

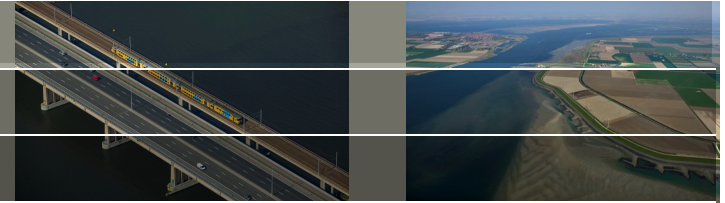


Sediment mixtures and bed stratigraphy

Bert Jagers

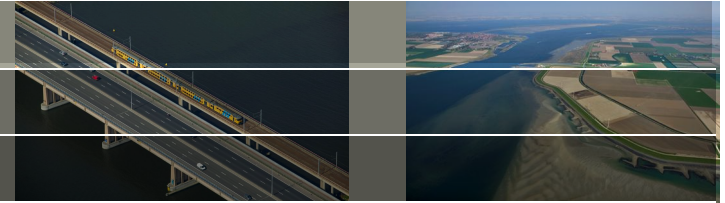
October 10, 2012

Overview



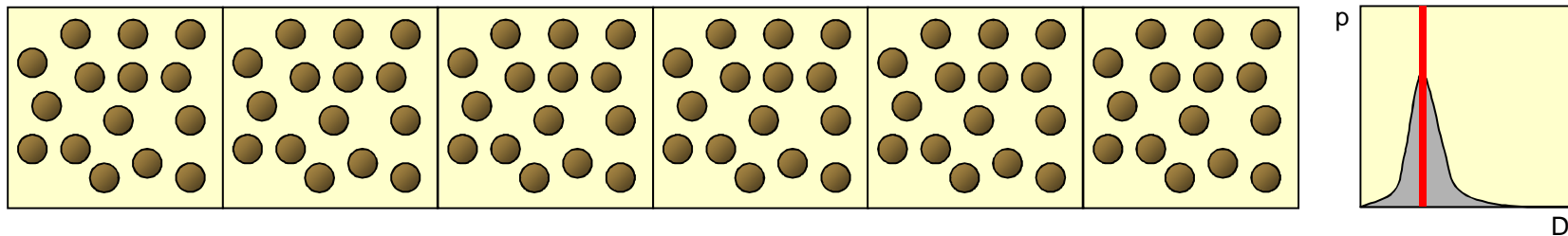
- Introduction
From uniform sediment to multi-fraction models
- Bed stratigraphy module
Basic and advanced features
- Usage
Some tips, tricks and warnings
- Ongoing developments
Plenty of features to improve ...

Introduction

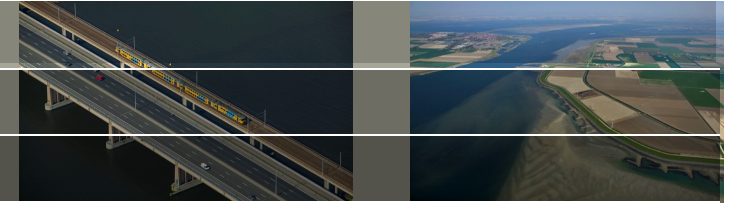


Traditionally, morphodynamic models used a single “representative” sediment diameter to characterize the local sediment properties.

This works fine for relatively small models in environments with fairly uniform sediment. Grainsize variability was only taken into account by means of secondary grain size diameters used in transport equations, e.g. D_{84} or D_{90} .

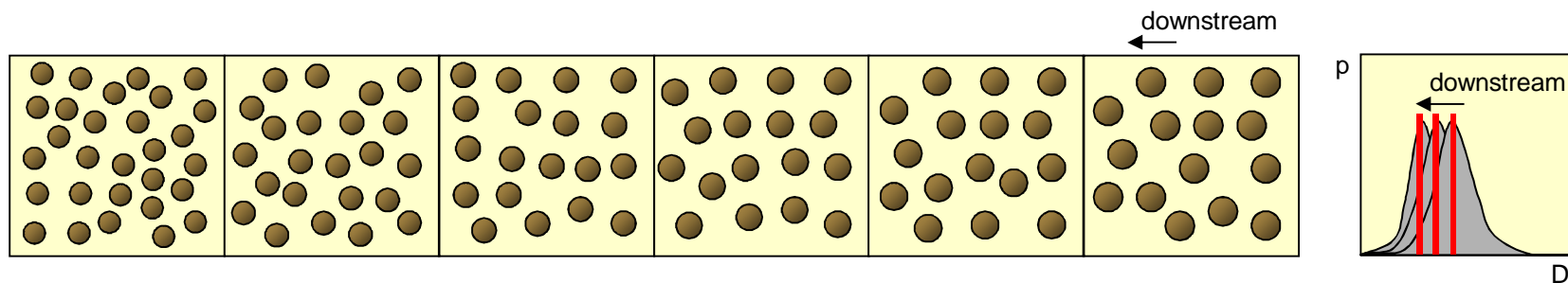


Introduction

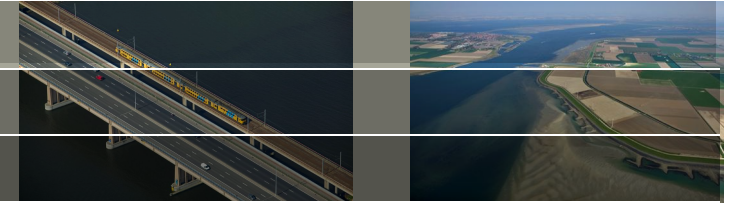


However, this doesn't work if models become larger and hence more likely heterogeneous. For example: downstream fining in rivers. It becomes impossible to properly calibrate the transport rates throughout the model domain. The quick fix was to make the grain size spatially varying.

