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## Coastal Modeling

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### Definition

Coastal Modeling includes physical modeling and mathematical modeling. Physical modeling is to build a replica of a coastal domain, use scale-down ocean and atmospheric forcing to drive the system and study physical processes in the system. Mathematical modeling is to use numerical methods to solve the mathematical equations for conservation of mass and momentum and to simulate waves, hydrodynamics, sediment transport, and morphology change in the coastal zone. Various coastal models provide coastal engineers and scientists an efficient tool for understanding coastal processes and for designing and managing coastal inlets, beaches, navigation channels, ports, and coastal structures.

### Introduction

Coastal physical processes include waves, storms, tide, current, and sediment transport. These processes can cause shoreline and beach changes, coastal inundation, and damages to coastal structures and properties.

Coastal waves are generated in open oceans due to winds, storms, or seismic activities, which carry energy and propagate to coastal areas. As approaching coasts, water becomes shallow, waves interact with sea bed, current, shoreline, and coastal structures. Due to shoaling and refraction, wave height and direction will change. When encountering coastal structures, stronger processes like wave diffraction, reflection, breaking, run-up, and overtopping will occur.

Ocean tide induces the regular rise and fall of sea surface and is driven by the combined gravitational forces of Moon, Sun, and Earth. Tidal periods may range from a few hours to more than 10 years, while the main tidal components include diurnal and semi-diurnal periods. Associated with tidal changes in water surface elevation are the horizontal water movement and tidal current. The regular water ups and downs in coastal regions correspond to the convergence and divergence of tidal current, including the interaction between tidal current and shoreline geometry.

Ocean current is driven by two classes of natural forces (Pond and Pickard 1983). Primary forces include gravitational, wind, atmospheric pressure, and seismic forces, and secondary forces are Coriolis and friction forces. On the contrary, coastal circulation are mainly driven by tide, wind, and density gradient. Depending upon the nature and the relative importance of forces, and geographical locations, coastal currents can be vertically uniform or varying with depth.

Storms generated in tropical oceans or in the polar regions move past coastal regions, induce water level rises and falls, and enhance coastal and estuarine circulation. Extreme water levels due to storms are storm surges, which, combined with storm winds and peak tides, may result in extensive coastal flooding, land recession, and massive loss of human lives and properties (Nummedal et al. 1980; Halverson and Rabenhorst 2013; Li et al. 2013a).

Coastal structures are built to protect coastal residents, shorefront properties, and infrastructure, to prevent shoreline erosion, and to improve environmental conditions for coastal community and ecosystems. These structures include seawalls, jetties, breakwaters, groins, weirs, culverts, and tidal gates.

The combination of physical forces acts on coastal systems and interacts with complex coastlines and coastal structures, which cause coastal sediment movement. Sediment transport processes in coastal zones include longshore and cross-shore


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sand migration due to wave action, navigation channel scouring and infilling, changes of beach face, coastal shoaling, and sandbar formation.

Accurate modeling of coastal physical processes is required in engineering studies for coastal inlets, shore protection, nearshore morphology evolution, harbor design and modification, navigation channel maintenance, and navigation reliability.

Physical modeling has been a powerful means used for coastal studies. With the fast development of computer technology and its cost efficiency, mathematical modeling has become more popular in the last couple of decades. In this write-up, coastal numerical modeling will be described in different aspects of coastal studies.

## Wave Modeling

Waves possess energy and propagate towards shoreline. As approaching surf zones, waves will break and dissipate energy. In coastal regions, released wave energy is partially transferred into the driving force for coastal current and coastal sediment movement. Therefore, waves are the most important factor in studying coastal processes. Because of the complexity in wave generation and nearshore wave transformation, understanding and predicting wave action always present a challenge.

Among various approaches conducted for wave analysis, numerical wave modeling has been widely used in recent years. Two types of wave models have been developed and applied for solving scientific and engineering problems in deep or coastal waters. The first type is phase-averaging wave models and the other is phase-resolving wave models.

Phase-averaging models calculate energy spectra of waves and are used to simulate waves in a large regional to global scale or a small coastal scale. Popular phase-averaging models include WAM (WAMDI Group 1988), WAVEWATCH III (Tolman 1991), SWAN (Booij et al. 1999), STWAVE (Smith et al. 2001), and CMS-Wave (Lin et al. 2008). The WAM and WAVEWATCH III models were developed to simulate wave generation for large scale, deep water applications. The National Centers for Environmental Prediction of NOAA operates the WAVEWATCH III model and provides wave analysis and forecast over global oceans and US coasts. Figure 1 shows a one-hour forecast snapshot of significant wave height on the East Coast of US. Three- to four-meter waves are observed in the open ocean and wave height is reduced to less than 0.5 m close to coastal areas. Waves propagate primarily in the wind direction, indicating that wind-waves are generated in open ocean areas.

While the SWAN and STWAVE models are used for wave generation in deep water and wave transformation in shallow water, the CMS-Wave model focuses on coastal wave processes, including diffraction, refraction, reflection, wave breaking and dissipation mechanisms, wave-current interaction, and wave generation and growth. In nearshore zones, wave energy dissipation and transfer due to bottom friction and depth-induced breaking is a great contributor to coastal currents, coastal sediment transport, and coastal structure impact. Four depth-limited breaking formula were examined and implemented in the CMS-Wave model (Lin et al. 2011). Figure 2 shows significant wave height distributions associated with different wave breaking criteria.

