APPLICATION OF DELFT3D IN THE NEARSHORE ZONE

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1. INTRODUCTION

A clear and accurate picture of the conditions of the littoral waters regarding waves, surf and currents is important for military planning involving operations such as beach assault landings, mine sweeping, and special operations conducted by the US Navy and Joint Forces. Maritime operations these days requires the flexibility of a more complete and rapid assessment of the nearshore environment. In addition research conducted by the Navy has identified the improvements gained by an inclusion of the roller formulation of breaking waves in the surf zone modelling (Morris, 2001).

The latest technology to meet these challenges, Delft3D (developed by Delft Hydraulics), provides a sophisticated, 3-dimensional modelling system. Compact enough to run on a laptop computer, Delft3D can be set up on-scene and run quickly at high resolution in order to provide that rapid and complete picture of the nearshore conditions anywhere in the world.

Delft3D is capable of providing wave, current and sediment transport depictions. This modular system is high configurable and frees up the scientist and developer from devoting inordinate amounts time to model set-up, system development and transition. As a result a best-suited, mission-specific configuration can be tested, fitted and transitioned rapidly to operations as needed. An operator would be given a minimal set of controls freeing up time for other concerns. Such a concept of close cooperation between researcher and operator becomes quite relevant.

2. HISTORY OF MODEL TRANSITIONS

Ever since computers were fast enough to run numerical models, there have been research efforts to provide wave and surf zone forecasts for naval operations. Much has been done to study and modelling of deep and shallow water waves (Komen et al., 1994), culminating in the development of superior wind wave models such as WAM (WAMDI, 1988) and WaveWatch III (Tolman and Chalnikov, 1996). The Navy quickly made use of these models for all their deep water wave predictions (Jensen et al., 2002). With increasing requirements for the predictions of wave conditions in the littoral, wave research turned emphasis from wind wave generation to transformation of deep water waves into the nearshore zone leading to shallow water models such as STWAVE (Resio, 1993) and SWAN (Holthuijsen et al., 1993; Booij et al., 1999; Ris et al., 1999). SWAN has been tested and fitted for operations (Hsu et al., 2000; Dykes et al., 2002) to provide shallow water forecasts for Navy use. For coastal engineering purposes research has been focused on the surf zone itself (Battjes and Janssen, 1978; Thornton and Guza, 1983) and particularly for the study of wave-induced littoral currents (Church and Thornton, 1993; Thornton and Guza, 1986). Navy needs instigated plans to predict coastal conditions and a current operational capability is the Navy Standard Surf Model (NSSM) (Hsu et al., 2000). These various model capabilities are tied altogether into an integrated system called DIOPS (Distributed Integrated Ocean Prediction System) that goes from deep water waves to the surf zone (Allard et al, 2002a; Allard, et al., 2002b).

The NSSM is a one-dimensional model that predicts surf conditions for an approach to the beach. Its domain is a transect drawn perpendicular to the coast from breaking zone to sand. However, nearshore currents are also strongly affected by longshore pressure gradients caused by longshore variability in areas of breaking; this effect is not contained in a one-dimensional model. Obviously, improvements to the predictions can be realised if we go to a 2-dimensional domain to account for bathymetry variations along the coast. This is where Delft3D comes in.

3. DESCRIPTION

Delft3D is a software package that was designed primarily as an application focused on water flow and quality. The package consists of several modules coupled together to provide a complete picture of three-dimensional flow, surface waves, water quality, ecology, sediment transport and bottom morphology in complicated, coastal areas. The modules initially to be used for modelling of littoral waters by the Navy will be FLOW, WAVE, and MOR. Additional software

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useful for set-up, RGFGRID and QUICKIN, and post-processing, QuickPlot, are also included. Each module comes with its own set of menus for run configuration.

3.1 *FLOW module*

FLOW is a three-dimensional hydrodynamic and transport simulation program (Delft Hydraulics, 2001a). It has with a 2D (depth integrated) option. In three dimensions a sigma coordinate system is used. In shallow water non-steady flows can be simulated and forced by time-varying inputs such as surface winds and tides. Wave forces provided by a wave model comes mostly from breaking waves and induce currents which in turn force the transport of particles and dissolved materials. FLOW can take into account water density variations, turbulence, and drying and flooding of tidal flats. A recent improvement to the FLOW module has been the incorporation of a "roller" description for breaking waves (Roelvink, 2003); this imparts a geometric quality to the breaking wave form and thus allows specific dissipation and mass flux quantities to be derived.

Important applications include predicting flooding due to storm surge, assessing changes in coastal conditions due to river flow, avoiding the hazards of rip currents, and assessing mine burial due to sediment transport.