However, this approach is not physically realistic in case of downstream coarsening, time variability is lacking and it doesn't work well for bimodal sediment mixtures.



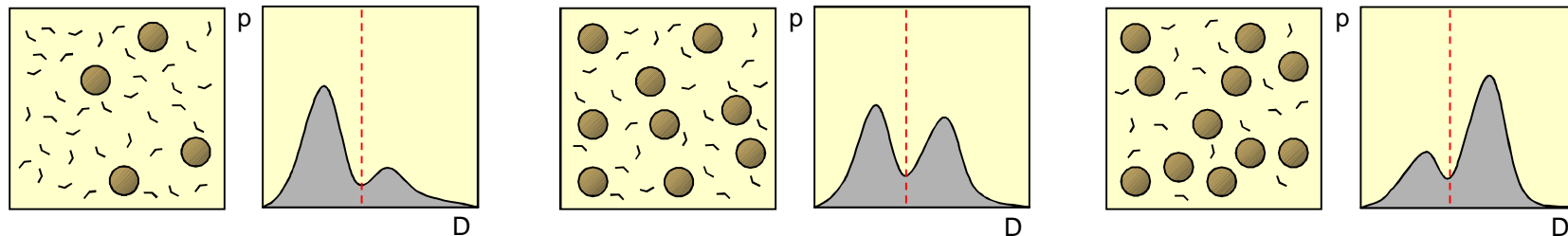
Introduction



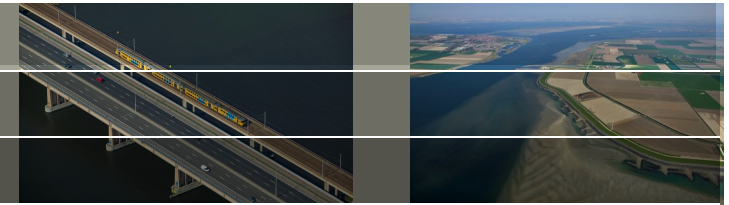
Hence the next logical step was to allow for multiple sediment fractions. The first Deltares 1D models of that type were created in the early 1990s. This feature was implemented in the old Delft3D MORSYS system in the second half of the 1990s, but that code was never released.

Multiple sediment fractions were included from the very beginning of the current sediment transport and morphology module integrated in Delft3D-FLOW. The primary focus being sand-mud mixtures.

Note that the boundary between fractions are constant in space and time, and in most cases so are the fraction properties!