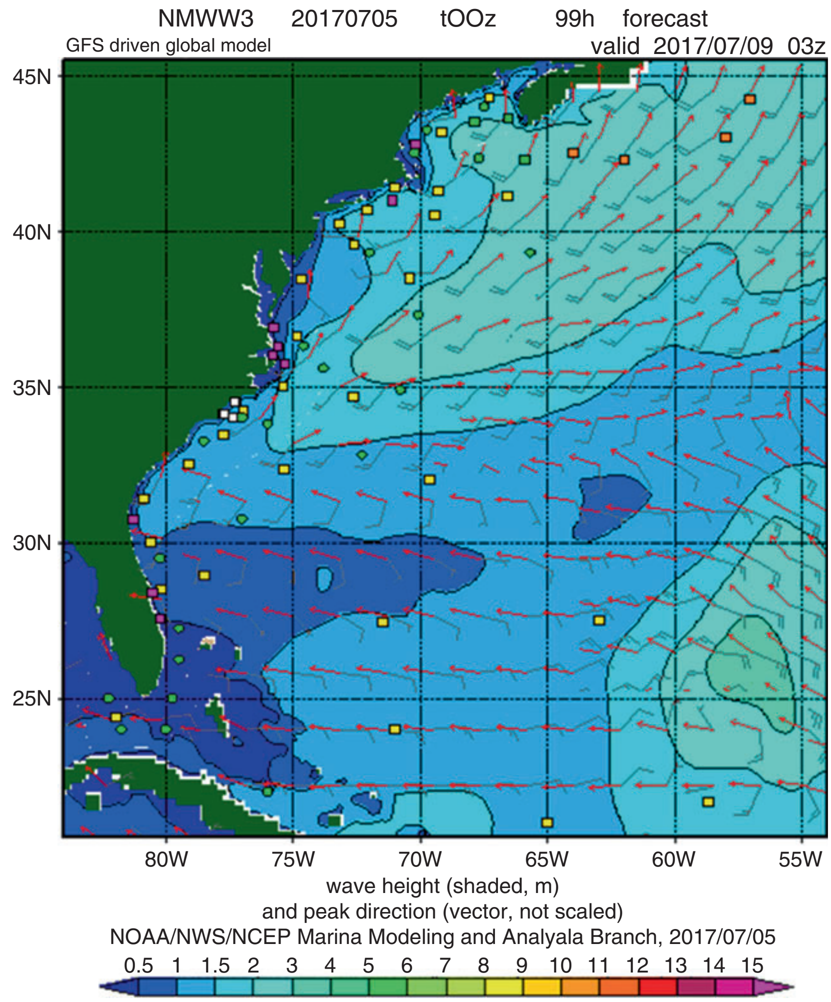
Phase-averaging models calculate wave generation and transformation by assuming uniformly distributed wave phases. In order to calculate wave propagation and wave processes more accurately, phase-resolving models focuses on detailed phase information. Because of the requirements for high temporal and spatial resolution, phase-resolving models are limited to the calculations of short-term processes in small-scale coastal domains. Such models include the mild-slope model (Berkhoff et al. 1982) and the Boussinesq model (Nwogu 1993). Demirbilek and Nwogu (2007) carried out Boussinesq model simulations to investigate wave energy transformation at a site along Guam's southeast coast near Ipan. The calculated wave propagation and corresponding significant wave height over the Ipan reef are shown in Fig. 3. The Boussinesq model simulations clearly display that wave shoaling and breaking processes and asymmetric bores over the reef.

## Circulation Modeling

Shallow coastal areas experience strong tidal mixing, receive high wind energy input, and are very often categorized as vertical well-mixed water bodies. Therefore, two dimensional modeling is a common practice for coastal applications, in which the shallow water equations are derived by depth-averaged equations of conservation of mass and conservation of momentum in the Cartesian coordinate system as follows:

$$\frac{\partial D}{\partial t} + \frac{\partial Du}{\partial x} + \frac{\partial Dv}{\partial y} = 0 \tag{1}$$

$$\frac{\partial Du}{\partial t} + \frac{\partial Du^2}{\partial x} + \frac{\partial Duv}{\partial y} + \frac{1}{2} g \frac{\partial D^2}{\partial x} \quad fDv = \frac{\partial}{\partial x}\left(A_x \frac{\partial Du}{\partial x}\right) + \frac{\partial}{\partial y}\left(A_y \frac{\partial Du}{\partial y}\right) + (\tau_{sx} \quad \tau_{bx}) \tag{2}$$



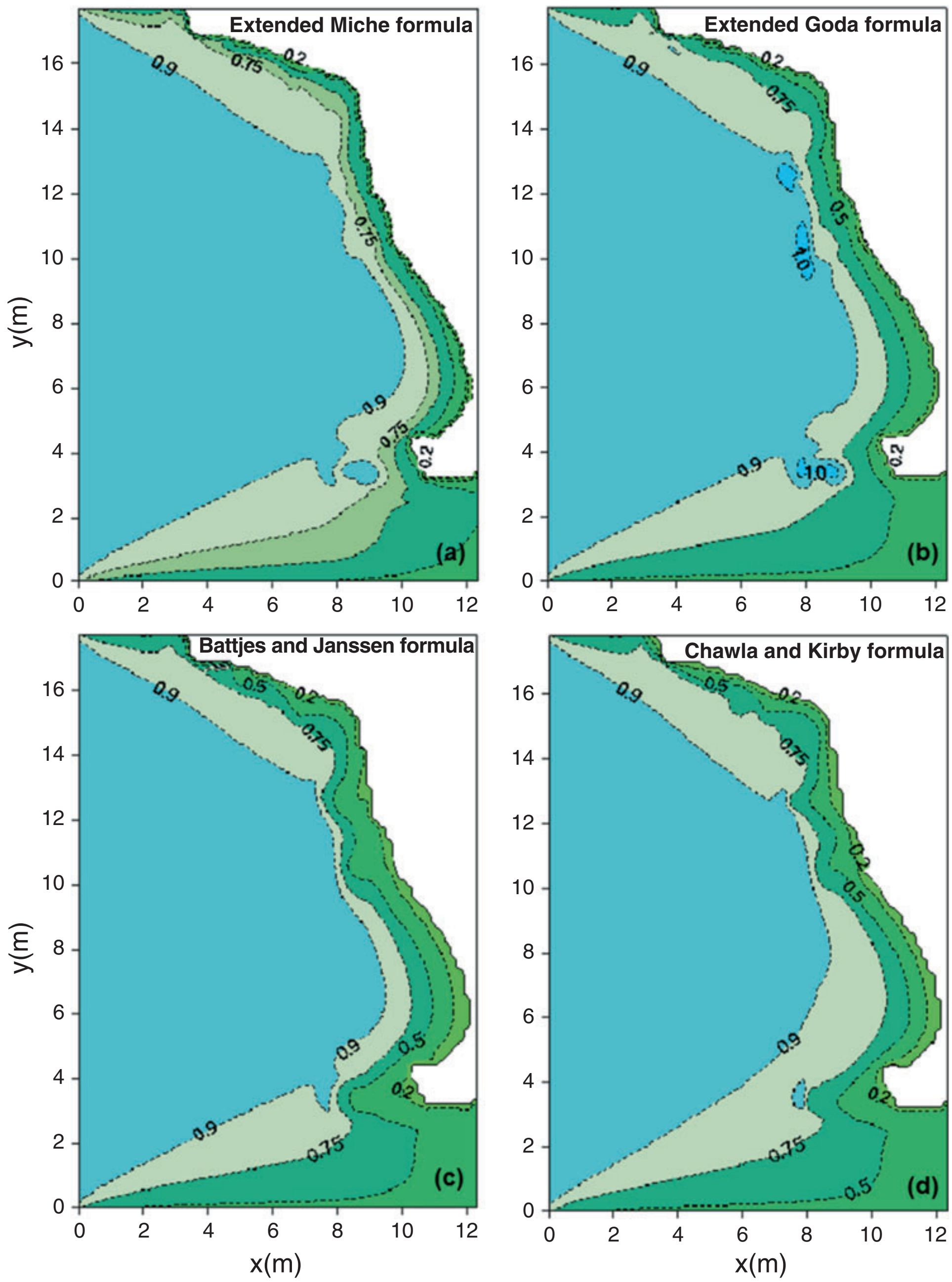

**Coastal Modeling, Fig. 1** WAVEWATCH III model product: one-hour forecast snapshot of significant wave height on the East Coast of US (http://polar.ncep.noaa.gov/waves/viewer.shtml?-multi_1-latest-hs-US_eastcoast, accessed 11 July, 2017)

