# Application of Two Dimensional Models to Simulate the Flow and Sediment Transport in the Middle Reach of Yangtze River, Renmin Island Region

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**Abstract:** In this paper, a process based on hydrodynamic, sediment transport and morphological model were presented. The main aim of the study was to assess the effect of sediment erosion and deposition on the bathometry of the Yangtze River in the Renmin island region. This study site was chosen because of the presence of large quantities of sediment transported and deposited in this island reach and thus, increases the area of the island yearly. These encroachments can trace back from the evolution of the island. In this study, Delft3D-Flow with an application of two dimensional models was used to simulate and evaluate the hydrodynamics and morphodynamics of the Renmin island region. Data on the discharge, water level and sediment concentration from June 1986 to June 1992 were used for the hydrodynamic and morphodynamic models. Comparisons were made between the computed model results and the observed data. The overall results revealed that, the sediment deposition in the left branch side was larger than that in the right branch side where continuous erosion and the tail part of the island increased in deposition. Hydrodynamic and sediment transport model has been calibrated and applied successfully with Delft3D-Flow sediment-online model.

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**Keywords:** Sediment; hydrodynamic; morphodynamic; erosion; deposition; bathometry; Delft3D-Flow; Renmin Island; Yangtze River

## 1. Introduction

The study of sedimentation is an important aspect of river planning and design. Such study can be supported by detailed analyses of flow patterns and sediment transport in rivers. It is usually conducted through numerical simulation, physical model and field investigation. Study of sediment transported in rivers is important because it concerns flood-control projects, erosion /deposition and the impact of erosion/sedimentation on the navigation on the river. The study area in the Yangtze River, the Yangtze River is the largest river in China. It is about 6300 km long with a catchment area of about 1.8 million km2 (about 19% of the total territory of China) (ZHIAN 1994). In the middle and lower reaches of Yangtze River, there are distinct dry and wet seasons. The flood season lasts from June to October. About 70%~75% of the water and 85%-98% of the sediment are transported in the flood season (Yun-Mei Zhu, 2007).

This study focused on the Renmin Island reach of Yangtze River. This area of the study is located in the middle reach of Yangtze River. The features of this reach have the general characteristic of the middle and lower Yangtze River, meanders with varying width, and islands in the river. From the landscape of this area, we can find the trace of the movement of old river and the discarded lakes in north of the river. This reach of Yangtze River moved southward into history. Renmin Island came into being at first as a bar in 1911and then evolved into an island. The island divides the river into two branches with its length extended from 400 meters to several kilometers now. This island plays an important role in the river bed morphology and the evolution of this island in the last decades is described in figure 1.

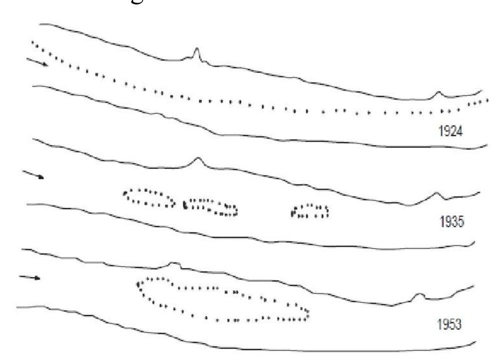



Figure (1): The development of Renmin Island

## 2. Material and Methods

### Model description

The modeling of island processes for this study was performed using the Delft3D modeling system. Delft3D is an integrated surface water modeling system developed by WL| Delft Hydraulics in The

Netherlands. The system was based on a flexible modular framework able to simulating two-dimensional and three-dimensional flow, sediment transport and morphology, waves, water quality and ecology and is capable of handling the interactions between these processes(Santiago Alfageme1 2005). Delft3D-Flow is the hydrodynamic module, and it was used to simulate a two dimensional (depth averaged) flows The Delft3D-Flow Sediment Transport, and Morphology adds on was coupled with the hydrodynamic to investigate sediment transport and morphological evolution. Delft3D-Flow solves the Navier-Stokes equations for an incompressible fluid under the shallow-water assumption. In the vertical momentum equation, the vertical acceleration is neglected, which leads to the hydrostatic pressure equation. The system of partial differential equations for conservation of mass and momentum was solved by a finite different method on an orthogonal curvilinear or spherical grid. The principal variables, such as water level, bottom level and velocities, are arranged in a special way known as the staggered grid (Deltares 2008).

