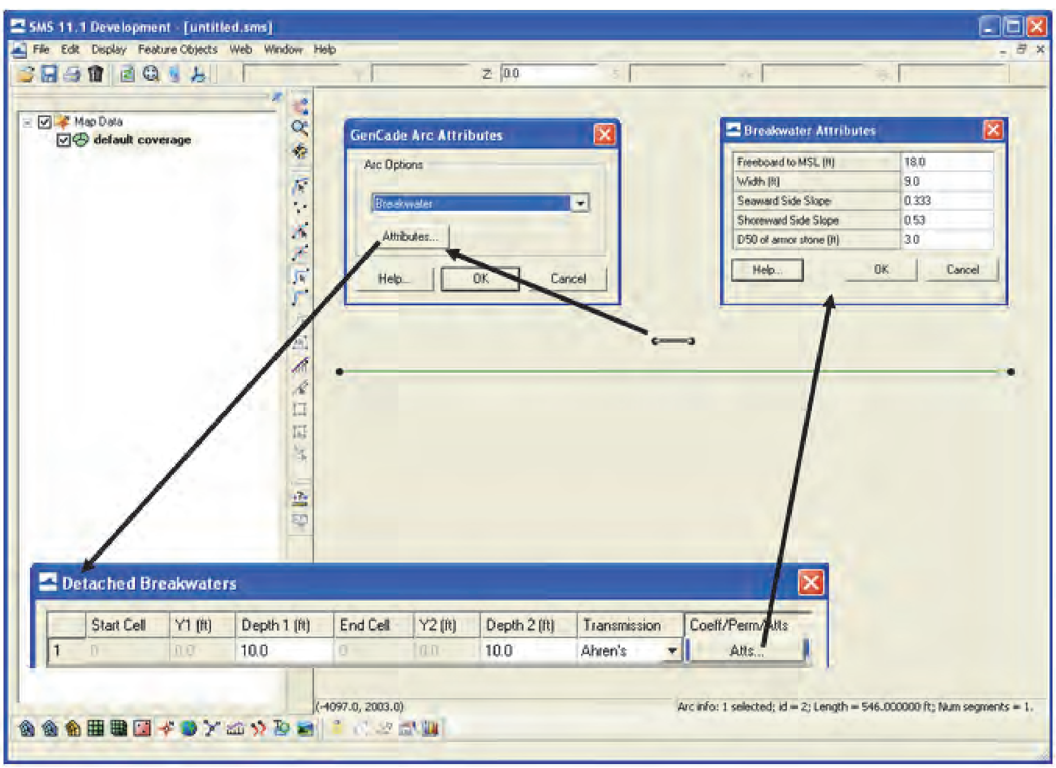


Figure 98. Define breakwater using Ahrens method for transmission.

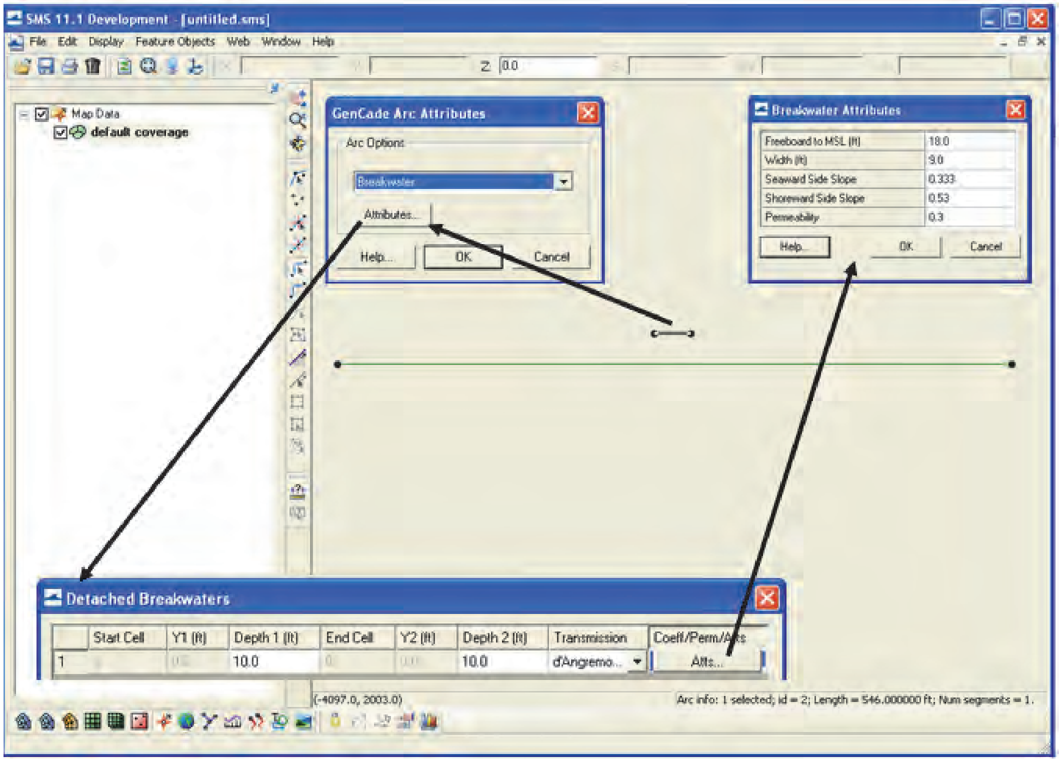


Figure 99. Define breakwater using d'Angremond method for transmission.

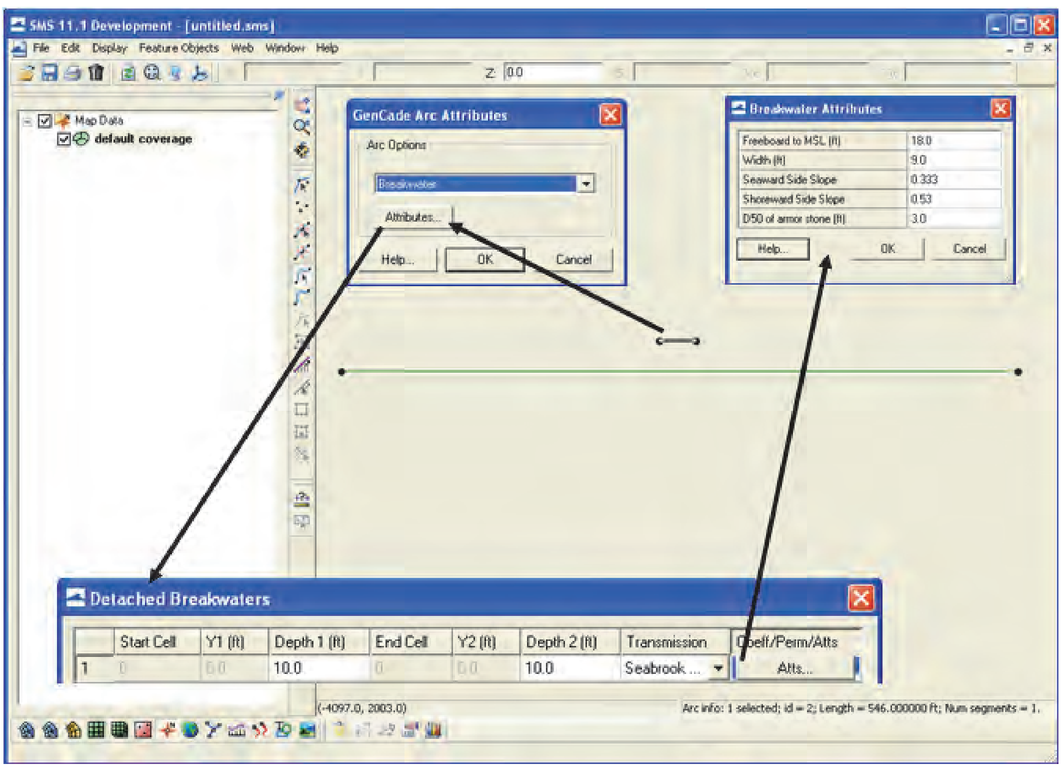


Figure 100. Define breakwater using Seabrook and Hall method for transmission.

4.2.14 Groins

Once the location for a groin is chosen, select the *Create Feature Arc* button. In many cases, the arc representing the groin will cross the regional contour and initial shoreline. Do not draw either end of the groin near the regional contour or initial shoreline. When this occurs, the node from the groin will connect to the initial shoreline or regional contour. This will divide the regional contour or initial shoreline into two separate arcs, where only one of the arcs will still be defined as the regional contour or initial shoreline. To remedy this, delete the arc that was created to represent the groin. Highlight the node that divides the initial shoreline into two segments. Under *Feature Objects*, select *Vertices*<->*Nodes*. The node will become a vertex, and the initial shoreline will once again be a single arc. After drawing the feature arc for the groin, click on the *Select Feature Arc* button. The *GenCade Arc Attributes* window will open. Select G*roin* in the *Arc Options* menu and click on *Attributes*. The window for groins is very similar to the window for jetties. The window for groins includes the *Permeability* and *Seaward Depth* (in the user specified units). The user may also define the groin as *Diffracting* or *Non-diffracting*. When the *Diffracting* option is checked, a *Seaward Depth* must be specified. Figure 101 illustrates the various windows associated with creating a groin.

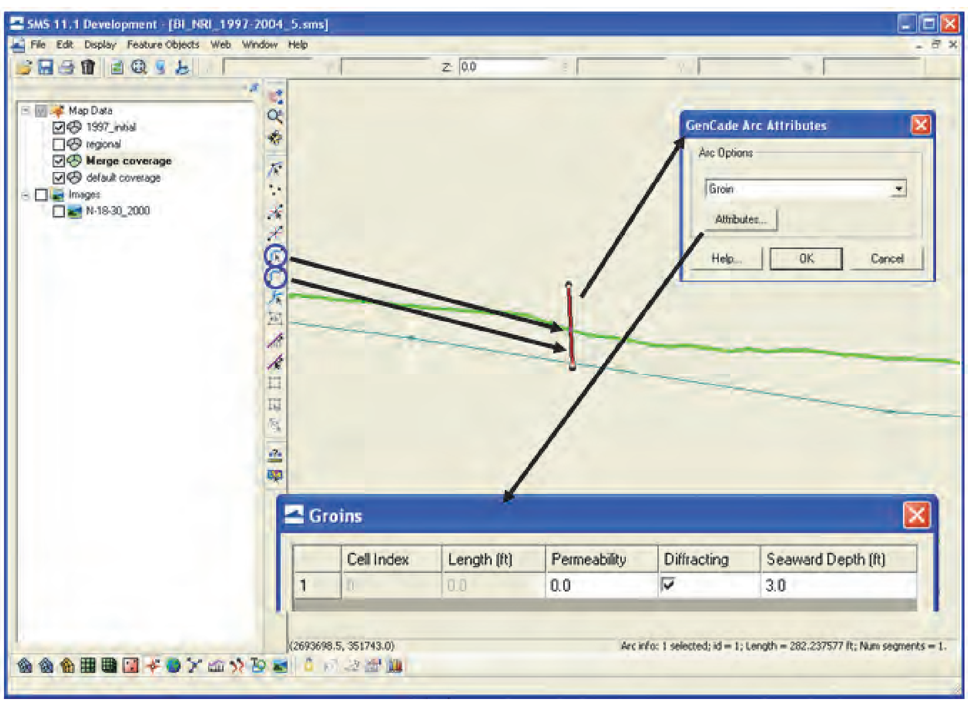


Figure 101. Define and create a groin.

4.2.15 T-groins

While a T-groin is not an option in the *GenCade Attributes* window, a detached breakwater and a groin can be combined to form a T-groin. If a T-groin is required, the user should first create a detached breakwater and fill in all of the information necessary for a detached breakwater in the *GenCade Arc Attributes* window. Then the user should create a groin that attaches to the detached breakwater. Once the conceptual model is converted to a 1-D grid, it is necessary to double-check the T-groin to ensure that the shape has been retained. It is possible that the groin or detached breakwater has moved to an adjacent cell number and no longer retains the shape the user defined in the conceptual model. The user may modify the cells for the detached breakwater or groin in the GenCade model under *Edit Breakwaters* or *Edit Groins* in the *GenCade* menu. If the shape of the T-groin is significantly altered, the user may want to consider decreasing the cell size for the entire grid or utilizing variable grid resolution (4.2.16). An example of a T-groin is shown in Figure 102.

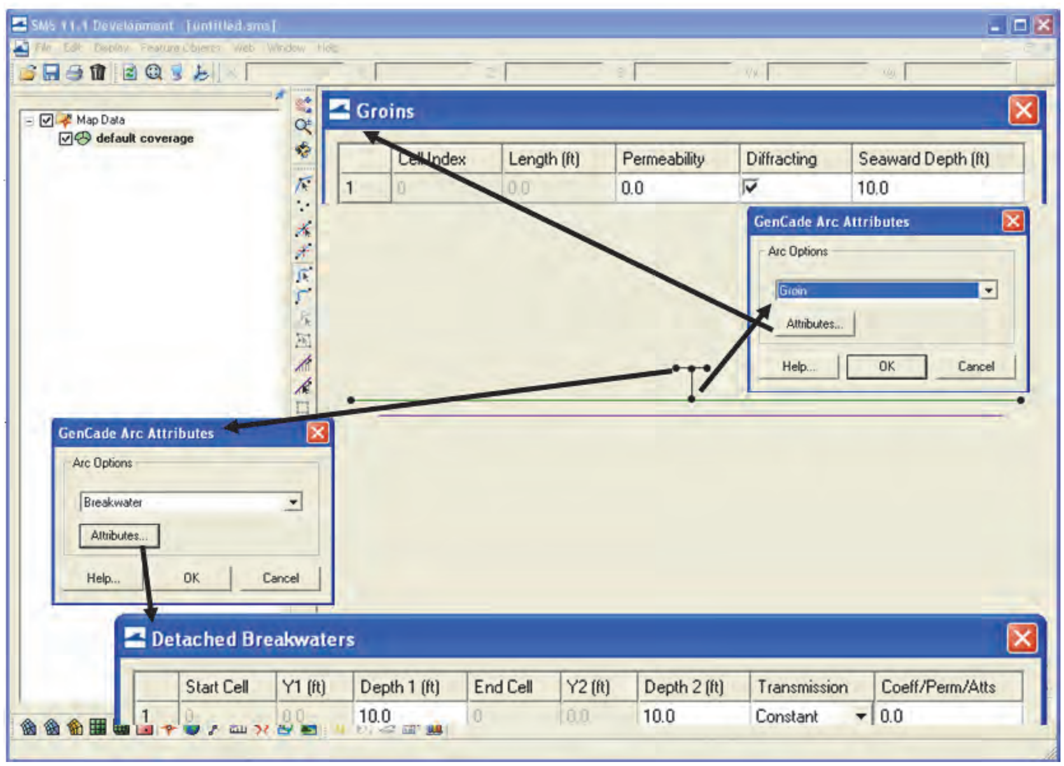


Figure 102. Create a T-groin.

4.2.16 Orientation, cell size, and variable grid resolution

After defining the shorelines and any necessary structures, the grid should be set up. To manually draw the grid frame, click on the *Create 1-D Grid Frame*. The GenCade grid frame is purple and has an arrow at one end. If a person followed the shoreline from the beginning to the end of the grid with the arrow, the water should always be to the left and the land should always be to the right. For example, if the GenCade grid was oriented from north to south where the arrow of the grid points to the south, the water would be to the east (left) and the land would be to the west (right). The grid can be modified by clicking the *Select 1-D Grid Frame* and double-clicking on the square in the center of the purple grid line. Alternately, the grid options can be changed by selecting the grid frame and right-clicking *Properties*. The *Grid Frame Properties* window will open, and the *Origin X*, *Origin Y*, *Angle*, and *I size* can be modified. The *I size* is the length of the grid. *Angle* refers to the sign convention in the conceptual model which is degrees counterclockwise from the *x* axis. This is different from the GenCade model convention (degrees clockwise from north). Therefore, once the map is converted to a 1-D grid, the *Azimuth* for the grid will be a different value. The cell size can be constant or variable. If the user chooses to change the cell size under *Define cell sizes*, the number of cells will change accordingly. The grid frame set up is shown in Figure 103.

A constant grid resolution is reasonable for most projects. However, there are some large scale projects that would benefit from variable grid resolution. Variable grid resolution can give more detail at specific locations of interest while having coarser resolution in other areas of the grid. By utilizing variable grid resolution, the simulation will run much more quickly than a grid with a constant, finer resolution. When the map is converted to a 1-D grid, one of the options under *I Cell Options* is *Use refine points*. This option refers to variable grid resolution.

