A Validation of Kitamura (1995) mud transport formula

A.1 Purpose

The purpose of this validation case is to examine the performance of implementation new sediment transport formula in Delft3D4 software.
Kitamura (1995) has been used and validated for Funagira Reservoir (Japan) as shown in the reference paper (Kitamura, 1995). In order to mimic cohesive sediment transport with Delft3D4 in Funagira Reservoir, it is proposed to use the above mentioned formula.

This validation focuses on comparing the results of Kitamura (1995) formula with Partheniades-Krone formulations (Partheniades, 1965) in order to make sure that the model is calculating the deposition and entrainment correctly.

A.2 Linked claims

Claims that related to the current test case are:

- Sediment transport of mud module is working well using Kitamura 1995 formula. The model calculates the deposition and the entrainment.
- Variable values for the parameters provide different morphological results

A.3 Implementation of Kitamura's mud transport formula

According to experimental results of Kitamura (1995), the following equation is derived to calculate the cohesive sediment transport. The non-dimensional critical shear velocity for erosion is described in term of void ratio as follows:

$$ {U_{*c}}^{2} \Big/ sgd = \mathrm{a}\, e^{-b} \qquad (a = 20 \sim 40, b = 2) \qquad \text{(A3.1)} $$

Where a is empirical constant, b is empirical constant, U_{*c} is the critical shear velocity, s is specific gravity of soil particles in water (s = σ - 1), σ is the density of soil particle, d is the representative particle size, g is the acceleration of gravity, e is the void ratio ($e = \lambda/1 - \lambda$) and λ is the porosity.

The erosion velocity defines as the erosion depth in unit time, depends (in Kitamura formula) on the shear stress acting on the bed surface and its critical shear stress value. Accordingly, the following formula is derived based on the experimental results:

$$ \frac{E}{U_*} = N \left[\frac{U_*^2 - U_{*c}^2}{U_{*c}^2} \right]^n , \left(\frac{N = 4\times10^{-5}, n = 1.5 \; for \; maximum}{N = 1\times10^{-1}, n = 1.0 \; for \; minimum} \right) \qquad \text{(A3.2)} $$

Where N is empirical constant, n is empirical constant and U_* is the shear stress.

To calculate the sediment transport discharge rate (q_w) the following equation is implemented:

$$ \frac{\partial B_s q_w}{\partial x} = B_s \, f_w \, E - B_b \, \alpha \, W_0 \, C \qquad \text{(A3.3)} $$

Where, B_b is reservoir bed width, B_s is effective reservoir bed width, f_w is sediment content of the suspended load, W_0 is the falling velocity of the cohesive sediment and α is the deposition coefficient.

This formula is implemented in Delft3D4 software having the keyword of “21 IFORM”. The following parameter can be specified by the user:

Table A.1 Shows Kitamua formula user input parameters and their default values

Parameter	Value	Default value	Reference
N or Acal	4e-5 ~ 1e-1	4e-5	Eq. (A3.2) and Eq.(5)**
n	1.5~1.0	1.5	Eq. (A3.2) and Eq.(5)**
a	20~40	20	Eq. (A3.1) and Eq.(4)**
b	2.0	2.0	Eq. (A3.1) and Eq.(4)**
λ	variable	0.64	Eq. (A3.1) and Eq.(4)*
α	variable	1.0	Eq. (A3.3) and Eq.(12)**

*** refers to the number of the equation in the main reference (kitamura,1995).*

Based on the above table the bed porosity (λ) is assumed constant during the simulation and user-defined. In fact, the porosity is expected to be calculated by the model as it is variable in time and space. However, at this stage, it has to be specified by the user and it is a constant. This makes the critical shear stress a constant value also as shown in Eq.(A3.1).

A.4 Approach

To make sure that the model computes properly the deposition and entrainment using the new formula, two similar models have been prepared. The only difference between the two models is the transport formula:

- Model A (PK): using Patheniades-Krone (1965) mud transport formula
- Model B (Kitamura): Using Kitamura (1995) mud transport formula

The following approach is considered:

- Setting the deposition parameters in both models’ values to ensure free deposition (deposition mode) based on the fall velocity. The results of both formulae are expected to be the same.
- Setting the entrainment parameters in both models to a certain limit to ensure “erosion mode”. The entrainment is not expected to be the same, however tuning the parameter to ensure that the formula is calculating the similar entrainment.