**Hydrodynamic Model in Delft3D**

Delft3D-Flow is the hydrodynamic program of Delft3D. It provides the hydrodynamic basis for morphological computations. Delft3D-Flow calculates non-steady flow and transport phenomena resulting from tidal and meteorological forcing.(Arjen Luijendijk 2001).

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial v}+g\frac{\partial \eta}{\partial x}-fv+\frac{\tau_{bx}}{\rho_w(d+\eta)}-\frac{F_x}{\rho_w(d+\eta)}-v\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)=0$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial v}+g\frac{\partial \eta}{\partial x}-fu+\frac{\tau_{bx}}{\rho_w(d+\eta)}-\frac{F_y}{\rho_w(d+\eta)}-v\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)=0$$

(1) (2) (3) (4) (5) (6) (7) (8)

Where:

d = water depth below plane of reference [m]
f = Coriolis parameter, f = 2 Ω sin ϕ [s-1]
Ω = angular rotation of the earth = $7.27\times10^{-5}$ [rad/s]
ϕ = latitude [degree]
$F_{x,y}$ = x- and y-component of external forces [$N/m^2$]
u ,v = depth averaged velocity [m/s]
U = absolute magnitude of total velocity,
U = (u2+v2)1/2 [m/s]
ρ w = mass density of water [$kg/m^3$]
ν = diffusion coefficient (eddy viscosity) [$m^2/s$]
η = water level variation above plane of reference[m]
g = gravity of acceleration [$m/s^2$]
$\tau_{bx,y}$ = x- and y-component of the bed shear stress[$N/m^2$]

The formulas consist of the following terms: first term is velocity gradients; second and third terms are advection terms; fourth is the barotropic pressure gradients; fifth is the Coriolis force terms; sixth is the bottom stress term, seventh is the external forces' term and the eighth is the viscosity term. The depth-averaged continuity equation for a Cartesian rectangular co-ordinate system can be formulated as follows:

$$\frac{\partial \eta}{\partial t}+\frac{\partial (d+\eta)u}{\partial x}+\frac{\partial (d+\eta)v}{\partial y}=0$$

The set of partial differential equations in combination with an appropriate set of initial and boundary conditions for water levels and horizontal velocities is solved by a finite different method.

Non-Cohesive Sediment Erosion and Deposition:

The transfer of sediment between the bed and the flow is modeled using sink and source terms acting on the near-bottom layer that is entirely above Van Rijn's reference height,

The erosive flux due to upward diffusion through the underside of the kmx layer is approximated by the expression(Deltares 2008):

$$E=\varepsilon_s\frac{\partial c}{\partial z}\approx\varepsilon_s\left[\frac{c_a-c_{kmx}}{\Delta z}\right]\approx\frac{\varepsilon_s c_a}{\Delta z}-\frac{\varepsilon_s c_{kmx}}{\Delta z}$$

Where:

$\varepsilon_s$ = sediment diffusion coefficient evaluated at the bottom of the kmx cell [$m^2/s$]
Ca = reference concentration of sediment [$kg/m^3$]
$C_{kmx}$ = average concentration of the kmx cell[$kg/m^3$]
Δz = difference in elevation between the centre of the kmx cell and
Van Rijn's reference height: Δ Z = Zkmx − a[m]

The deposition flux of sediment through the underside of the kmx cell is approximated by:

$$D=\omega_s c_{kmx,bot}\approx\omega_s c_{kmx}$$

Combining the latter two equations result in a total source and sink term:

$$Source=c_a\left[\frac{\varepsilon_s}{\Delta z}\right]$$

$$Sink=c_{kmx}\left[\frac{\varepsilon_s}{\Delta z}+\omega_s\right]$$

The reference height is calculated in accordance with (Van Rijn 1993):

$$c_a=SUS.0.015\rho_s\frac{d_{50}(T_a)^{1.5}}{a(D_*)^{0.3}}$$

Where:

SUS = multiplication factor for calibration [-]
$\rho_S$ = density of the sediment [$kg/m^3$]
$d_{50}$ = characteristic grain size [m]
$T_a$ = non-dimensional bed-shear stress [-]
$D_*$ = non-dimensional particle diameter [-]

**Model Setup:**

A computational model can be a powerful

for investigating sediment transport and in stream hydrodynamic processes.

