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Use of the PTM with CMS Quadtree Grids

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PURPOSE: This Coastal and Hydraulics Engineering Technical Note (CHETN) describes procedures to set up a particle tracking simulation through coupling the Coastal Modeling System (CMS) with a quadtree grid and Version 2.1 of the Particle Tracking Model (PTM) in the Surface-water Modeling System (SMS). A CMS/PTM application is presented to demonstrate the recent changes in the SMS interface of the PTM.

INTRODUCTION: The CMS, developed by the Coastal Inlets Research Program (CIRP), is an integrated wave, current, sediment transport, and morphology change model for coastal and inlet applications (Sanchez et al. 2011; Lin et al. 2008). The Particle Tracking Model (PTM) was developed jointly by CIRP and the Dredging Operations and Engineering Research (DOER) program as a tool to compute the fate and pathways of sediments and other waterborne particulates in coastal engineering and dredging operations (MacDonald et al. 2006). Coupling of the CMS with the PTM is implemented in the SMS (Demirbilek et al. 2008; Aquaveo 2010; Li et al. 2011).

Recently, the CMS model has been extended by introducing a quadtree grid solution scheme (Wu et al. 2010), a local grid refinement that can be used to better resolve nearshore hydrodynamic processes. The quadtree approach uses successive splitting of neighboring cells into four sub-cells as often as required. This produces non-uniform cells in parts of modeling domain (e.g., cell size is not constant). All cells are numbered in sequence and pointers are used to determine the connectivity with neighboring cells. An example of a typical quadtree grid with five different cell sizes is shown in Figure 1. Figures 2 and 3 show two grids generated for Humboldt Bay, CA.

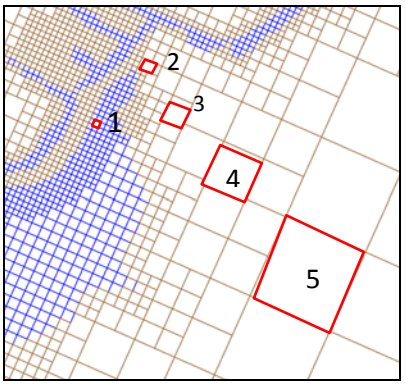

Figure 1. Example of a quadtree grid with five different cell sizes.

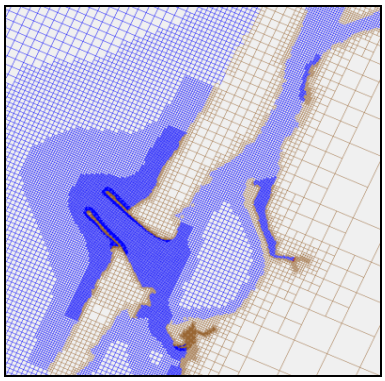

Figure 2. Humboldt Bay CMS quadtree grid.

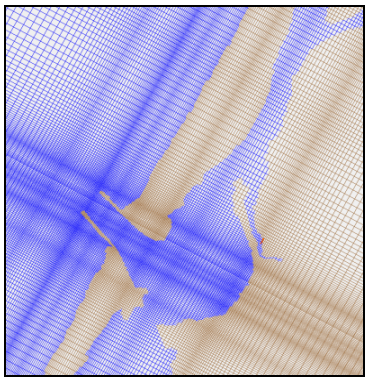

Figure 3. Humboldt Bay CMS extended variable grid.

In the quadtree grid, small cells are used to resolve the geometry where necessary (e.g., around the two jetties) in an attempt to improve hydrodynamic calculations. In the extended variable

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grid, the grid refinement will produce small cells along an entire row or column, and small cells occur in parts of the modeling domain where they are not required. The quadtree grid example of Humboldt Bay shown in Figure 2 (and used as an example later in this CHETN) has less ocean cells (30,962) than the extended variable grid spanning the entire rows/columns (32,058), yet provides better resolution in the areas of interest and greater spatial coverage of the study domain. Modifications have been made to the PTM v2.1 so that quadtree-based CMS results can be used in project applications as input. A summary of these changes is provided next.

CODE CHANGES (PTM v2.1): Several significant changes were made to the PTM v2.1 for the model to handle quadtree grids when applied with the CMS. These changes include a new internal solution mesh, reading a quadtree grid file, and some simplification of the input requirements. None of these changes affect the application of the PTM with other hydrodynamic models.

