Evaluation of Cross-Shore Profile Behavior in Medium-Term Timescales Using XBeach: A Case Study of Zarabad Fishery Harbor, Iran

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ARTICLE INFO	ABSTRACT
	Among the numerous problems that decrease the capability of a harbor in the country, seasonal sedimentation is identified as a major problem for many fishery harbors. In 2007, Zarabad Fishery Harbor conditions were also identified as critical due to the large volume of sand accumulation and consequent closure of its entrance. Numerical modeling of coastal bed level change was implemented to provide insight into the typical response of the Zarabad beach to regular wave attacks, and to obtain an operational and validated model for the site. Advanced numerical models employed to predict coastal evolution at a variety of time and spatial scales usually include many free parameters that require calibration to the available field data. The XBeach numerical model was selected for its capacity to accurately model hydrodynamic and morphological processes over a two-dimensional domain. It comprises about 250 model settings that approximately 150 of these settings relate to physical and numerical Behavior and the other 100 are case-specific parameters. In this research, 11 parameters are adopted to optimize the model prediction efficiency for Zarabad Fishery Harbor area. For calibration and validation stages, two cross-shore profiles and two medium-term time periods are selected. The model showed great promise in predicting the evolution of cross-shore profiles under water, but as expected, the dry part results showed major errors. XBeach proved to be an operational tool to predict cross-shore profiles in the area, in such timescales. Although, more tests are needed to utilize the model in longer time periods with regard to the duration of simulations.

1. Introduction

As the effect of medium to long term morphological change to coastal sustainability is increasingly recognized, developing methodologies that support predictions over such time scales has become a major concern. Connected to this is the growing prevalence of process-based morphodynamic modeling. These two factors have resulted in a requirement for the application of process-based models to be extended, to allow the assessment of beach change beyond short term time scales [1].

Shore-normal beach profiles are essential for quantifying processes in the coastal zone and for developing the basis for designing coastal structures such as groins, jetties, revetments, and seawalls. The entire range of a standard beach profile captures the active region of coastal processes, starting with the landward bluff or dune and continuing to the point where sediment displacement caused by waves is negligible [2].

Many models which use process-based methods (UNIBEST - TC [3], CROSSMOR2000 [4] and SBEACH [5]) have been available for some time to model cross-shore beach behavior. Van Rijn et al. (2003) present a thorough review of the capacities of these methods to predict cross-shore profile evolution [6]. XBeach is a two-dimensional model for wave propagation, long waves and mean flow, sediment transport and morphological changes of the nearshore area, beaches, dunes, and backbarrier during storms.

XBeach concurrently solves the time-dependent short wave action balance, the roller energy equations, the nonlinear shallow water equations of mass and momentum, sediment transport formulations and bed update on the scale of wave groups [7].

Seasonal sedimentation is known as a major problem for many fishery harbor among the numerous problems that reduce the efficiency of harbor in the country. Out of all fishery harbor, conditions of Zarabad Fishery Harbor were identified as critical in 2007 due to the extensive volume of sand accumulation and consequent closure of its entrance.

The construction of Zarabad Fishery Harbor was completed in 2006 (Figure 1). The Harbor is located at Sistan and Balouchestan Province, Iran (25°23́N 59°36́W), which is under constant attacks of south and southwest waves during monsoon season and Shamal winds/waves in winter. As a result of the insufficient reservoir behind the main breakwater to block the high rate of westward Longshore Sediment Transport (LST), a significant volume of sedimentation was observed at the Harbor entrance in a short interval after construction. The large sedimentation forced the authorities to organize a regular monitoring plan of periodic hydrography surveys from 2006 to 2008. A long groin, started at the turning point of the main breakwater, was later constructed to improve the reservoir capacity and to stop the sediment bypassing (Figure 1) [8].

This paper presents the application and validation of XBeach in a specific setting for a medium-term morphological assessing by applying the model to Zarabad Fishery Harbor.