**Computational Grid**

The computational grid is generated by Delft3D-Rgfgrid, a module of Delft3D system, which is a module of Delft3D system. The computational grids should investigate the two main characteristics, firstly; the grid should be smooth enough to minimize errors in the finite difference approximations and secondly; the grid is orthogonalised with orthogonal factor not bigger than 0.01(Deltares 2008) .
Grid that was used in this model is verifying for these two characteristics. The length of study area in this model was about 18.5 km and schematized by a computational grid with 2225 grid cells, including 89 cells in long direction and 25 cells in the short direction. Figure (2) below shows the computational grid and location of Renmin Island.

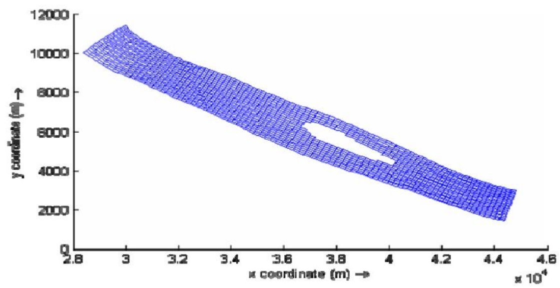



Figure (2): Computational Grid

**Bathymetry**

The bathymetry of the study area in figure(3) was digitized from navigation maps. The digitized file was converted to Delft3D format to enter through Delft3D-Quickin module of delft3D system. Delft3D-Quickin was used to create, manipulate and visualize bathymetries model for Delft3D-Flow. The data from digitized file consisting of x, y, z coordinates are called the samples, these samples are loaded at the middle of computational grid in the Delft3D-Quickin. Finally, we obtained the bathymetry as a depth file by using triangular interpolation.(Deltares 2008

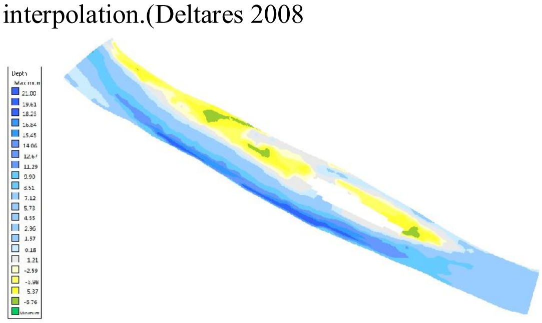


Figure (3): Bathymetry survey in 1986

**Initial Conditions and Open Boundary Conditions**

Initial conditions are usually needed for the computations of the hydrodynamic model. In this model, a restart file was used to read initial conditions. It was provided by running hydrodynamic model for seven days with constant discharge of 26,700 m3/s and constant water level of 7. 45m. For the open boundary conditions, there are two open boundaries that were used in the model: inflow and outflow boundary. In the inflow boundary (upstream boundary), the discharge time series can be specified at this boundary. Whereas in the outflow boundary (downstream boundary), the water level time series can be specified.

**Time Step**

The time step used in Delft3D-Flow was based on accuracy arguments. The accuracy mostly depends on the Courant number. In practice, this number should not be larger than 10. Courant number for two-dimensional models is defined as shown in the equation below (Stelling 1984):

$$C = 2\Delta t\sqrt{gh\left(\frac{1}{\Delta x^2}+\frac{1}{\Delta y^2}\right)}$$

Where:

$\Delta t$ is the time step [sec],{ $\Delta x$ , $\Delta y$ are characteristic values of the grid spacing in x, y direction
g is the acceleration of gravity [m/s2], and h is the local water depth [m].

This characteristic value can be calculated in the Delft3D-Quickin program for the entire grid. A time step of Δt = 1 minute is used in this model.

**Morphodynamic Model Set-up**

After the hydrodynamic model is calibrated, the sediment transport can be added to the simulation. For the morphodynamic model, all the data in hydrodynamic model (grid – bathymetry – open boundary conditions – time frame ….etc) were used and then two files were added, one of them for sediment concentration data (*.sed) and the other one for morphological data (*.mor).