A.5 Model description

Two simple models have been prepared, namely with structured grid as shown in Figure A.1. The length of straight channel is 5 km and the width is 500 m. This test-cases are run with constant Manning friction of 0.02 $s/m^{(1/3)}$.

A variable current (Velocity) at upstream boundary, varying from 0 to about 0.6 m/s, and a constant downstream water level of 0.0 m have been imposed. Uniform bed level of -5 has been selected for both models. The computation time is two days with a time step of 0.5 minute.

It is to be noted that all test scenarios with morphology includes morphological boundary condition, i.e. sediment concentration inflow at the upstream boundary condition specified with 1.0 kg/m^3 inflow (specified in “*.bcc” file).

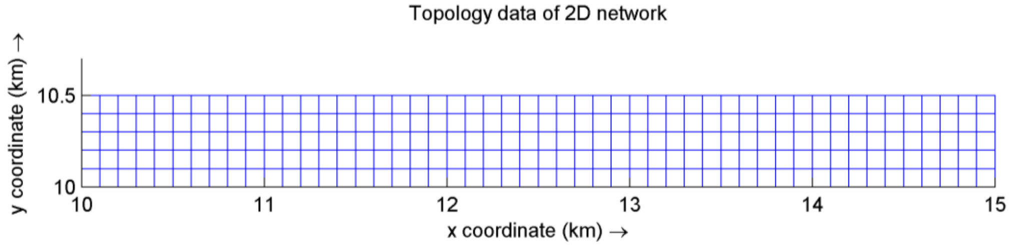

Figure A.1 The grid used in both models.

Notes: Following are the coordinates of the slices, used for plotting longitudinal profiles:

- The results are plotted at “y” equals to 10.25 km and along “x-direction” equals to “10025.71, 10253.72; 14981.60, 10268.60” (refer to Figure A.1).

A.5.1 Morphological setup of Model A (PK):

The morphological setup of sediment input is shown in Figure A.2, while the other morphological input is shown in Figure A.3.