Figure 1. Location of study area and port location

2. Model Description

Originally, XBeach has been developed to model the nearshore responses under storm conditions. It is a 2DH (depth-averaged) model that solves coupled short wave energy, flow and infragravity wave propagation,

sediment transport and bed level changes. XBeach simultaneously solves the time-dependent short wave action balance, the roller energy equation, the nonlinear shallow water equation of mass momentum, sediment transport formulation and bed update on the scale of wave groups. The wave action and roller energy are employed to compute the radiation stresses. Depth-averaged shallow water equations are used to compute the mean flow. Sediment transport rates are calculated by using advection-diffusion equations [9]. Further, the equilibrium sediment concentration is calculated with the Soulsby-Van Rijn formulation [10]. Application of XBeach has been given successful results for the dune erosions under storm and hurricane conditions with verifications. By using the existing modeling capabilities of XBeach (e.g. modeling of physical processes and using advanced options such as "hard structure"), nearshore coastal processes around a Harbor structure are reproduced to explain the sand accretion and erosion patterns of beach nearshore profile in this study.

2.1. Main Equations
A summary of most important equations which has been used in XBeach model is described in the following sections:

2.1.1. Wave Action Equation
In XBeach, the wave force is defined by a time-dependent version of the wave action balance equation in the shallow water momentum equation. The balance of the wave action is shown as follows (Eq. (1)) [11]:

$$\frac{\partial A}{\partial t} + \frac{\partial c_{gx}A}{\partial x} + \frac{\partial c_{gy}A}{\partial y} + \frac{\partial c_{\theta}A}{\partial \theta}$$
$$= -\frac{D_w + D_f + D_v}{\sigma} \tag{1}$$

Where, wave action is defined as:

$$A(x,y,t,\theta) = \frac{S_w(x,y,t,\theta)}{\sigma(x,y,t)} \tag{2}$$

Where θ represents the angle of incidence with respect to the x-axis, S_w represents the wave energy density in each directional bin and σ the intrinsic wave frequency. The intrinsic frequency σ and group velocity c_g is obtained from the linear dispersion relation. D_w, D_f and D_v are dissipation terms for waves, bottom friction, and vegetation, respectively. The intrinsic frequency is for instance obtained with [11]:

$$\sigma = \sqrt{gk \tanh kh} \tag{3}$$

The wave action propagation speeds in x, y, and directional space are given by:

$$c_{gx}(x, y, t, \theta) = c_g \cos(\theta)$$

$$c_{gy}(x, y, t, \theta) = c_g \sin(\theta)$$

$$c_\theta(x, y, t, \theta) = \frac{\sigma}{\sinh 2kh}\left(\frac{\partial h}{\partial x}\sin\theta - \frac{\partial h}{\partial y}\cos\theta\right) \qquad (4)$$

Where h represents the local water depth and k the wave number. The intrinsic frequency of the wave σ is determined without the interaction of the wave current (keyword: wci=1), meaning that it is equal to the absolute radial frequency, ω [11].

2.1.2. Roller Energy Equation
In the XBeach model, roller energy is coupled with the wave action equation, where wave energy dissipation is taken as a source term for the equation of roller energy balance. The roller energy balance is shown as follows (Eq. (5)):

$$\frac{\partial E_r}{\partial t} + \frac{\partial E_r c \cos\theta}{\partial x} + \frac{\partial E_r c \sin\theta}{\partial y} = D_w - D_r \qquad (5)$$

Where E_r is representing roller energy in each directional bin. The speed of propagation of roller energy is given by c. The total dissipation of wave energy and the dissipation of roller energy are represented by D_w and D_r respectively [11].

