# Modeling Sediment-related Loading, Transport, and Inactivation of Fecal Indicator Bacteria at a Nonpoint Source Beach

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## INTRODUCTION

- U.S. Environmental Protection Agency requires regular monitoring of fecal indicator bacteria (enterococci for marine waters) to protect human health at recreational beaches [1].
- Traditional culture-based methods need 18-24 hours for laboratory analysis so that water quality exceedance cannot be identified until next day.
- The study site (Fig.1), Hobie Beach (Miami, USA), is characterized by frequently elevated enterococci levels and high percentages of exceedance [2].
- Recent studies indicated that **beach sand** and runoff are nonpoint sources of fecal indicator bacteria and pathogens [3, 4].
- This study develops a uniquely coupled **microbe-hydrodynamic-morphological** model capable of simulating enterococci loading from nonpoint sources [5].
- The objective is to elucidate the effects of various hydrodynamic, morphological, and microbiological processes on the transport and fate of enterococci.

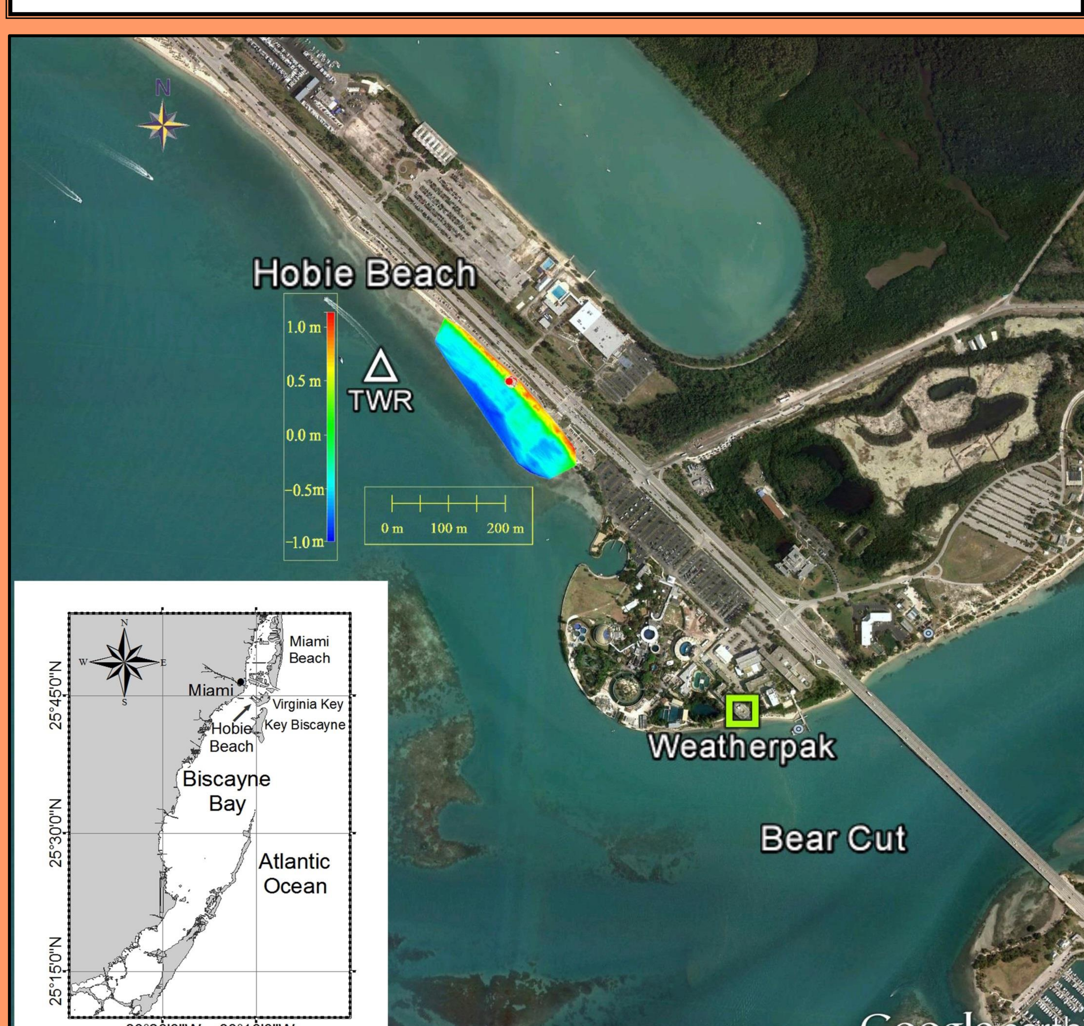


Fig.1 The study site Hobie Beach. Surveyed topography is illustrated by a color contour and color bar shows depth from -1.0 to 1.0 m with respect to mean sea level. The position of tide and wave recorder (TWR) is indicated by the white triangle. Water and sand were sampled along a transect oriented normally to a reference point (red dot). The hydrometeorological observations are obtained from a Weatherpak station (green square).

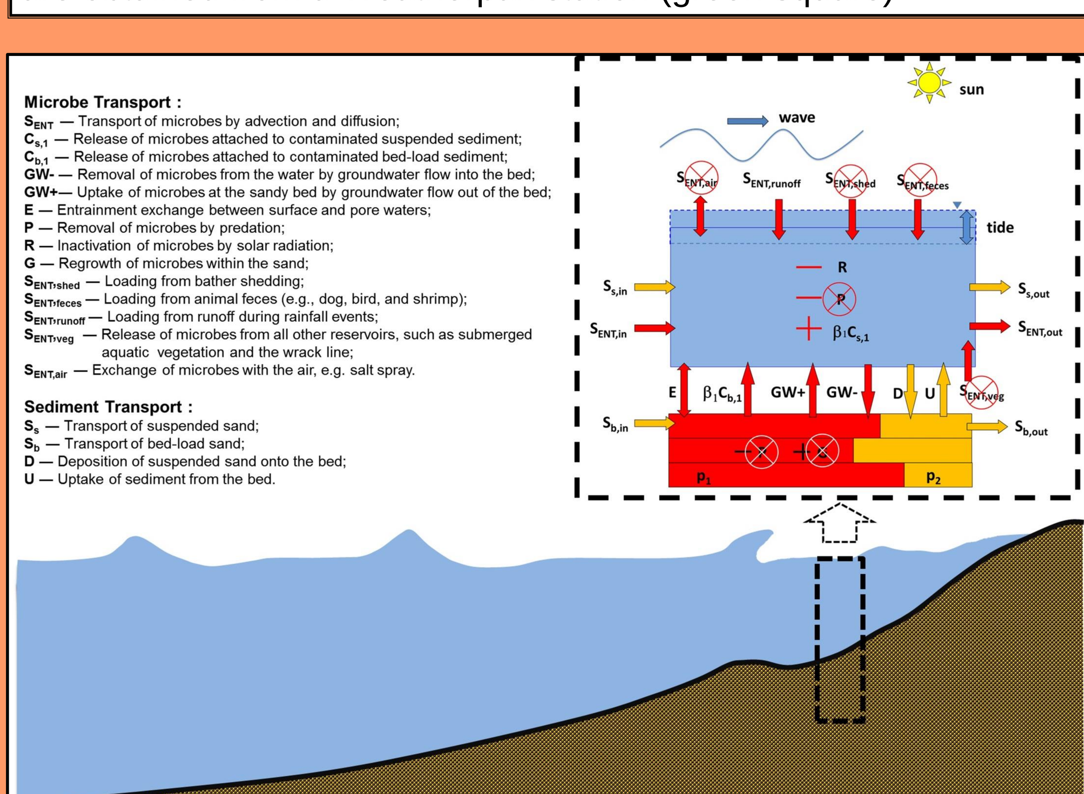


Fig.2 A sketch of cross-shore section of a beach and a control volume corresponding to one model cell. Within the box, surface water column is shown with light blue, affected by both waves and tides. Contaminated and clean sands are shown with red and yellow colors, the factions ($p_1$ and $p_2$) of which can vary with depth. Yellow arrows indicate processes related to the sediment transport, while red arrows indicate processes related to microbe transport. The microbial processes and loads not taken into account in the model are crossed out.