First, it is necessary to determine which part of the grid needs a finer resolution. There are two ways to set up finer grid resolution. The user can decide to use one point or two points. For both of these options, click the *Create Feature Point* button. If only one feature point is created, put the point at the location of interest. Click on the *Select Feature Point* button and double-click on the point. The *Refine Point* window will open (Figure 104). Check the *Refine grid in I direction* and specify a base cell size. The base cell size is the size of the cells nearest to the refine point. This will be the smallest cell size in this location of the grid. Once the refine point is

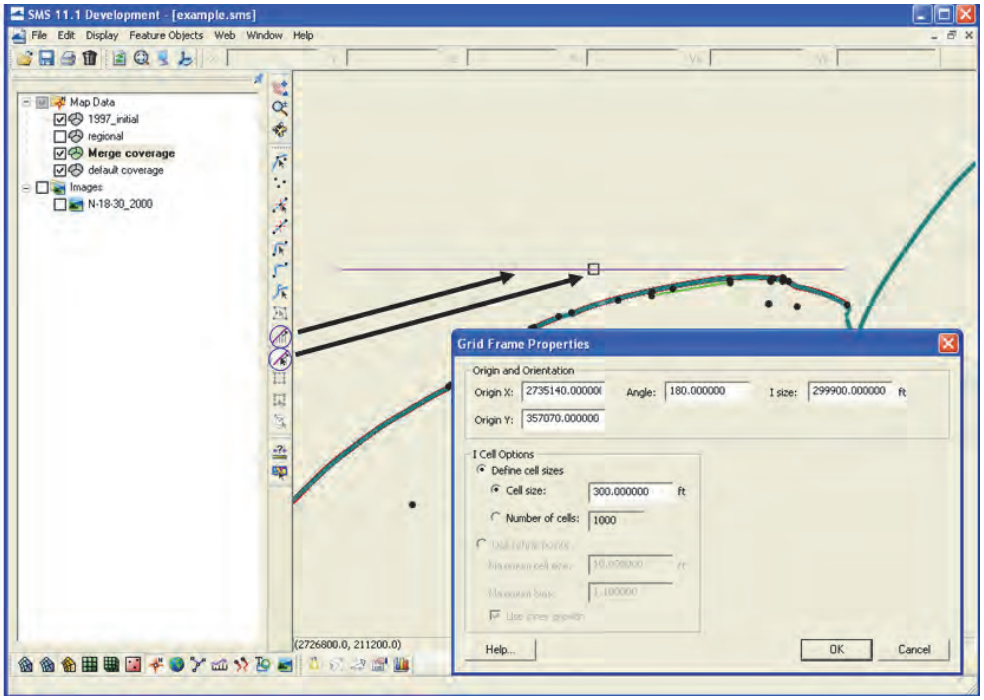


Figure 103. Create and define the grid frame.

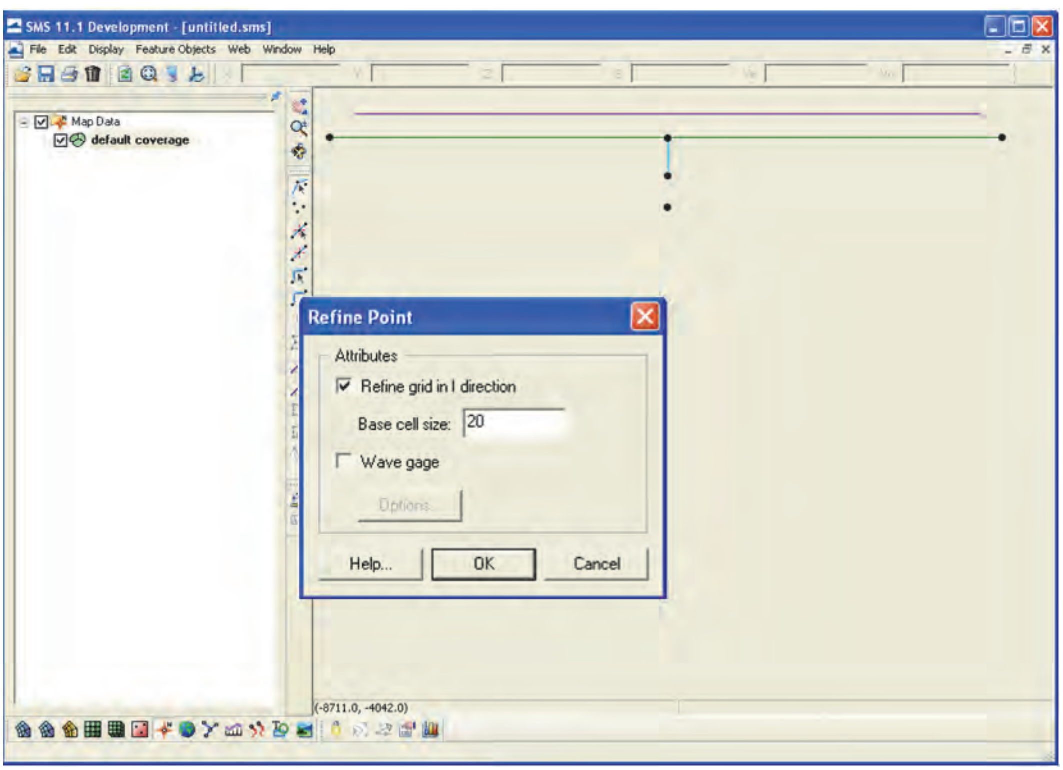


Figure 104. Refine the grid for variable resolution.

specified, click on the *Select 1-D Grid Frame* to open the *Grid Frame Properties* window (Figure 105). Under *I Cell Options*, click the button to specify the *Use refine points* option. Type the maximum cell size and the maximum bias. The maximum cell size represents the largest cell size in the grid. Moving out from the one refine point, the cells will grow in size until a cell reaches the maximum cell size. The remaining cells in the grid will also be the maximum cell size. The maximum bias represents the amount each adjacent cell grows. For example, the default value is 1.10. This means each cell will grow 10 percent, so in a case with a base cell size of 10, the adjacent cells will have a size of 11. The cells will continue growing at this rate until a cell reaches the maximum cell size. In a case with only one refine point, do not select the *Use inner growth* option.

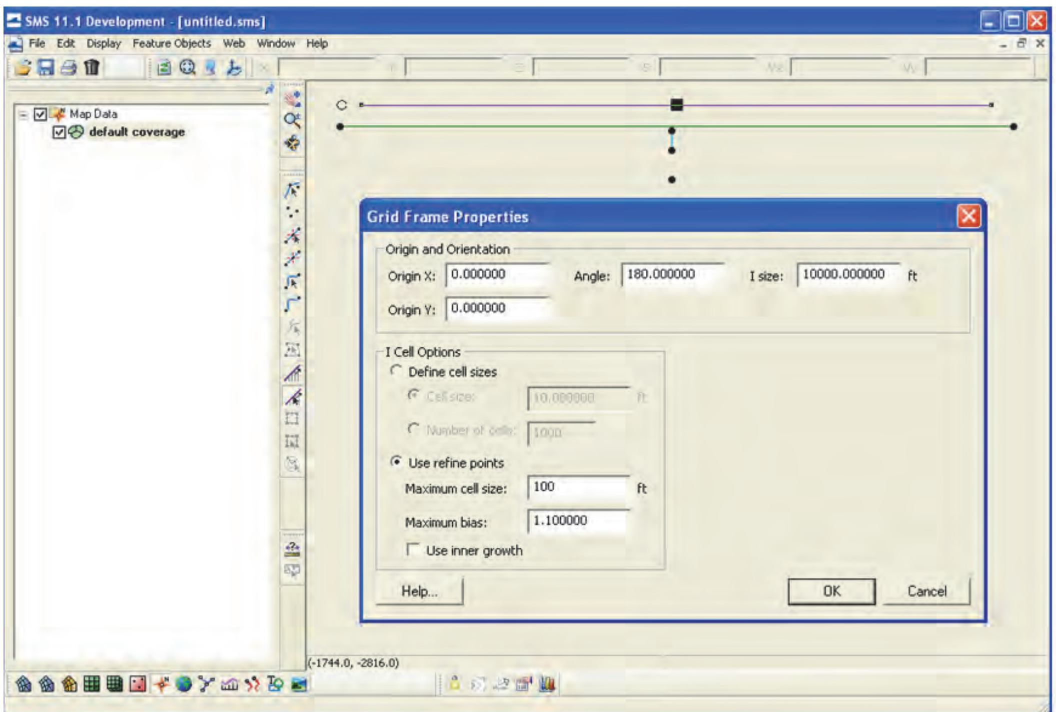


Figure 105. Use refine points.

It is also possible to have a finer, constant resolution for a certain section within the grid. A groin field is a good example where a finer, constant resolution could be beneficial. For this case, select the *Create Feature Point* button and create points on either side of the desired finer resolution area. Click on the *Select Feature Point* button, double-click on each point, check the *refine grid in I direction* option, and choose a base cell size (make this number the same for both refine points). Once again, open the *Grid Frame Properties* window and select the *Use refine points* option. Follow the same procedure as the case with only one refine point for the maximum cell size and maximum bias. If the *Use inner growth* option is left unchecked, the cells between each refine point will be constant (at the same cell size as specified for each refine point). The cells outside of the two refine points will continue to grow up to the specified maximum bias number. If the *Use inner growth* option is selected, the cells will also grow between the two refine points. If the two refine points are close together, the cell size most likely will not reach the maximum cell size, but the cells between the two refine points will be larger than the base cell size.

After the *Use refine points* option is chosen in the *Grid Frame Properties* window, the resulting GenCade grid will have variable resolution when converted to a 1-D grid (4.2.17). After saving the project, the *.shdx file is also created. This file lists the size of each cell in the grid. This file is needed to make shoreline change or transport plots outside of SMS in cases with variable grid resolution.

4.2.17 Convert to 1-D grid

Once all of the shorelines, inlets, structures, and refine points have been added to the conceptual model, select the merged coverage, right click on the name, click on *Convert*, and select *Map->1-D Grid* (Figure 106). A window will open showing the origin and orientation of the GenCade grid and the different cell options. This is the same window that was opened when the grid frame was created. Once the map has been converted to a 1-D grid, the data tree in the SMS will show *GenCade Data* and *GenCade Grid*. If the user highlights *GenCade Data*, the GenCade menu at the top of the interface will appear. The newly developed GenCade grid can be seen in the viewing window.

4.2.18 Wave data

Wave gauges should be defined after converting from the conceptual model to the GenCade model. After the GenCade grid has been created, highlight the coverage under *Map Data* to return to the conceptual model. Wave gauge data may be entered in GenCade in four conventions: shore normal, meteorological, oceanographic, and Cartesian. Regardless of the convention, wave directions will be converted to shore normal convention in the *.wave files. Therefore, the grid must be created first, so that GenCade can convert the wave directions to shore normal.

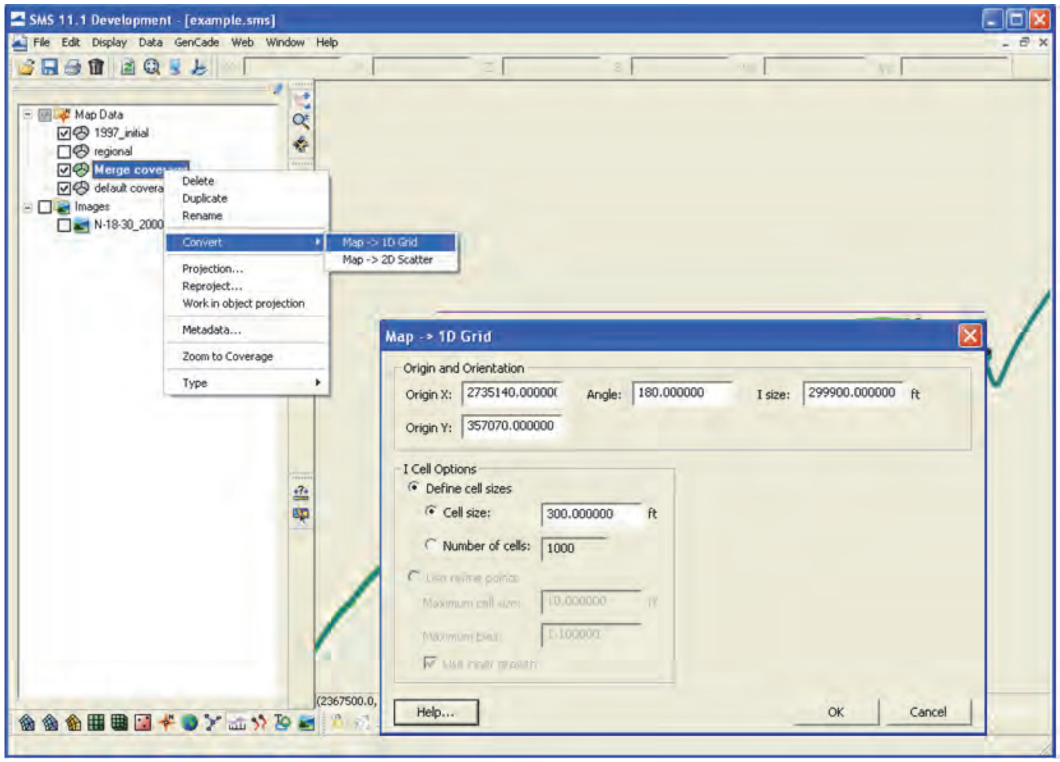


Figure 106. Convert to GenCade grid with constant cell size.

There are two ways to represent wave gauges in the conceptual model. In both cases, the user needs to create and select the feature point. If the coordinates of the wave gauges are in the same coordinate system as the conceptual model, it is very easy to create a point at the location of each gauge. Drag the file with the coordinates representing the wave gauges into the SMS interface. The *Open File Format* window will open. Select *Use Import Wizard* and click *OK*. Follow the directions for the *File Import Wizard* and select *OK*. The wave gauges will be represented as scatter data. Simply select the *Create Feature Point* button in the conceptual model and draw a feature point directly on top of each point. Now, the wave gauge locations are represented in the conceptual model. Instead of defining the feature point as a refine point, check *Wave Gage*. The *Options* button will open a window where the water depth may be defined. Click on *Data* to open the *Wave Events* window (Figure 107). This window will allow the user to copy and paste data or import the wave information from a text file. Regardless of the format of the wave information, the user first needs to define the coordinate convention under *Angle Settings*. Depending on the source, the wave information will likely be in meteorological and oceanographic convention. Before importing the wave information, double-check to make sure there are no missing or incorrect data. In previous versions of the interface, the SMS could not handle wave directions from land; however, this has been corrected.

If the wave information is in Microsoft Excel or a similar format, it may be easiest to directly copy and paste. To paste the data correctly, the information must be divided into four columns (Figure 108). The first column represents the date (month, day, year, and time), the second is the wave height, the third column is the wave period, and the fourth column is wave direction.

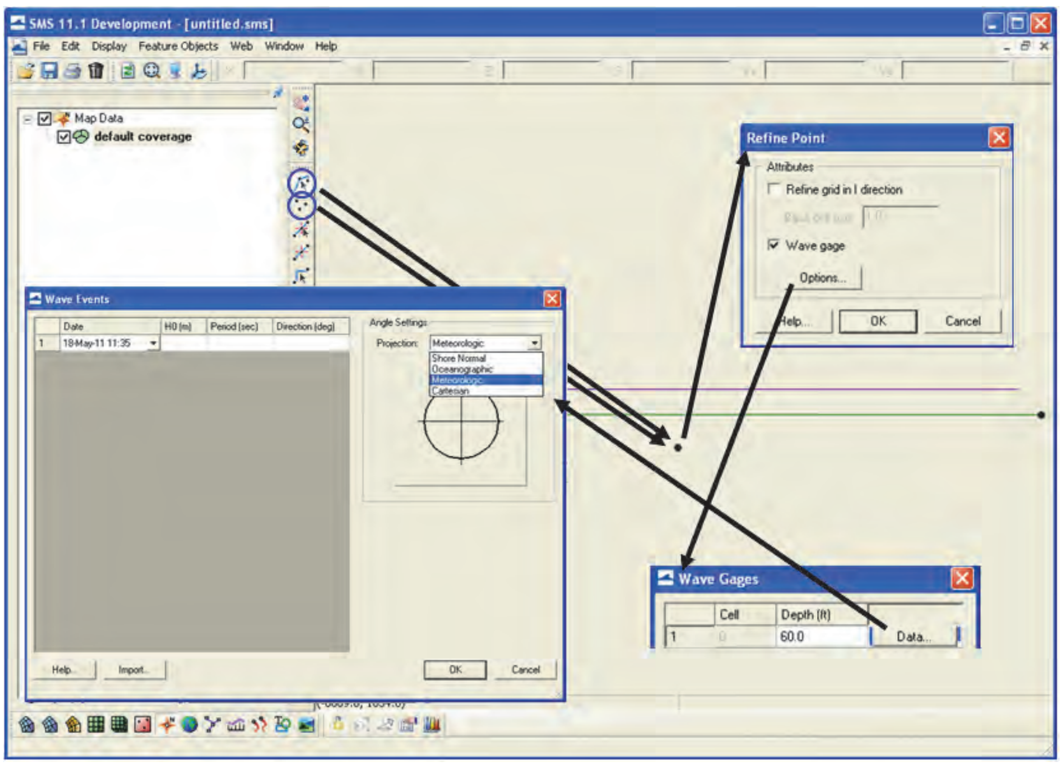
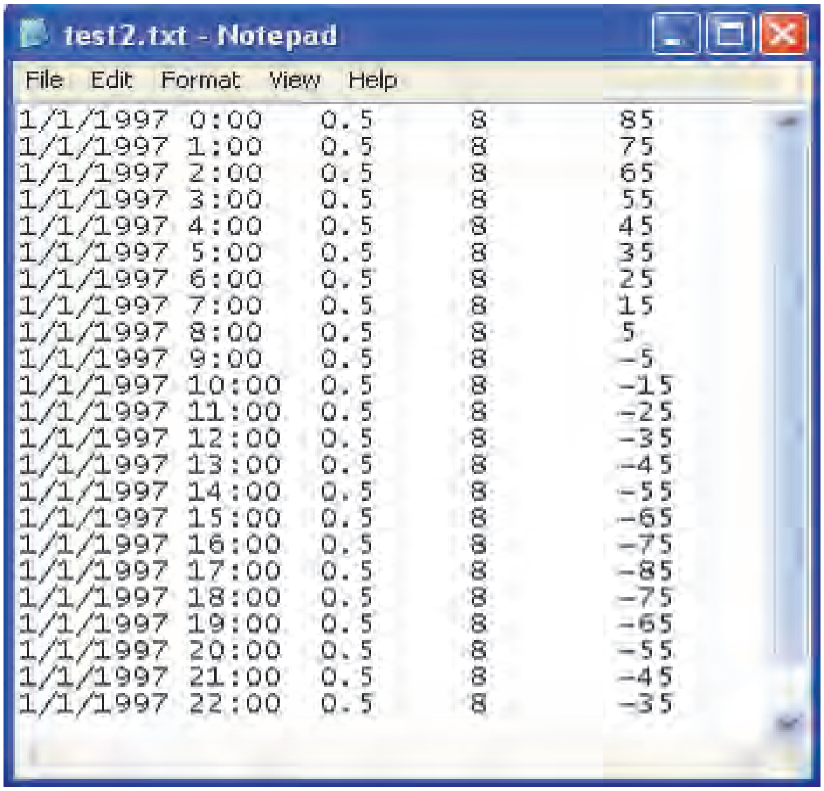


Figure 107. Create and define wave gauge.