**Sediment Parameter**

The sediment which was observed from the area studied, was fine grained sediment of a specific density ρs of 2650 kg/m3 and a parameter delta (Δ) with has a value of 1.65, defined as

$$\Delta = \frac{\rho_s - \rho}{\rho}$$

Where $\Delta$ is sediment parameter, $\rho_s$ sediment specific density and $\rho$ is water density. In this case study, initial sediment layer thickness at bed was 5m in thickness and the sediment has the characteristics of sand with the median diameter (D50) of sediment about 64 µm. The distributions of sediment grain size are shown in figure 4.(Lane 1947)

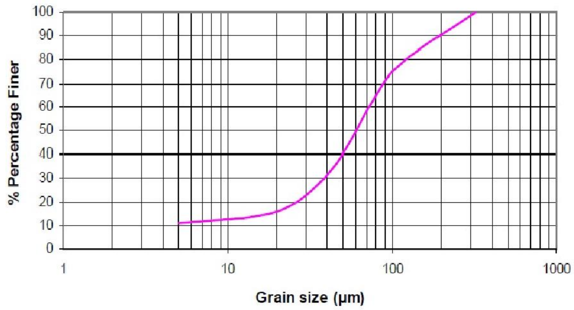
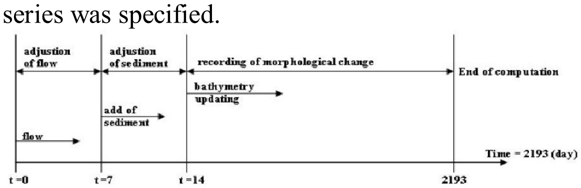



Figure (4): Distribution of sediment grain size

**Initial and Boundary Conditions**

The initial and boundary conditions have to be provided with information on the sediment concentration. The restart file has been used to define the initial conditions for the morphodynamic simulation. As for the boundary conditions, it was specified that the sediment input start after seven days of running time, after the flow had stabilized. Seven days more (computed flow time) pass in which the sediment transport has time to stabilize before the bathymetry updated begins at t=14 days. At the upstream boundary, the sediment concentration time series was specified.




**3. Results**

**Hydrodynamic model Calibration**

The adjustment of a numerical model to match the measured values was denoted as calibration. Several parameters were controlled to make the comparison between computed and measured values. For the hydrodynamic simulation, it is important to correctly reproduce the water level. For the hydrodynamic calibration, the main parameter calibrated bed roughness. The bed roughness expressed in terms of the Chézy value and for calibration of Chézy roughness, the model has been run for six years from 1986 to 1992. The value of Chézy roughness used was 65 m0.5/s, this value was found to be more suitable for calibration when the computed water level is compared with observed values. The result is demonstrated in figure 5. (Luitze .M. Perk 2006).

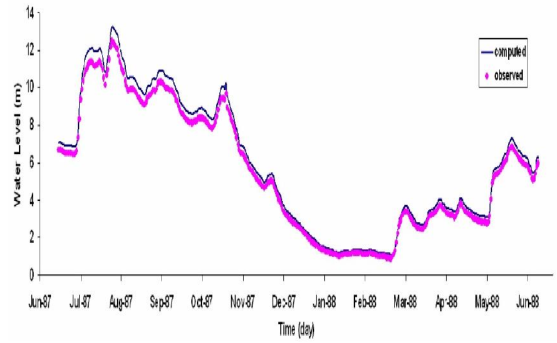



Figure (5): Comparison between computed and observed water level in 1987

**Morphodynamic Model Calibration**

After the hydrodynamic model was calibrated, the sediment transport data were added to the simulation.

For the morphodynamic model all data in hydrodynamic model were used and then two files were added; one of them for sediment data and the other one for morphological data. Before the calibration of the model, the parameter D50 has been chosen with average value of 64 µm. The main parameter of sediment transport model is the factor of suspended sediment reference concentration (SUS). The model has been run for four months by using constant discharge, water level and sediment concentration and using different factor values of suspended sediment reference concentration (SUS) ranging between( 0.1 - 0.4). The factor (3) was chosen for the calibration of this parameter because it was found to be suitable for the sediment transport model when the model was used for long term simulation and the value of this factor was 0.23 as shown in figure 6.