$$\frac{\partial Dv}{\partial t} + \frac{\partial Duv}{\partial x} + \frac{\partial Dv^2}{\partial y} + \frac{1}{2} g \frac{\partial D^2}{\partial y} + fDu = \frac{\partial}{\partial x}\left(A_x \frac{\partial Dv}{\partial x}\right) + \frac{\partial}{\partial y}\left(A_y \frac{\partial Dv}{\partial y}\right) + \left(\tau_{sy} \quad \tau_{by}\right), \tag{3}$$

where $x$ and $y$ are the horizontal coordinates; $u$ and $v$ are the horizontal velocity components in the $x$- and $y$-directions, respectively; $D$ is the total water depth and is the sum of the still water depth, $h$, and the free surface deviation from the still water surface, ; $g$ is the gravitational acceleration; $f$ is the Coriolis coefficient; $A_x$ and $A_y$ are the diffusion coefficients in the $x$- and $y$-directions, respectively; $\tau_{sx}$ and $\tau_{sy}$ are the surface stress in the $x$- and $y$-directions, respectively; and $\tau_{bx}$ and $\tau_{by}$ are the bottom stress in the $x$- and $y$-directions, respectively.

Numerical solutions of water surface elevation and depth-averaged current are obtained in Eqs. (1), (2), and (3). Princeton Ocean Model (POM) is an early ocean circulation model (Blumberg and Mellor 1987), based on which the Estuarine Coastal Ocean Model (ECOM) was developed (Blumberg et al. 1992). Successful applications of POM and ECOM include many coastal and estuarine sites in US and around the world. ECOM is the core model of an operational forecast modeling system for the Mississippi Sound/Bight (Blumberg et al. 2002). Figure 4 shows the model forecasted surface current and salinity and the drifter trajectories. Considerable spatial variability in current and a persistent ocean eddy were exhibited in the figure.

The coastal modeling system (CMS) was developed at coastal and hydraulics laboratory of U.S. Army Engineer Research and Development Center. The CMS is an integrated suite of numerical models for simulating water surface elevation, current, waves, sediment transport, and morphology change in coastal and inlet applications. This modeling system includes representation of relevant nearshore processes for practical applications of navigation channel performance and sediment management at coastal inlets and adjacent beaches. The CMS consists of a hydrodynamic and sediment transport model (CMS-Flow) and the previously mentioned spectral wave transformation model (CMS-Wave). CMS-Flow is a two-dimensional (2D) finite-volume model that solves Eqs. (1), (2), and (3) on a telescoping grid




**Coastal Modeling, Fig. 2** Calculated wave height distributions using (**a**) the extended Miche formula (Battjes 1972), (**b**) the extended Goda formula (Sakai et al. 1989), (**c**) the Battjes and Janssen formula (Battjes and Janssen 1978), and (**d**) the Chawla and Kirby formula (Chawla and Kirby 2002)

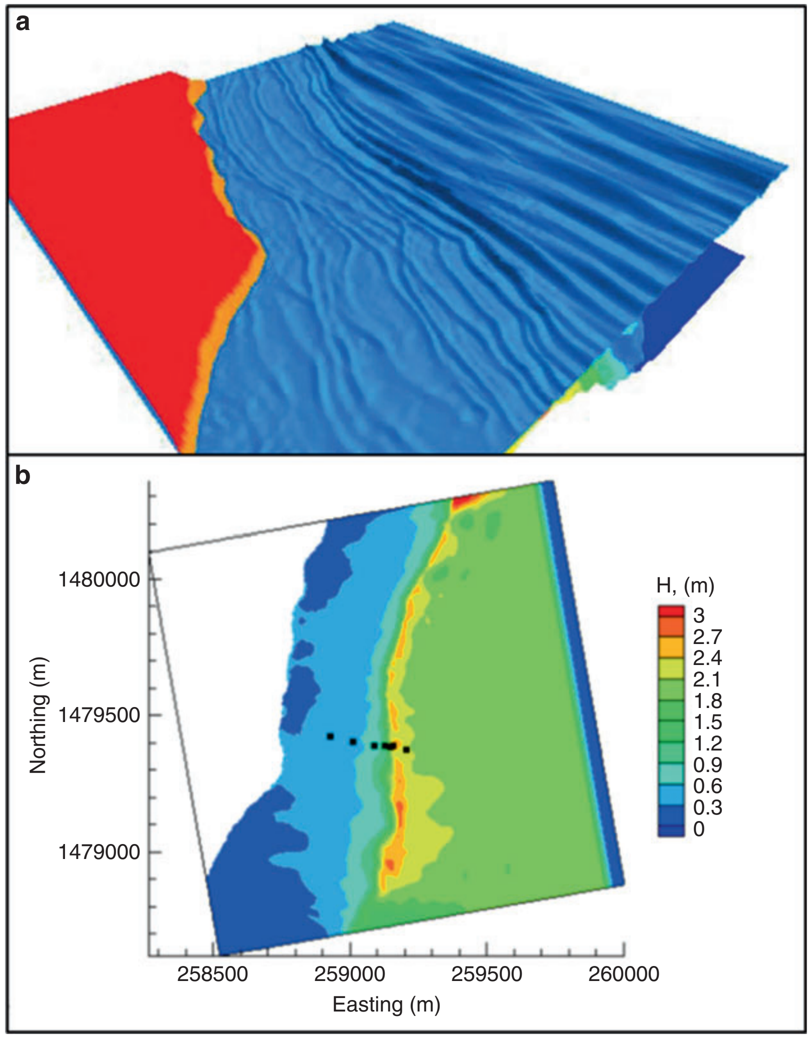
(Sánchez et al. 2011; Wu et al. 2011). Typical applications of the CMS include analyses of past and future navigation channel performance; wave, current, and wave-current interaction in channels and in the vicinity of navigation structures; and sediment management issues around coastal inlets and adjacent beaches.

The CMS was set up to conduct numerical modeling investigation adjacent to Merrimack Inlet, Newburyport, and nearshore in the vicinity of Salisbury Beach and Plum Island, Massachusetts (Li et al. 2014). Concerns at the site include beach erosion, shoreline retreat on Plum Island downdrift of and within the inlet, and reduced navigability of the inlet. Figure 5 shows the CMS configuration and calculated residual current around the inlet system.

## Sediment Transport Modeling

Combined action of waves and current in nearshore areas causes significant shoreline change and sediment migration. Simulating and understanding coastal sediment transport and morphodynamic processes is an important component in coastal modeling practice.