The date must be in MM/DD/YYYY HH:MM format. If the information is copied from a text file, the time and date must be separated by a space. If a tab is used, the SMS will read the information in five columns and the information will not be pasted correctly. ***Regardless of the units used in the conceptual model, H_o must be in meters***. The reason the grid must be created before adding the wave information is due to the shore normal convention. To convert from any convention to shore normal, the SMS must know the angle of the shore (grid). It is important to note that the conceptual model and GenCade model use different sign conventions.

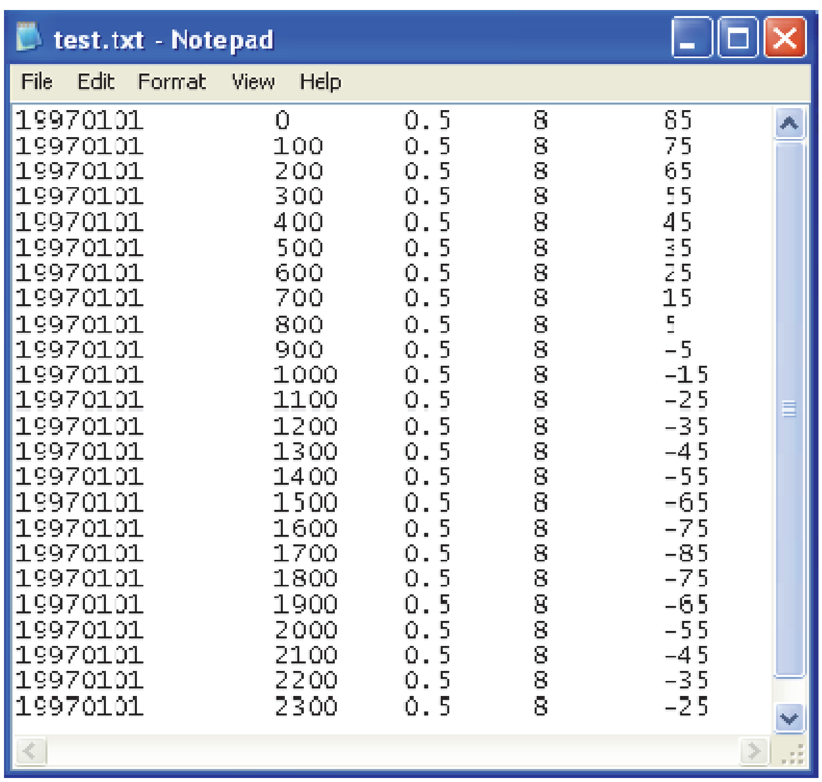
To import the correct wave directions in shore normal coordinates, the user should go to *GenCade->Edit Grid* when in the GenCade Model. The *Azimuth* is the correct angle to determine shore normal coordinates. The *Angle* in the *Grid Frame Properties* window will list a different value since the sign convention for the conceptual model is different from the GenCade model. If the value for *Angle* is used to determine shore normal coordinates, the wave directions will be incorrect. After pasting the information in the *Wave Events* window, click *OK* in all of the open windows. Then convert to the 1-D grid. To double-check the pasted wave information, go to *Edit Wave Data* in the newly created *GenCade* menu. The wave gauge is now assigned a cell and the water depth is listed. Click on *Data* to open the *Wave Events* window. All of the information in this window should be identical to the information pasted. The convention used to define the direction should be the same as the user defined in the conceptual model. Once the project is saved, the wave information will be output in the *.wave files. If the user defined the wave directions in oceanographic, meteorological, or Cartesian, the wave directions will be automatically converted to shore normal convention in the *.wave files. However, if the project is reopened after saving, the user should note that regardless of the defined convention in the conceptual model, the *Wave Events* window under *Edit GenCade* will now list directions in shore normal convention. The reason this occurs is because the wave information is drawn directly from the *.wave files which are in shore normal convention. The *Wave Events* window in the conceptual model will remain in the user specified convention. For example, if the user defined the direction in meteorological convention, the directions in the *Wave Events* window in the conceptual model will still be relative to meteorological convention.

A second way to enter the wave information is by clicking *Import* at the bottom of the *Wave Events* window. The *Import* function allows the user to find an existing text file with the wave information. Text files must have five columns representing the wave information (Figure 109). The last three columns are in the same format as in the copy and paste option (wave height, wave period, and wave direction). The first column lists the date in YYYYMMDD format. The second column lists the time in HHMM format. Once the file is read by the SMS, each column must be identified (Figures 110 and 111). Once *Finish* is clicked, a *Direction Angle Convention* window should open (Figure 112). The angle convention should be the same as the convention identified under *Angle Settings*. After pushing *OK*,



1/1/1997	0:00	0.5	8	85
1/1/1997	1:00	0.5	8	75
1/1/1997	2:00	0.5	8	65
1/1/1997	3:00	0.5	8	55
1/1/1997	4:00	0.5	8	45
1/1/1997	5:00	0.5	8	35
1/1/1997	6:00	0.5	8	25
1/1/1997	7:00	0.5	8	15
1/1/1997	8:00	0.5	8	5
1/1/1997	9:00	0.5	8	-5
1/1/1997	10:00	0.5	8	-15
1/1/1997	11:00	0.5	8	-25
1/1/1997	12:00	0.5	8	-35
1/1/1997	13:00	0.5	8	-45
1/1/1997	14:00	0.5	8	-55
1/1/1997	15:00	0.5	8	-65
1/1/1997	16:00	0.5	8	-75
1/1/1997	17:00	0.5	8	-85
1/1/1997	18:00	0.5	8	-75
1/1/1997	19:00	0.5	8	-65
1/1/1997	20:00	0.5	8	-55
1/1/1997	21:00	0.5	8	-45
1/1/1997	22:00	0.5	8	-35

Figure 108. Format for wave gauge data using copy/paste option.



19970101	0	0.5	8	85
19970101	100	0.5	8	75
19970101	200	0.5	8	65
19970101	300	0.5	8	55
19970101	400	0.5	8	45
19970101	500	0.5	8	35
19970101	600	0.5	8	25
19970101	700	0.5	8	15
19970101	800	0.5	8	5
19970101	900	0.5	8	-5
19970101	1000	0.5	8	-15
19970101	1100	0.5	8	-25
19970101	1200	0.5	8	-35
19970101	1300	0.5	8	-45
19970101	1400	0.5	8	-55
19970101	1500	0.5	8	-65
19970101	1600	0.5	8	-75
19970101	1700	0.5	8	-85
19970101	1800	0.5	8	-75
19970101	1900	0.5	8	-65
19970101	2000	0.5	8	-55
19970101	2100	0.5	8	-45
19970101	2200	0.5	8	-35
19970101	2300	0.5	8	-25

Figure 109. Format for imported wave gauge data.

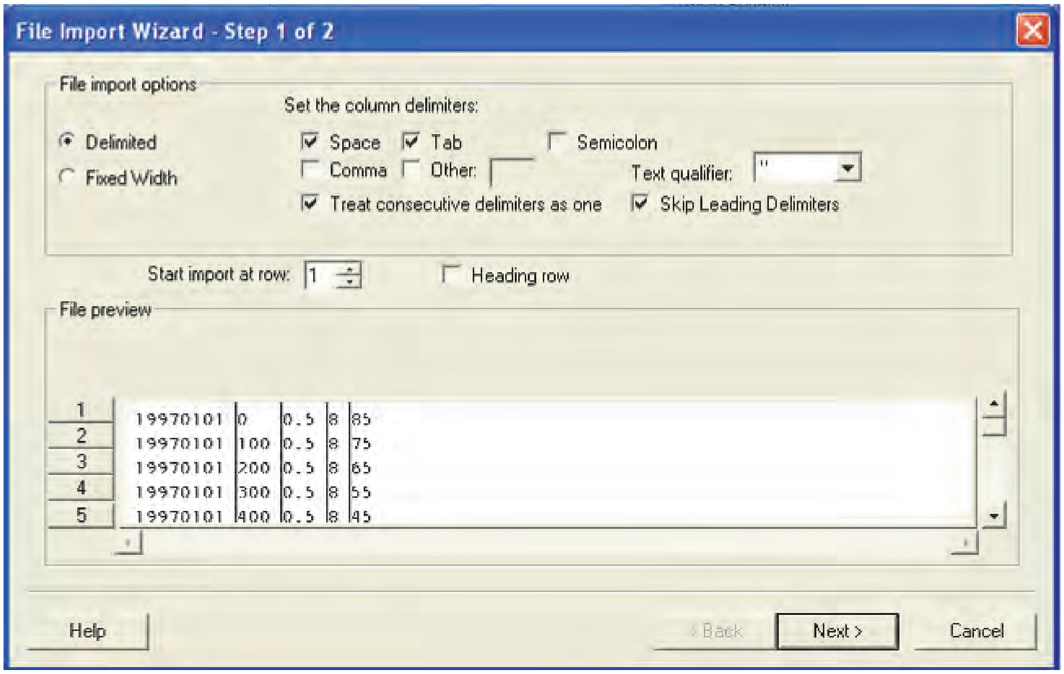


Figure 110. Step one of file import wizard.

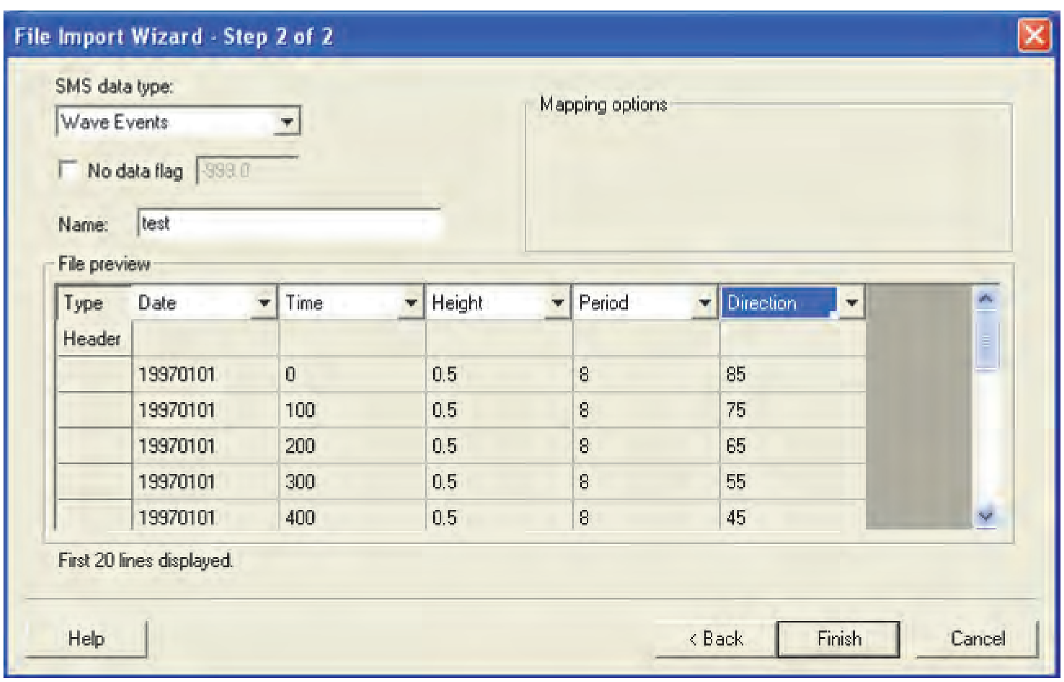


Figure 111. Step two of file import wizard for wave gauge data.

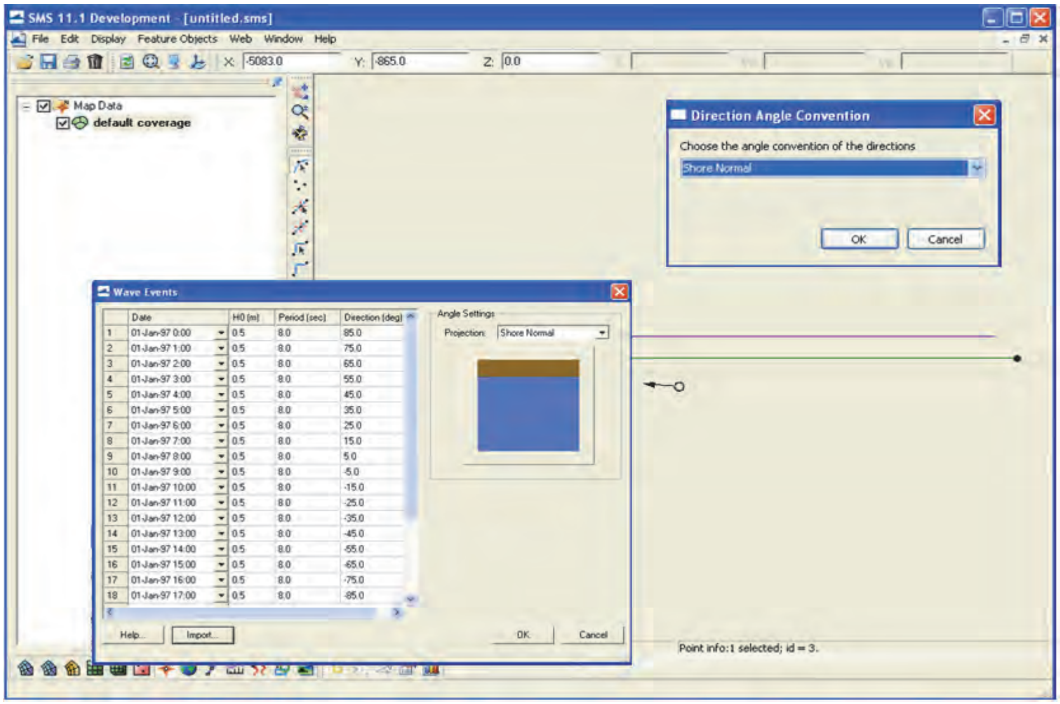


Figure 112. Define angle convention and check wave data.

the wave information should be in the proper format under *Wave Events*. Once all of the wave gauges are populated, the user may convert to the 1-D grid. After the project is saved, the *.wave files will be created. Regardless of the specified projection, the directions in the wave file will be in shore normal convention. As with the copy/paste wave information option, the wave information in the conceptual model will remain in the specified convention.

4.3 GenCade model control

Once the conceptual model is converted to the 1-D grid, the *GenCade* menu will appear between *Data* and *Web* in the menu bar (Figure 113). This menu can be used to make minor changes to the project and to double-check that all features defined in the conceptual model are represented in the grid. An example of a minor change to make in the GenCade model is modifying the cells representing the left and right bypassing under the *Edit Inlets* menu. If the user is calibrating the model, it is best to return to the conceptual model to make any changes to the attributes or positions of the arcs (inlets, seawalls, etc.), feature points (wave gauges, refinement points), shorelines, and grid. Changes made in the conceptual model will be applied to the grid each time it is generated, but changes made within the GenCade menu will be lost if the grid is generated.