The PTM uses an ADCIRC-based unstructured triangular mesh to perform its calculations. In applications that use CMS hydrodynamic input, this mesh is automatically generated internally by the PTM using the CMS grid. The earlier PTM mesh scheme did not cover the entire CMS grid domain. The changes made to PTM v2.1 allow the full CMS-Flow domain to be modeled in the PTM.

Previous versions of the PTM required the user to construct boundary cellstrings around the active part of the domain when used with the CMS. This task is now performed automatically in PTM v2.1 and all the required information is generated and stored in a boundary condition file (*boundary_conditions_filename*.bc). The user only needs to provide a name for this file. Once generated, the model reads the data from the file in subsequent runs.

The PTM results for any particles released in a simulation are recorded in a particle file, which contains static and/or dynamic output; steady-state or temporally varying seabed characteristics (e.g., sediment transport rate, native sediment mobility) are output to a map file. To visualize map-based PTM data in the SMS, an associated unstructured triangular mesh must be opened first. In applications that use CMS-Flow, the mesh data is imbedded in the automatically-generated boundary condition file described above.

PTM v2.1 is the first version that can be used with the quadtree grids of CMS-Flow, as well as extended variable grids of the CMS. It can also be used with the output of implicit or explicit CMS-Flow simulations. PTM v2.1 uses the CMS control card file (*card_filename*.cmcards) to specify type of CMS grid being used in a simulation. PTM v2.1 now accepts a single set of native sediment grain sizes for the entire domain, and no longer requires generating a native sediment grain size file.

PTM INTERFACE CHANGES: A few changes were made to the PTM interface in SMS so that PTM v2.1 can work with the telescoping grids of the CMS. These changes are described next.

The *Files* page of the PTM interface is used to edit much of the model run-time control parameters (Figure 4). The PTM inputs are described elsewhere (Demirbilek et al. 2008; Li et al. 2011) and will not be repeated here. Only parts of the input modified for PTM v2.1 will be discussed.

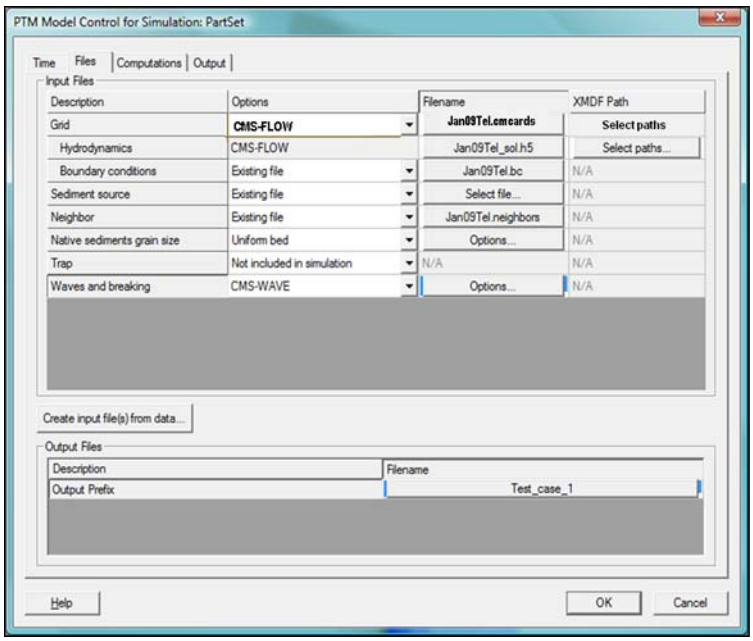

Figure 4. *Files* page of the PTM control window.

- *Grid* - Select CMS-Flow under the *Options* tab and specify the name of the cards file in the *Filename* column. The PTM v2.1 will read the card file to determine the type of simulation (e.g., standard, variable or quadtree grid) from the contents of the cards file.

- *Boundary conditions* - This file has information about what to do for the PTM along the boundaries of the CMS-Flow computational domain. The PTM v2.1 now generates this file for CMS-based simulations automatically. If this is the first simulation using this CMS-Flow grid, select the *Options* tab to set "*Create when model is run*". If a boundary condition file has been generated in a previous PTM simulation, select "*Existing file*" in the *Options* column and specify its name in the *Filename* column. This file is also required to view PTM map output files.