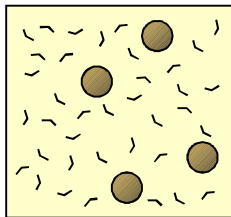


Introduction

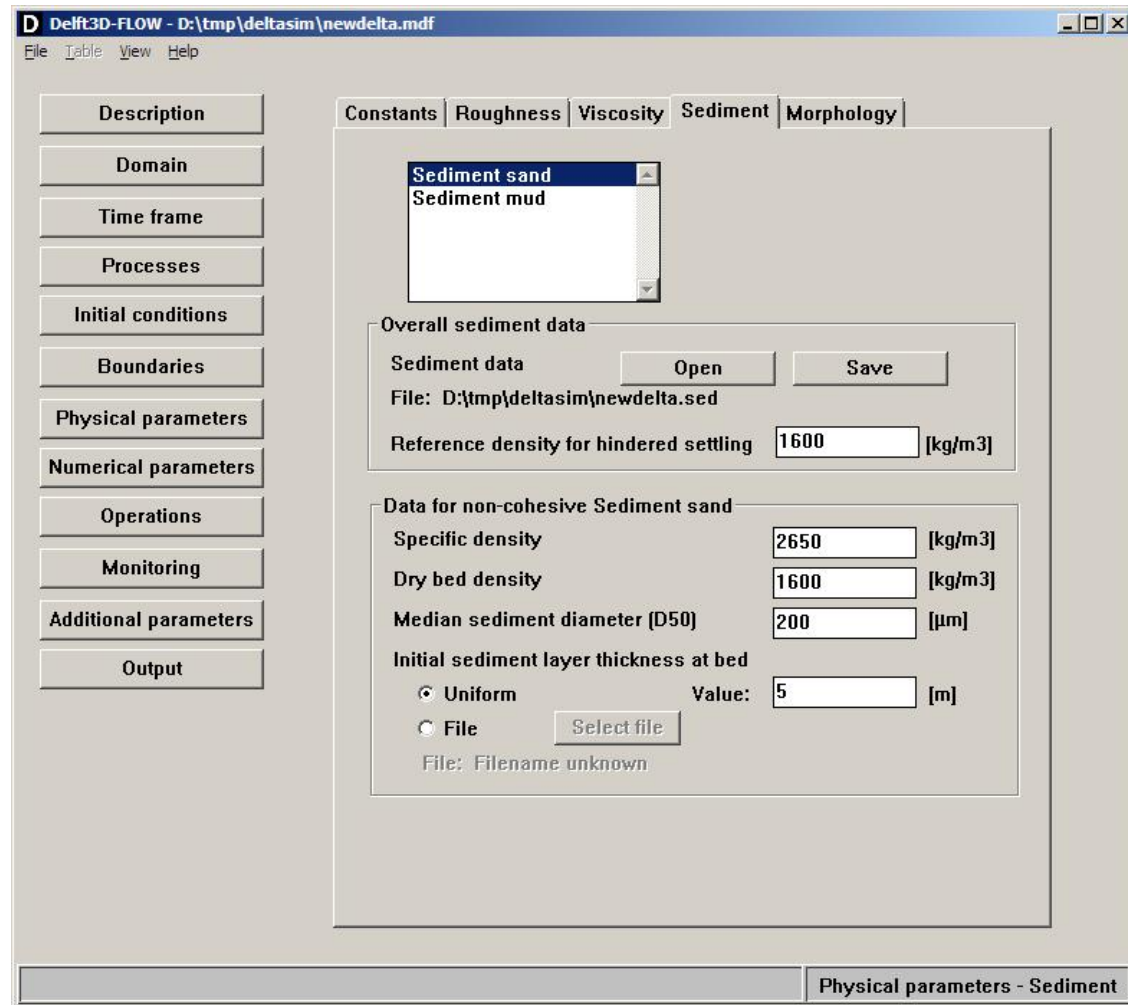


Multiple sediment fractions in the current Delft3D user interface.

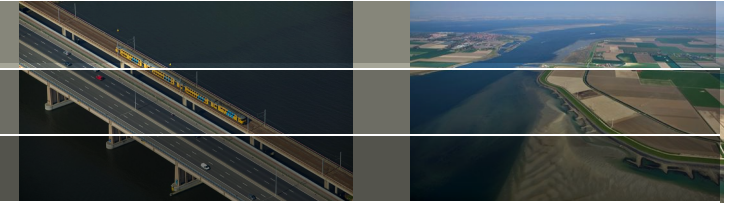
Distinguishes between non-cohesive (“sand”) and cohesive (“mud”) fractions but can simulate any



number of fractions up to 99



Introduction

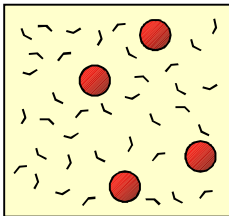


Per non-cohesive sediment fraction you need to specify:

- Specific density of the material (for quartz typically 2650 kg/m^3)
- Dry bulk density of the sediment once deposited in the bed: specific density divided by $1 - \text{porosity}$

Note that this is a typical “uniform sediment” parameter

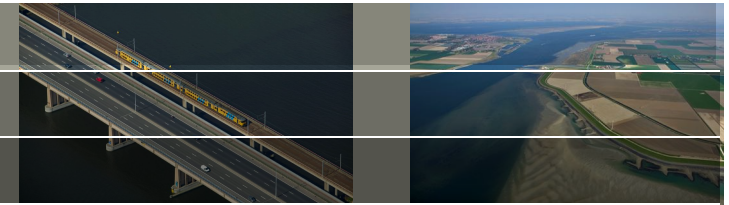
- Median sediment diameter D_{50}
- Initial thickness of sediment layer for that specific fraction



Data for non-cohesive Sediment sand

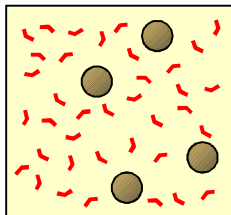
Specific density	<input type="text" value="2650"/>	[kg/m ³]
Dry bed density	<input type="text" value="1600"/>	[kg/m ³]
Median sediment diameter [D50]	<input type="text" value="200"/>	[μm]
Initial sediment layer thickness at bed		
<input checked="" type="radio"/> Uniform	Value:	<input type="text" value="5"/> [m]
<input type="radio"/> File	<input type="button" value="Select file"/>	
File: Filename unknown		

Introduction



Per cohesive sediment fraction you need to specify:

- Specific density of the material (usually 2650 kg/m³)
- Dry bulk density of the sediment once deposited in the bed: specific density divided by 1-porosity
- Critical shear stresses for sedimentation and erosion

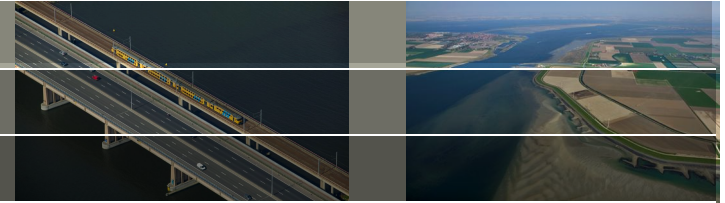


- Erosion parameter
- Initial thickness of sediment layer for that specific fraction