## MATERIALS & METHODS

- A 10-day intensive field experiment was conducted from June 1st to 11th, 2010.
  - Water and sand sampling at the knee and waist depths every hour and 6 hours, respectively;
  - Walking topography survey with a back-pack GPS;
  - Tide & wave recorder (TWR);
  - Hydrometeorological measurements from a Weatherpak station (solar radiation, rainfall, and wind).
- Coupled Microbe-Hydrodynamic-Morphological Model based on XBeach [6]
  - A new module solves a microbe transport-decay equation, which includes reworked sand, porewater, and runoff as microbial source terms and a solar-radiation-dependent decay term (Fig.2).
  - Model simulations in a 1-D single cross-shore transect with varying grid spacing.
  - Measured tides and waves imposed at offshore boundary.

## RESULTS

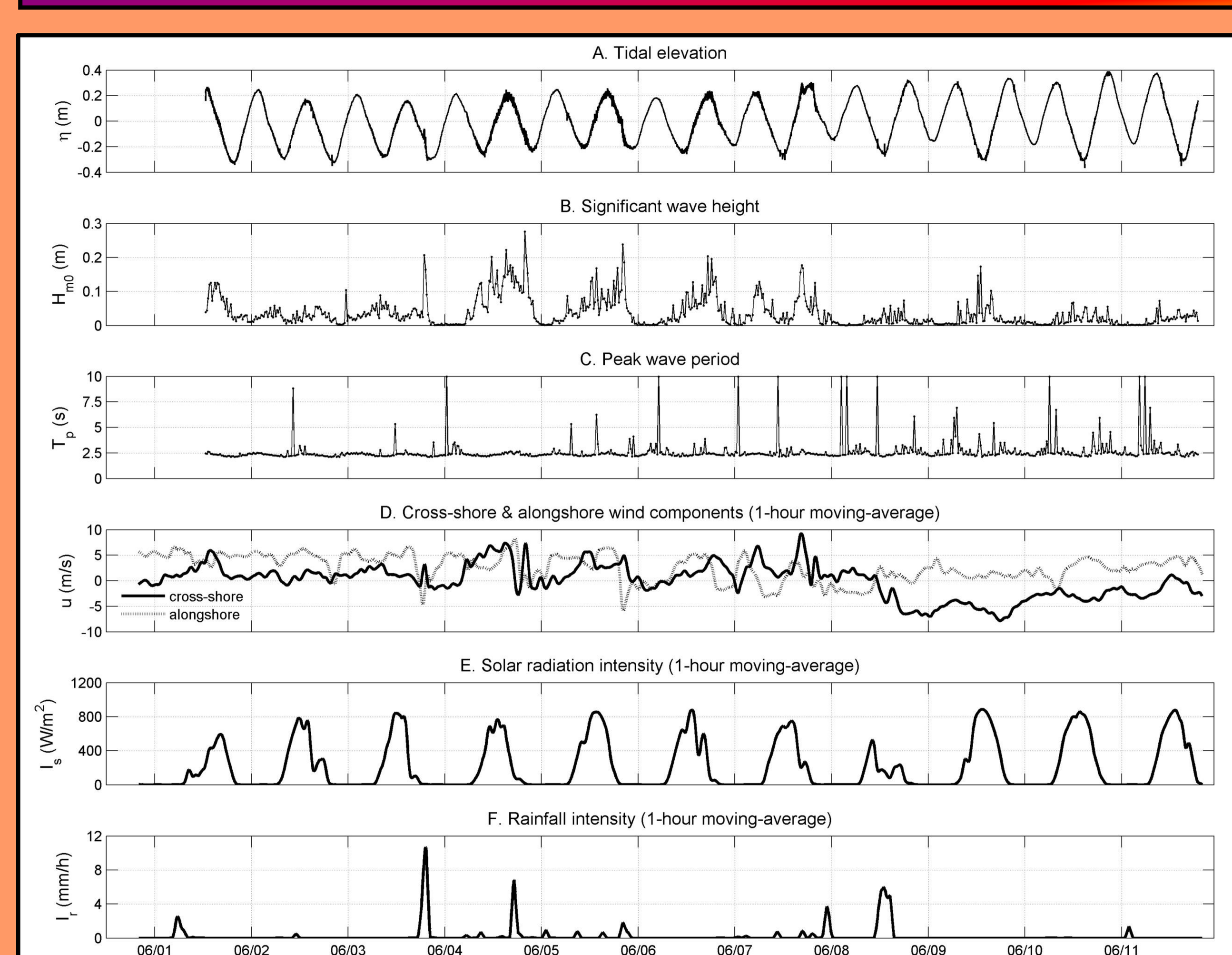


Fig.3 Time-series measurements of environmental variables