- *Native sediments grain size* - This allows the user to input information for the bed sediments over the domain. Previous versions of the interface have required that a full map of the sediments be generated or input; this can still be done and the process is described in detail in Li et al. (2011). However, in PTM v2.1, specification of uniform sediment field for the entire domain is done by selecting "*Uniform bed*" from the *Options* column and clicking "*Options...*" in the *Filename* column. This opens a pop-up window where the three representative grain sizes can be entered (Figure 5).

- *Visualization of map file* - The automatically generated *Boundary conditions* file by the PTM has the filename extension ".bc". The boundary information in this file determines what PTM will do with particles at the limits (boundaries) of the CMS-Flow domain. This information is also used for viewing the PTM map output files. The boundary condition file contains node location, element connectivity and boundary nodestrings for a triangular mesh. To view a PTM map output file, first open the boundary conditions (.bc) file using the *File | Open* command.

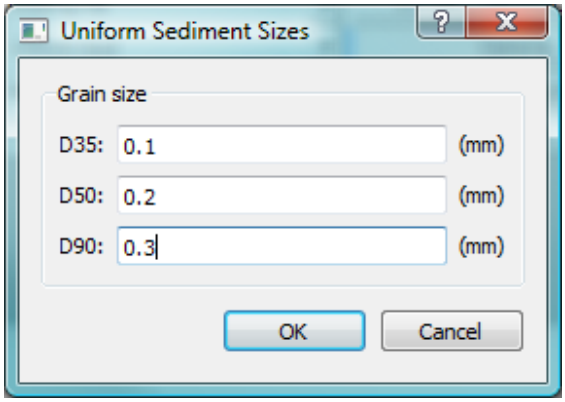

Figure 5. Pop-up window used to identify uniform bed grain size.

The .bc file will appear as "Mesh" with a single elevation data set. After this file is opened, the map file can be opened and visualized. Figure 6 shows the SMS data tree for a simple PTM v2.1 simulation before and after the map file is opened. Note that the SMS associates the map file output with the Mesh object, instead of the CMS-Flow grid.

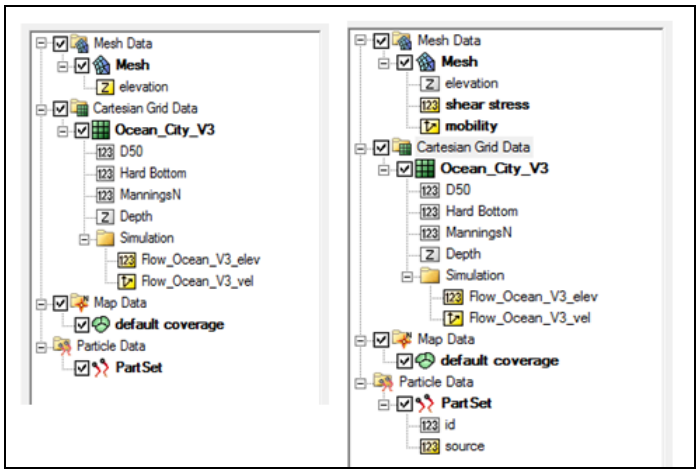

Figure 6. Example data tree: after opening boundary conditions file (left); after opening map and particle files (right).

Figure 7 shows the CMS-Flow grid and PTM boundary condition files for a quadtree grid for an inlet simulation. Note that the PTM mesh only exists over the water cells of the CMS-Flow grid.

- *Editing of boundary file* - The nodestrings generated outside the PTM's unstructured mesh are used by the model to identify open and closed boundaries for handling the behavior of particles at each modeling boundary. In the process of generating these nodestrings, the SMS will attempt to connect as many of the nodestrings as it can, and also identify nodestrings as either open (particles can pass through) or closed (particles cannot pass through). These nodestrings can be edited by the user to merge two or more nodestrings, split an individual nodestring, or to change the open/closed setting of a nodestring, if any of these adjustments

are necessary or desired. This would require the user to have ADCIRC interface enabled (in the SMS license) to perform these operations.

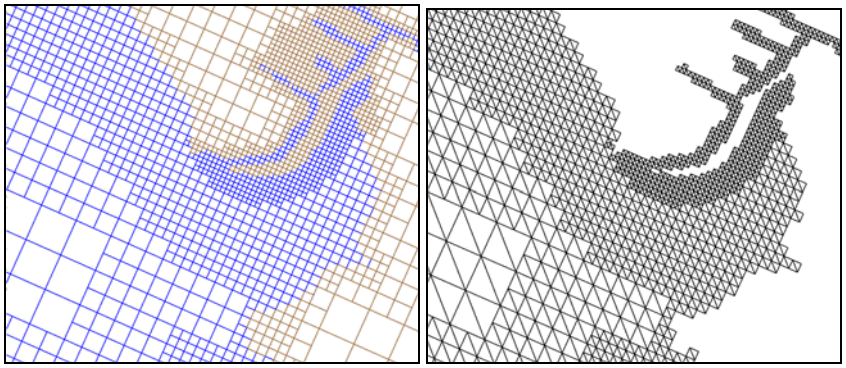

Figure 7. Example simulation: CMS-Flow model domain (left), and; PTM boundary condition file (right).