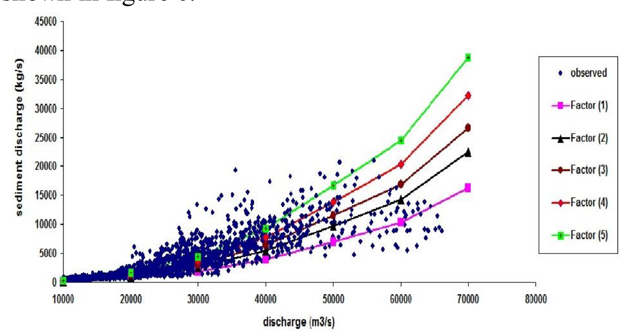



Figure (6): Calibration of sediment transport model (SUS Parameter)

**Flow velocity results**

During the flood season the peak discharge which occurred in September 1988 was 66,100 $m^3/s$. At this time the averaged flow velocity computed by this model in the right branch was 2.4 m/s and in the left branch the averaged flow velocity was smaller than the flow velocity in right branch which was about 1.46 m/s as shown in figure 7. The result denotes that the sediment deposition occurrence in left branch was larger than sediment deposition occurrence in right branch.

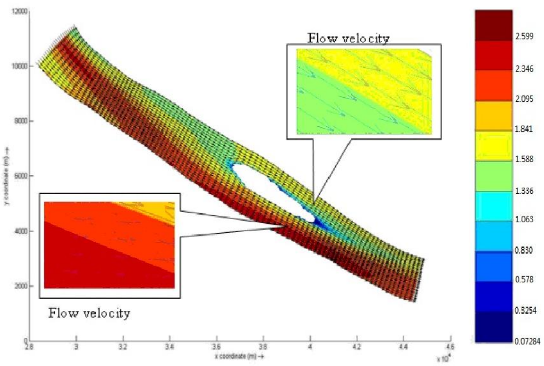



Figure (7): Flow velocity magnitude at peak discharge

**Erosion Deposition Pattern**

Changes of forms in the erosion deposition pattern during flood season given annually within the time of simulation for whole study area and for the area around the island were shown in figure 8. This figure has been inferred that, in the area around the island, the left branch of the river was continuously deposited and the right branch of the river was eroded and the thalweg of the right branch encroached southward. Therefore, more deposition in the tail part of the island can be seen.

**Morphological results of Renmin Island Reach**

To investigate the morphological results of Renmin Island, five longitudinal grid lines (fig. 9) in this area were chosen to analyze the results of accumulative erosion and deposition in six years time (1986-1992).

**Erosion/deposition in longitudinal sections in the branches of the river**

From the longitudinal sections in right branch (grid line1, grid line5) and in the left branch (grid line21, grid line25) of the Renmin Island, it was found that most of the areas from the longitudinal sections in right branch were eroded with maximum value of about 5m, and most areas of the longitudinal sections in left branch were deposited with maximum value ranging between 3m and 5.5m respectively, shown figure (10).