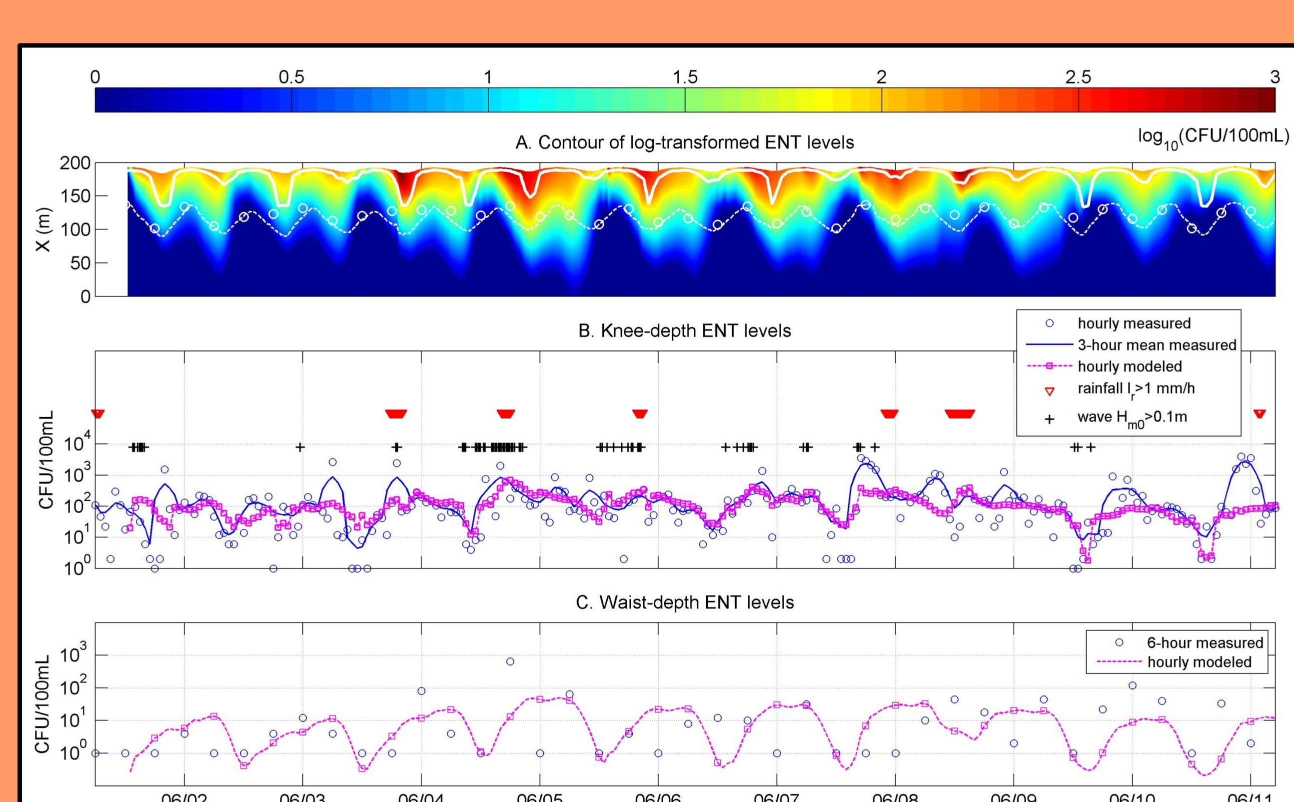


Fig.4 Model results of enterococci levels during the 10-day period. (A) Contour of $\log_{10}$-transformed enterococci levels, showing the cross-shore transect from beach shoreline to offshore boundary. (B) Comparisons of simulated and measured enterococci levels at knee-depth locations. (C) Comparisons of simulated and measured enterococci levels at waist-depth locations.

- Enterococci levels substantially decrease from the shoreline to offshore, by one to two orders of magnitude in a 100-m distance away from the shore.
- Diurnal variations of enterococci are caused by solar inactivation during the day, showing higher levels in the nighttime than the daytime.
- Tidal variations of enterococci are due to higher enterococci levels in the sand near the high tide lines, resulting in higher levels in the water during the high tides than low tides.