Merging nodestrings is performed by selecting two or more nodestrings, the nodestring selector tool ( ) and the pull-down menu selection *Nodestrings* | *Merge*. A nodestring can be split by selecting a node using the node selector tool ( ) and applying the pull-down menu selection *Nodestrings* | *Split*. Set the boundary conditions along one or more nodestrings by selecting the nodestring(s) and using the pull-down menu selection *ADCIRC* | *Assign BC...* Assign the boundary type *Ocean* for open boundaries and *Mainland* for closed boundaries.

A PTM EXAMPLE WITH CMS QUADTREE GRID: The PTM v2.1 is applied to Humboldt Bay, CA, and the CMS quadtree grid covers the bay and offshore areas. The grid domain is approximately 20 km x 25 km (Figure 2). The CMS calculates water levels, currents and waves through the coupling of a hydrodynamic model (CMS-Flow) and a spectral wave model (CMS-Wave). CMS-Flow simulates hydrodynamics, sediment and salinity transport, and morphological changes. It is driven by time-dependent water surface elevation at the offshore open boundaries, and wind forcing over the surface boundary. The PTM results are presented and compared to those produced using CMS with an extended variable grid. A comparison of the two grids is shown in Figure 2. The aim of this example is to demonstrate the differences between PTM v2.1 and earlier versions.

Because development of a PTM simulation has been presented in other publications (Demirbilek et al. 2008; Li et al. 2011), only steps that have changed are discussed in this section.

Start with the *Files* page (Figure 8) of the PTM interface in SMS:

1. Grid: Identify as "*CMS-FLOW*" and enter the name of the cmcards file (**.cmcards*).

2. Boundary conditions: Select "*Create when model is run*" and give a new file name with extension *.bc*. The process of generating this file can be time-consuming, but it will be written to disk and can be read rather than generated in subsequent runs.

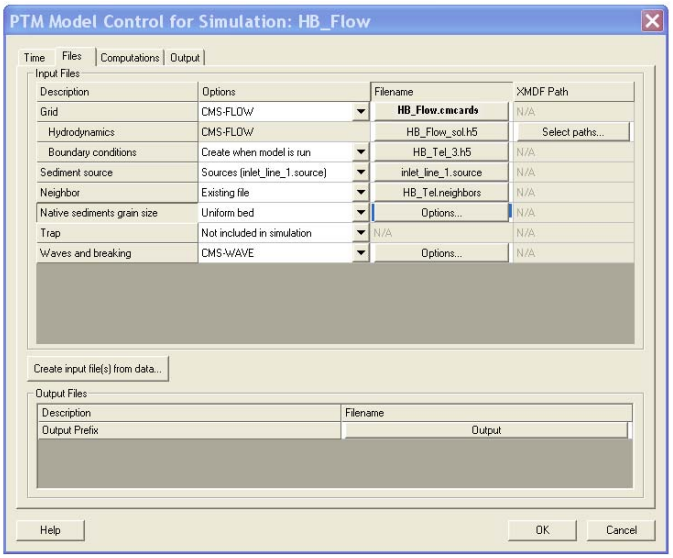

Figure 8. Completed model control Files page of Humboldt Bay PTM.

Go to the *Time* page (Figure 9) and follow these instructions:

1. Complete the desired simulation time input. In the present case, a short 1.0 sec time step is used because the *Advection* will be set to *3-D*.

2. Set the two update frequencies to 300 steps, since the flow is not expected to vary strongly over five minutes between updates.

3. Set the output frequencies to appropriate values. Note that the *Mapping Output* will only become editable once a map output box is checked on the *Output* page.