2.1.3. Shallow water equations
Shallow water equations are employed to calculate mean flow in XBeach. The depth-averaged Generalized Lagrangian Mean (GLM) formulation is used to include the wave-induced mass-flux and the return flow. In that context, the momentum and continuity equations are formulated in terms of the Lagrangian velocity (u^L), which is defined as the distance, a water particle travels in one wave period, divided by that period. The resulting GLM momentum equations are presented by the following equations [12]:

$$\frac{\partial u^L}{\partial t} + u^L\frac{\partial u^L}{\partial x} + v^L\frac{\partial u^L}{\partial y} - f\,v^L - v_h\left(\frac{\partial^2 u^L}{\partial x^2} + \frac{\partial^2 u^L}{\partial y^2}\right) =$$

$$\frac{\tau_{sx}}{\rho h} - \frac{\tau_{bx}^E}{\rho h} - g\frac{\partial\eta}{\partial x} + \frac{F_x}{\rho h} - \frac{F_{v,x}}{\rho h}$$

$$\frac{\partial v^L}{\partial t} + u^L\frac{\partial v^L}{\partial x} + v^L\frac{\partial v^L}{\partial y} + f\,u^L - v_h\left(\frac{\partial^2 v^L}{\partial x^2} + \frac{\partial^2 v^L}{\partial y^2}\right) = \qquad (6)$$

$$\frac{\tau_{sy}}{\rho h} - \frac{\tau_{by}^E}{\rho h} - g\frac{\partial\eta}{\partial y} + \frac{F_y}{\rho h} - \frac{F_{v,y}}{\rho h}$$

$$\frac{\partial\eta}{\partial t} + \frac{\partial hu^L}{\partial x} + \frac{\partial hv^L}{\partial y} = 0$$

where τ_{sx} and τ_{sy} are the wind shear stresses, τ_{bx} and τ_{by} are the bed shear stresses, η is the water level, F_x and F_y are the wave-induced stresses, $F_{v,x}$, and $F_{v,y}$ are the stresses induced by vegetation, v_h is the horizontal viscosity and f is the Coriolis coefficient [11].

2.2. Boundary conditions

2.2.1. Wave Boundary Conditions
Based on the given values of Hrms (root mean square wave height), Tm01 (spectral period), wave direction and directional distribution power, we used stationary wave boundary conditions (instat=0), as it is suggested to be used in mild conditions. The surf beat effects, resulted from extreme storm conditions are assumed to be negligible in this study. Since infragravity motions (where 30 < wave period < 300 sec) do not play an influential role, the "instat=0" option was implemented to solve the stationary problem directly using forward marching technique. Wave data were extracted at a depth of 20 m near the harbor area where XBeach grid y-axis is located. Boundaries, which are perpendicular to the coastline, are known as lateral boundaries. For the stationary wave mode Neumann boundaries are the only option. It allows a correct representation of the wave propagation near the lateral boundaries, without the usual shadow zones in e.g. SWAN. By neglecting the longshore gradients, the model automatically computes a consistent 1D solution [11]. However, in order to minimize the undesirable effects of lateral boundaries, these boundaries have been set far enough from the area of interest (i.e. fishery Harbor). In this sense, their influence is assumed to be insignificant for the study area.

2.2.2. Flow Boundary Conditions
An offshore or lateral boundary is typically an artificial boundary which has no physical significance. On the offshore boundary wave and flow conditions are imposed. In the domain, waves and currents will be generated which need to pass through the offshore boundary to the deep sea with minimal reflection. One way to do this is to impose a weakly reflective-type boundary condition (absorbing-generating)(keyword: front). With option front = abs2d (default value) the formulation by Van Dongeren and Svendsen (1997) is activated which allows for obliquely-incident and obliquely-reflected waves to pass through the boundary [11]. Lateral boundaries are placed away from the area of interest to minimize the influence of boundaries on the results. For this purpose, Neumann boundaries (no - gradient) were activated as lateral boundaries, by setting options "left = neumann" and "right = neumann"

2.3. Model input and output data
The surveys taken after 2006 are used as bathymetry input and wave condition series provided by Wave Watch III is used as wave condition input in this study. Furthermore, the nearest accessible tide station (Chabahar station) is used as a single tide location (tideloc = 1) input.