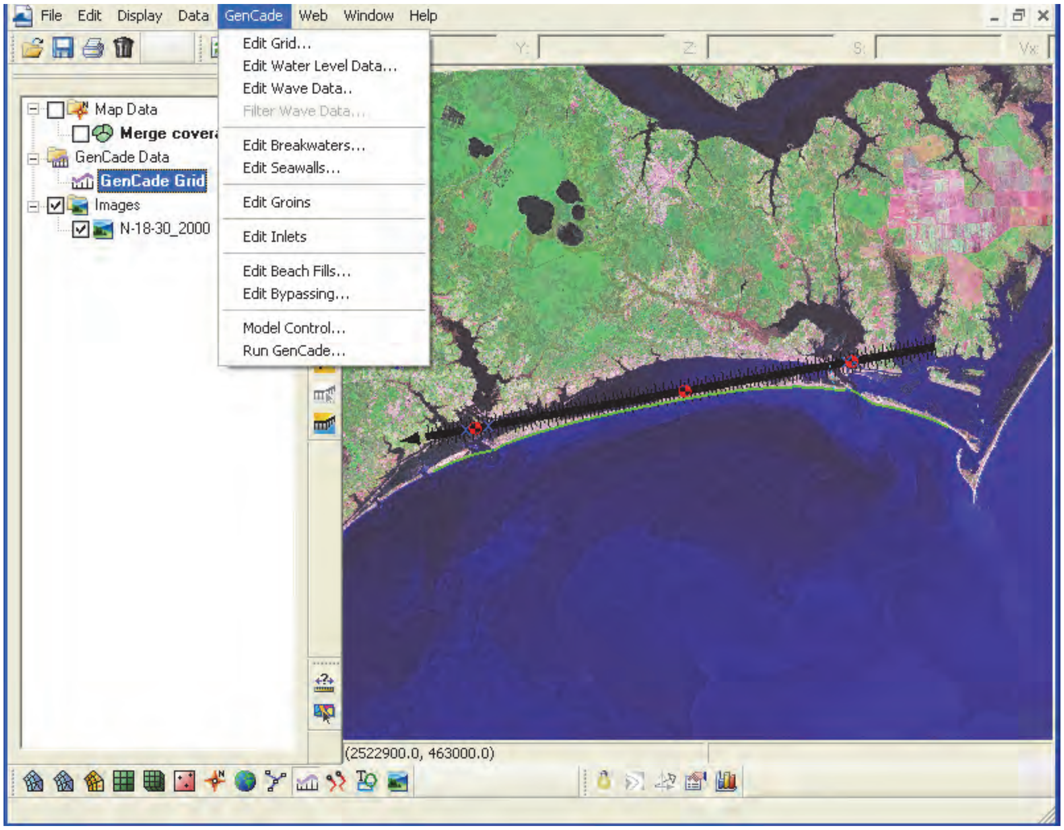


Figure 113. GenCade menu in GenCade model.

4.3.1 GenCade model setup

Once the user has determined that all of the features defined in the conceptual model have been retained in the GenCade grid, the user should begin to set up the model. This is accomplished by selecting *Model Control* under the *GenCade* menu. The first tab in the *GenCade Model Control* window is the *Model Setup* (Figure 114). This tab allows the user to specify the starting and ending date of the simulation, the time step, and the recording time step of the output files. The simulation time step must be equal to or less than the wave time step. If the wave time step is smaller than the simulation time step, an error will occur and GenCade will not run. The default time step is 1.0 hour, and the default recording time step is 168.0 hours. The user may also give the simulation a title. The bottom right of the menu states *Print Dates*. Mean annual net transport (*.mql, *.mqn, *.mqr) is recorded yearly on 1 January if no additional dates are specified in the *Print Dates* box. Several dates of interest may be added under *Print Dates*.

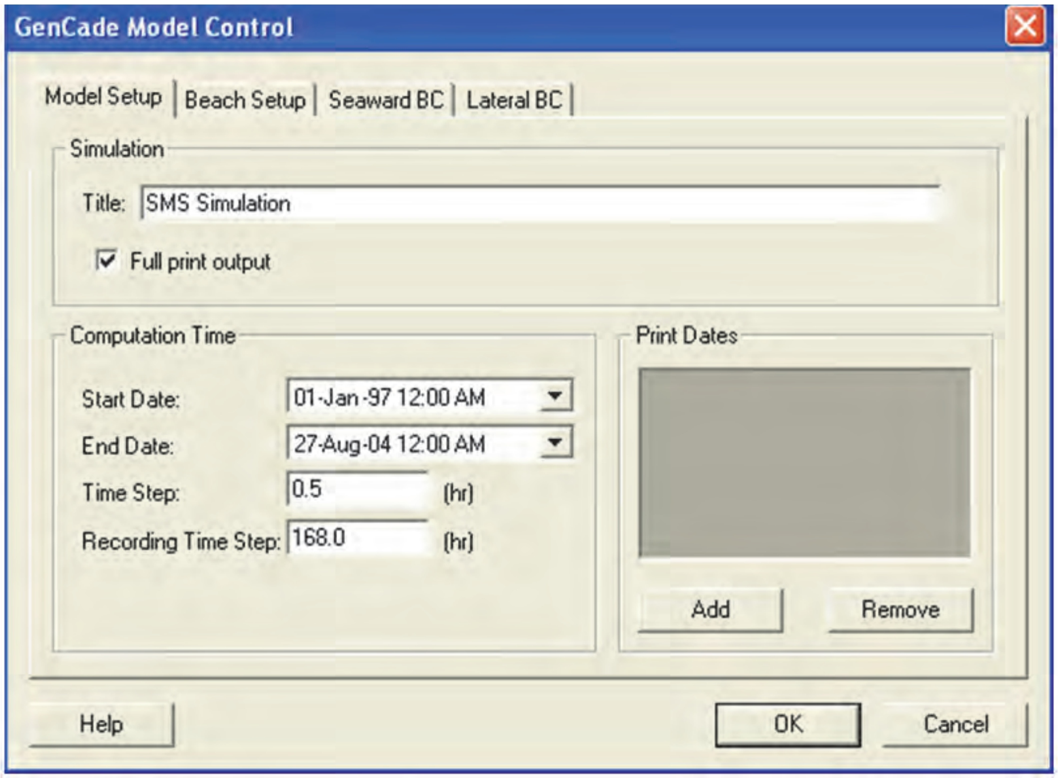


Figure 114. Model setup window.

4.3.2 Beach setup

The second tab under *GenCade Model Control* is the *Beach Setup* tab (Figure 115). The first section under this tab refers to the *Sand and Beach Data*. Here the user may enter the *Effective Grain Size* (always in mm), the *Average Berm Height*, and the *Closure Depth*. The default *Effective Grain Size* is 0.2 mm. Depending on the specified units, the default *Average Berm Height* is 1.0 ft or 1.0 m and the default *Closure Depth* is 10.0 ft or 10.0 m. *Longshore Sand Transport Calibration Coefficients* can also be found under *Beach Setup*. The defaults values for K1 and K2 are 0.5 and 0.25, respectively. These values should be adjusted during the calibration process.

4.3.3 Seaward BC

The next tab under *GenCade Model Control* is the *Seaward BC* (or Boundary Condition) tab (Figure 116). The two main options in this tab are the *Input Wave Adjustments* section and the *Other Options* section. Under *Input Wave Adjustments*, the user may modify the *Height Amplification Factor*, *Angle Amplification Factor*, and *Angle Offset*. In the *Other Options* section, the user may define the *Number of Cells in Offshore*

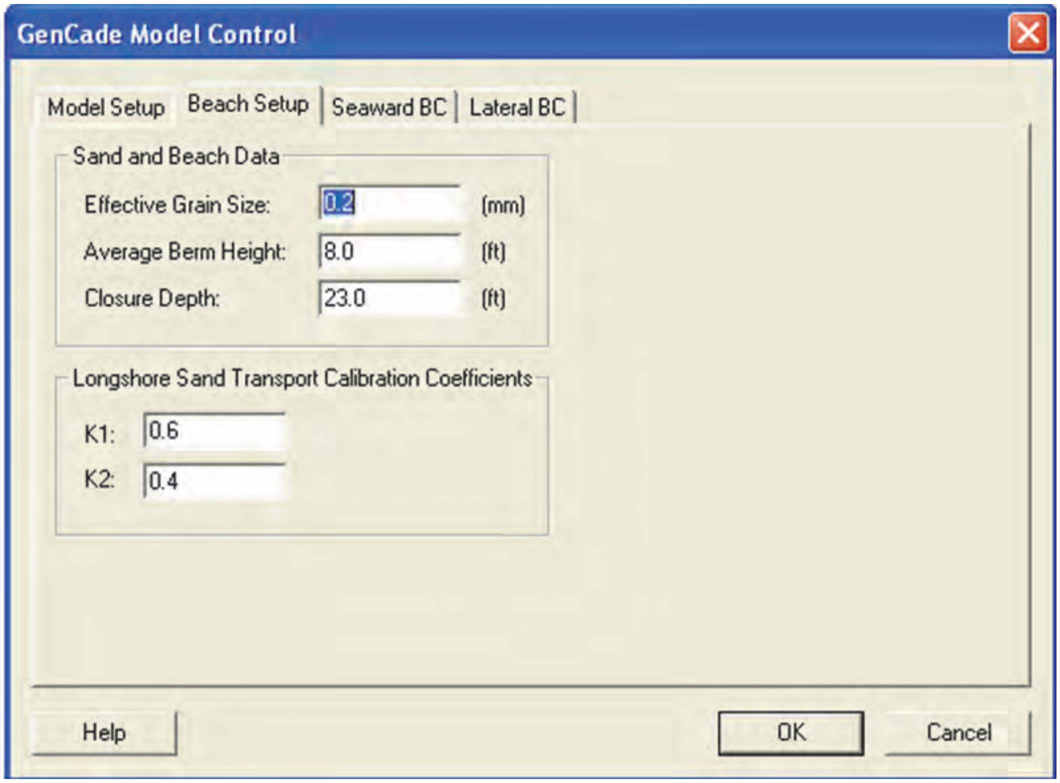


Figure 115. Beach setup window.

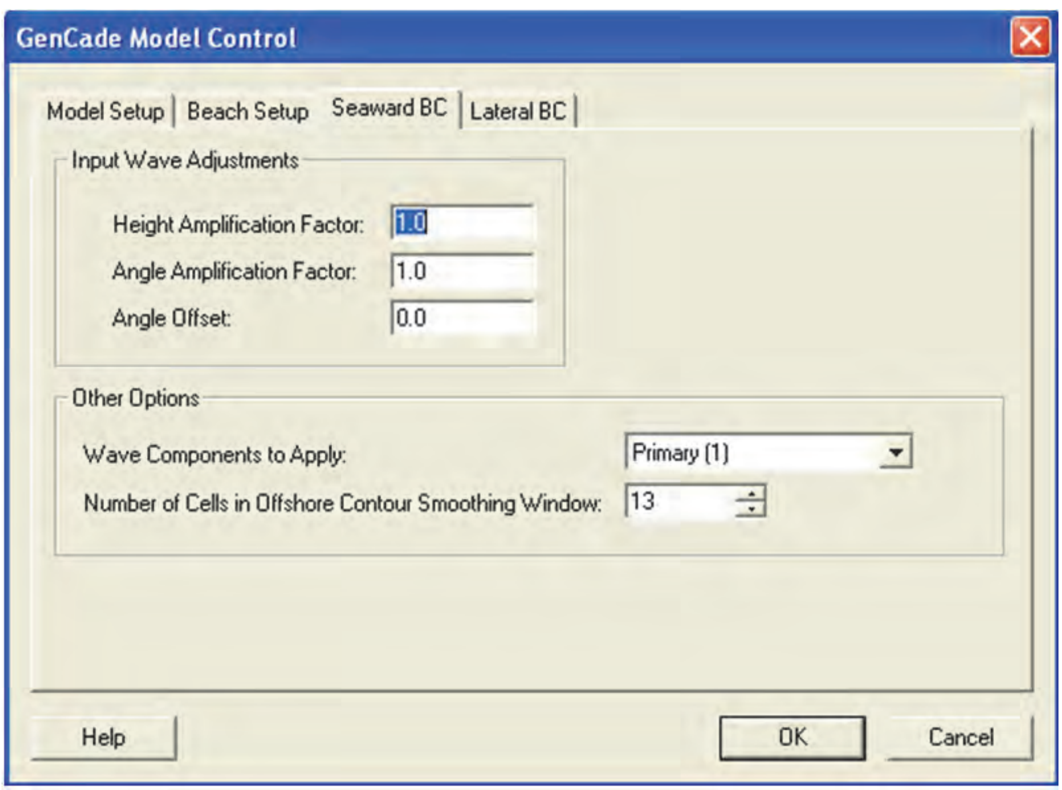


Figure 116. Seaward boundary condition window.

Contour Smoothing Window. The default *ISMOOTH* value is 11, but it is suggested that this number range between 11 and 101. This is another value that must be adjusted during the calibration stage.

4.3.4 Lateral BC

The final tab under *GenCade Model Control* is the *Lateral BC* (or Boundary Condition) tab. There are three options for the *Left Lateral BC* and *Right Lateral BC*: Pinned, Gated, and Moving.

4.3.4.1 Pinned boundary condition

The pinned boundary condition is the default condition. A boundary specified as pinned will not move from the initial shoreline. When the pinned boundary condition is selected, all other options under *Lateral BC* will be grayed out. The pinned lateral boundary condition is shown in Figure 117.

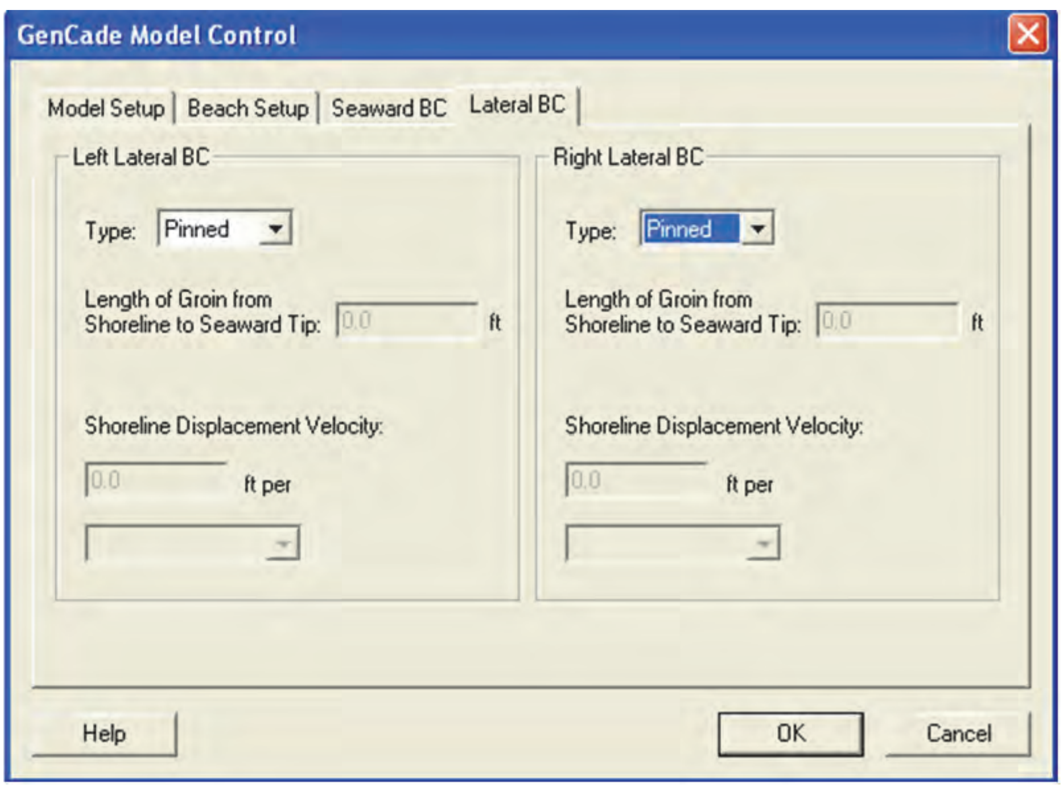


Figure 117. Pinned lateral boundary condition window.

4.3.4.2 Moving boundary condition

If a moving boundary condition is selected (Figure 118), the boundary will move a certain distance over a time period entered by the user. When a moving boundary is selected, the *Length of Groin from Shoreline to Seaward Tip* will still be grayed out, but the *Shoreline Displacement Velocity* will be active. Under *Shoreline Displacement Velocity*, the user should enter the shoreline displacement in the same units used to set up the grid. This shoreline displacement may occur over the entire simulation period, a day, or a time step. Shoreline displacement over the entire simulation is the most common input for a moving boundary condition, because many users have measured shorelines corresponding to the beginning and end of a simulation. If the user chooses to specify the shoreline displacement per time step, it should be noted that this number should be very small. For example, with a time step of 0.5 hr and a shoreline displacement of 0.5 ft per time step, the total shoreline displacement during a two year simulation would be 17,520 ft.