**Coastal Modeling, Fig. 3** (**a**) Wave propagation and (**b**) significant wave height over Ipan reef, Guam during a storm event (Demirbilek and Nwogu 2007)




Sediment transport models simulate bedload, suspended load, or total-load (combined bedload and suspended load) transport of noncohesive and cohesive sediments. For muddy sediment bed (cohesive material), suspended load transport is the process to be considered; for sand sediment bed (noncohesive material), both bedload and suspended load transport processes have to be taken into account. As displayed below, the depth-averaged advection-diffusion equation is solved for sediment concentration and sediment flux in water column.

$$\frac{\partial DC}{\partial t} + \frac{\partial CDu}{\partial x} + \frac{\partial CDv}{\partial y} = \frac{\partial}{\partial x}\left(K_x D \frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y D \frac{\partial C}{\partial y}\right) + (E_b \quad D_b) \tag{4}$$

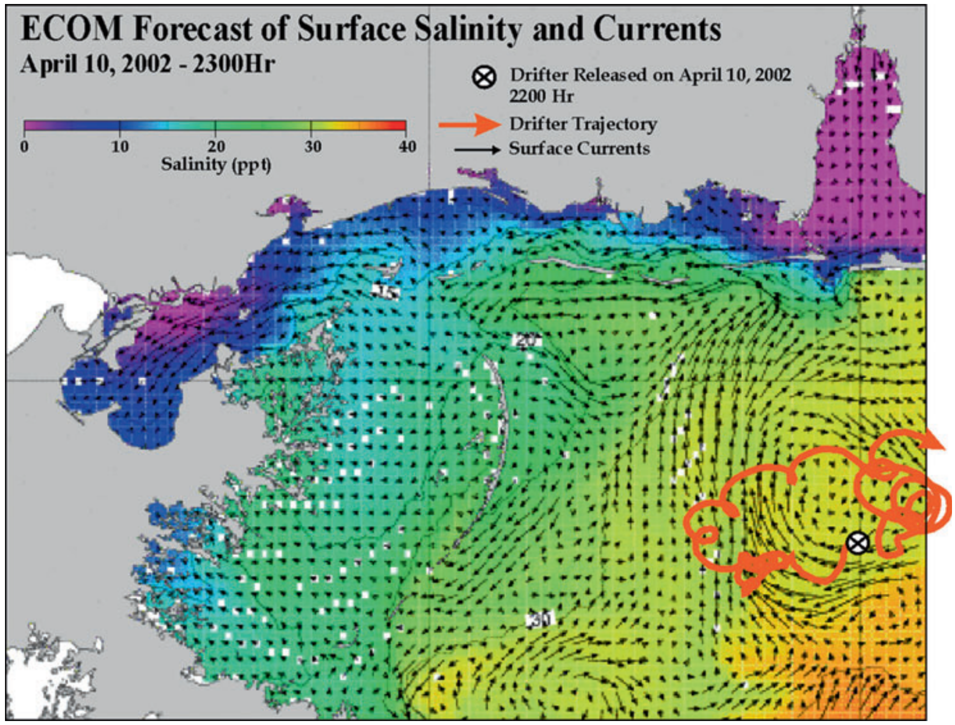
where $C$ is the depth-averaged sediment concentration; $K_x$ and $K_y$ are the diffusion coefficients in the $x$- and $y$-directions, respectively; and $E_b$ and $D_b$ are the erosion and deposition rates, respectively. The bedload transport in noncohesive sediment or in mixed cohesive and noncohesive sediment calculations have been obtained by researchers using empirical formulas in laboratory experiments (van Rijn 1984, 1993; Watanabe 1987; Soulsby 1997; Camenen and Larson 2005).

In sediment transport models, the advection-diffusion equation and various transport formulas are used to calculate total load sediment transport. Once transport rates are determined, depth change (bed elevation change) can be calculated by the sediment continuity equation,

$$(1 \quad p)\frac{\partial z_b}{\partial t} = \frac{\partial q_{t,x}}{\partial x} + \frac{\partial q_{t,y}}{\partial y} \tag{5}$$

where $p$ is the porosity of sediment; $z_b$ is the bed elevation; and $q_{t,x}$, and $q_{t,y}$ are the total load sediment transport rates in the $x$- and $y$-directions, respectively.

CMS-Flow in the CMS has three noncohesive sediment transport models which differ mainly in the assumption of the




**Coastal Modeling, Fig. 4** ECOM forecasted coastal current and salinity fields (Blumberg et al. 2002)

local equilibrium transport for the bed and suspended loads (Buttolph et al. 2006; Sánchez and Wu 2011). CMS-Flow can simulate any number of sediment size fractions, the interactions between size fractions, bed sorting and layering, and morphology change. The sediment transport model also includes processes such as avalanching, nonerodible surfaces (hard bottom), and bed slope effects.

Grays Harbor estuary is located on the southern coast of Washington, USA. A large natural inlet on the west connects the harbor to the Pacific Ocean through a deep draft navigation channel. In recent years, the elongation of Damon Point, a spit on the northeast portion of the harbor entrance, has caused the channel thalweg to migrate. The purposes of the CMS development for the Grays Harbor estuary are to evaluate potential shoaling in the navigation channel and its possible link with the growth of the Damon Point spit and to investigate physical consequences of the Damon Spit encroachment and associated channel migration. Figure 6 shows the conceptual sediment transport pathways and the calculated net total-load sediment transport rates around the inlet system (Li et al. 2013b).

Delft3D-SED is the sediment transport and morphology module in Delft3D modeling suite (DELFT HYDRAULICS 2006). For noncohesive sediment (sand), both bedload and suspended load transport are calculated; for cohesive sediment (mud), suspended load transport is calculated with the incorporation of flocculation and consolidation processes.