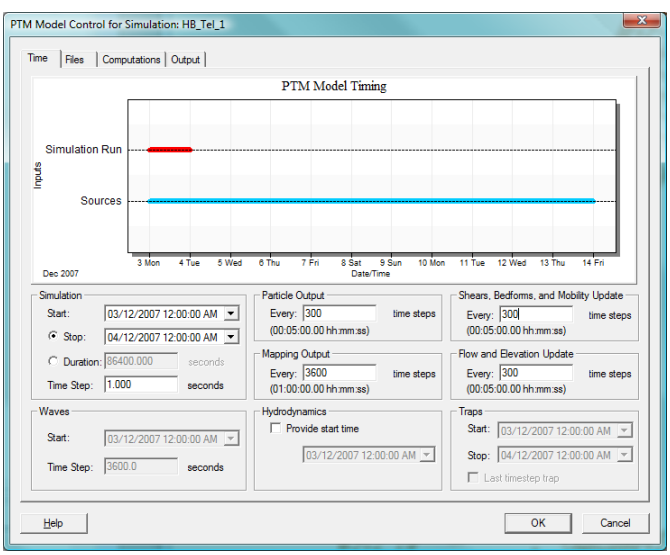

Figure 9. Completed Humboldt Bay PTM model control *Time* page.

Once the remaining input is specified on all other control pages, it is recommended that the user check the PTM setup (*PTM | Model Check...)*. Next, the model is executed (*PTM | Run Model*). Since this is the first simulation using this model grid, the PTM will generate boundary nodestrings. The user should check the nodestrings to ensure that the open/closed boundary settings are correct. By opening the **.bc* file and selecting the nodestring(s), the boundary condition setting of one or more nodestrings can be changed. Use the boundary type *Ocean* for open boundaries and *Mainland* for closed boundaries.

VIEWING SIMULATION RESULTS: In this example, the results will be shown for a continuous release of 0.1 mm sediment from a line source in the inlet throat (Figure 10). The simulation time is 24 hours, although the source is set up for a longer period (Figure 11).

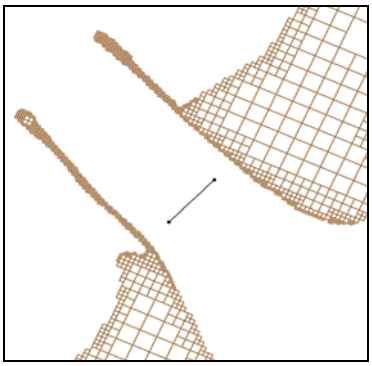

Figure 10. Line source location.

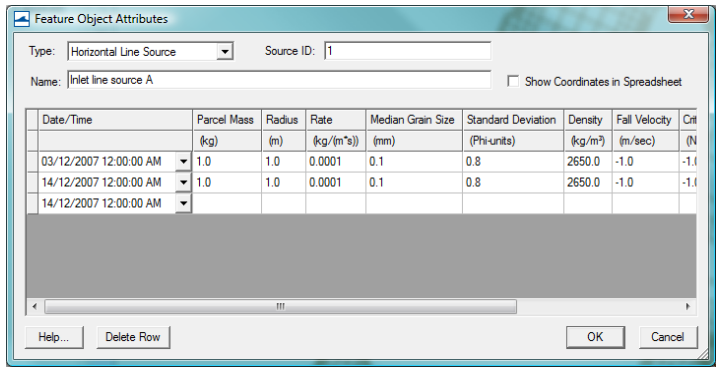

Figure 11. Line source: location release details.

The snapshot results are shown at hours 6 and 24 in Figures 12 through 15. The plots to the left show the particles' grain size (*D*) and those on the right show the particles' mobility (*M*), where a particle becomes immobile if $M < 1$. In the early stages of this simulation during ebb tide, the particles are mostly located seaward of the source location. The finer particles have traveled further (Figure 12) and only those in the throat of the inlet are mobile at this time (Figure 13). At the start of the flood tide, flows in the inlet increase, and more particles become active (mobile). During the ebb tide, the majority of the particles are mobilized in the entire inlet area. At 24 hours (Figures 14 and 15), the particles have been dispersed over a large area inside and outside the inlet. Larger particles remain close to the release area while the smaller particles move the furthest. Particles transported the furthest away from the inlet throat become immobile throughout the entire tidal cycle.

PTM simulations were also conducted using CMS-Flow results with a quadtree and an extended variable rectangular grid, respectively. The PTM produces identical results regardless of the type of hydrodynamic model grids, as long as the simulation parameters and flow fields are identical and the grid resolutions are similar.