Data for cohesive Sediment mud

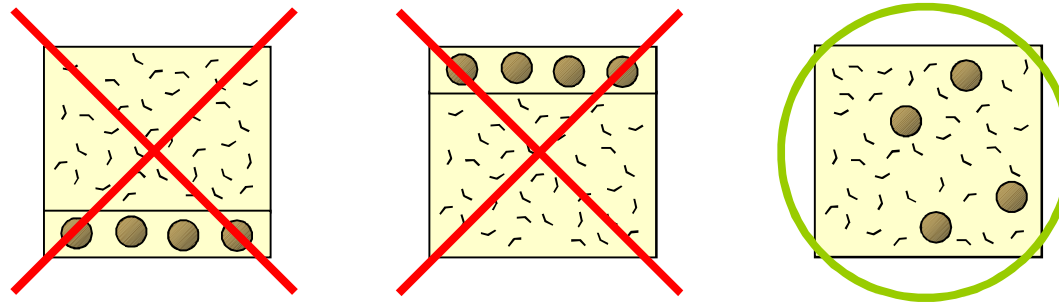
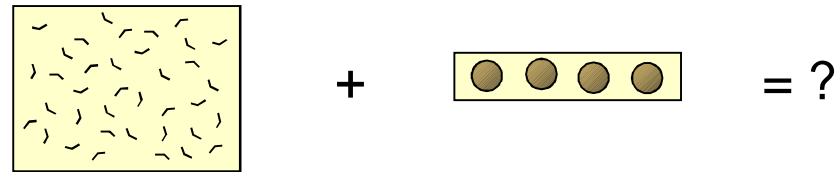
Specific density	<input type="text" value="2650"/>	[kg/m ³]
Dry bed density	<input type="text" value="500"/>	[kg/m ³]
Settling velocity	<input type="text" value="0.25"/>	[mm/s]
Critical bed shear stress for sedimentation		
<input checked="" type="radio"/> Uniform	Value: <input type="text" value="1000"/>	[N/m ²]
<input type="radio"/> File	<input type="button" value="Select file"/>	
File: Filename unknown		
Critical bed shear stress for erosion		
<input checked="" type="radio"/> Uniform	Value: <input type="text" value="0.5"/>	[N/m ²]
<input type="radio"/> File	<input type="button" value="Select file"/>	
File: Filename unknown		
Erosion parameter		
<input checked="" type="radio"/> Uniform	Value: <input type="text" value="0.0001"/>	[kg/m ² /s]
<input type="radio"/> File	<input type="button" value="Select file"/>	
File: Filename unknown		
Initial sediment layer thickness at bed		
<input checked="" type="radio"/> Uniform	Value: <input type="text" value="0.050000001"/>	[m]
<input type="radio"/> File	<input type="button" value="Select file"/>	
File: Filename unknown		

Introduction



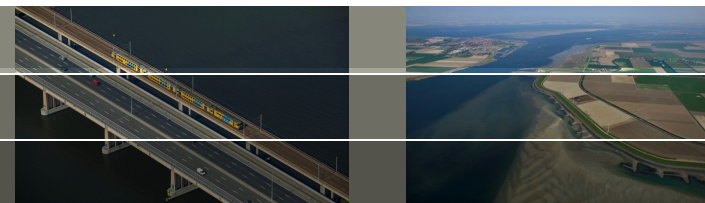
“Initial sediment layer thickness at bed”

What does it mean to have 0.8 m mud + 0.2 m sand?



So, by default we have multiple sediment fractions in a well mixed bed

Introduction

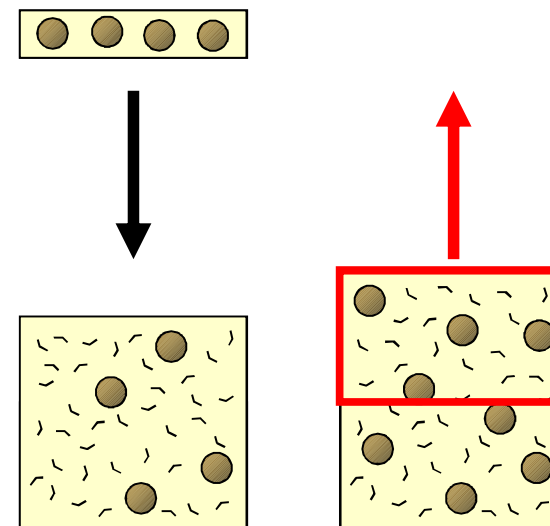


“Well mixed bed”

What does it mean?

When sediment is deposited ...

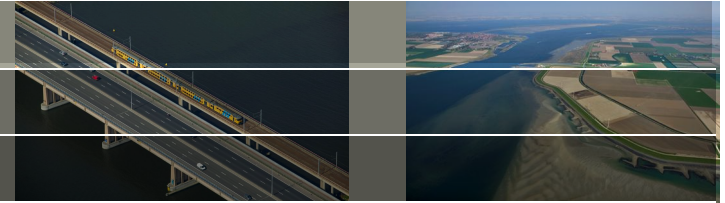
... it is mixed instantaneously with
all the sediment already present
in the bed



So, when sediment is eroded ...