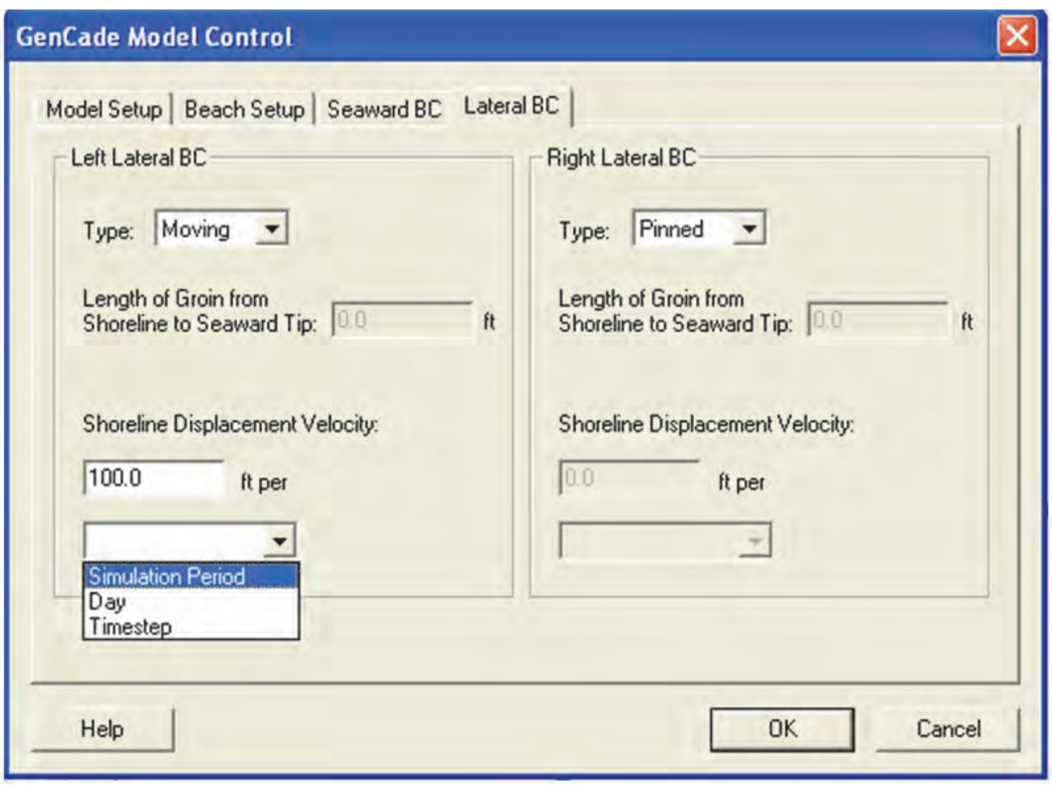


Figure 118. Moving lateral boundary condition window.

4.3.4.3 Gated boundary condition

The final boundary condition available in GenCade is a gated boundary condition (Figure 119). A gated boundary condition is bounded with a groin, so this is beneficial in cases where a groin or a jetty is located near the boundary. In the case of a gated boundary condition, it is also necessary to create and define a groin at the left or right boundary in the conceptual model. If the right lateral boundary is defined as a gated boundary, the groin should have a cell number of N+1. For example, if the grid has 100 cells, the groin should be located at cell number 101. After a gated boundary condition is selected, the *Length of Groin from Shoreline to Seaward Tip* will be active.

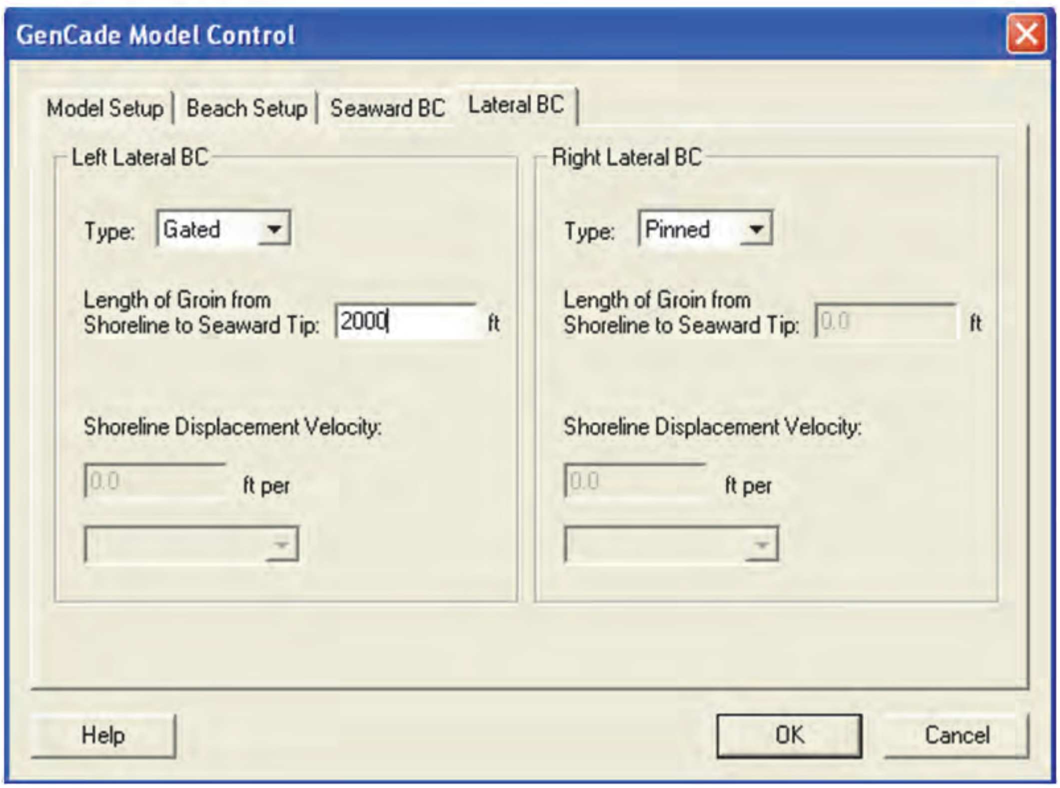


Figure 119. Gated lateral boundary condition window.

4.3.5 Running GenCade

Once the GenCade grid and all of the parameters in *Model Control* have been updated, it is possible to run GenCade. Please remember to save the project before running GenCade. If the project is not saved prior to running GenCade, the most recent additions to the grid will not be written in the *.gen file. To run GenCade, go to the *GenCade* menu and select *Run GenCade* (Figure 120). A window will open that will describe the simulation. This window will notify the user if an error has occurred. Although there is no time bar stating the amount of time left in the simulation, the window will show when GenCade has finished calculating each year in the time simulation. The window will alert the user when the model is finished and will prompt to exit. A typical GenCade simulation will last a few minutes on a desktop computer.

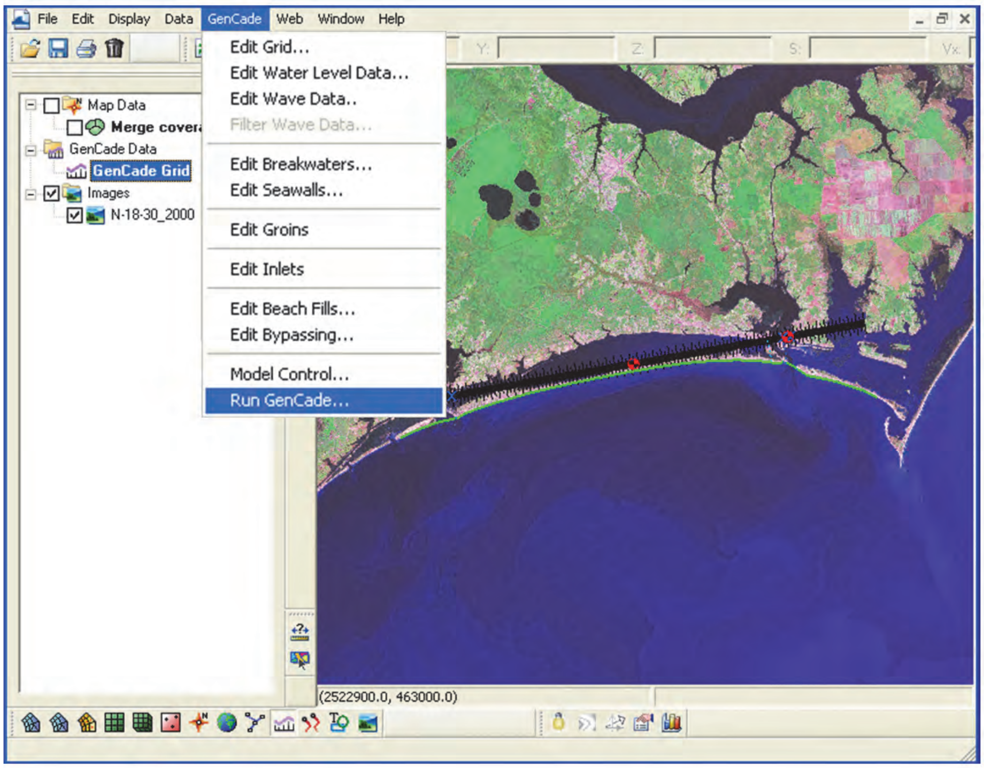


Figure 120. Run GenCade.

4.4 Visualizing results

Following a simulation, several output files will be created. These were described in section 4.1 and shown in Table 9. Many of these files may be opened in the SMS for visualization. The first of these files is the *.slo file, or shoreline change file. This file can be opened through the *File*->Open menu or by dragging and dropping into the SMS window. Once this file is opened in the SMS, an arc representing the calculated shoreline should appear in the grid window. The default color and size of the calculated shoreline may be difficult to view. Go to *Display*->*Display Options* and click on *1-D Grid* to change the size and color of the calculated shoreline (Figure 121). The size and color of the initial shoreline, regional contour, and structures can also be changed. A box with the header *Time Steps* will also appear when the *.slo is opened in the SMS. The default time under

Time Steps is *Relative Time*. To view the simulated dates, right click on the words *Time Steps* and select *Time Settings*. Change the zero time to represent the first date in the simulation. Under *Time Display*, change *Relative Time* to *Absolute Time/Date*. The user can view the calculated shoreline at any date during the simulation and compare it with the initial shoreline or other reference line (Figure 122). The *.mqn, *.mqr, *.mql, *.qtr, and *.off files may also be opened in the SMS in a similar way.

Plots of the loaded output files (*.slo, *.qtr, and *.mqn) can also be created in SMS. Under *Display*, click on *Plot Wizard* (Figure 123). In the first window, select *GenCade Shoreline* as the plot type. Select *Specified dataset(s)* under *Dataset*, select the appropriate dataset and time step, and click *Finish*. A new window will appear showing the data for the selected time step (Figure 124). Once one plot has been created, simply highlight a different dataset from under the *GenCade Grid* in the data tree to change the plot.

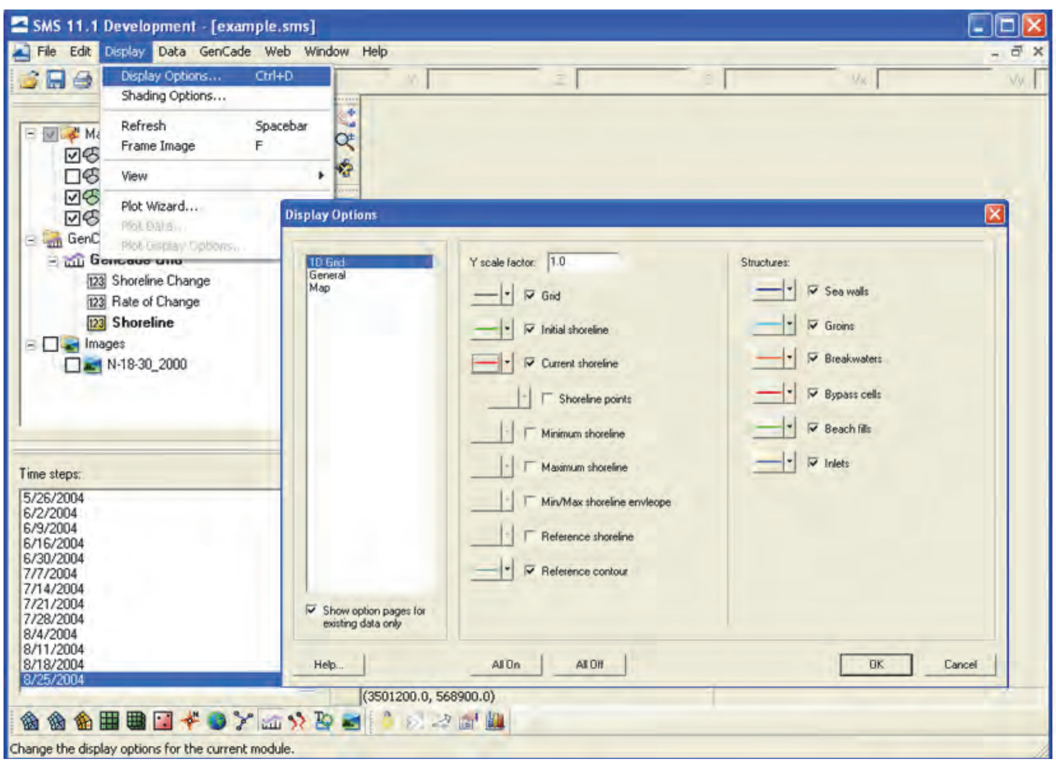


Figure 121. Window for display options.

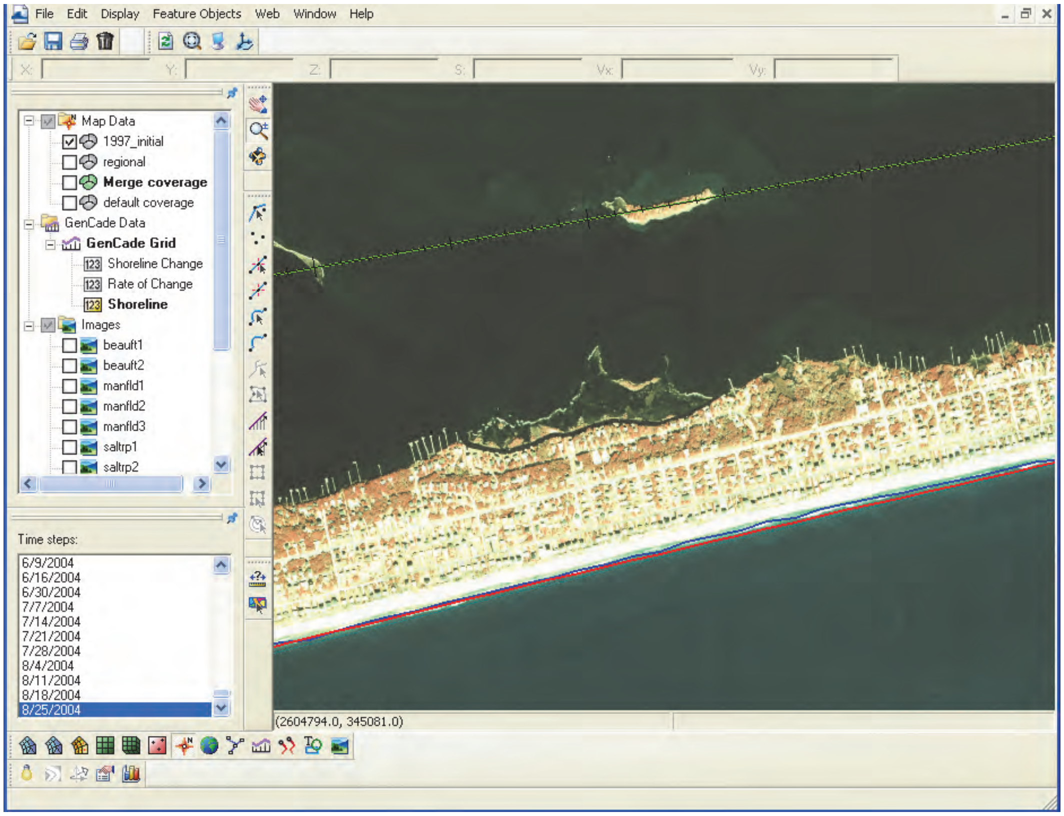


Figure 122. Example of initial shoreline and calculated shoreline with regional contour.

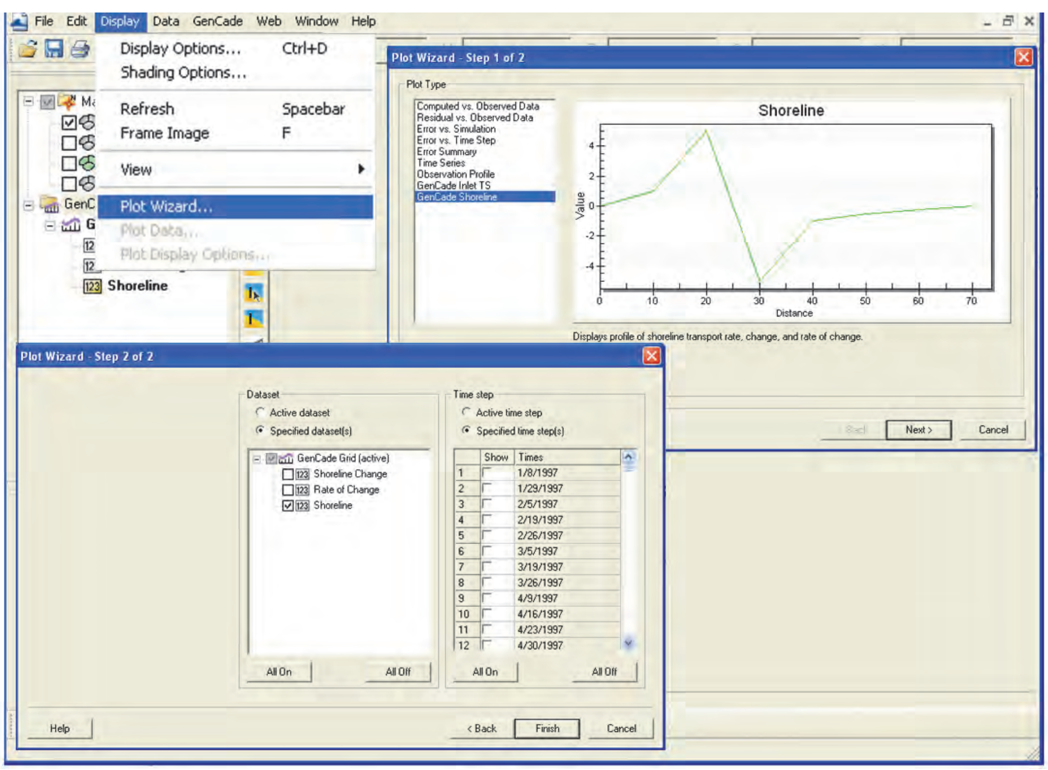


Figure 123. Plot wizard for GenCade shorelines.