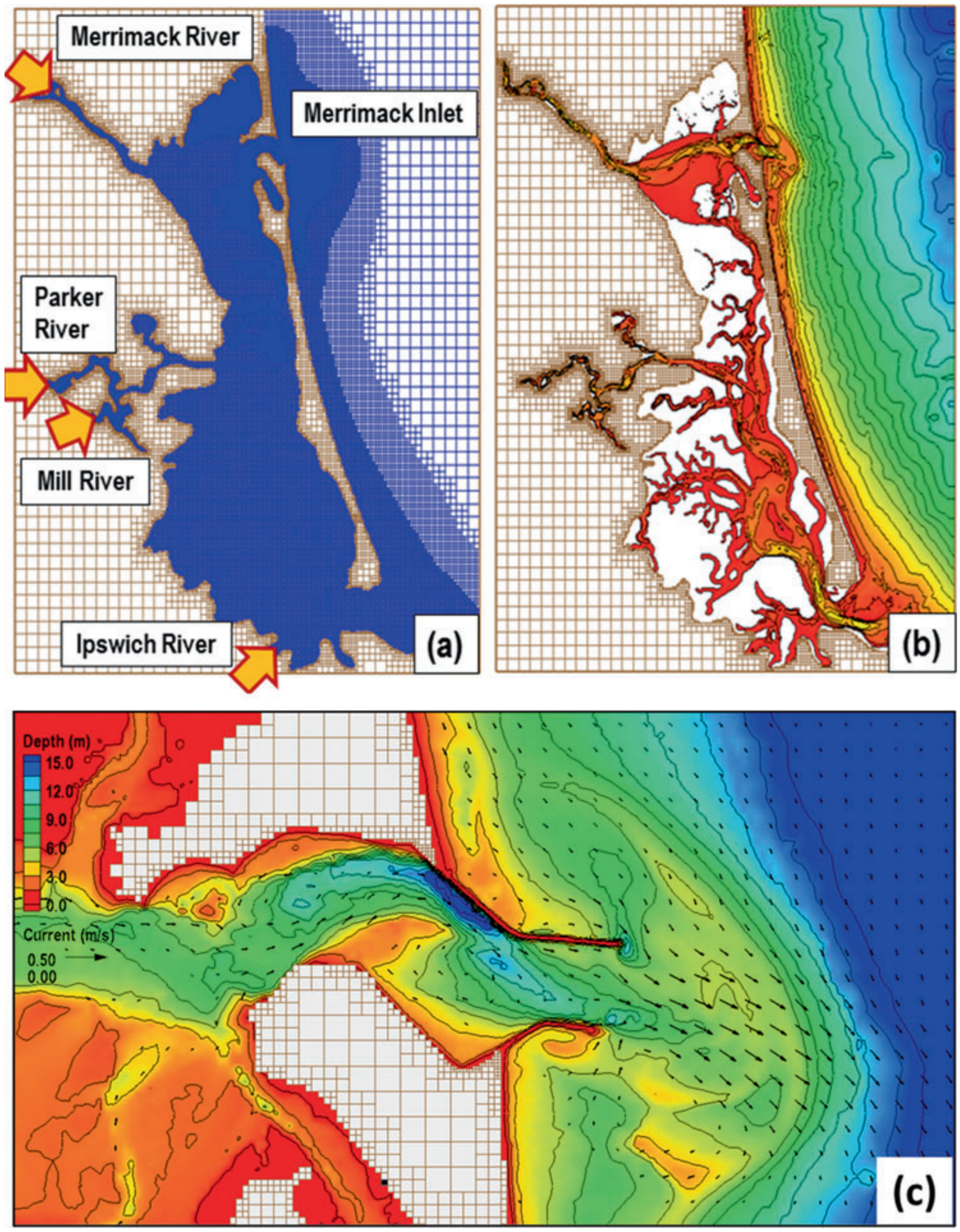
Sloff et al. (2012) developed a numerical morphological model at the mouth of Rhine and Meuse Rivers, which is an extension of the existing Delft3D model of the Rhine branches in the North and the West of the Netherlands. The modeling study is to improve the understanding of hydrodynamics and morphodynamics in this estuarine system and help develop local sediment management strategies in response to flow pattern changes and erosion variations due to the construction of the Deltaworks.

The morphological model was implemented by specifying fractions of both cohesive and noncohesive sediments from silt to coarse sand. Figure 7 shows the calculated suspended sediment transport rates of silt and sand material. As found in the study, Sloff et al. (2012) indicated that suspended load transport is the dominant process comparing with bedload transport in the estuarine system. Therefore, bed elevation change shown in Figure 8 is well corresponding to the distribution of sediment transport rates in Fig. 7.

## Shoreline Change Modeling

Coastal engineering practice and regional sediment management require understanding of beach evolution and shoreline change, and numerical modeling of dominant sediment transport and morphologic evolution processes in coastal littoral zones.

GENESIS, GENEralized model for SImulating Shoreline change, is such a numerical model to calculate longshore sand transport and simulate shoreline change in response to wave action (Hanson and Kraus 1989). The equation of the model is



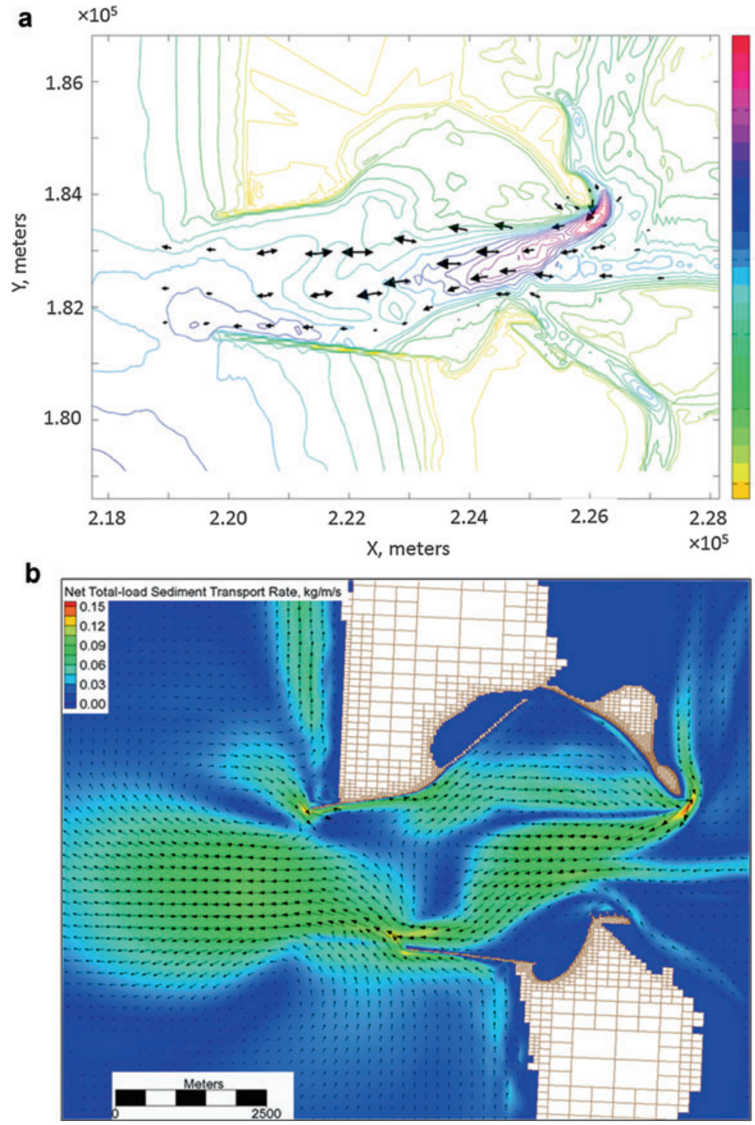

**Coastal Modeling, Fig. 5** (**a**) The CMS telescoping grid and (**b**) bathymetry at Plum Island Sound and Merrimack Inlet. (**c**) Calculated residual current for January 2011 (Li et al. 2014)

governed by conservation of sediment mass under assumptions of constant beach profile shape, impact of longshore sediment transport, and existence of a long-term trend in shoreline change et al. and is described as below:

$$\frac{\partial y}{\partial t} + \frac{1}{(D_B + D_C)}\left(\frac{\partial Q}{\partial x} \quad q\right) = 0 \qquad (6)$$

where $x$ is the alongshore coordinate; $y$ is the cross shore coordinate, representing the shoreline position; $D_B$ and $D_C$ are the newly formed berm height and the closure depth, respectively, relative to a vertical datum; $Q$ is the alongshore sand transport rate parallel to the $x$-coordinate; and $q$ is the sand input in the $y$-direction. The solution of shoreline position obtained from Eq. (6) is interpreted in Fig. 9.