The output is bed level change which is presented as two cross-shore profiles selected to evaluate the model (Figure 2).
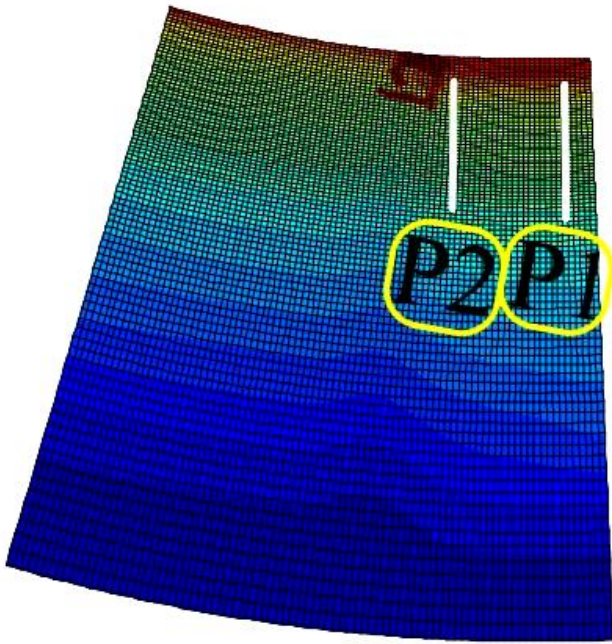

Figure 2. Model grid and cross-shore profiles selected for evaluation in this study

2.2. Model Calibration and Validation

Two time periods (2006.02.20 to 2006.09.23 and 2007.02.20 to 2006.10.23) are selected for calibrating and validating the model, respectively. Furthermore, two cross-shore profiles (p1 and p2) are selected for this purpose. Evaluating the results is done by employing the Brier Skill Score (BSS) and also visual observation.

BSS represents how well the model predicts the bathymetry compared with the initial bathymetry. The following classification was given for the BSS by Van Rijn et al. (2003) [13]:

Table 1. Classification of Brier Skill Score by Van Rijn et al. (2003).

Score	Classification
<0	Bad
0-0.3	Poor
0.3-0.6	Reasonable
06-0.8	Good
0.8-1.0	Excellent

Nine specific XBeach parameters (i.e. fw, cf, gammax, beta, wetslp, alpha, facSk, facAs, and gamma) have a major influence on the model results. These parameters are also optimized for the Dutch coast for 1D storm models and are referred to as WTI settings [14]. With regard to the literature review, these parameters plus hmin and dryslp are employed to optimize the model in this study.

