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# HYDRODYNAMIC MODELING OF TIDAL STREAMS: LOCAL SCALE STUDIES OF ABU DHABI COAST

Balaji Ramakrishnan[1]

***Abstract**: Two different local scale numerical model studies have been carried out by Sogreah to assess the hydrodynamics of Abu Dhabi coastal area, during different investigations and are presented in this paper. The local scale numerical models are developed using a finite element method based numerical scheme, RMA2 (Donnell et al, 2006). The boundary conditions for the local scale models are given in terms of water levels, which were extracted from a large scale numerical model covering entire Abu Dhabi coast. The large scale model was developed in-house using TELEMAC-2D (TELEMAC, 2000, Hervouet, 2000) modeling system. The hydrodynamic results of the local scale models are calibrated and validate with that of large scale model. The comparison of hydrodynamic results obtained from the local scale and the large scale model are found to be good. The efficiency and accuracy of the local scale models have been demonstrated. The details of the numerical scheme, model setup and methodology are presented and discussed in this paper.*

***Keywords**: Abu Dhabi coast, RMA2, Telemac2D, hydrodynamics and tidal currents.*

## INTRODUCTION

The city of Abu Dhabi, situated off the North-West coast, is the political capital of the United Arab Emirates. The coastal area of Abu Dhabi is a complex topography which includes several shoals, islands, lagoons, channels and deltas, as can be seen in Figure 1. Among the various coastal features along this coastline, the natural and manmade channels play a significant role in the variation of tide induced currents. The Mussafah channel, which is running along the length of mainland Abu Dhabi, is one among the various channels being effectively used for navigation of large vessels. Due to the increase in the demand of ship transport these channels have been constantly deepened by dredging.

Apart from this, there is a growing trend in the coastal development activities along the coast of Abu Dhabi, which constantly requires update of the understanding of the hydrodynamics associated with changes in the coastal features. The general development activities include dredging of channels and reclamations of new islands. Generally, the tide induced current velocities along the Abu Dhabi coast are significantly high, due to the presence of deep channels and any changes in the existing features are sensitive to the tidal currents. It is important to

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understand to the existin g hydrodynamic characteristics of Abu Dhabi coastlin e, in order to assess the impact of any other man-made features.

Local scale num erical models generally cover a relatively less are a of the c oastline and are effective in minimizing the computation time by reducing the number of computational elements. These m odels also im prove the ac curacy of representing t he c oastal fe atures and thereby enhancing the understanding of hydrodynamics. In the present study, two different local scale finite element numerical models are developed to understand the tidal hydrodynamics at different locations of Abu Dhabi coast. The zones of the case studies are highlighted in Figure 1. The efficiency of the local scale m odels on the assessment of the tidal currents has been demonstrated.


**Fig. 1. General view of Abu Dhabi coastline (image courtesy: Google, 2009).**

## PREVIOUS NUMERICAL MODEL STUDIES

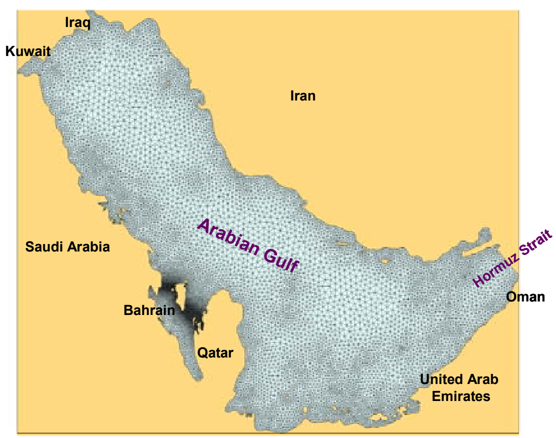
### Global Regional Model

Sogreah (2001) has developed aglobal regional numerical model covering entire Arabian Gulf to be able to carry out marine environment studies along its coasts inthe shortest time and with the best possible results. This model helps in prediction of sea levels and currents due to the tidal variations. The global regional numerical models were developed using TELEMAC software (Telemac, 2000, Hervouet, 2000) which is capable of simulating free-surface flows in the two dimensions of horizontal space and solves the Saint-Venant equations using the finite-element method on a computation mesh of triangular elements. TELEMAC numerical scheme has been developed by the Laboratoire National d'Hydraulique et Environnement (EDF-DRD – French Electricity Board). TELEMAC uses an unstructured mesh technique that allows representing complex coastal features such as manmade navigational channels, tidal flats, dredged area and harbor structures.