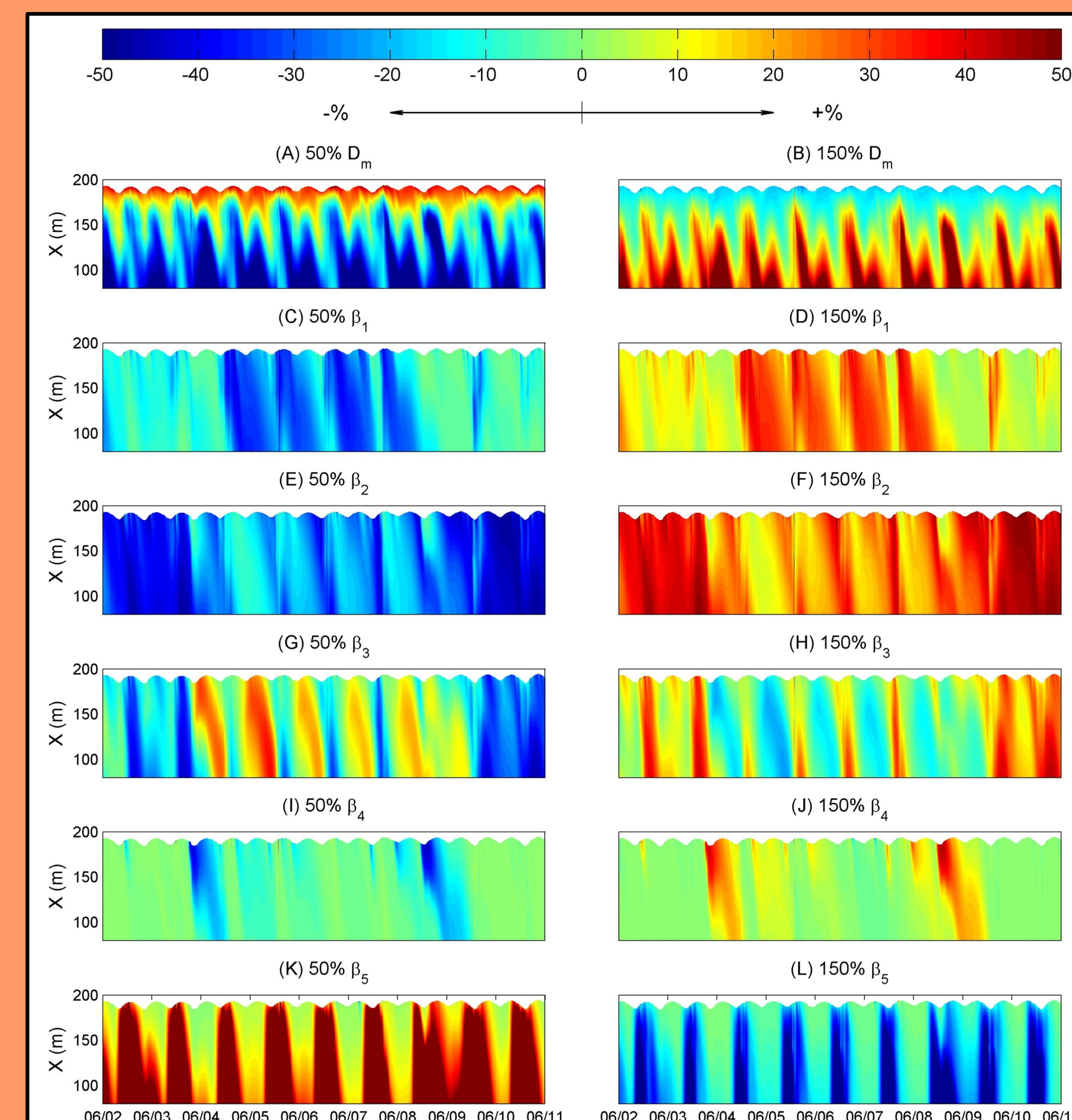


Fig.5 **Sensitivity analyses** on six key parameters that may change model output of enterococci levels.
$D_m$ : Microbe diffusion coefficient;
$\beta_1$ : Enterococci sediment release coefficient;
$\beta_2$ : porewater concentration coefficient;
$\beta_3$ : Entrainment coefficient;
$\beta_4$ : Rainfall-runoff loading coefficient;
$\beta_5$ : Solar inactivation coefficient.

## CONCLUSIONS

- We have developed a water quality model on the basis of XBeach.
- The model successfully simulate observed spatial and temporal patterns of enterococci in the beach water.
- This study highlights the mechanisms of waves and tides in moving enterococci out from the sediment reservoir to the water.
- Diffusion is a major process in transporting enterococci from shoreline region to the offshore.
- Solar inactivation is a key process in reducing enterococci levels during the day.
- Sensitivity analyses suggest that the processes and coefficients related to enterococci loading have quasilinear characteristics, while model results are sensitive to both diffusion and inactivation coefficients, showing high nonlinearity and spatial and temporal dependence.

## REFERENCES

[1] U.S. Environmental Protection Agency (1986), Ambient water quality criteria for bacteria, EPA 440/5-84-002. U.S. Environmental Protection Agency, Washington, DC.