3. Results

Numerous simulations have been performed to optimize all parameters for Zarabad Fishery Harbor. All simulation settings are selected as extended as defined in the model manual to cover the whole range possible. After optimizing each parameter individually, a simulation including all optimizations has performed to reach the final calibration. Table 2 presents a summary of parameter optimization including BSS for each case. BSS is divided by shoreline into 2 parts (i.e. wetBSS and dryBSS) to avoid the XBeach typical lack of accuracy in predicting dune evolution.
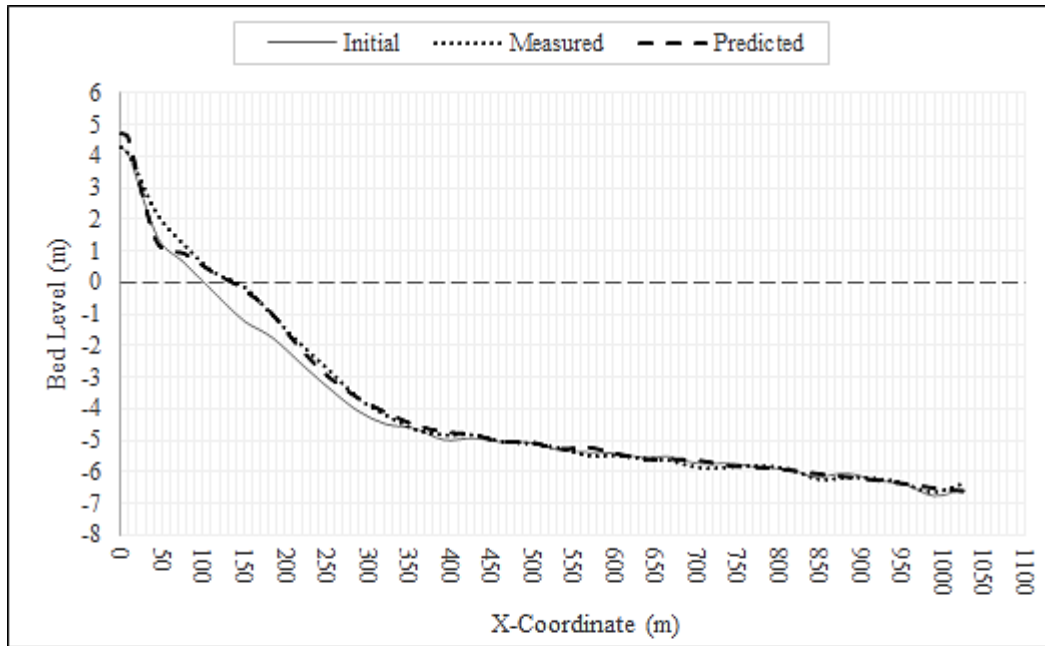
According to Table 2, default values are selected for 3 parameters (i.e. fw, dryslp and facAs), beta and optimization showed the best BSS in wet and dry part, respectively.

Table 2. Parameters selected for model optimization and resulted Brier Skill Scores
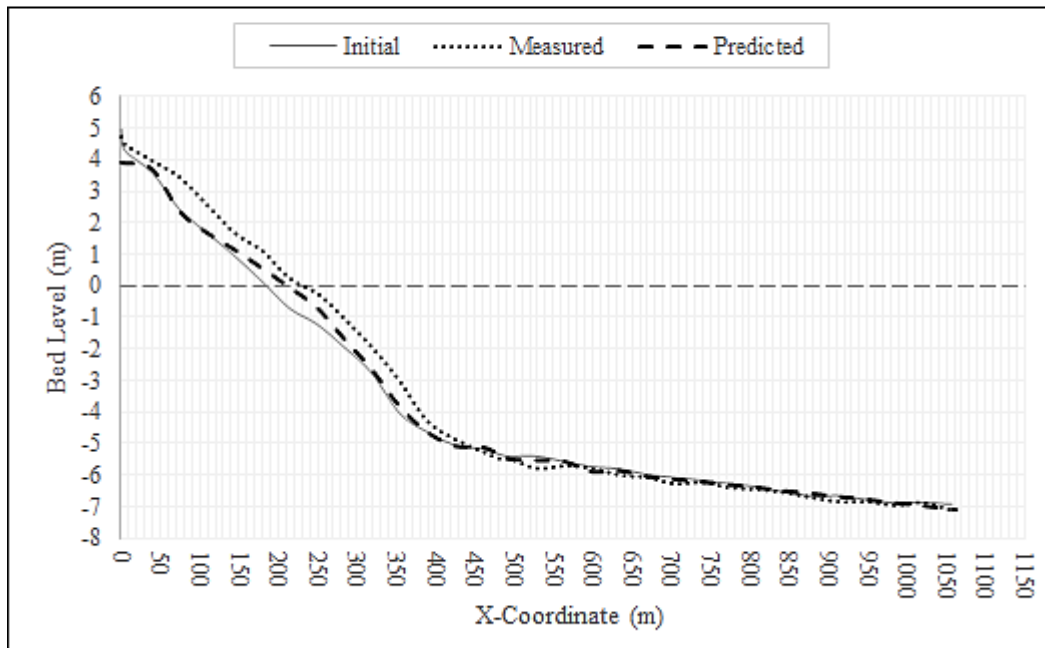