... it removes sediment irrespective of how long ago it was deposited

Introduction



How to get a more realistic behaviour?

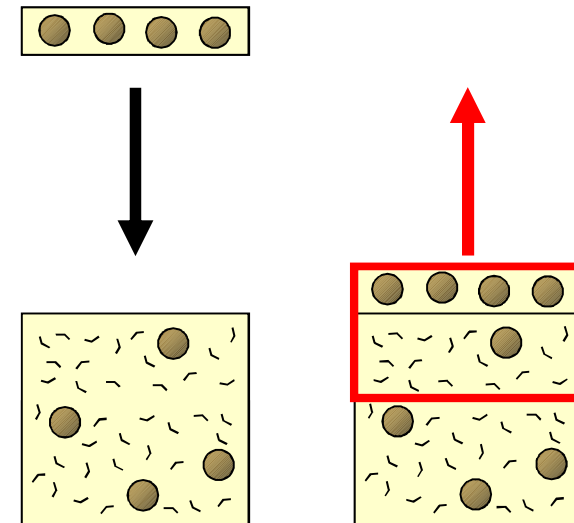
When sediment is deposited ...

... it shouldn't be mixed (completely)
with the sediment in the bed

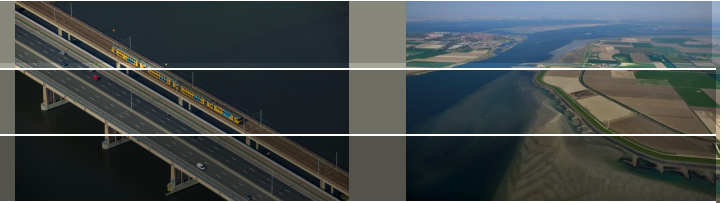
So, when sediment is eroded ...

... it should recently deposited sediment first

This is done by means of the bed stratigraphy module

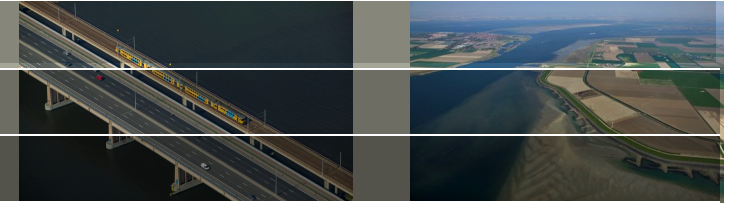


Overview



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Features

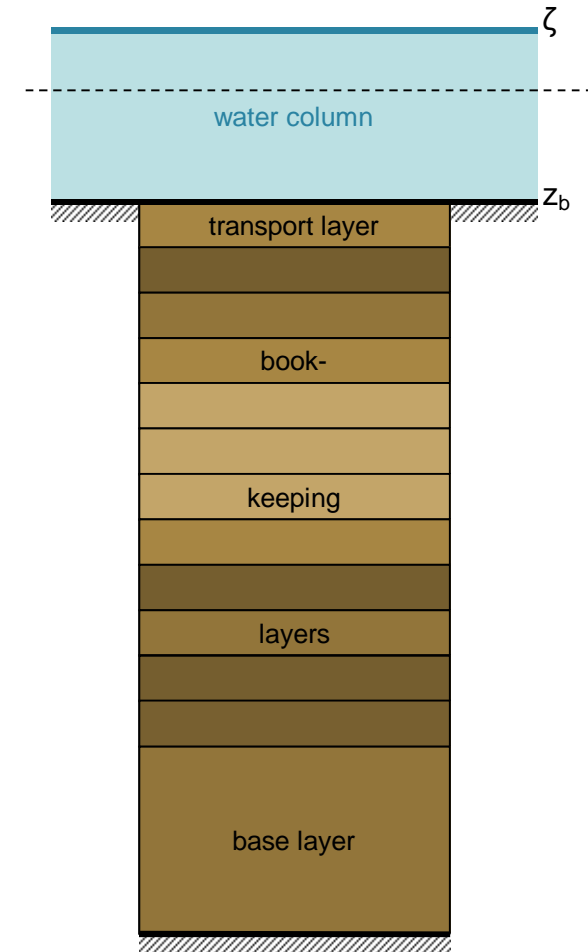


Default well mixed bed

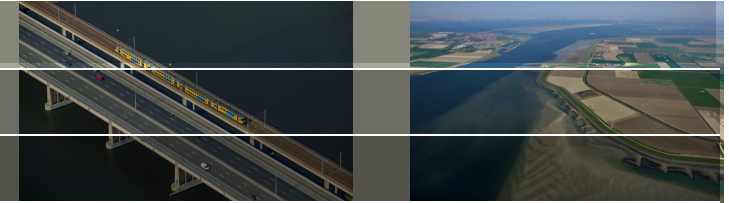
- one mixed sediment layer

Bed stratigraphy

- 1 transport (or active) layer
- N bookkeeping layers (also: underlayer)
- 1 base layer
- non-erodible “rock”