The quadtree grids of CMS-Flow allow the modeler to increase cell resolution in areas of interest, where the solution is expected to vary spatially. In some cases, the smaller cells of the quadtree grids may help to improve the accuracy of flow calculations, which in turn can affect the PTM results. To illustrate this, two simulations were conducted using a point release at a location where the two CMS-Flow models have very different cell sizes (Figures 16 and 17).

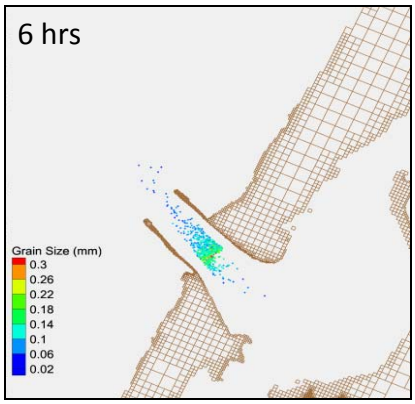

Figure 12. Particle distribution at 6 hrs (grain size).

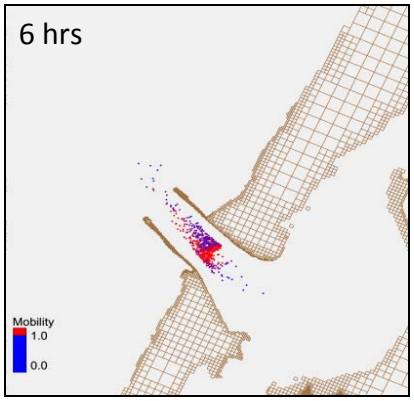

Figure 13. Particle distribution at 6 hrs (mobility).

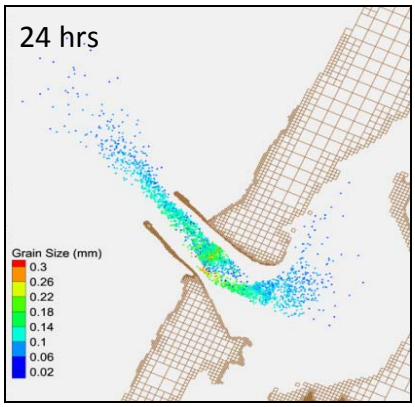

Figure 14. Particle distribution at 24 hrs (grain size).

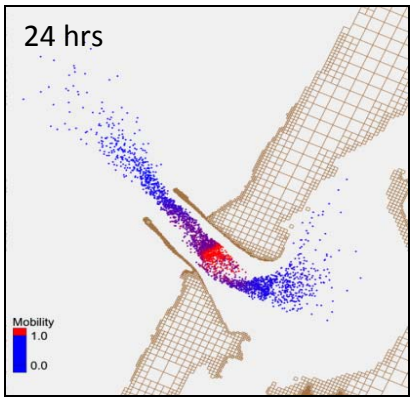

Figure 15. Particle distribution at 24 hrs (mobility).

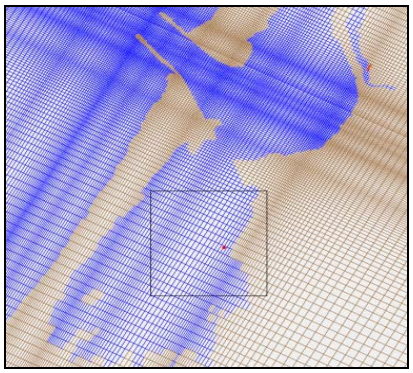

Figure 16. Extended variable grid near point release (red dot).

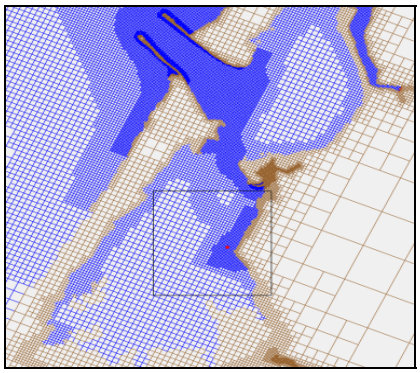

Figure 17. Quadtree grid near point release (red dot).

Because of the differences in the flow patterns in this area with two different grids, the pathways of sediment released are different (Figures 18 through 21). These figures show the results from both models at 6-hourly increments (the release location and view window extent is shown in Figures 18 and 19). Although the path of sediment moving along the shore is similar, the offshore deposit locations differ by over 250 m.