Parameter	Definition	Range	Default	Selected	P2 WetBSS	P2 DryBSS	P1 WetBSS	P1 DryBSS
fw	Short wave friction coefficient	0.0~1.0	0.00	0.00	0.487	-0.064	0.851	-0.203
cf	Dimensionless friction coefficient flow	3.5e-05~0.9	0.003	0.0025	0.502	-0.073	0.854	-0.072
gammax	Maximum wave height to water depth	0.4~5.0	2.000	2.2	0.496	-0.032	0.851	-0.053
beta	Breaker slope coefficient	0.05~0.3	0.100	0.06	0.515	-0.919	0.862	-0.145
wetslp	Critical avalanching slope under water	0.1~1.0	0.300	0.26	0.487	-0.065	0.851	-0.199
dryslp	Critical avalanching slope above water	0.1~2.0	1.0	1.0	0.487	-0.064	0.851	-0.203
alpha	Wave dissipation coefficient	0.5~2.0	1.000	1.25	0.500	-0.062	0.850	-0.0826
facSk	Skewness factor	0.0~1.0	0.100	0.35	0.488	-0.071	0.853	-0.194
facAs	Asymmetry factor	0.0~1.0	0.100	0.1	0.487	-0.064	0.851	-0.203
gamma	Breaker parameter for Baldock	0.4~0.9	0.550	0.8	0.491	-0.081	0.852	-0.197
hmin	Threshold water depth above which Stokes drift is included	0.001~1.0	0.2	0.5	0.488	-0.057	0.856	-0.062