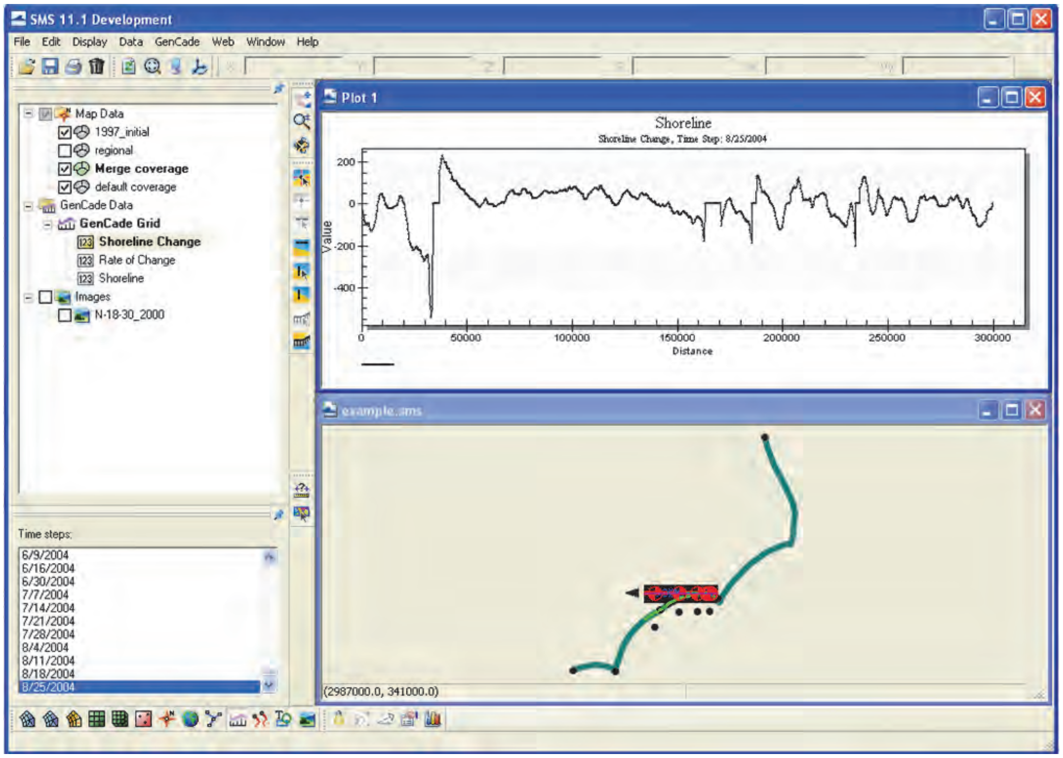


Figure 124. Shoreline plot in the SMS.

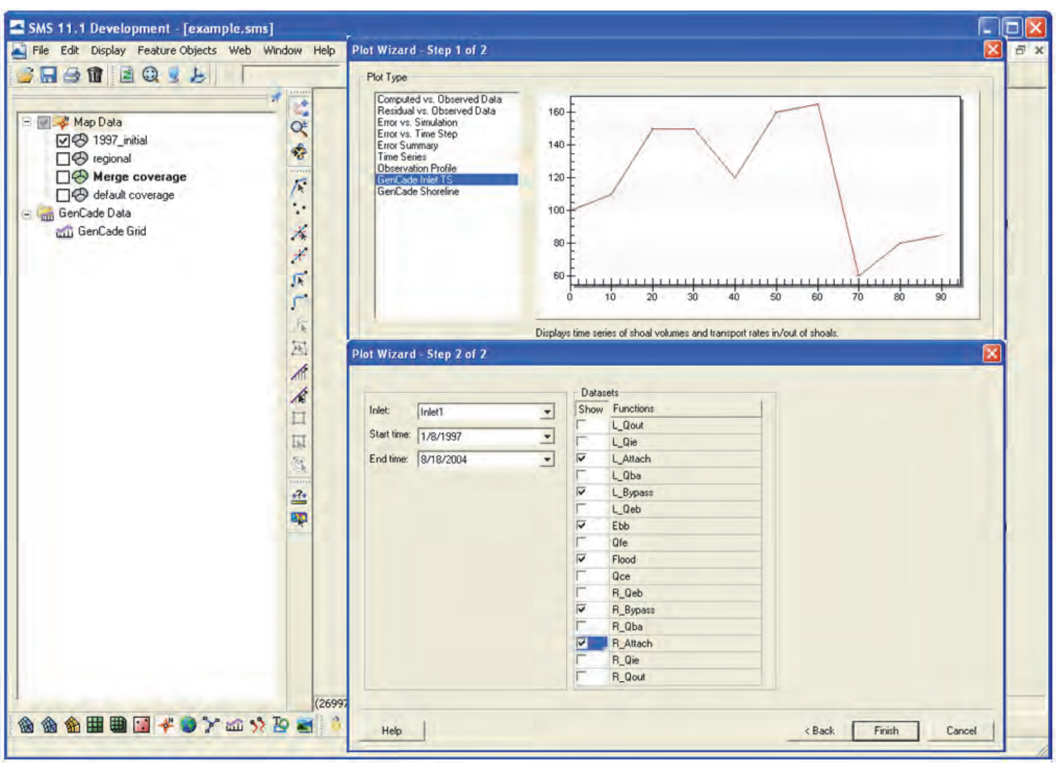


Figure 125. Plot wizard for inlet shoal volumes.

The inlet shoal volumes over the entire simulation may also be viewed in the SMS. Go to *Display* to *Plot Wizard*. Under *Plot Type*, select *GenCade Inlet TS* and click *Next* (Figure 125). The user may select any of the inlets included in the project and may choose the entire simulation or only a few years. The user may select one shoal or many shoals. After selecting the inlet, time, and corresponding shoals, click *Finish*. A new window with the shoal volumes over the course of the selected dates will open (Figure 126).

It is possible to modify axis, font and line properties of the plot by right-clicking on the plot or going into the *Display->Plot Display Options* menu.

Final figures can be saved in *.emf, *.wmf, *.bmp, *.jpg or *.png format using the *Export/Print* function that appears when right-clicking on the plot (Figure 127). The *Export/Print* function is particularly useful to extract output data that can easily be pasted in an external spreadsheet (column formatted). Choose the *Export/Print* option from the drop down menu and select *Text/Data*. The data can be written in a separate file (select *File* as *Export Destination*) or copy to the Clipboard if the data are to be pasted in a spreadsheet.

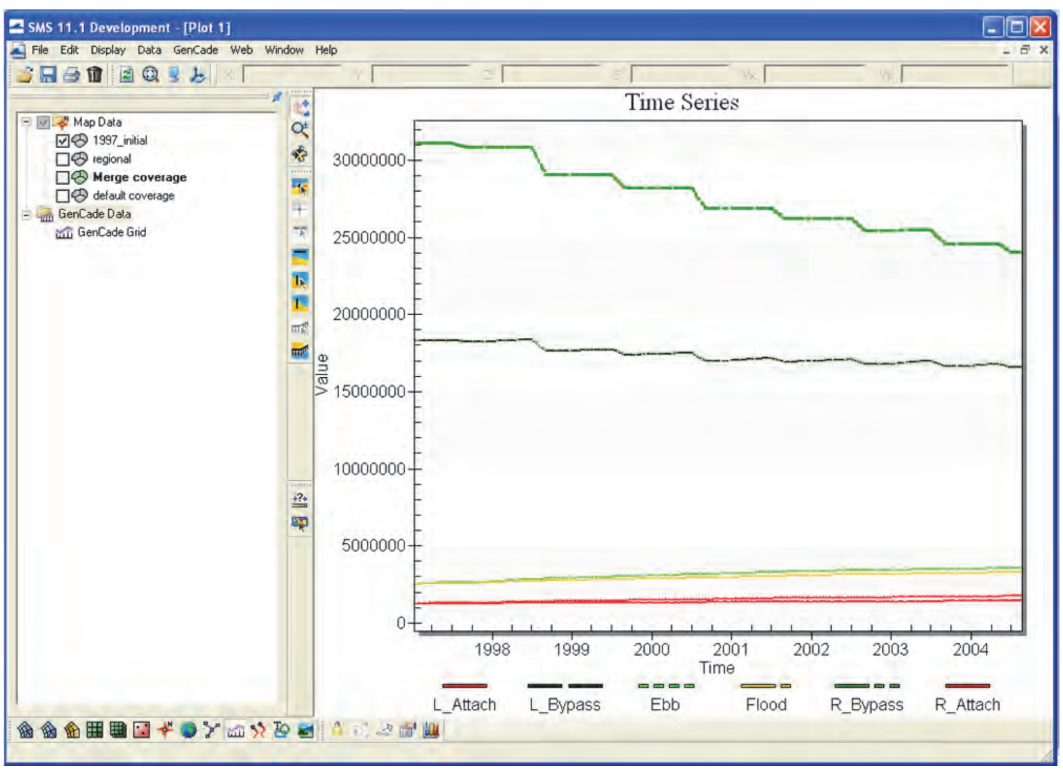


Figure 126. Inlet shoal volumes plot in the SMS.

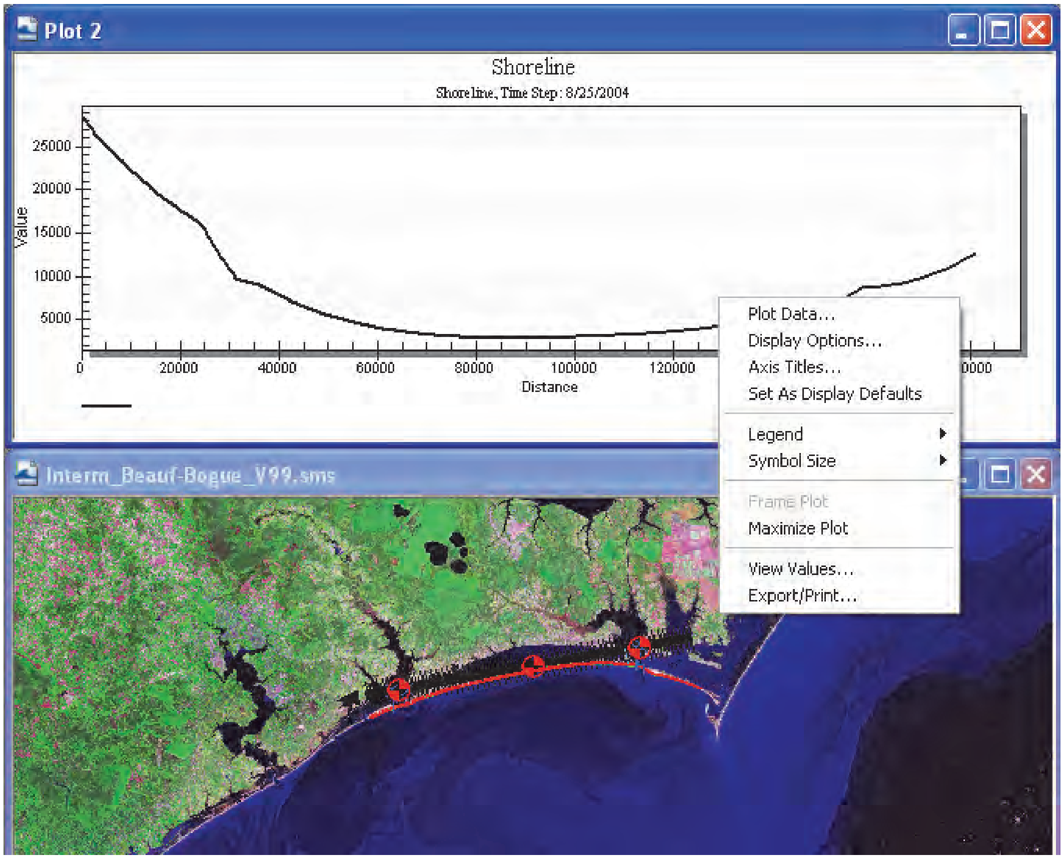
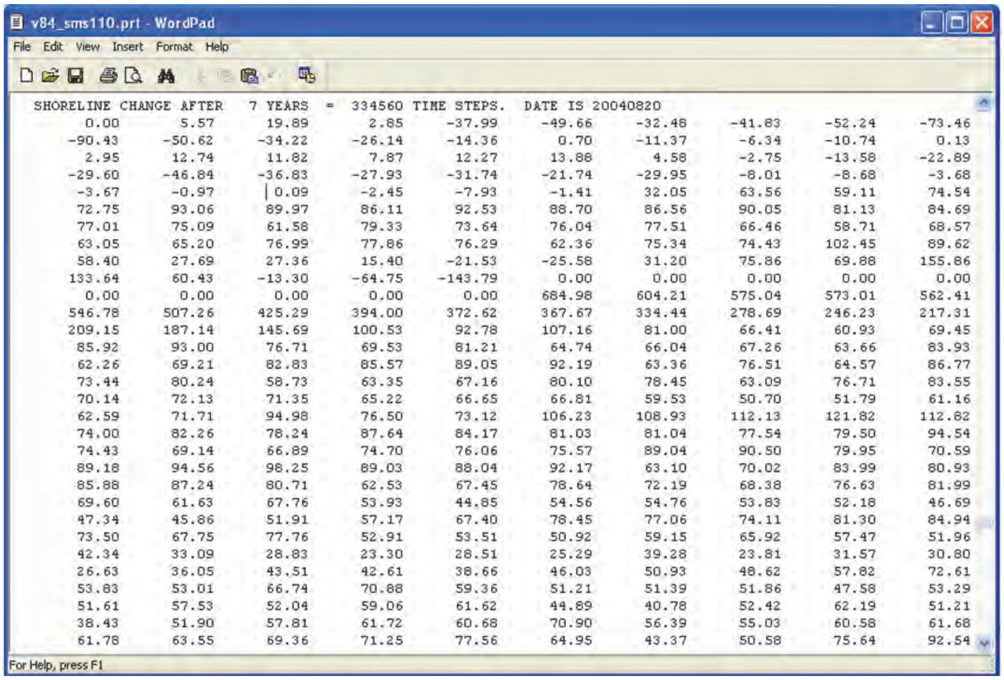


Figure 127. Export/Print option.

Note that the data in the shoreline evolution file (*.slo) represent the distance from the GenCade grid for each cell. The first row is the initial shoreline, therefore when exporting the data from the shoreline plot, the first column after the time column will be the initial shoreline position relative to the grid.

If the user is interested, he or she may view more details about the shoreline change or net annual transport in the *.prt file. Figure 128 shows a screenshot of some of the information available in the *.prt file. If the user is doing post-processing analysis of the results outside of the SMS, the *.prt file may be the easiest source of model results data.

The user may be interested in comparing the calculated shoreline to a measured shoreline. To do so, the measured shoreline must be in a similar format and defined with the same grid as the project shorelines. One way to achieve this is to open the measured shoreline in a new SMS project and define it as the initial shoreline.



v84_sms110.prt - WordPad

File Edit View Insert Format Help

SHORELINE CHANGE AFTER 7 YEARS = 334560 TIME STEPS. DATE IS 20040820

0.00	5.57	19.89	2.85	-37.99	-49.66	-32.48	-41.83	-52.24	-73.46
-90.43	-50.62	-34.22	-26.14	-14.36	0.70	-11.37	-6.34	-10.74	0.13
2.95	12.74	11.82	7.87	12.27	13.88	4.58	-2.75	-13.58	-22.89
-29.60	-46.84	-36.83	-27.93	-31.74	-21.74	-29.95	-8.01	-8.68	-3.68
-3.67	-0.97	0.09	-2.45	-7.93	-1.41	32.05	63.56	59.11	74.54
72.75	93.06	89.97	86.11	92.53	88.70	86.56	90.05	81.13	84.69
77.01	75.09	61.58	79.33	73.64	76.04	77.51	66.46	58.71	68.57
63.05	65.20	76.99	77.86	76.29	62.36	75.34	74.43	102.45	89.62
58.40	27.69	27.36	15.40	-21.53	-25.58	31.20	75.86	69.88	155.86
133.64	60.43	-13.30	-64.75	-143.79	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	684.98	604.21	575.04	573.01	562.41
546.78	507.26	425.29	394.00	372.62	367.67	334.44	278.69	246.23	217.31
209.15	187.14	145.69	100.53	92.78	107.16	81.00	66.41	60.93	69.45
85.92	93.00	76.71	69.53	81.21	64.74	66.04	67.26	63.66	83.93
62.26	69.21	82.83	85.57	89.05	92.19	63.36	76.51	64.57	86.77
73.44	80.24	58.73	63.35	67.16	80.10	78.45	63.09	76.71	83.55
70.14	72.13	71.35	65.22	66.65	66.81	59.53	50.70	51.79	61.16
62.59	71.71	94.98	76.50	73.12	106.23	108.93	112.13	121.82	112.82
74.00	82.26	78.24	87.64	84.17	81.03	81.04	77.54	79.50	94.54
74.43	69.14	66.89	74.70	76.06	75.57	89.04	90.50	79.95	70.59
89.18	94.56	98.25	89.03	88.04	92.17	63.10	70.02	83.99	80.93
85.88	87.24	80.71	62.53	67.45	78.64	72.19	68.38	76.63	81.99
69.60	61.63	67.76	53.93	44.85	54.56	54.76	53.83	52.18	46.69
47.34	45.86	51.91	57.17	67.40	78.45	77.06	74.11	81.30	84.94
73.50	67.75	77.76	52.91	53.51	50.92	59.15	65.92	57.47	51.96
42.34	33.09	28.83	23.30	28.51	25.29	39.28	23.81	31.57	30.80
26.63	36.05	43.51	42.61	38.66	46.03	50.93	48.62	57.82	72.61
53.83	53.01	66.74	70.88	59.36	51.21	51.39	51.86	47.58	53.29
51.61	57.53	52.04	59.06	61.62	44.89	40.78	52.42	62.19	51.21
38.43	51.90	57.81	61.72	60.68	70.90	56.39	55.03	60.58	61.68
61.78	63.55	69.36	71.25	77.56	64.95	43.37	50.58	75.64	92.54

For Help, press F1

Figure 128. Shoreline change in *.prt.