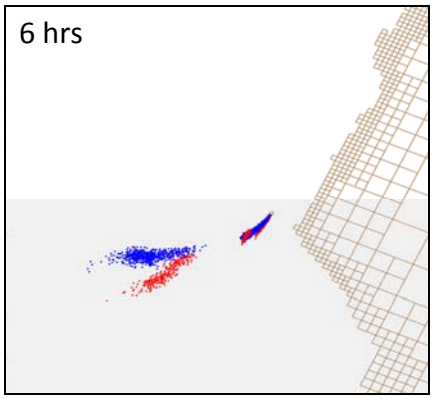

Figure 18. PTM results at 6 hrs: extended variable grid (blue) and quadtree grid (red).

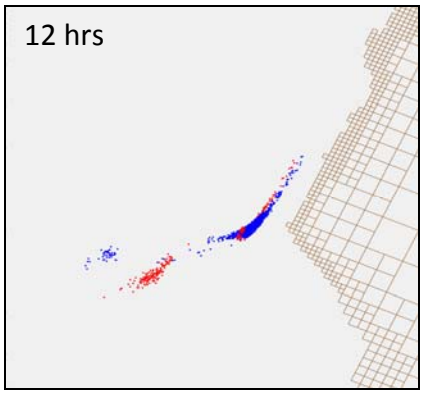

Figure 19. PTM results at 12 hrs: extended variable grid (blue) and quadtree grid (red).

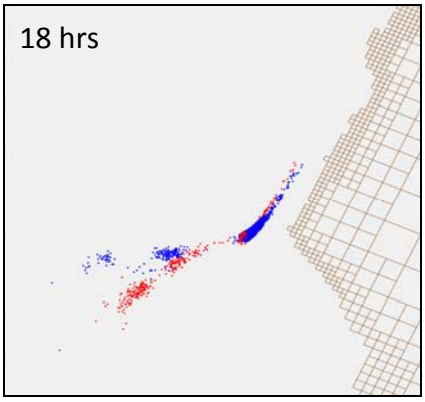

Figure 20. PTM results at 18 hrs: extended variable grid (blue) and quadtree grid (red).

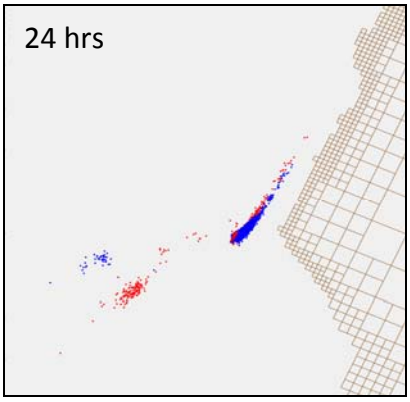

Figure 21. PTM results at 24 hrs: extended variable grid (blue) and quadtree grid (red).

SUMMARY: This CHETN describes use of the PTM with CMS quadtree grids. The example application shows that the PTM produces similar results with CMS hydrodynamics calculated on an extended variable rectangular grid and quadtree grid with similar resolution in the area of interest. In another region of these two grids, the example demonstrated that improved refinement with the quadtree grid resolved PTM results more accurately as compared to the extended variable rectangular grid. The quadtree grids allow modelers to use high levels of local resolution that may lead to improved flow calculations and PTM results. Feedback and suggestions from users on the design, implementation and usage of the PTM with the CMS are welcome. Please direct any comments to the lead author.

ADDITIONAL INFORMATION: This CHETN was prepared and funded under the CIRP and was written by Dr. Honghai Li (*Honghai.Li@usace.army.mil*, voice: 601-634-2840, fax: 601-634-3080) of the U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory and Dr. Neil MacDonald of Coldwater Consulting Ltd. (*nmacdonald@coldwater-consulting.com*). For information about the CIRP, please contact the Program Manager, Dr. Julie

Dean Rosati (tel: 251-694-3719) or by email (*Julie.D.Rosati@usace.army.mil)*. This CHETN should be referenced as follows:

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An electronic copy of this CHETN and I/O files for the example are available from:

> *http://chl.wes.army.mil/library/publications/chetn/*

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Wu, W., A. Sanchez, and M. Zhang. 2010. An implicit 2-D depth-averaged finite-volume model of flow and sediment transport in coastal waters. Proceedings of the International Conference on Coastal Engineering, No. 32 (2010), Shanghai, China. Paper 306: sediment.22. Retrieved from *http://journals.tdl.org/ICCE/*.

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