As a one-dimensional shoreline change model, GENESIS was designed to simulate shoreline/beach evolution over a period from months to several years. With wave input as the major driving forcing, the model can be used to assist coastal engineering projects, such as coastal structure design and evaluations, beach nourishment, and berm placement. While GENESIS focuses on shoreline change studies in a local spatial scale (project dimension) and a relatively short temporal scale of several year, the Cascade shoreline change model was developed to simulate alongshore sediment transport and morphologic evolution of shoreline in a large regional scale and a long-term temporal scale. The Cascade



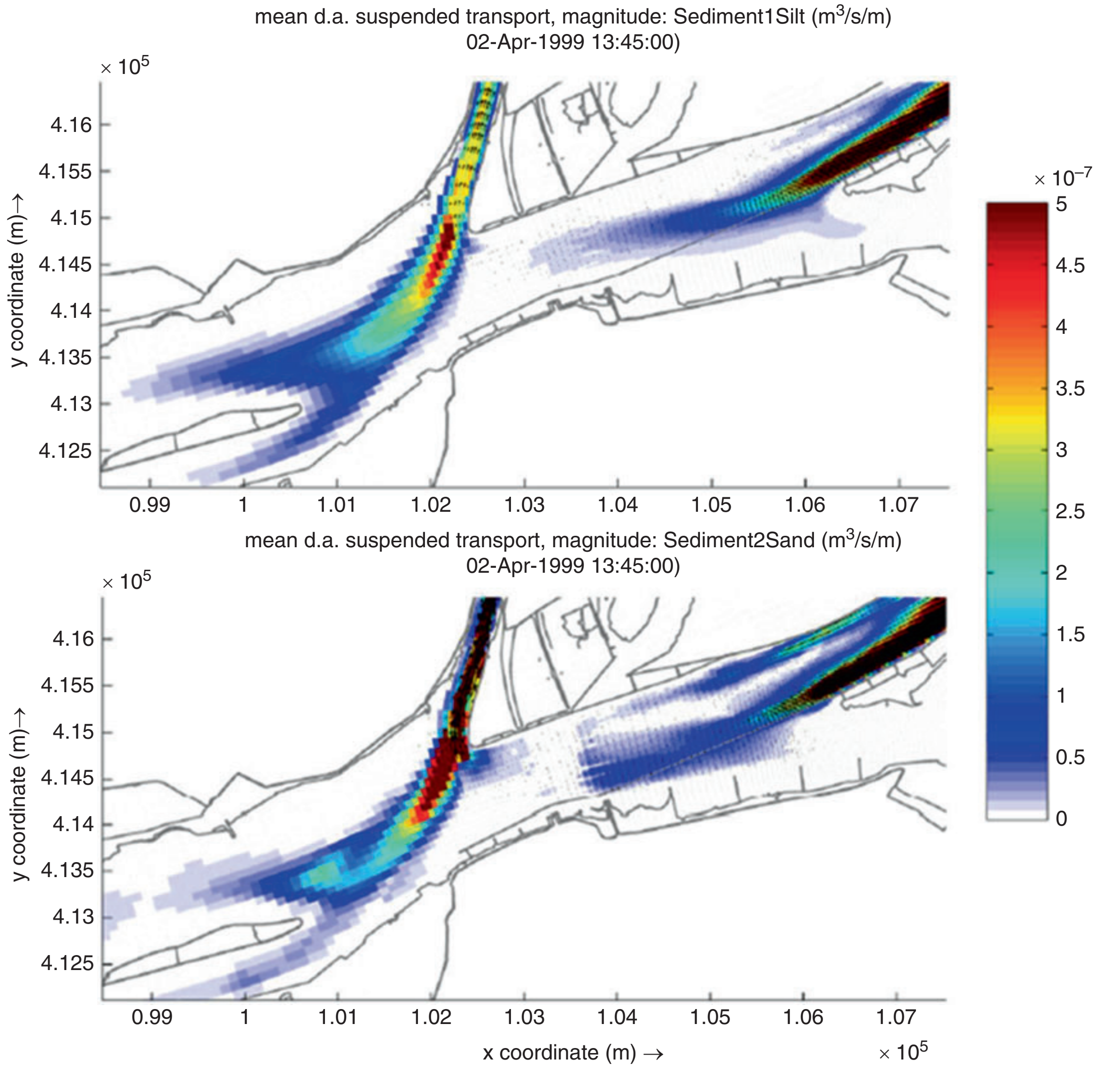

**Coastal Modeling, Fig. 6** Calculated sediment transport pathways and net total-load sediment transport rates (Li et al. 2013b)

model can cover a coastal domain up to hundreds of kilometers and simulation periods can be extended to more than a century to address long-term influence of natural processes on coastal changes (Larson et al. 2006).

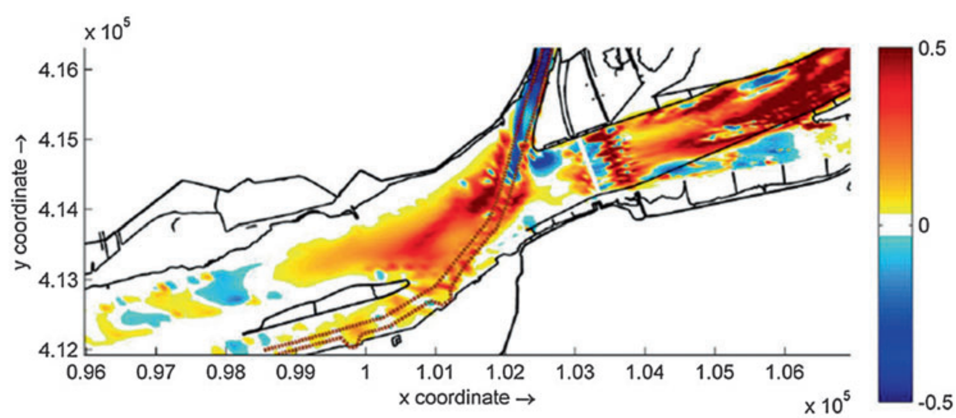
Based on theoretical framework of GENESIS and capabilities of Cascade in calculating large spatial scale longshore transport, morphological change, and interaction between coastal processes and coastal structures (inlets) over a long period of time, GENCADE was developed (Frey et al. 2012). Figure 10 shows a test case with a single inlet along a straight shoreline. Under constant wave forcing with the assumption of equilibrium morphological elements, the simulation results display the shoreline response of updrift sediment accumulation and downdrift erosion.