Features: .mor file



```
[MorphologyFileInformation]
FileCreatedBy = Delft3D FLOW-GUI, Version: 3.42.00.17790
FileCreationDate = Fri Dec 16 2011, 15:14:50
FileVersion = 02.00
[Morphology]
EpsPar = false Vertical mixing distribution according to van Rijn
IopKCW = 1 Flag for determining Rc and Rw
RDC = 0.01 [m] Current related roughness height (only used if IopKCW <> 1)
RDW = 0.02 [m] Wave related roughness height (only used if IopKCW <> 1)
MorFac =
MorStt = morphological changes
Thresh = erosion reduction
MorUpd =
EqmBc =
DensIn =
AksFac =
RWave =
AlfaBs =
AlfaBn =
Sus =
Bed =
SusW =
BedW =
SedThr = 1.000000e+000 minimum water depth for sediment computations
ThetSD = 5.000000 [-] Factor for erosion of adjacent dry cells
HMaxTH = 1.000000e+000 [m] Max depth for variable THETSD. Set < SEDTHR to use global value only
FWFac = 1.0000000e+000 [-] Vertical mixing distribution according to van Rijn
[Underlayer]
IUnderLyr = 2 [-] Flag for underlayer concept
TTLForm = 1 [-] Transport layer thickness formulation
ThTrLyr = 0.2 [m] Thickness of the transport layer
MxNULyr = 75 [-] Number of underlayers (excluding final well mixed layer)
ThUnLyr = 0.1 [m] Thickness of each underlayer
```

Activate the bed stratigraphy module
by adding a [Underlayer] block
and keywords to the .mor file

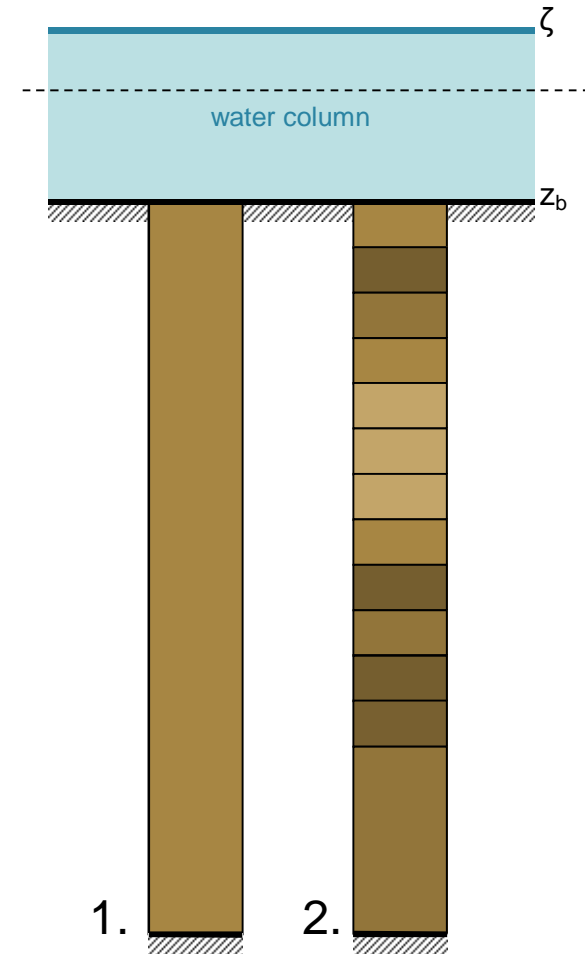
(not supported by the GUI)
(see Table B.9 in Appendix B.9.2)

Features: bed composition model

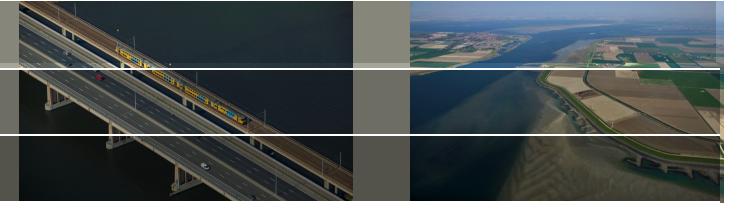
IUnderLyr = 2

Flag for underlayer concept

1. Well mixed bed (default)
2. Bed stratigraphy



Features: transport layer



$$\mathbf{TTLForm} = 1$$

Transport layer thickness formulation

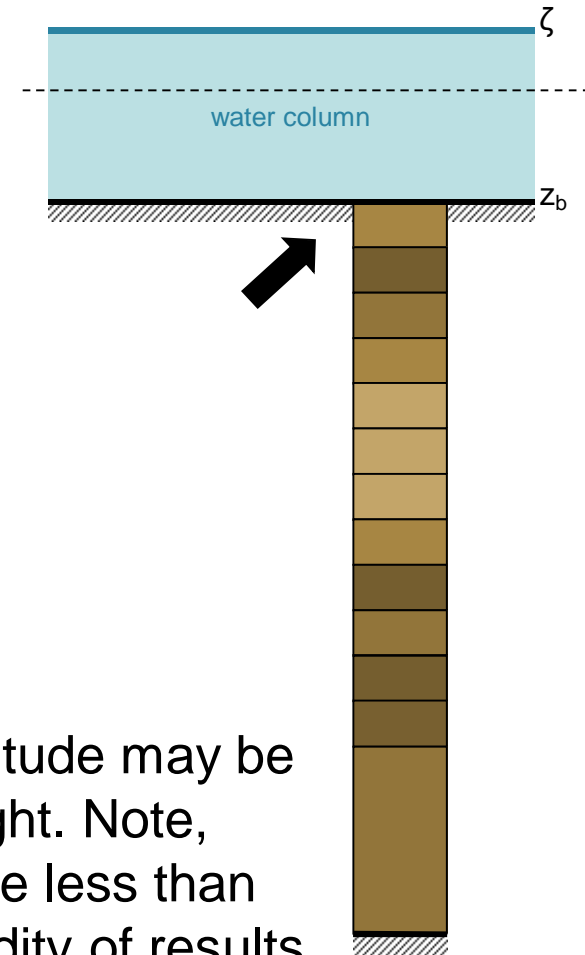
1. Constant thickness
2. Proportional to the water depth
3. Proportional to the dune height