Overall calibration result (first period) is shown as cross-shore profiles in Figure 3. Setting resulted from calibration is used in the validation step (second period) to ensure model proficiency. The results show "Good" and "Excellent" accuracy for the wet part of the Profile 1 since the model's BSS is close to 1, according to Van

Rijn et al. 2003 (Table 1). Nevertheless, for Profile 2, since dominated longshore flow is westward in this study, the results are simply "Reasonable" due to neglecting longshore sediment transport in storm condition by XBeach.
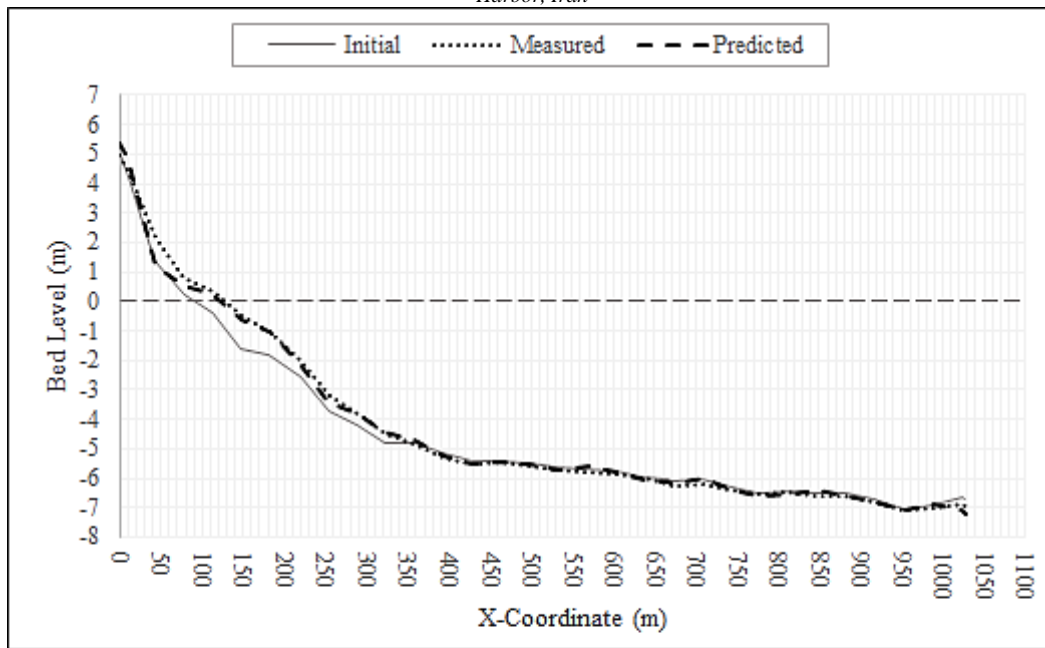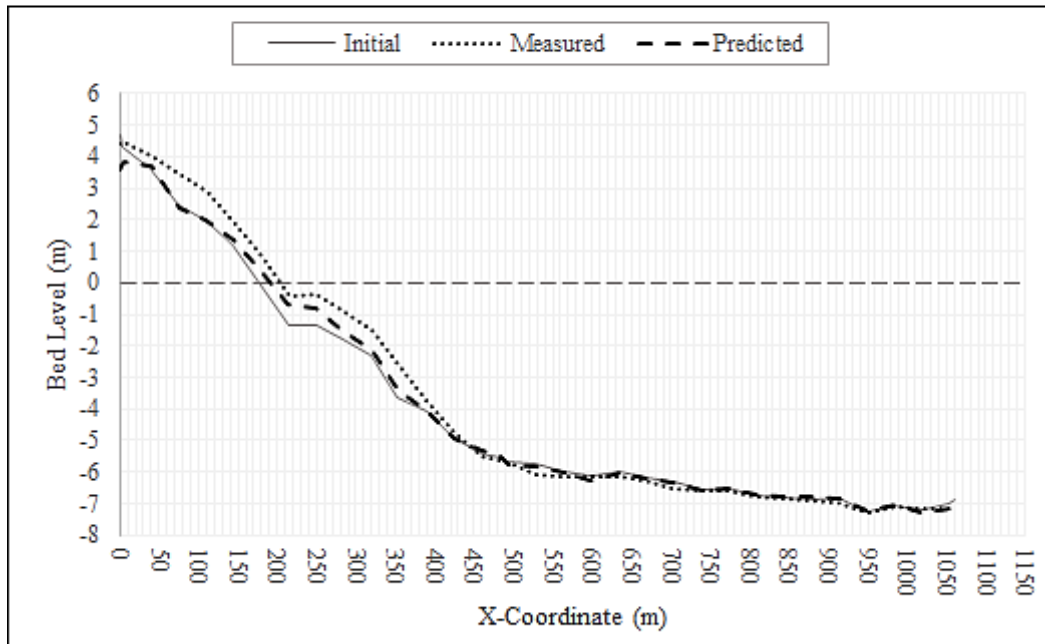

(a)

(b)

Figure 3. Profile 1 (a) and Profile 2 (b) bed level change in calibration step (2006.02.20 to 2006.09.23)

Figure 4 shows how well the calibrated model performs in a simulation of about 8 months (254 days) compared to the corresponding bathymetric surveys

conducted at the beginning and end of the modeling timespan (validation step).

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(a)

(b)

Figure 4. Profile 1 (a) and Profile 2 (b) bed level change in validation step (2007.02.20 to 2007.10.23)

Validation step showed similar results to calibration step as it was expected. Final results of both steps are summarized in Table 3.

Table 3. Overall result of Validation and Calibration steps

		Calibration	Validation
P1	WetBSS	0.877	0.863
	DryBSS	-0.063	-0.019
P2	WetBSS	0.533	0.461
	DryBSS	-0.052	-0.037

5. Conclusions

The XBeach model was tested for two periods in order to calibrate and validate the model for Zarabad fishery Harbor area. Eleven Parameters were selected with regard to the literature reviews to calibrate the model, accurately.

In the calibration and the validation phase, the threshold depth of sediment movement (depth of closure) was recognized to be about -7m. Though, both phases showed significantly excessive dry shoreface erosion.