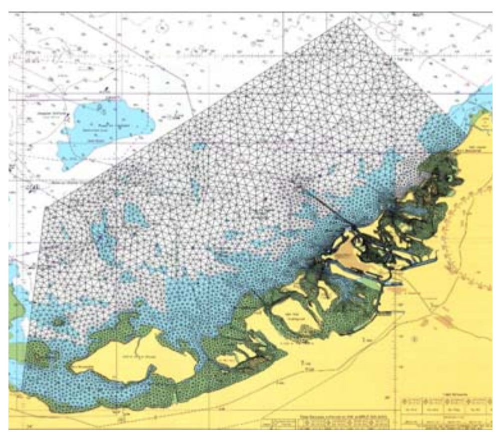
The global regional model comprises a triangular grid, with meshes varying in size from 1km to 10km depending on depth. The purpose of the hydrodynamic model of the entire Arabian Gulf is to provide boundary conditions for two-dimensional high-resolution local scale coastal models for performing coastal studies. The mesh used in the global regional model, shown in Figure 2(a), represents a relatively fine grid near the coastline and around islands. The global regional model has been developed using hydrographic charts of the different sea areas around the Gulf coupled with local bathymetry from bathymetric surveys. The boundary condition of the model is forced at the Straits of Hormuz by real data. The global regional model has been calibrated and validated against tidal data from a large number of stations located around the Gulf. The results of the global regional model are used to provide boundary conditions for several large scale models.

**Large Scale Numerical Model of Abu Dhabi**

Using the results of the global regional model, several large scale numerical models have been developed using finer grid sizes and bathymetries for individual coastal stretches (Bahrain, Oman, Qatar, Abu Dhabi, Dubai, Sharjah and Fujairah). Each of these large scale models are also further validated with available tide measurements. Typical view of Sogreah's (2005) large scale model domain covering the Abu Dhabi coast can be seen in Figure 2(b). This finite-element based large scale numerical model represents the main tidal flats, deep channels and other coastal features of the Abu Dhabi coast. The hydrodynamic current circulations due to tidal variations were studied for the large scale model domain and the engineering parameters such as velocity and water surface elevation are extracted for each node. The results obtained from the numerical model were compared with available data from tide gauge measurements along the Abu Dhabi coast.




(a) Gulf model



(b) Abu Dhabi model

**Fig. 2 View of global regional and large scale model domain mesh**

## LOCAL SCALE MODELS

**Brief Software Description**

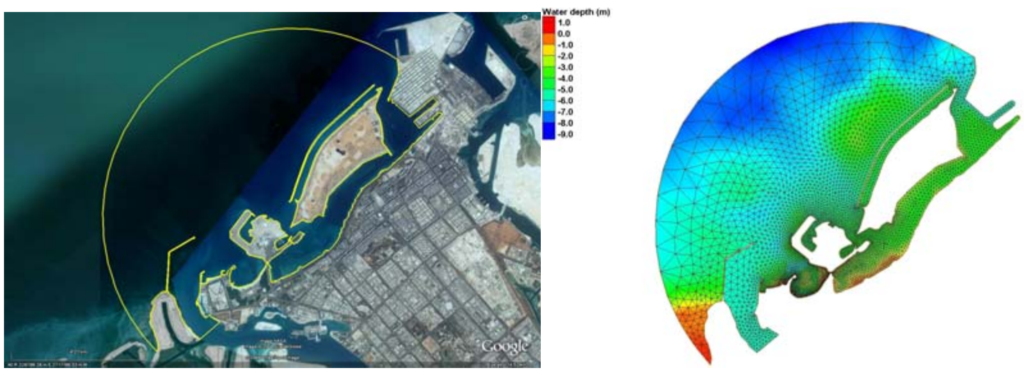
In the present study, the hydrodynamic characteristics of the local scale models were studied using the RMA2 numerical scheme (Donnell *et al*, 2006), which is a time-dependent two-dimensional depth integrated finite element hydrodynamic code developed by the U.S. Army Corps of Engineers. RMA2 can be applied to calculate water levels and flow distribution around islands due to static and dynamic boundary conditions. RMA2 is capable of simulating wetting and drying events due to the variations in the tidal elevations.