We have so far nearly always used option 1.

$$\mathbf{ThTrLyr} = 0.2 \quad [\text{m}]$$

$$\mathbf{ThTrLyr} = \#\mathbf{QNfile.ttl}\#$$

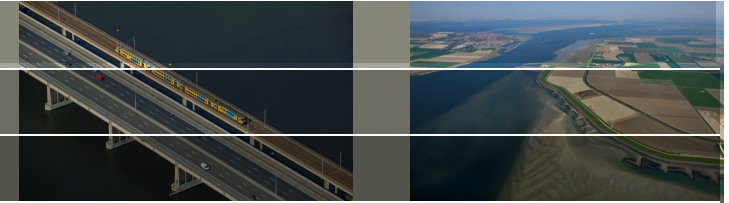
Thickness of the transport layer; order of magnitude may be estimated as 50% of observed bedform height. Note, however, the erosion per time step should be less than this thickness to guarantee stability and validity of results.



So, $\mathbf{ThTrLyr}$ is typically $\geq 0.1 \text{ m}$

Deltares

Features: transport layer



TTLForm = 2 or 3

gives

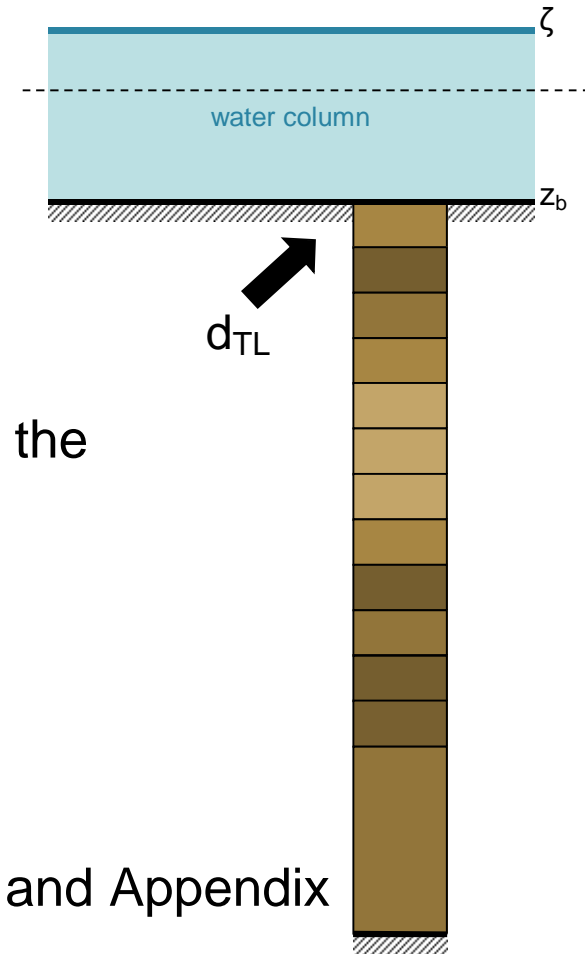
$$d_{TL} = \max(\alpha \cdot h, d_{TLmin})$$

where h is water depth or dune height, requires the parameters α and d_{TLmin} to be defined

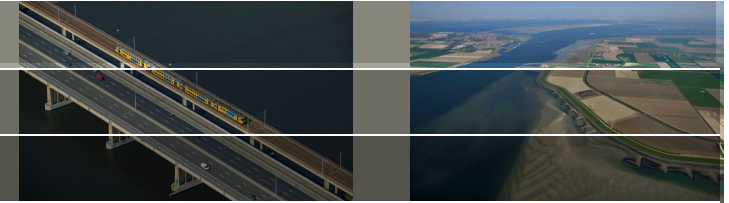
TTLAlpha = 0.2

TTLMin = 0.1 [m]

For the dune height options see Section 9.11.1 and Appendix B.16 of the Delft3D-FLOW manual.