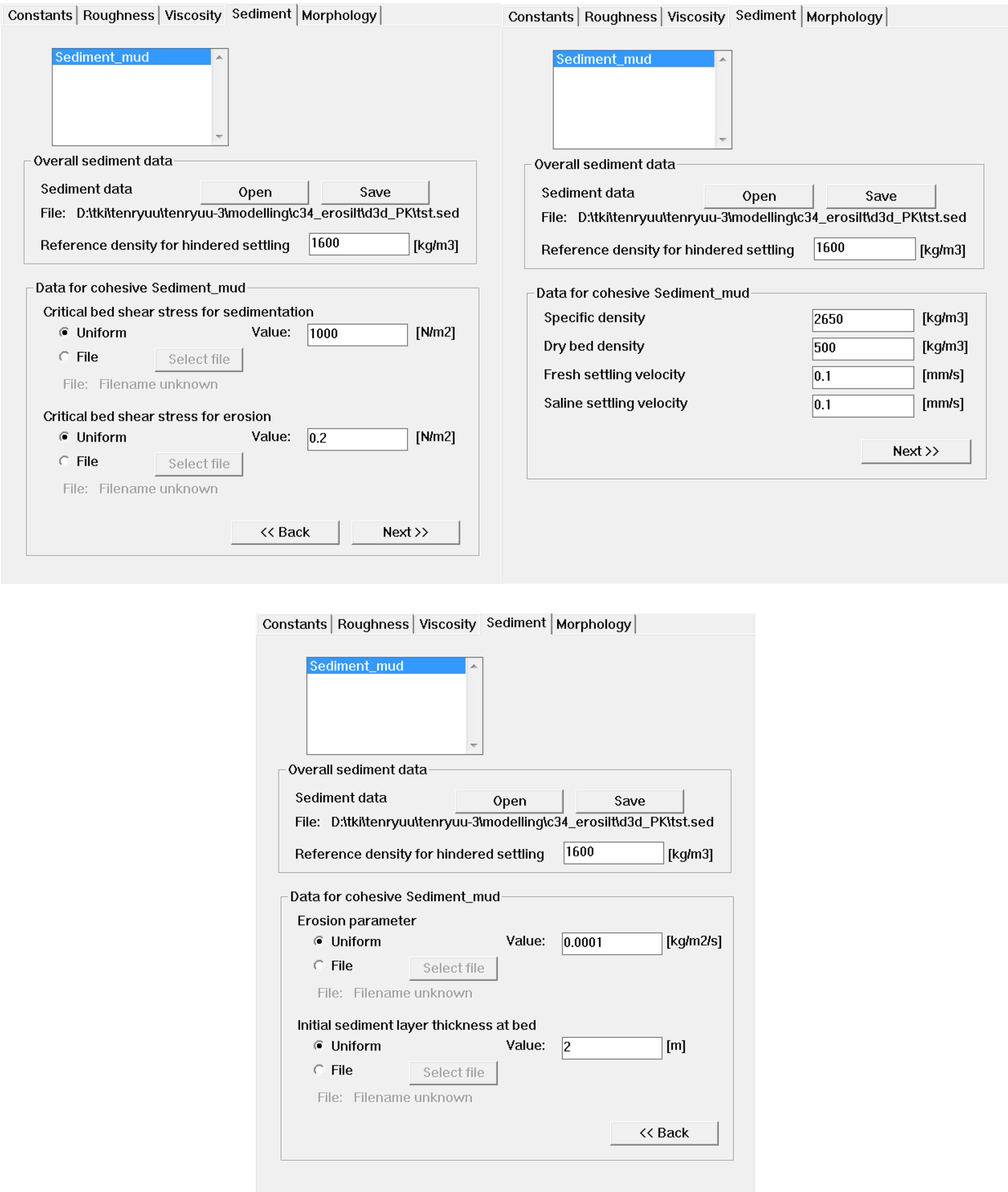

Figure A.2 The sediment input parameters.

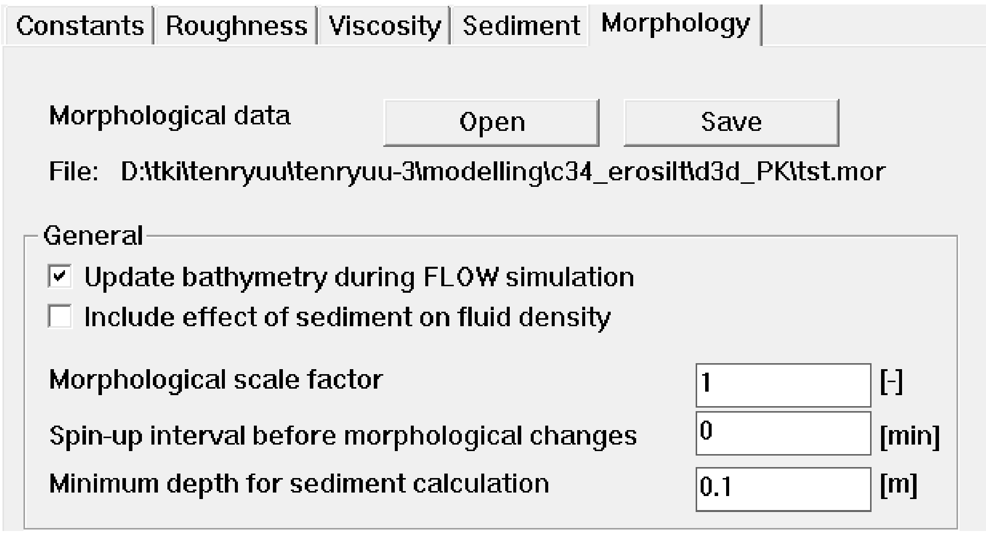

Figure A.3 Part of the morphological input file.

The morphological setup of both models is the same except for the sediment characteristics and the transport formula used. Model B setting with respect to sediment and transport formula is explained below.

A.5.2 Morphological setup of Model B (Kit):

In kitamura simulation, the sediment file of cohesive sediment has to have the d_{50} of the mud. The sediment file used for Kitamura simulations is shown below.

```
[SedimentFileInformation]
   FileCreatedBy      =  Delft3D FLOW-GUI, Version: 3.56.29165
   FileCreationDate   =  Tue Aug 19 2014, 10:20:12
   FileVersion        =  02.00
[SedimentOverall]
   Cref           =   1.6000000e+003    [kg/m3]   CSoil Reference density for hindered settling
calculations
   IopSus    = 0   If Iopsus = 1: susp. Sediment size depends on local flow and wave conditions
[Sediment]
    Name         = #Sediment_mud#          Name of sediment fraction
   SedTyp        = mud                     Must be "sand", "mud" or "bedload"
   RhoSol        =  2.6500000e+003     [kg/m3]  Specific density
   SalMax        =  0.0000000e+000     [ppt]    Salinity for saline settling velocity
   WS0           =  1.0000000e-004     [m/s]    Settling velocity fresh water
   WSM           =  1.0000000e-004     [m/s]    Settling velocity saline water
   CDryB         =  5.0000000e+002     [kg/m3]  Dry bed density
   IniSedThick   =  2.0000000e+000  [m] Initial sediment layer thickness at
   FacDSS        =  1.0  [-]  = Initial suspended sediment diameter factor. Range [0.6 - 1.0]
   SedD50        =  1.1e-05            [m]      d50
   TraFrm        =  #Kitamura95.tra#
```