**Case Study 1: Entrance of Mussafah Channel**

The numerical model domain is set-up for the Mussafah channel entrance covering an area of 11.0km alongshore and 5.0km offshore, as can be seen in Figure 3(a). The model domain is discretized with a total number of 18281 nodes making a total number of elements of 8647. The average mesh size is about 750m at the offshore boundary and size of elements is gradually decreased towards shallow waters. The size of smallest mesh along the nearshore is about 20m. The tidal wavelength to mesh size ratio (Westerink *et al*, 1994), as given below, is greater than 100 for the entire numerical model domain:

$$\frac{\lambda}{\Delta x} = \frac{\sqrt{gh}}{\Delta x} T \qquad (1)$$

where $\lambda$ is the tidal wavelength, $\Delta x$ linear dimension of mesh element, $h$ the water depth, and $T$ the tidal wave period. As the tidal wavelength decreases with decrease in water depth, $\Delta x$ is also decreased towards shallow waters. The seabed levels for the numerical model are extracted from different Admiralty charts (No.: 2889 and 2837) A typical view of the meshed Mussafah channel entrance and the bathymetry can be seen in Figure 3(b). The resolution of the grid is increased in the vicinity of islands and other coastal features.




(a) Model domain (image courtesy: Google, 2009) (b) Mesh

**Fig. 3 Model domain, mesh and bathymetry for Case study 1**

The mesh elements with land borders are imposed with slip boundary condition, where the flow is restricted in the direction perpendicular to shore. Two tidal boundary conditions (BC1 and BC2), representing the water surface elevations at the end-boundaries, were imposed on the local scale model; the locations of the same are presented in Figure 4. One boundary condition is introduced from the sea side of the model representing the incoming tide and another boundary condition represents the water levels at the curtailed end of Mussafah Channel. The input tidal elevations for the present study are extracted from the large scale model. Bed friction characteristics in RMA2 are basically controlled through Manning coefficient, which is initially applied as 0.03 for all the mesh elements. In the calibration process, the friction coefficients were varied systematically throughout the model domain. The final model is employed with Manning's friction coefficients varied between 0.02 and 0.035, depending upon the regional bed features. The energy losses due to the turbulent eddy viscosity are approximated by turbulence exchange coefficients. In the present study, the automatic dynamic assignment of turbulent exchange coefficients, Peclet method, was adopted. The Peclet number, *P*, as defined below, is set to a recommended value (Donnell *et al*, 2006) of 20 for the present study.

$$P = \frac{\rho u \Delta x}{E} \quad (2)$$

Where, $\rho$ is the fluid density, $u$ the average elemental velocity and $E$ eddy viscosity.

As the shallow nearshore area experience wetting and drying due to the tidal cycles, the model is employed to simulate the inundation and drying of mesh elements. To maintain the simulation stability, the steady state and dynamic depth convergence of the numerical model is set to 0.001m, which proved to be sufficed for the validation of the model.