Generate a grid that has the same parameters as the one in the project, convert to 1-D grid, and save as a new project. This will save the measured shoreline as the initial shoreline in the *.shi file. The values in the *.shi file represent the distance from the initial shoreline to the grid for each cell. Once transformed in the proper column format, it can be pasted in a spreadsheet. Subtract the initial shoreline from the measured shoreline and the calculated shoreline to get shoreline change for the measured and calculated shorelines.

4.5 Calibrating the model and developing alternatives

4.5.1 Minor changes to the regional contour or initial shoreline

After setting up and running the model and looking at results, it may become necessary to make a minor modification to the regional contour or initial shoreline. For example, the initial shoreline may need to be smoothed near an unstructured inlet or the regional contour may need to be adjusted to account for a large ebb shoal.

To make changes to the regional contour or initial shoreline, return to the merged coverage with all of the shorelines, structures, and wave gauges under *Map Data*. Click *Select Feature Vertex* and drag each vertex to the desired location (Figure 129).

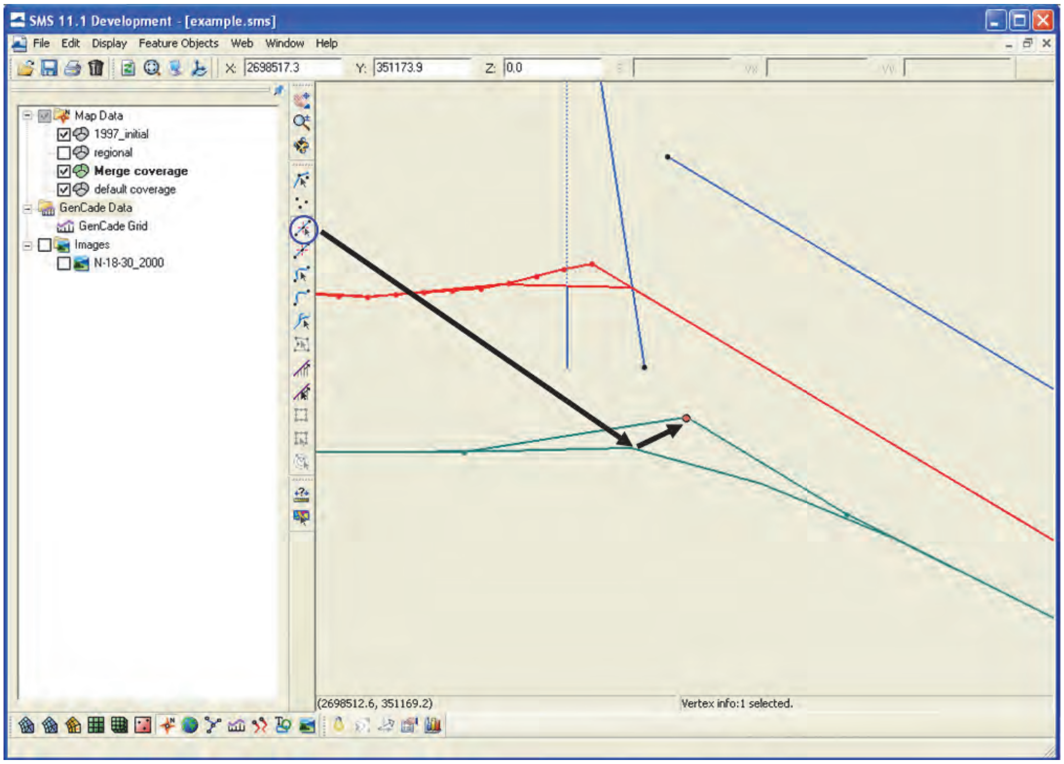


Figure 129. Modify the shape of the regional contour.

It is also possible to add vertices by clicking *Create Feature Vertex*, adding the vertex, and moving it to the selected location. Extra vertices can be deleted after they are selected. Once the required updates to the regional contour or the initial shoreline are made, highlight the modified shoreline with the *Select Feature Arc* tool, right click on the merged coverage, and convert *Map->1-D Grid*. The initial shoreline or regional contour must be selected by clicking on the *Select Feature Arc*. If the arc is not selected and highlighted prior to converting, the old regional contour or initial shoreline will not be replaced. It should also be mentioned that only minor changes such as smoothing should be made to the regional contour or initial shoreline.

4.5.2 Modify existing structures or beach fills

For some alternatives, a beach fill or structure may need to be extended. To extend a structure, click on *Select Feature Point*. Click on the node at the end of the structure and extend it to the desired length. Beach fills can be modified in the same way. Right click on the merged coverage and convert *Map->1-D Grid*. The modified structure must be selected (by clicking on *Select Feature Point*) for the changes to be noted in the GenCade model.

4.5.3 Replace initial shoreline or regional contour

Some projects may require analysis for several different time periods. If the structures exist during multiple time periods and the wave gauge data span many decades, it may be easiest to replace the initial shoreline in the conceptual model. Do not delete the existing GenCade grid. Right click on *Map Data*, click *New Coverage*, and select *GenCade*. It is best to give the new coverage a specific name that can be identified easily. Right click on this new coverage and scroll down to *Type->Models->GenCade*. Open the new shoreline in the new coverage. Click on *Select Feature Arc* and define the arc. Right click on the new coverage and convert *Map->1-D Grid*. The new initial shoreline will replace the original. If the user determines that a new regional contour is necessary, the same process should be followed. For example, the regional contour may need additional smoothing or averaging. The regional contour should not be changed when looking at alternatives or different time periods for the same project.

4.5.4 Add structures or beach fills

When a project has many different alternatives, it may be necessary to add new structures. Instead of developing a new grid for each alternative, features can be modified or added to a base grid that already has the initial shoreline, regional contour, wave gauges, and basic structures and beach fills. Right click on *Map Data* and select *GenCade* under *New Coverage*. Right click on this coverage and confirm that the model type is *GenCade*. In this new coverage, add new structures and beach fills by selecting the *Create Feature Arc* button. Specify the type of arc. Once all the new structures are included, right click on the new coverage and convert *Map->1-D Grid*. The new arcs will be added in the GenCade grid. Additional structures or beach fills can also be added directly to the merged coverage that already has the initial shoreline, regional contour, and existing structures.

4.5.5 Modify wave gauges

The instructions above regarding adding new features can also apply to adding new wave gauges. However, sometimes the wave gauge data need to be modified. In reviewing the wave gauge information, a user may find that a few of the dates or values may be incorrect. If only a few values need to be modified, click on the merged coverage and select the wave gauge by clicking on *Select Feature Point* and double-click on the point representing the wave gauge. Click on *Options* and click on *Data*. Manually update the incorrect wave information. Once finished, convert *Map->1-D Grid*. The wave gauge will now include the updated wave information. The steps to modify a wave gauge are shown in Figure 130.

A user may also determine that an entire set of wave gauge information may be incorrect. This can occur by selecting the wrong wave gauge when pasting values or by incorrectly manually transforming waves. This can be remedied by deleting the existing wave gauge, creating a new wave gauge, and following the steps to add information to the wave gauge.

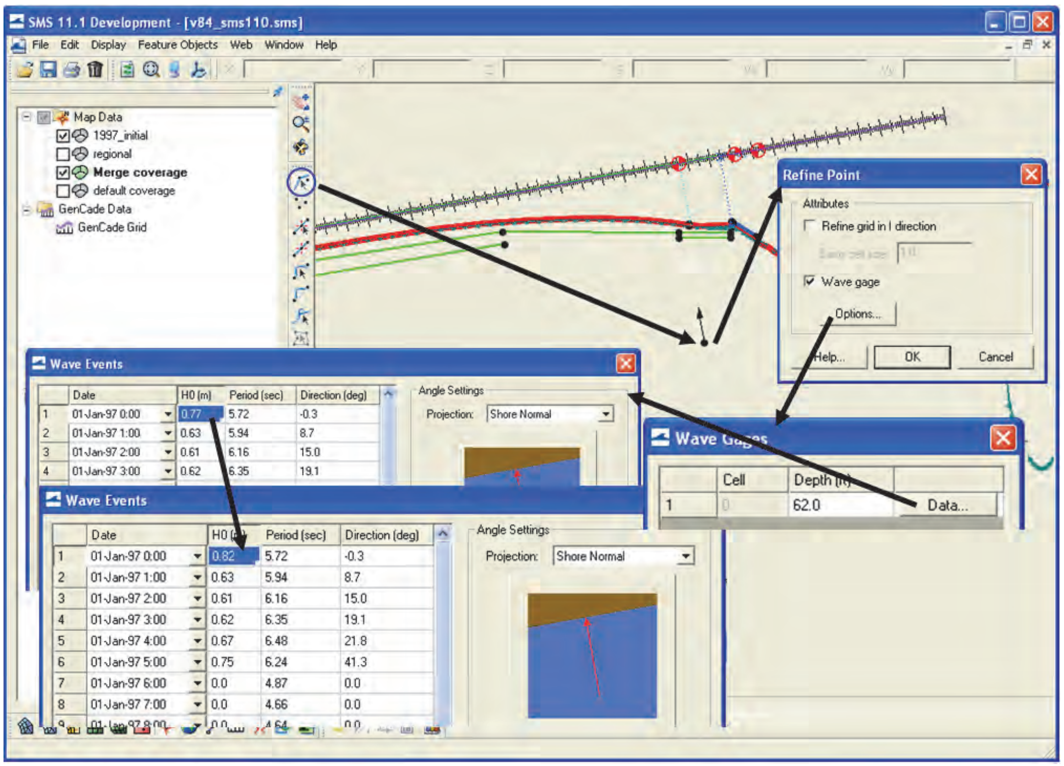


Figure 130. Modify specific wave events.

5 GenCade Application at Long Island, NY

A GenCade model application is presented for the south shore of Long Island, NY, as a validation of relevant processes over multi-decadal time scales. The south shore of Long Island (Figure 131) was selected as an appropriate test site for examining the capabilities of GenCade because of the availability of a long-term regional coastal database and because the site includes multiple inlets and barrier islands with coastal structures and ongoing coastal engineering projects that are maintained at irregular intervals. The data and morphological composition of the site provide a challenging application to test the unified coastal predictive capabilities of GenCade. The simulations build upon work conducted by Hanson et al. (2011) and generally follow the procedure conducted by Larson et al. (2003) to determine regional consistency between GenCade and Cascade. Additional simulations are conducted with the same grid to examine the sensitivity to ebb shoal excavation of the beach fill material (e.g., dredged from local inlets within this littoral cell) compared to fill brought in to the littoral system (e.g., trucked in).

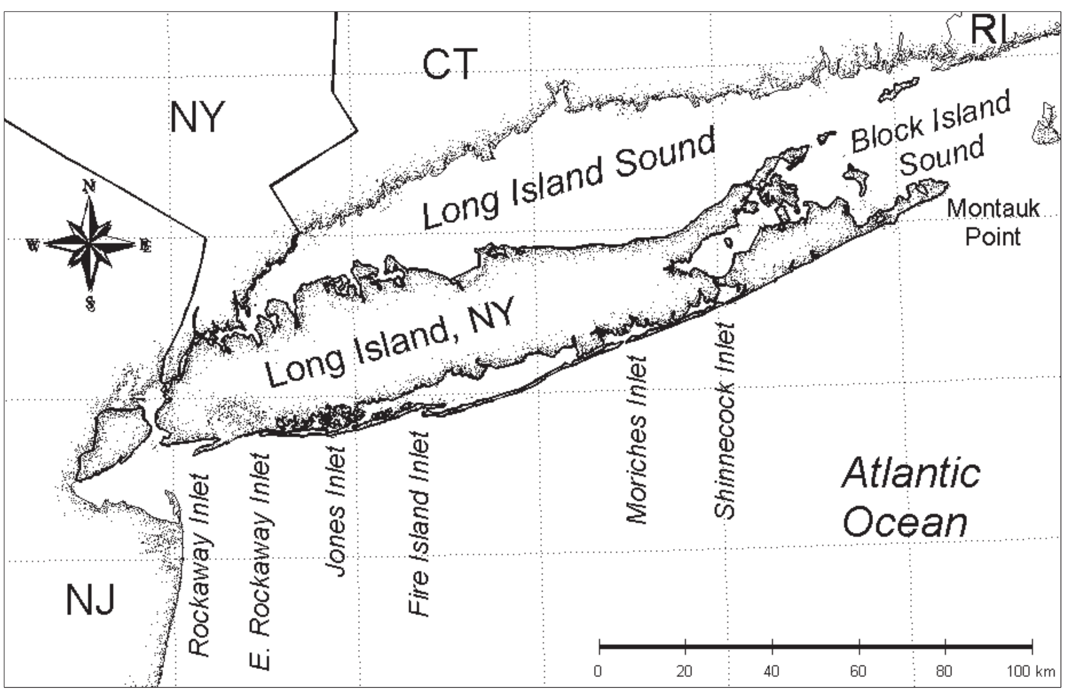


Figure 131. Location map listing all the maintained inlets on the south shore of Long Island.

5.1 Model domain

The GenCade model domain extends from The Ponds immediately west of Montauk Point at the eastern terminous to Fire Island Inlet in the west and includes two inlets within the domain: Shinnecock Inlet and Moriches Inlet. The grid was developed to represent the relevant coastal structures and coastal engineering processes along the Fire Island to Montauk Point (FIMP) reach. The modeling represents sediment bypassing and tidal shoal evolution at Moriches Inlet and Shinnecock Inlet, as well as 15 groins along Westhampton, which have interrupted the sediment supply to Moriches Inlet and Fire Island and require fine spatial resolution to capture relevant morphology change between the narrowly spaced groins. The model grid is 122 km long with the two inlets assigned as structured (jettied) inlets and the full domain is positioned in UTM coordinates. Model grid cell resolution was set to be variable between 50 m and 100 m (669 cells total), where grid cells with higher resolution applied to areas with groins and jetties. Evolution of the region was simulated for 12 years between January 1983 and January 1995 to capture the time period for which shoreline data were available. Figure 132 shows the extent of the Long Island domain.

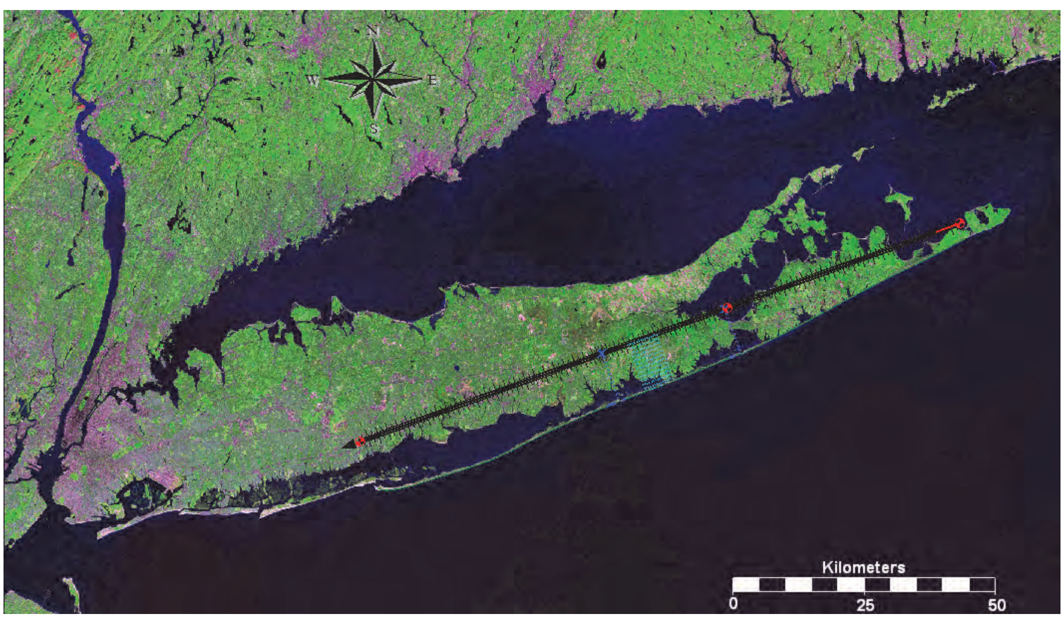


Figure 132. GenCade Long Island domain extending from Montauk Point to Fire Island Inlet.