[2] Shibata, T., H.M. Solo-Gabriele, L.E. Fleming, and S. Elmir (2004), Monitoring marine recreational water quality using multiple microbial indicators in an urban tropical environment, *Water Res.*, 38, 3119-3131, doi:10.1016/j.watres.2004.04.044.
[3] Wright, M.E., A.M. Abdelzaher, H.M. Solo-Gabriele, S. Elmir, and L.E. Fleming (2011), The inter-tidal zone is the pathway of input of enterococci to a subtropical recreational marine beach, *Water Sci. Technol.*, 63(3), 542-549, doi:10.2166/wst.2011.255.
[4] Shah, A.H., A.M. Abdelzaher, M. Phillips et al. (2011), Indicator microbes correlate with pathogenic bacteria, yeasts and helminthes in sand at a subtropical recreational beach site, *J. Appl. Microbiol.*, 110, 1571-1583, doi:10.1111/j.1365-2672.2011.05013.x.
[5] Feng, Z., A. Reniers, B.K. Haus, and H.M. Solo-Gabriele (2013), Modeling sediment-related enterococci loading, transport, and inactivation at an embayed nonpoint source beach, *Water Resour. Res.*, 49, 693-712.
[6] Roelvink, D., A. Reniers, A. van Dongeren, J. van Thiel de Vries, R. McCall, and J. Lescinski (2009), Modeling storm impacts on beaches, dunes and barrier islands, *Coast. Eng.*, 56, 1133-1152, doi:10.1016/j.coastaleng.2009.08.006.

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NSF
National Institute of Environmental Health Sciences
CSDMS Community Surface Dynamics Modeling System
Deltares Enabling Delta Life