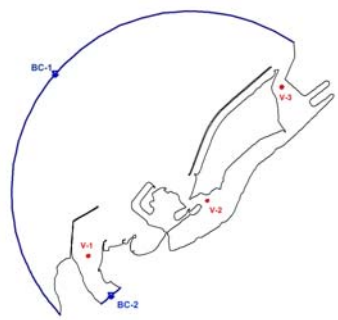
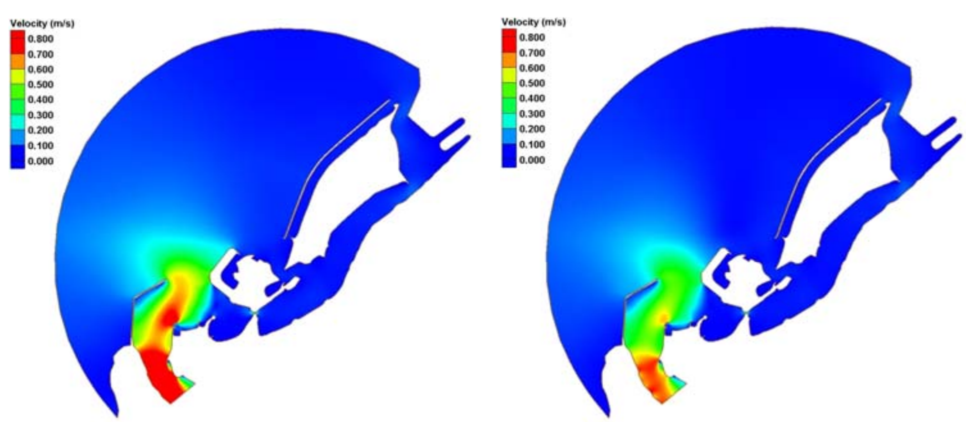


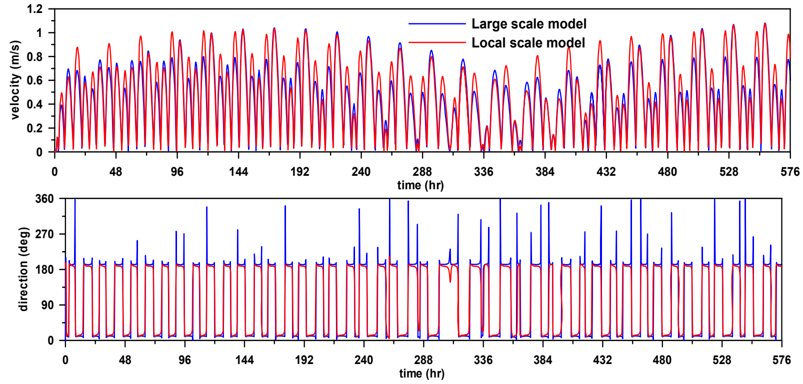

**Fig. 4 Model boundaries and validation points for Case study 1**

The tidal current velocities and water surface elevations at each grid point is obtained from the numerical model. The typical distribution of current velocities for a typical neap and spring tides are presented in Figure 5. Three distinct locations are selected, as shown in Figure 4, for the validation of the present numerical model. These three locations represent narrow water area, where the tidal currents are expected to be significant. The tide induced current velocities and their directions are extracted at the selected points and compared with that of large scale model. Typical such comparison, shown in Figure 6, demonstrates the capability of the present local scale numerical model. It is also observed from the figure that the current velocities at the entrance of the Mussafha channel (V1) reach up to 1m/s during the spring tide conditions, as described in Admiralty sailing directions (2005).