Under water, both phases showed less sediment accumulation than is recognized in the surveys. In both steps, Profile 2, which is close to the main breakwater and in downstream of main longshore flow, shows less accuracy; However, it can be because of shortage of selected area in longshore direction that

influence the extent of longshore sediment transport. Also, the model showed significant uncertainty in downstream of longshore sediment flow.

Generally, the model showed great promise in predicting the overall shape of cross-shore profiles under water; however, it showed significant errors in dry part of cross section. According to the results presented in this study, XBeach can be used for predicting the morphological changes in Zarabad Fishery Harbor area with "Reasonable" to "Good" Brier Skill Score. Furthermore, It is necessary to test the model in long-term periods to be more operational.

8. References

1- Pender, D., & Karunarathna, H. (2013). *A statistical-process based approach for modelling beach profile variability*. Coastal Engineering, 81, 19-29.

2- Albert, K. M. (2017). *Modeling Morphological Change on Western Kenai Peninsula Beaches* (Doctoral dissertation, University of Alaska Anchorage).

3- Reniers, A. J. H. M., Roelvink, J. A., & Walstra, D. J. R. (1995). *Validation study of UNIBEST-TC model*. Report H2130, Delft Hydraulics, Delft, The Netherlands.

4- Van Rijn, L. C., & Wijnberg, K. M. (1996). *One-dimensional modelling of individual waves and wave-induced longshore currents in the surf zone*. Coastal Engineering, 28(1-4), 121-145.

5- Larson, M., & Kraus, N. C. (1989). *SBEACH: numerical model for simulating storm-induced beach change. Report 1. Empirical foundation and model development* (No. CERC-TR-89-9). Coastal Engineering research center Vicksburg Ms.

6- Van Rijn, L. C., Walstra, D. J. R., Grasmeijer, B., Sutherland, J., Pan, S., & Sierra, J. P. (2003). *The predictability of cross-shore bed evolution of sandy beaches at the time scale of storms and seasons using process-based profile models*. Coastal Engineering, 47(3), 295-327.

7- Roelvink, D., Reniers, A., Van Dongeren, A. P., de Vries, J. V. T., McCall, R., & Lescinski, J. (2009). *Modelling storm impacts on beaches, dunes and barrier islands*. Coastal engineering, 56(11-12), 1133-1152.

8- Tabasi, M., Soltanpour, M., & Ravindra, M. P. *Study And Modeling Of Cross-Shore Sediment Transport At Zarabad Fishery Port*.

9- Galapatti, R, and Vreugdenhil, CB (1985). *A depth integrated model for suspended transport, Report 83-7, Communications on Hydraulics*, Department of Civil Engineering, Delft University of Technology.

10- Soulsby, R. (1997). *Dynamics of marine sands: a manual for practical applications*. Thomas Telford.

11- Roelvink, D., Van Dongeren, A., McCall, R., Hoonhout, B., van Rooijen, A., van Geer, P. ... & Quataert, E. (2015). *XBeach Technical Reference: Kingsday Release. Model Description and Reference Guide to Functionalities*. Delft-The Netherlands.

12- Andrews, D., & McIntyre, M. E. (1978). *An exact theory of nonlinear waves on a Lagrangian-mean flow*. Journal of fluid Mechanics, 89(4), 609-646.

13- Van Rijn, L. C., Walstra, D. J. R., Grasmeijer, B., Sutherland, J., Pan, S., & Sierra, J. P. (2003). *The predictability of cross-shore bed evolution of sandy beaches at the time scale of storms and seasons using process-based profile models*. Coastal Engineering, 47(3), 295-327.

14- Van Geer, P., den Bieman, J., Hoonhout, B., & Boers, M. (2015). *XBeach 1D–Probabilistic model: ADIS, Settings, Model uncertainty and Graphical User Interface*. Tec. Rep 1209436-002-HYE, 1.