Coastal change and shoreline evolution have been greatly influenced by coastal flooding due to storm conditions and could be impacted by future sea level rise. Driven by waves and water levels, SBEACH, the Storm Induced BEAch CHange model, is a storm-scale numerical model for simulating beach profile change, the formation and movement of longshore bars, troughs, and berms, and dunes (Larson and Kraus 1989). By neglecting longshore transport components, beach profile change is obtained from the calculation of cross-shore transport rate and the mass conservation equation along cross-shore transects.

SBEACH can be applied to determine the fate of proposed beach fill alternatives under storm conditions and to compare the performance of different beach fill cross-sectional designs, and to predict volumetric overtopping rates for catastrophic events in open coasts. King et al. (2011) applied the model to evaluate beach profile and shoreline change in response to storm surges along Wallops Island, Virginia. As shown in Fig. 11, the hurricane induced surge had caused berm and dune erosion.

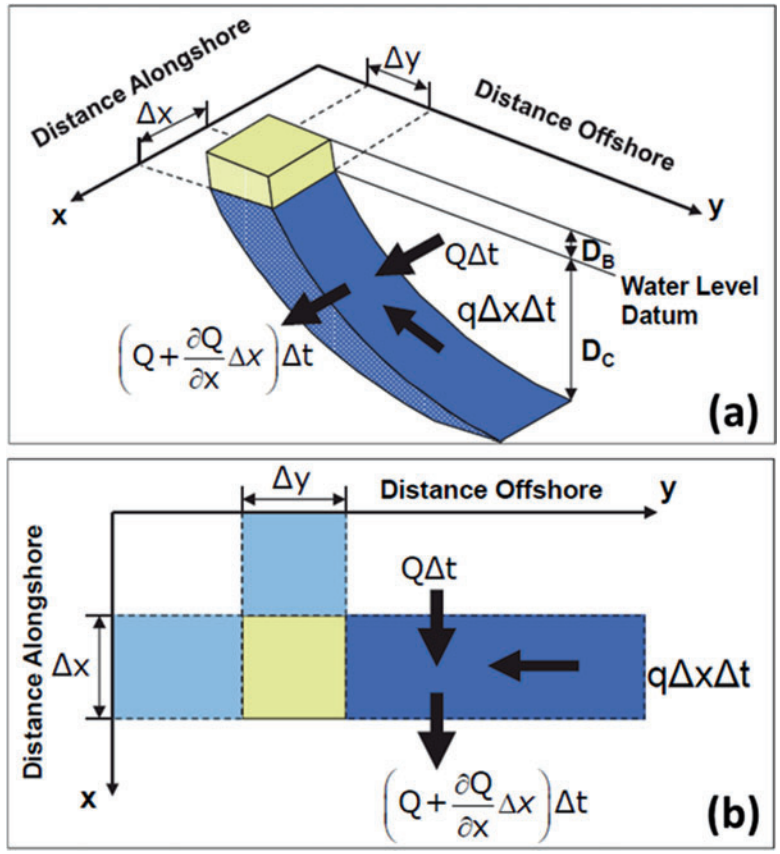



**Coastal Modeling, Fig. 7** Cohesive and noncohesive suspended sediment transport (Sloff et al. 2012)

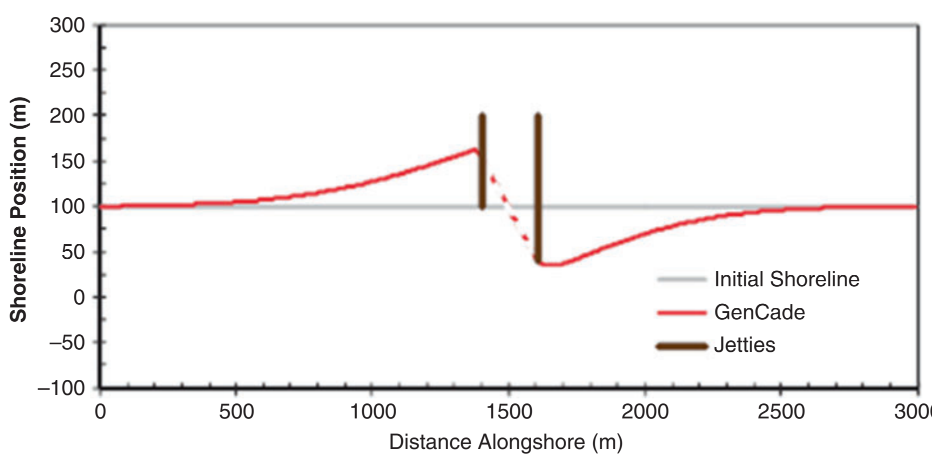



**Coastal Modeling, Fig. 8** Bed elevation change. The warm color represents accretion and the cold color erosion (Sloff et al. 2012)

As a one-dimensional numerical model, GENCADE simulates shoreline change and SBEACH calculates cross-shore profile change under various wave forcing. Both models can predict beach profile change, berm, and dune migration in different spatial and temporal scales but with limitations of the assumptions of equilibrium sediment transport and



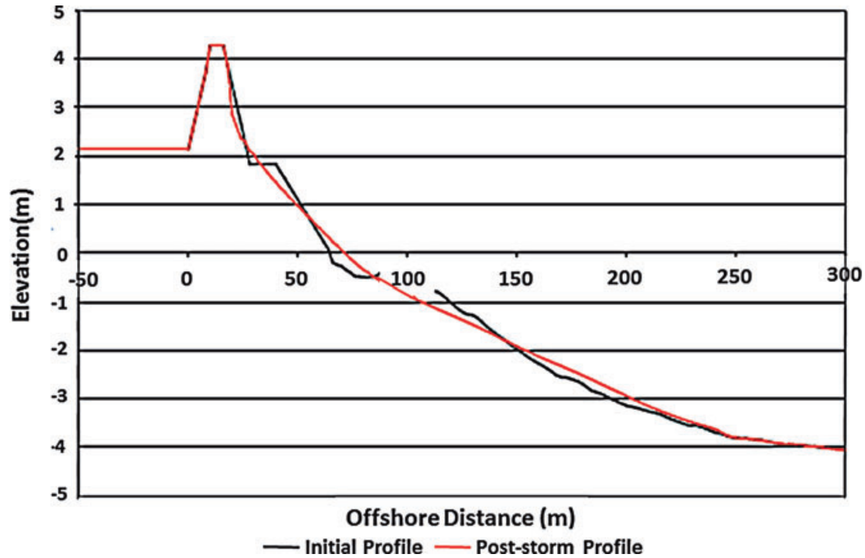

**Coastal Modeling, Fig. 9** (**a**) Side view and (**b**) Plan view of solution procedure of Eq. (6) (Frey et al. 2012).