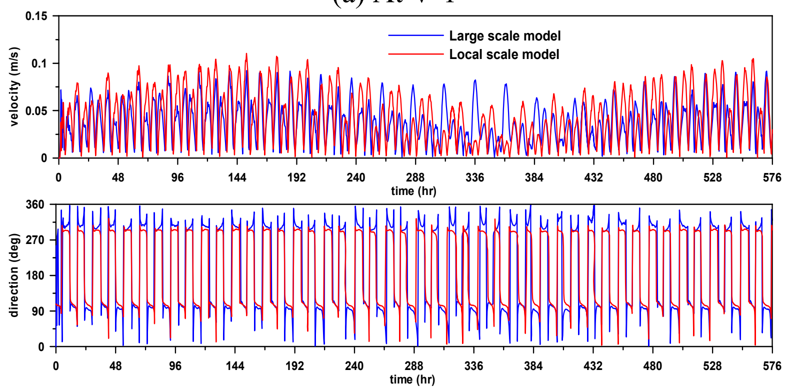



(a) spring flood tide (b) neap flood tide

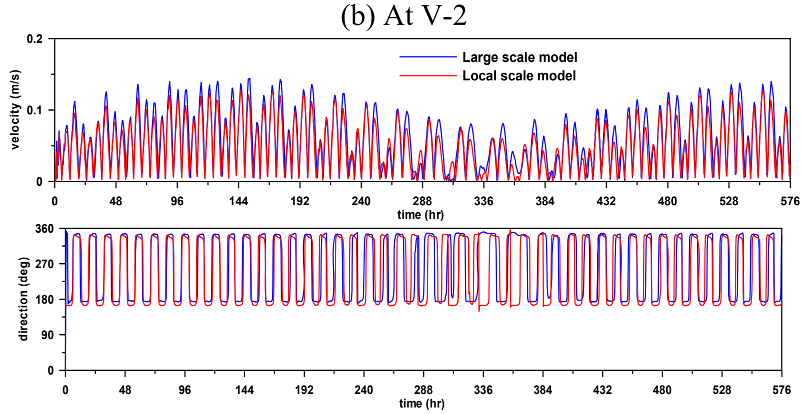
**Fig. 5 Tide induced current velocities for Case study 1**




(a) At V-1




(b) At V-2



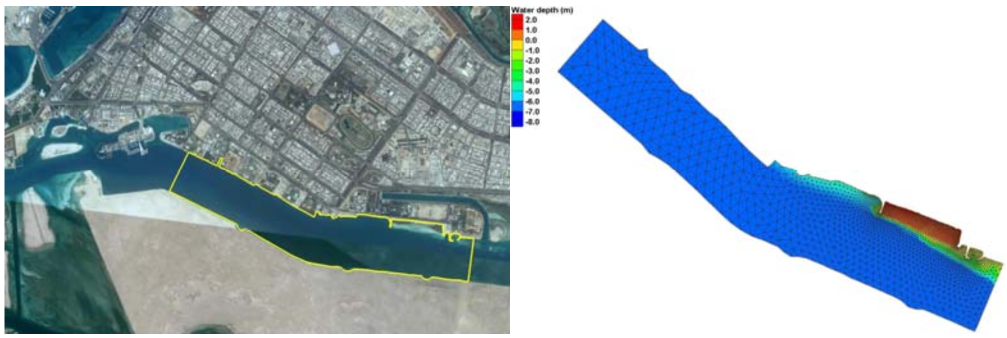

(c) At V-3

**Fig. 6 Comparison of current velocities and directions for Case study 1**

**Case Study 2: Mid-section of Mussafah channel**

For the Case study 2, the m odel domain co nsidered spans approxim ately 6.0km along the Mussafah channel and covers entire width ofthe channel, as shownin Figure 7(a). The domain is modeled with a to tal number of 7949 nodes m aking a total number of elem ents of 3824. A typical view of the m eshed model domain along with bathymetry can be seen in Figure 7(b). Two different boundary conditions (as indicated BC1 and BC2 in Figure 8), representing the water surface elevations at the end-boundaries, are imposed. The input water levels, shown in

Figure 9, were extracted from the large scale model of Abu Dhabi and used for the present study. The distribution of current velocities for a typical neap and spring tides are presented in Figure 10. Three locations indicated as C1, C2 and C3 in Figure 8, are selected from which the magnitudes of tide induced current velocity and its directions are extracted for validation purposes. The tide induced current velocity magnitude and its directions obtained from the local scale model at the three locations are compared with that obtained from the large scale model, presented in Figure 11, and are in good agreement.