5.1.1 Model forcing: waves

The wave climate along the south shore of Long Island is characterized by moderate Atlantic waves typically from the southeast quadrant with a relatively strong seasonal component of fairly mild waves during summer, severe waves associated with extratropical storms frequent during winter and spring, and severe waves associated with tropical storms during fall. Mean wave height over a 25-year period at NOAA NDBC buoy 44025 is 1.2 m and mean wave period is 8-sec. One recent study has estimated 50-year and 100-year return period waves at 16.0 m and 17.1 m, respectively (Nyserda 2010). Nearshore waves are substantially reduced in energy as waves shoal across the shelf and Wave Information Study (WIS) station 50-year storm waves are estimated at 8.7 m. The wave climate at this location shows that the majority of waves are from the southeast and the more severe waves associated with extratropical storms are from the east-southeast. This results in a net westerly longshore transport direction along the studied coast. Figure 133 shows the wave rose for the a 25-year record at NOAA NDBC buoy 44025 and the relative position of the three WIS stations employed for the wave forcing of the GenCade simulations.

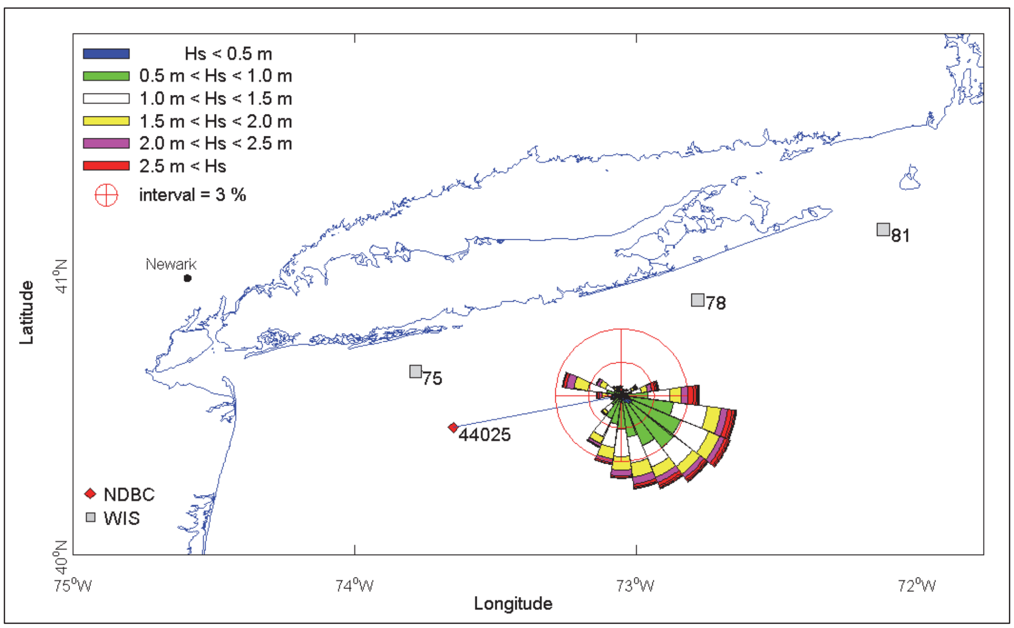


Figure 133. Wave rose at NDBC buoy 44025 and location of WIS stations relative to Long Island.

5.1.2 Model parameters

A 12-year simulation (1983-1995) was executed, forced by WIS stations 75, 78, and 81. The computational time step was 30 min (0.5 hour) and a “pinned” (i.e., no shoreline change) boundary condition was employed at both lateral ends. Calibration of the model consisted of first adjusting K1 and K2 values to result in transport rates that were consistent with sediment budget derived transport rates at various locations in the domain. Next, calculated shoreline after the simulation was compared to measured shoreline for agreement. The median grain size (d_{50}) was set at 0.3 mm as a representative value of the average median grain size reported in Morang (1999). The berm height was set to 1-m and the depth of closure was set to 8-m. GenCade calibration parameters were adjusted to calibrate the model to transport rates estimated from a literature review of sediment budget studies (e.g., Rosati et al. 1999; Kana 1999), and measured shoreline change from shorelines collected 12 years apart. The first calibration was conducted with the K1 parameter to obtain average longshore transport rates in agreement with the estimated sediment budget-based average longshore transport rates. Next, K2 and ISMOOTH parameters were adjusted to improve calculated transport and shoreline evolution in the lee of structures. Finally, the calculated ebb shoal evolution was reviewed and verified against estimates of shoal volumes (Morang 1999). Table 10 lists the best fit values obtained.

Table 10. Model parameters.

Parameter	Value
K1	0.40
K2	0.20
# Cells in smoothing window	3

5.2 GenCade model results and discussion

The simulated results for net annual mean transport averaged over the 12-year period of the simulation at Long Island (Figure 134) demonstrate that GenCade is in close agreement with results compiled in Rosati et al. (1999) based on a sediment budgets for eastern Long Island over much of the domain. However, the model does not agree with the transport estimates at the east end of the domain near Montauk Point and the data points near Moriches Inlet are not in alongshore spatial distribution of the transport reduction imposed by the presence of the inlet. The results are not identical to the Cascade calculations presented by Larson et al. (2003) because the input parameters and numerical method for GenCade are different and at higher resolution than those presented for Cascade. For example, GenCade supports variable grid resolution and representation of more detailed treatment of engineering structure attributes, which improves capability to more accurately represent the inlets and groins in the domain.

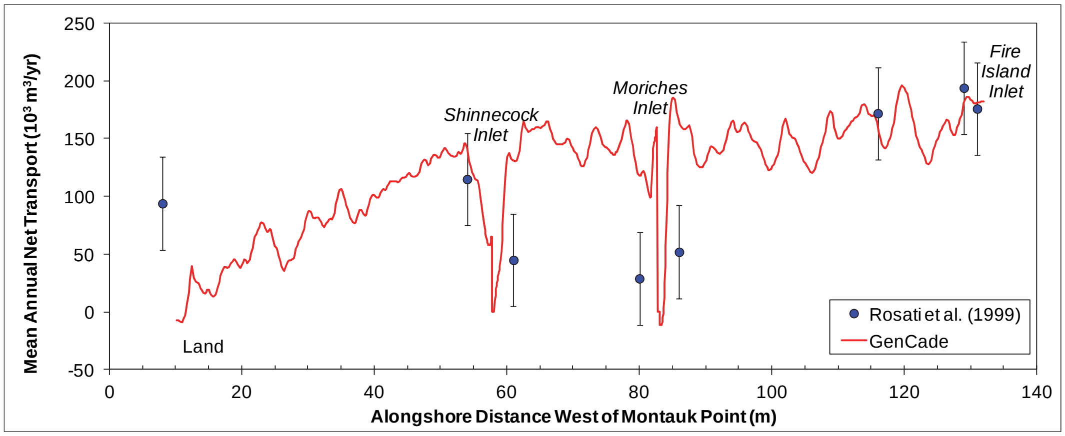


Figure 134. Calculated average transport rate for south shore of Long Island, NY.

Figure 135 presents a comparison of the GenCade calculated shoreline after the 12-year simulation compared to a measured 1995 shoreline and the initial 1983 shoreline. Regionally, the calculated shoreline is in agreement with the measurements and the calculated shoreline maintains the regional large-scale convex curvature observed in the measured shoreline. It is clear that the regional morphological trend is maintained over the entire length of the domain. Over the majority of local areas, the shoreline calculations agree with the measurements as well. This agreement is presented in Figure 136 as a comparison of shoreline change across the FIMP reach. The peaks in shoreline change at the two inlets are where the greatest error relative to the measured shoreline is encountered. This could be linked to sensitivity of the position of the inlet bypassing bar and attachment point and the uncertainty of the shoal bypassing. However, the trends in shoreline change are well represented.

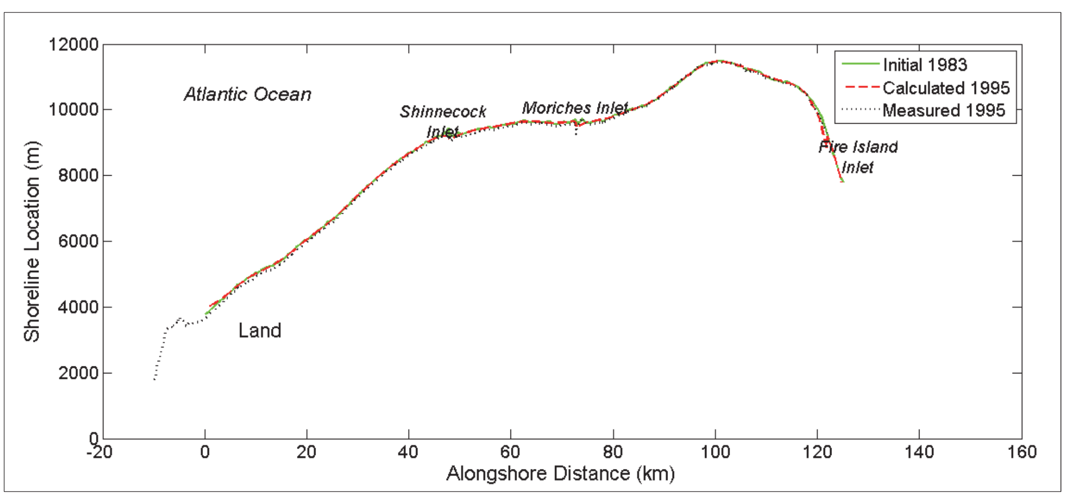


Figure 135. Calculated and measured shoreline position, for south shore of Long Island, NY.

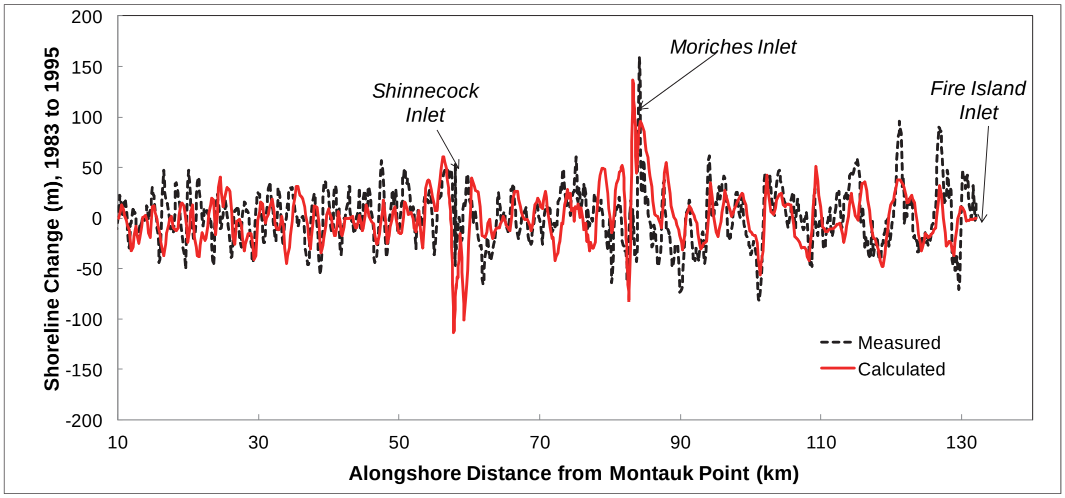


Figure 136. Calculated shoreline change between Montauk Point and Fire Island Inlet.

Figure 137 shows the calculated volume evolution of the ebb shoal complex at Shinnecock Inlet and Moriches Inlet relative to ebb tidal delta volumes calculated from analysis of field measurements by Morang (1999). These results show relatively close agreement with the measured data, but the rapid increase in volume observed in the late 1990s is not represented in the model calculations. As the calculated curves approach the equilibrium volume rapid expansion of the ebb shoal complex becomes less likely without a major influx of sediment into the inlet. Figure 128 also depicts the calculated volumes at the ebb shoal complex with and without dredge excavation of the ebb shoal. The differences between the two curves show the shoal recovery potential when comparing shoal mining at local inlets versus importing beach fill from external sources. These calculations have significant value to coastal management as the modifications to the shoals also impact transport rates and shoreline erosion at beaches in the vicinity of the inlets.

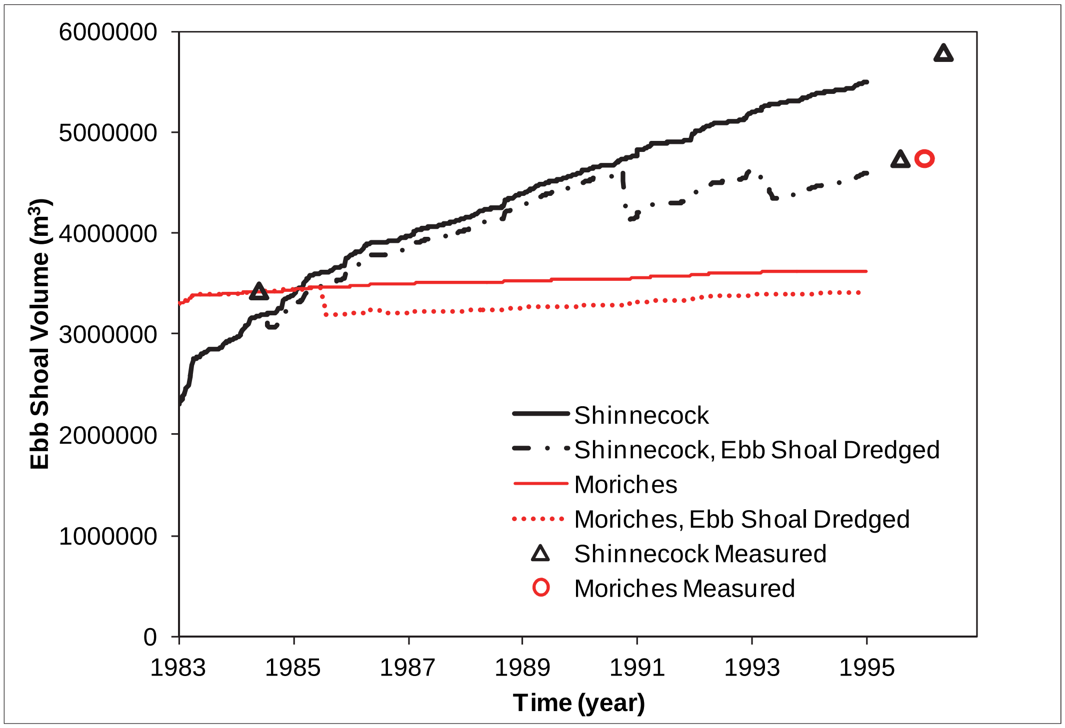


Figure 137. Calculated ebb tidal delta volume evolution with and without ebb shoal dredging.

6 Summary and Conclusions

GenCade, a newly developed model for calculating shoreline change and sand transport, was developed to combine and increase the capabilities of the GENESIS model (Hanson and Kraus 1989) and the Cascade model (Larson et al. 2003). GenCade combines project-scale, engineering design-level calculations with regional-scale, planning-level calculations to analyze and accurately resolve both local modifications and regional cumulative effects of coastal projects and inlets. A Graphical User Interface was created for GenCade in the SMS 11.1, and it provides the user a straight-forward and clear approach to set up the conceptual model, create the model grid, and execute the model.

This report presented the theory and a user's guide for GenCade, and included validation of the model for simple idealized cases. The model theory section of the report included details about the basic assumptions of the model as well as some of the limitations. The section also described the governing equation, boundary conditions, wave calculation, and representation of structures and inlets. The model validation section included a study at the Large-Scale Sediment Transport Facility, a series of standardized benchmark cases, and validation cases at Jucar River in Spain. The LSTF experiment showed that the calculated shoreline and shape of the tombolo and salient in GenCade were in close agreement to the GENESIS results. The Jucar River case was completed in the late 1990s using GENESIS, so the grids were recreated in GenCade and compared with the GENESIS results. The user's guide should give a reader enough information to feel comfortable creating and running a simple GenCade grid. Application of the model to the south shore of Long Island, NY, demonstrated the capability to calculate cumulative coastal structure impacts over large regional domain and over long time periods while preserving regional geomorphic trends. The impact of dredging on shoal recovery was also demonstrated at two inlets in Eastern Long Island.

Limitations of GenCade include the limited cross-shore process calculation, single grain size across the full model domain, and no means of calculating migration of inlets or newly opening inlets. Many of these limitations have become opportunities for present and ongoing development of model routines and methods to address the limitations either directly or by parameterizing the processes for efficiency. It is expected that many of these present limitations will be incorporated in Version 2 of GenCade.

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14. ABSTRACT

This is the first report to describe the new shoreline change and sand transport model, GenCade. GenCade is based on the synthesis of GENESIS (Hanson and Kraus 1989), a project-scale, engineering design-level model, and Cascade (Larson et al. 2003), a regional-scale, planning-level model. This report describes GenCade model theory, model validation and benchmark cases. The first model validation was performed with data from an experiment conducted in the CHL Large-Scale Sediment Transport Facility while the second focuses on the Jucar River in Spain. A series of simple idealized cases was developed to demonstrate GenCade model capabilities and verify results against the established legacy model, GENESIS. Additionally, this report includes a user's guide that describes the process of setting up and running GenCade. This section should include enough detail for a user with no previous GenCade experience to run a simple GenCade case. The report also describes a GenCade model application on the south shore of Long Island, New York. This report should give a new user enough information to understand the theory behind the model and create a grid and run a GenCade simulation.

15. SUBJECT TERMS

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Shoreline Change	User's guide	Validation
	Model theory	Surface-Water Modeling System

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