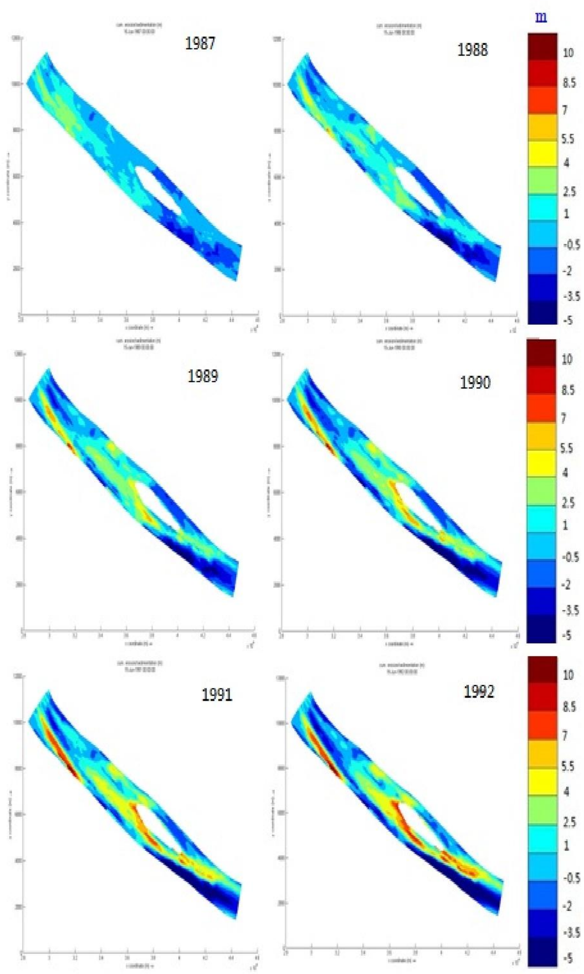



Figure (8): Erosion/deposition pattern annually for whole study area

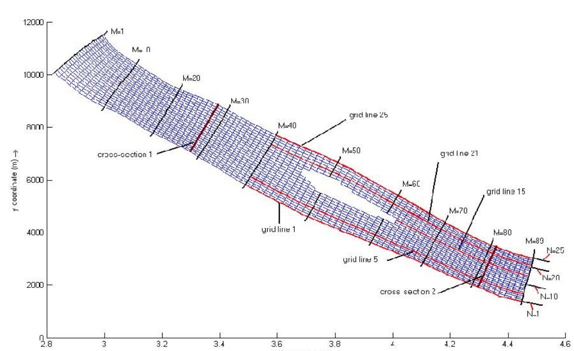
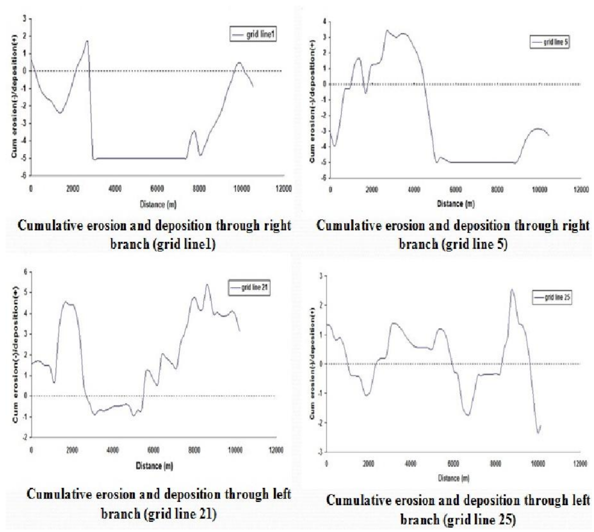



Figure (9): Description of the longitudinal grid lines analyzed




Figure(10):Cumulative erosion and deposition for the longitudinal grids Line on two left and right branches

**Erosion/deposition in the tail part of the island**

The longitudinal grid line 15 was chosen for the tail part of the Renmin Island and has been analyzed. When we compare cumulative erosion and deposition in 1987 with 1992, it was found that more sediment deposition occurred in 1992 in the tail part of the island (fig.11); this refers to increase extension of the island in downstream direction.

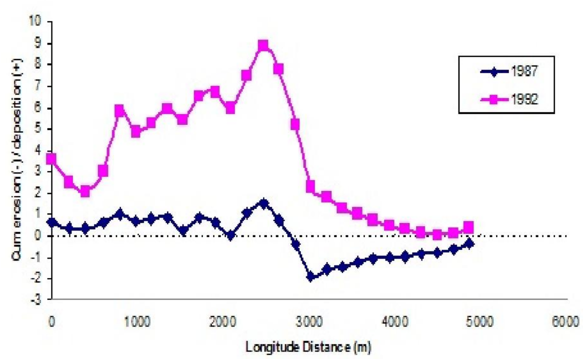



Figure (11): Comparison between cumulative erosion and deposition in 1987&1992 (grid line 15)

**Total accumulative Sediment Transport**

For the comparison of accumulative sediment transport in the area between cross section 1 and cross section 2, the result is shown in figure (12). Total accumulative sediment transport for six years through cross section 1 was about 110.85 Mm3, and for cross section 2 was about 86.77 Mm3. Therefore, the accumulative total sediment deposited in this area was 24. 081Mm3. This denotes that more sediment deposition occurred in this area between two cross sections.