3.2 *WAVE module*

Two wave models are available in this module: HISWA (Holthuijsen, 1989) and SWAN both developed at Delft University of Technology in the Netherlands (Delft Hydraulics, 2001). HISWA is a second generation wave model while SWAN, a third generation model, is a successor of HISWA and thus offers increased capability. SWAN physics is more explicitly formulated while physics in HISWA is highly parameterised. A HISWA grid must be oriented in the mean wave direction (and wave angles are restricted to +- 90 degrees about the mean direction) whereas SWAN requires no restrictions on wave approach angle or directional width.. HISWA is strictly a steady-state model, but SWAN can be steady-state or time-dependent, thus allowing greater flexibility in the size of the domain of interest. Given the advantages of SWAN over HISWA, and plans to transition SWAN into operations, it makes sense that SWAN will be the model of choice in the future.

Wave prediction alone is important for safe navigation of ships in open water and harbours and surf conditions for amphibious landings.

3.3 *MOR module*

The intent of this module is to incorporate the effects of waves, currents and sediment transport on morphology of the seafloor (Delft Hydraulics, 2001b). Basically this module coordinates running the FLOW, WAVE, and other modules not currently addressed here, in order to predict the dynamic state of the bottoms of rivers, estuaries, and coasts in time scales ranging from days to years. Using MOR as a steering module, wave and surf conditions, alongshore currents and movement of water parcels are available for close coupling between FLOW and WAVE. Using a tree structure, each module can be set to run any number of iterations to meet certain criteria automatically and exchange output parameters as frequently as desired. The WAVE model is run in stationary mode at desired intervals. The FLOW mode is time varying and maintains continuity through out the run time.

3.4 *Model Domain Set-up*

A new aspect in operational modelling of the littoral zone is the use of curvilinear grids. This approach highly resolves areas of interest on the coast while allowing for low resolution grids far away at the domain boundaries; this is particularly advantageous for complex coastlines. The RGFGRID module is an application that makes it easy to create smooth, orthogonal curvilinear grids that follow land boundaries and better resolve complicated subsurface features. While visualising his work, the user can begin with splines that outline the area of interest, and then through an iterative process move and refine grids until satisfied. Of course, a simple rectilinear grid, really a special case of a curvilinear grid, can be easily constructed.

The QUICKIN module incorporates bathymetric data onto model grid points in an easy and convenient manner. Data can be specified on a curvilinear grid created in RGFGRID or on a rectangular grid made within this module. A set of depth values at scattered XY locations or 'samples' may be interpolated to the grid. Where the samples are denser than the local grid, grid cell averaging of the samples gives better model results rather than using local data only. Otherwise triangulation interpolation and diffusion methods are available for assigning values to grid cells. Also, QUICKIN can be used to discriminate between sets of samples based on their quality, because QUICKIN will not allow subsequently loaded data to contaminate data already incorporated onto the grid.

4. TEST CASE

4.1 *Simulation Set-up*

To test Delft3D, we set up runs using a well documented experiment called the DUCK94 Nearshore Field Experiment, held at the US Army Corps of Engineers Field Research Facility at Duck, NC during October 1994 (Birkemeier and Thornton, 1994). DUCK94 was focussed on sediment transport and morphology, and wave and nearshore circulation. Since the bed levels change considerably over time, bathymetry must be selected for a particular date; in this case, 10 October 1994. A portion that was used in this case spans 500 metres alongshore and 700 metres from shore seaward. The bar, a typical summer profile, is more pronounced on about 125 metres from shore (Figure 1).

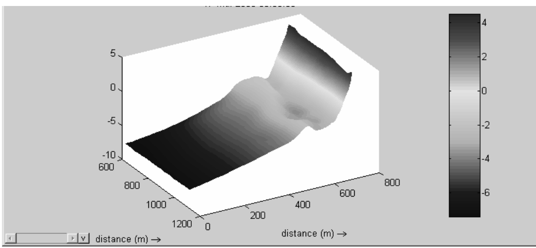

Figure 1. A sample bathymetry of Duck94 field experiment showing a barred beach.

The grid of the domain was created using RGFGRID. The curvilinear grid is rectangular with varying grid cell size, finer cells in the middle close to the coast. The domain was created such that enough space with sufficient resolution was placed between the area of interest as defined by the depths shown above and the boundaries. The grid cells at the 'padded' areas need not be as fine as those in the middle where it is more critical to better define the bathymetric and coastal features. Actually, two similar grids were used, one for SWAN and one for FLOW. The only difference between each is that FLOW has slightly less padding setting its lateral boundaries inside the SWAN domain.