The setup of kitamura formula used can be seen in #Kitamura95.tra#. This file is shown in the table below.

The value of a and b is selected out of the range provided in equation (A3.1), in order to get low critical bed shear stress which provides erosion process to the bed. For the deposition simulation, the default setting of the parameters is used.

```
21      IFORM
#21     IFORM Kitamura 1995
4e-5    Acal (coefficient N in Eq (A3.2)) default 4e-5
1.5     N (coefficient n in Eq (A3.2)) default 1.5
1       A (coefficient a in Eq (A3.1)) default 20
3.9     B (coefficient b in Eq (A3.1)) default 2
0.64    Poros (coefficient λ in paper) default 0.64
1.0     Alpha (coefficient α in Eq (A3.3)) default 1
```

A.6 Results

The following are the results of the test:

- The comparisons between the results of water level in both models are same as shown in Figure A.4. The two simulations give similar water level.

- The result of the bed level updates is shown Figure A.5. The two simulations are compared using free deposition of sediment. This means the critical shear stress for sedimentation in Partheniades-krone simulation setting is set to 1000 N/m^2, while "α" in Kitamura simulation setting is set to 1.0. The critical shear stress of erosion is set higher than the expected bed shear stress to avoid the erosion. Accordingly, the two simulations with different formula provide the same bed level change as shown in Figure A.5.

- The two simulations are adjusted again to create erosion of the bed. However, the two formulae do not expected to provide the same results. Figure A.6 depicts the erosion simulations. As can be seen, the bed result is lower than the initial bed which is -5 m. The results are unlike as the entrainment of both formulae is different.

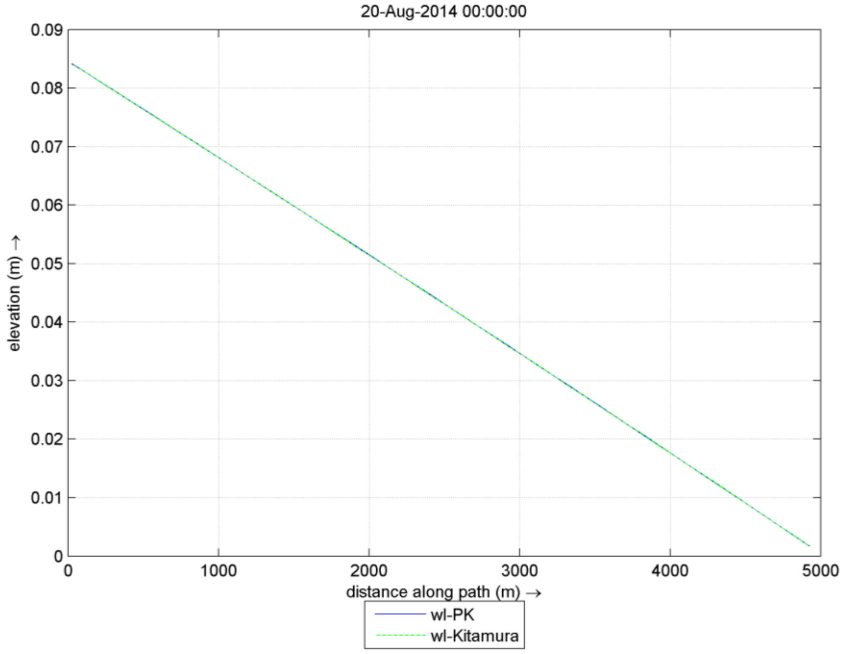

Figure A.4 Result of water level comparison between both models.