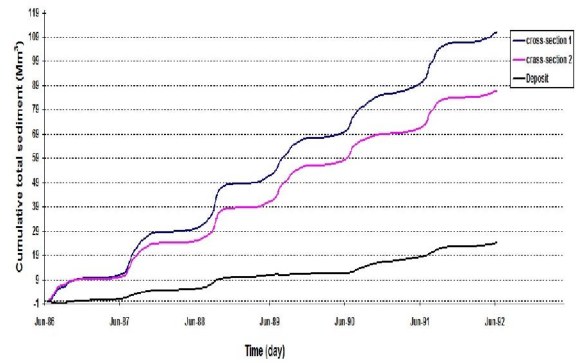



Figure (12): Cumulative total sediment transport for the area between two cross sections from(1986-1992)

**Influence of Sediment Concentration on the Morphological Computations**

To investigate the influence of sediment concentration on morphological computations, the peak discharge of 66,100 m3/s occurred in the 1988 floods and the average flood discharge of about 35,000 m3/s was chosen to simulate on the calibrated model with different sediment concentration (0.08, 0.18) kg/m3. The model has been run for four months during flood season from June to October. Figure (13) shows the erosion deposition pattern of the peak flood discharge in 1988 with low sediment concentration in the left plot and with high sediment concentration in the right plot. Figure (14) shows the erosion deposition pattern of the average flood discharge with low sediment concentration in the left plot and high sediment concentration in the right plot. In figures (13) and (14), it can be seen that erosion takes place seriously when the sediment concentration was low and it can be seen more erosion in upstream of this reach and in the right branch with the average of maximum erosion depth about 5m and the deposition only close to left branch and in the tail part of the island. The deposition was also serious when the sediment concentration was high, and it can be seen more deposition in the upstream of this reach and the average of maximum deposition in this area was about 4m. It can also be seen the deposition in right branch and left branch of the river with average maximum deposition about 1.5 m, but the erosion only in a small area in the downstream of the reach.

**4. Discussions**

From the results above we can summarized as follows: Delft3D-Flow model has been applied in this paper to study complex application for two-dimensional river flow such as surface flow, sediment transport and bed level change in Renmin Island reach to investigate the sedimentation problem. The model was calibrated by comparing water level and sediment transport between computed and observed values and there was good agreement between observed and computed results. The maximum average erosion depth during flood season in upstream and right branch of the river was about 5m and the maximum average of deposition depth during flood season in the upstream of the reach was about 4m. The channel in the left branch of the river in Renmin Island became shallow, which was difficult for transportation on the river through large vessels.

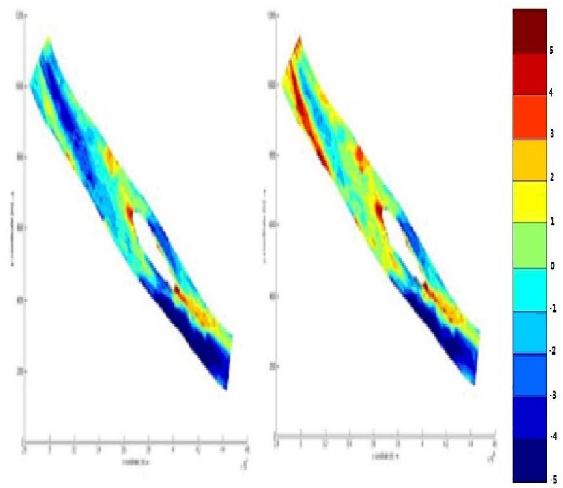


Figure (13): Erosion/deposition pattern of the peak flood discharge in 1988, Low sediment concentration (Left plot), high sediment concentration (Right plot)

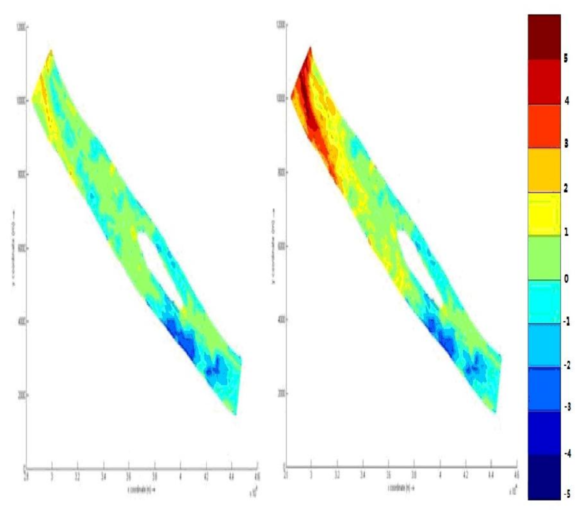


Figure (14): Erosion/deposition pattern of the average flood discharge, Low sediment concentration (Left plot), high sediment concentration (Right plot)

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