This simulation was set up to run SWAN and then FLOW for a one-hour time frame, which was long enough to reach a steady state. The focus is to study wave-induced alongshore currents in this domain. No tide or wind input was included, but the bathymetry has included the tide adjustment. To reduce the effects of open boundary conditions out of the FLOW run, a Neumann condition for the lateral boundaries was used. This Neumann condition was set on the longshore gradient of the water level only; this had the effect of greatly reducing the governing equations solved at the lateral boundaries and thus allowed the remaining variables to evolve realistically. The Neumann condition is particularly important to contain the behaviour of the pressure gradients at the boundaries when the roller is turned on. As a recent improvement to the wave forcing in Delft3D, the roller calculation distributes the momentum due to wave breaking further away from the actual breakpoint, allowing higher flow velocities into the bar trough. For a barred beach, a flow model without roller model has been shown to predict the velocity peak at the crest of the bar whereas the measured data shows the peak is always located in the trough. In his evaluation of Delft3D, Morris (2001) showed that the inclusion of the rollers improved the longshore current prediction.

4.2 *Results*

Based on the measured data at 8 m wave gage array, the wave input is set to significant wave height 1.3 metres, the mean period 6 seconds, the mean direction 18 degree relative to the shore normal, and the width of the energy distribution 4 at all boundaries. Using QuickPlot the results are extracted from the output files. Depth averaged currents are plotted over the bathymetry. Figure 2 shows the currents without the roller calculation in the lighter colour. Currents with the roller turned on, in the darker colour, are much larger alongshore and show a larger seaward component of flow moving out through the bar opening.

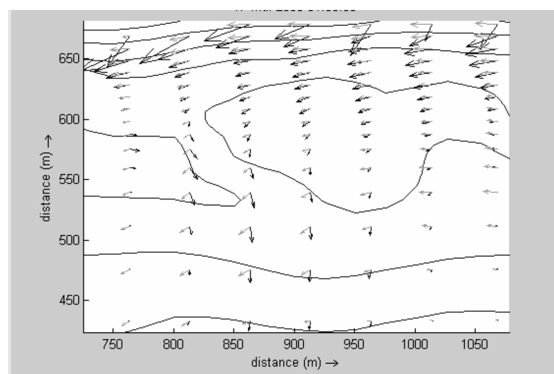

Figure 2. Depth averaged velocities. Darker arrows are currents with roller turned on.

With the roller turned on, the shear stress from the roller breaking moves the velocity peak towards the trough as expected. Figure 3 depicts the water depths of a cross section, and Figure 4 shows in that same section the flow comparison between results with and without roller. A typical Chezy coefficient of 65 is used corresponding to a bottom friction coefficient (C_f) of 0.0023. Morris (2001) used the White-Colebrook bottom friction formulation which requires selection of bottom roughness. He reported that best fitted cross-shore averaged C_f is 0.002 for barred beach in Duck94 and 0.004 for planar beach in Santa Barbra beach, CA. We are in the process of evaluating the effect of bottom friction on velocity distribution and establishing the model sensitivity.

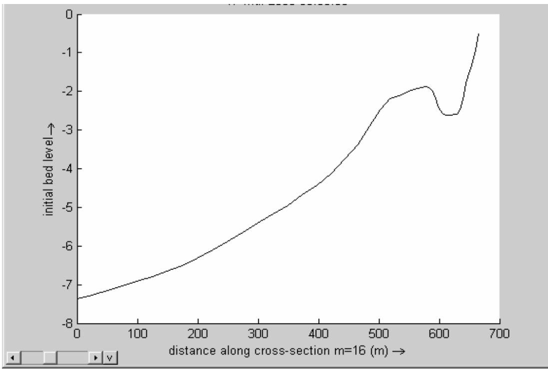

Figure 3. Beach profile at x=650 m where a distinct bar and trough is preset.

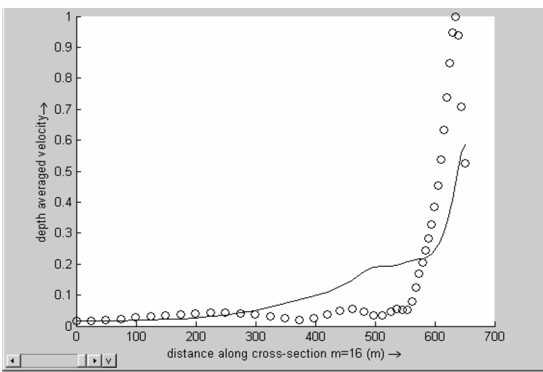

Figure 4. Comparison between magnitudes of averaged currents with roller (circles) and without (solid line).

5. CONCLUSION

Delft3D is a comprehensive numerical model, which includes wave, hydrodynamic flow, sediment transport, and morphologic response modules. We are only tapping into a portion of its capability which cannot simply be passed onto for operational use yet. Some parameter values such as bottom friction need to be established or defining rules of thumb for a small list of settings. Conducting more experiments like what is described in this paper will be necessary to establish those values. Once they are set, Delft3D can be integrated into existing modelling system such as DIOPS to effectively support the quick response operations. Meanwhile the flexible capability of the existing menu system can be used by the research community to continue the nearshore research.

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