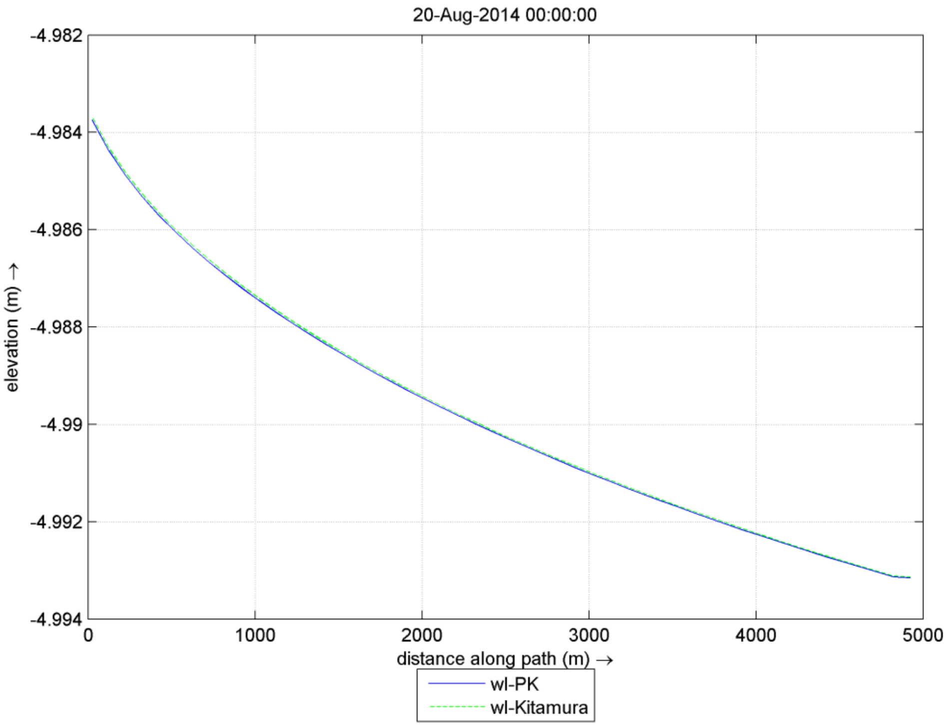

Figure A.5 Result of bed level along "y" equals to 10.25 km. This is the results to compare the deposition behaviour.

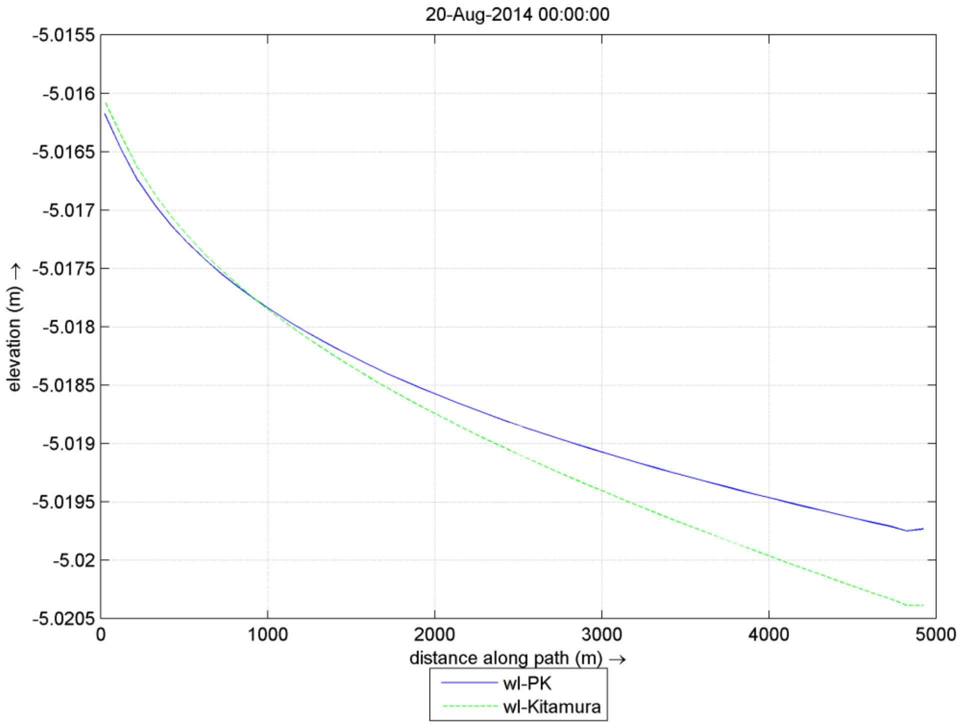

Figure A.6 Result of bed level along "y" equals to 10.25 km. This is the results to compare the entrainment behaviour.