(a) Model domain (image courtesy: Google, 2009) (b) Mesh

**Fig. 7 Model domain, mesh and bathymetry for Case study 2**

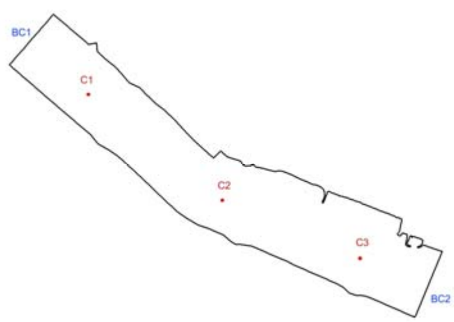
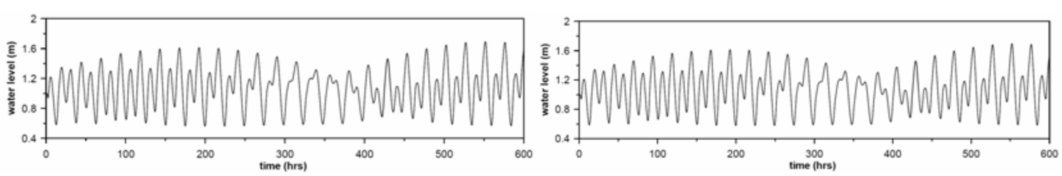
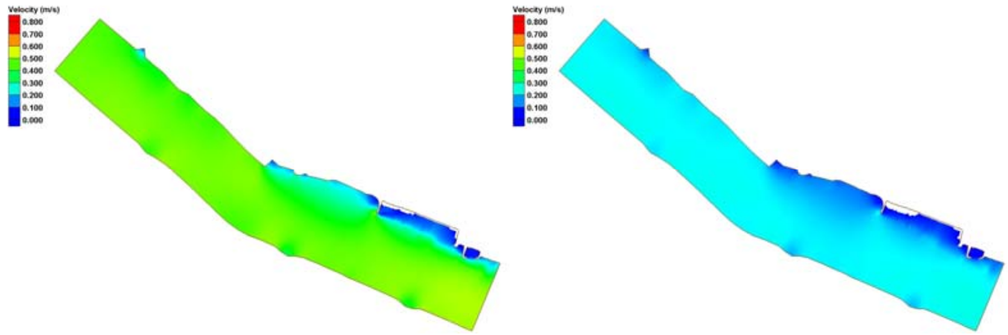



**Fig. 8 Model boundaries and validation points for Case study 2**



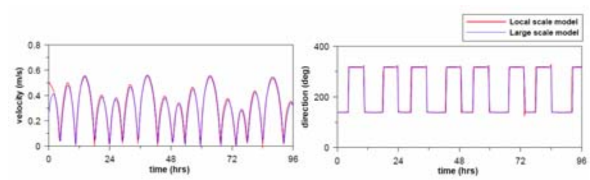

(a) at BC1 (b) at BC2

**Fig. 9 Water levels imposed at end boundaries for Case study 2**

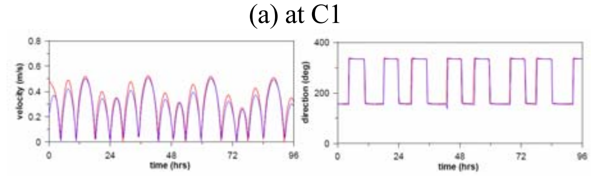



(a) spring flood tide (b) neap flood tide

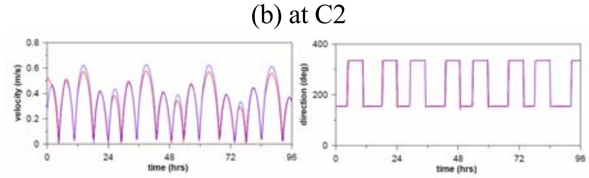
**Fig. 10 Tide induced current velocities for Case study 2**




(a) at C1




(b) at C2




(c) at C3

**Fig. 11 Typical comparison of current velocities for Case study 2**

## SUMMARY

The local scale hydrodynamic models of two different locations along the Abu Dhabi coastline have been developed and their efficiencies are tested against the results obtained from a large scale numerical model domain covering the entire Abu Dhabi coast. The local and large scale models were setup using two different finite-element methods based numerical schemes, namely RMA2 and TELEMAC-2D. The capabilities of the present local scale numerical model to represent the effect of various coastal features on the hydrodynamic conditions are demonstrated. The advantages of the local scale models are that they can be modeled with finer mesh to represent the coastal features close to reality and improved insight into the hydrodynamic conditions.

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