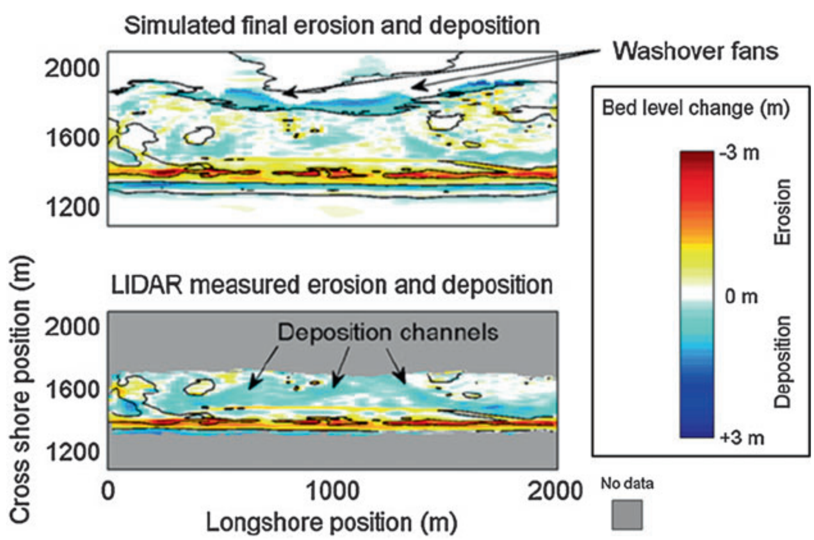

**Coastal Modeling, Fig. 10.** Calculated shoreline position (Frey et al. 2012)

breaking of short-period waves. XBeach is a two-dimensional time dependent swash and surf zone model (Roelvink et al. 2009). This model solves coupled short wave energy, flow, sediment transport, and bed level change equations for cross-shore and longshore hydrodynamic and morphodynamic processes on a spatial scale of kilometers and a temporal scale of storms.

Coastal physical processes included in the model are wave transformation, wave setup and overwashing, longshore, and cross-shore hydrodynamics, bed load and suspended load sediment transport, dune erosion, etc. McCall et al. (2010) set up the XBeach model to calculate morphological change and coastal inundation due to Hurricane Ivan at Santa Rosa Island, Florida. The simulation period is 36 h. Figure 12 shows the comparison between the calculated morphological changes at the end of the simulation and the LIDAR measurements. The figure clearly indicated that the storm surge and wave action resulted in the dune inundation and sediment transport over the barrier islands, and two washover fans were created in the back barrier bay.




**Coastal Modeling, Fig. 11** Beach profile response for a hurricane (King et al. 2011)




**Coastal Modeling, Fig. 12** Simulated erosion and deposition at the end of the simulation (36 h). Measured erosion and deposition (McCall et al. 2010)

## Coastal Structure Modeling

Various coastal engineering structures are built to protect shoreline, harbors, and navigation waterways, which include rubble mounds, weirs, culverts, tidal gates, et al. (Fig. 13). Since these structures are a significant component in controlling hydrodynamics and sediment transport in the coastal zone, it is important for a coastal numerical model to properly represent them and to simulate their effects. In coastal models, structure effects are usually treated as the obstructions in flow fields and are represented as energy loss in the governing equations. The term has the form of a friction term with an empirical dimensionless coefficient. Depending on the type of structures, the energy loss can be evaluated by a linear or a nonlinear form.

Rubble mound structures are typically used as seawalls, groins, breakwaters, and jetties. The design of rubble mound structures often consists of a core of small- to medium-size rock or riprap covered with larger rock or riprap to armor against wave energy. In coastal modeling, it is reasonable to assume that the flow through these structures is negligible, since the flow is controlled through laminar flow through small pores, and they are therefore often represented as solid structures, impermeable to both flow and sediment transport. However, some designs may implement larger diameter riprap in the core, and the resulting structure can be sufficiently porous to allow flow across the structure. The flow resistance in these structures can consist of both laminar and turbulent components; the pore space can provide significant storage for sediment and act as a sediment trap. Fine, grain-sized sediments may pass through the structure (Li et al. 2015).

The Forchheimer (1901) equation describes unidirectional flow in porous media, in which the laminar (linear) and turbulent (nonlinear) components of flow resistance are


**Coastal Modeling, Fig. 13** Implementation of coastal structures in coastal modeling

represented. The numerical implementation of the formulation in the CMS is to incorporate the resistance equation into the governing equations, representing the drag force of the rubble mounds. Both the linear and nonlinear coefficients in the equation are determined using data from studies by Sidiropoulou et al. (2007).

Weirs are common coastal structures typically used in weir jetties or in wetlands to control discharges, provide flood control, act as salinity barriers, and optimally distribute freshwater to manage salinity regimes and sedimentation rates and deposition patterns. Weirs are also used in inland streams to increase navigation channel depth, collect water runoff from agricultural fields, control sedimentation, and stabilize channel morphology.

Two approaches are developed to implement weir structures in the CMS model. The first approach is based on the standard weir equation for either sharp-crested or broad-crested weirs, with a foundation in Bernoulli's equation. The second approach is to add local resistance force over a weir structure in the momentum equations.

In coastal applications of culverts, the culverts often connect open water bodies of similar water surface elevation with two coupled locations, for instance, to enhance flushing or provide controlled flow through levees or causeways. Therefore, the implementation of culverts assumes subcritical flow conditions. In the CMS, the implementation of culverts is based on equations developed by Bodhaine (1982).

Gates along with levees, dikes, and roadways are often used in tidal areas to control the water flow. They can increase flushing, improve water quality and also provide passage for fish and other aquatic animals to coastal lagoons and bays. Some gates may be self-regulating (controlled by water level) and some are manually operated according to certain schedules to meet the requirements of flood control, navigation, water quality management, and aquatic ecosystem rehabilitation. Figures 4, 5, 6 and 7 show some typical weirs, tide gates, and culverts used in coastal engineering and other areas.

Similar to the treatment of weirs, two approaches are used to simulate gate functions in the CMS model. The first approach determines the underflow through gates using the orifice flow equation. The second approach adds the local resistance force due to gates in the momentum equations.

## Summary

Coastal modeling covers a wide variety of coastal, estuarine, and riverine processes that include wave dynamics, coastal circulation, storm surge and coastal flooding, tidal hydraulics and flushing, sediment transport, and shoreline change and beach erosion. Proper representation of coastal physical processes in physical or numerical models will greatly assist coastal engineering design and improve coastal management.

Presently, as mentioned early, many coastal models are available for applications. However, not one model fits every single situation and it depends on the discretion of coastal modelers (engineers and scientists) to select the right model to apply for a specific site to solve a specific problem.

## Cross-References

- ▶ Beach Erosion
- ▶ Coastal Circulation
- ▶ Coastal Engineering
- ▶ Coastal Flooding
- ▶ Coastal Management
- ▶ Coastal Morphology Change
- ▶ Coastal Processes
- ▶ Coastal Structures
- ▶ Coastal Waves
- ▶ Estuarine Processes
- ▶ Riverine Processes
- ▶ Sediment Transport
- ▶ Shoreline Evolution
- ▶ Storm Surge
- ▶ Tide

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