Features: underlayers

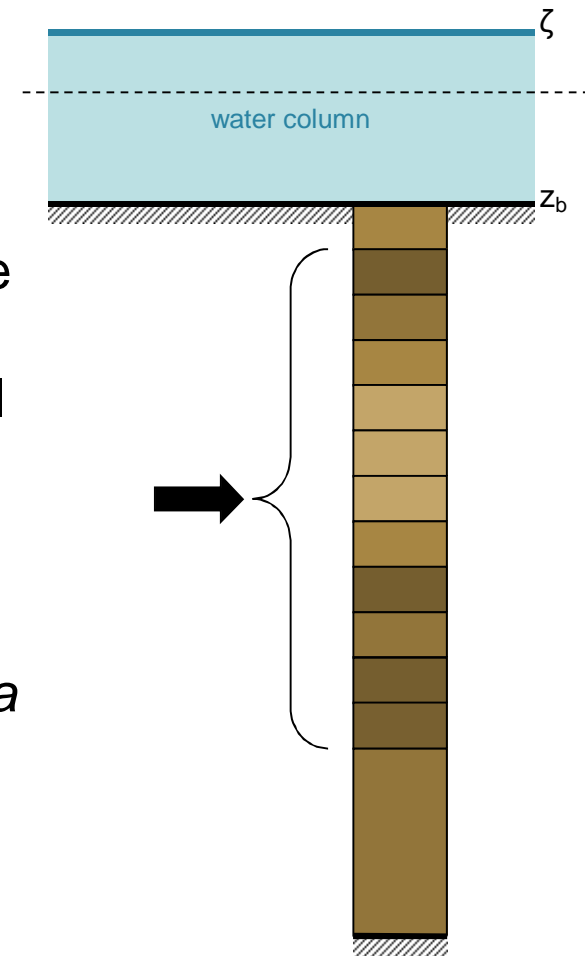


$$\mathbf{MxNULyr} = 75$$

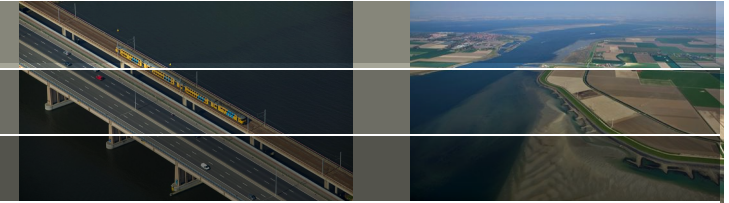
Maximum number of underlayers (excluding transport and base layers) This determines the memory allocation (75 is really a lot); the number of underlayers active at any point during the simulation is always less or equal to this number.

$$\mathbf{ThUnLyr} = 0.1 \quad [\mathbf{m}]$$

Maximum thickness of each underlayer *during a period of gradual sedimentation*
(more about this shortly)



Features: base layer

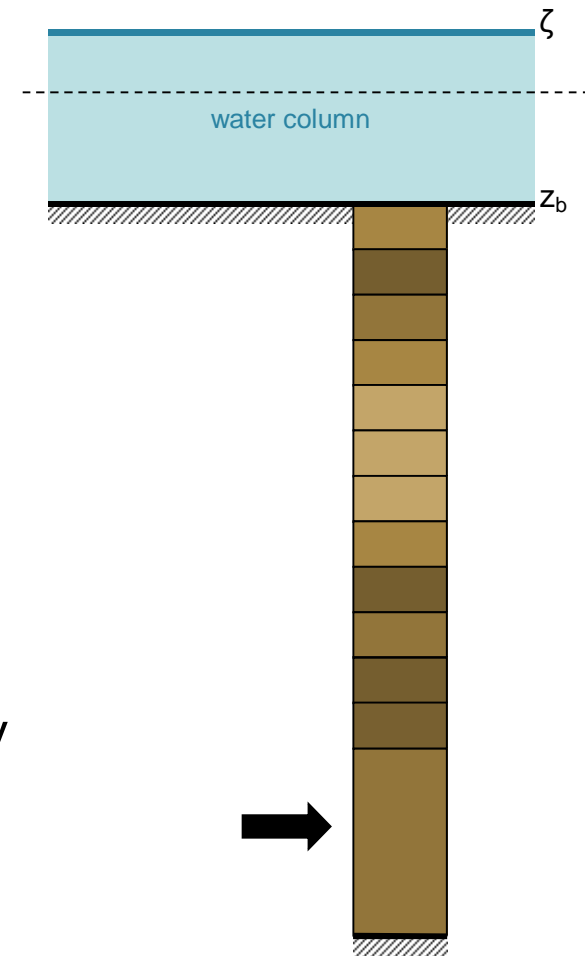


UpdBaseLyr = 1

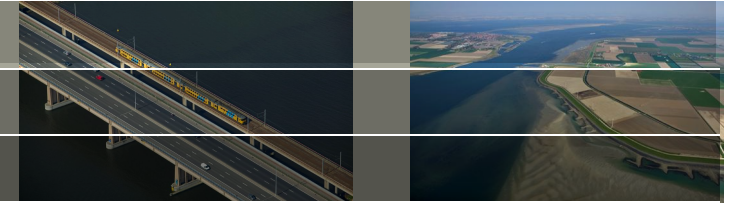
Update option for composition and thickness of base layer

1. composition and thickness computed
2. composition constant, thickness computed
3. composition copied from layer above, thickness computed
4. composition and thickness constant

Always use option 1. The other options are only included to mimic older bed composition algorithms in literature.



Features: initial condition



The initial condition may be based on either

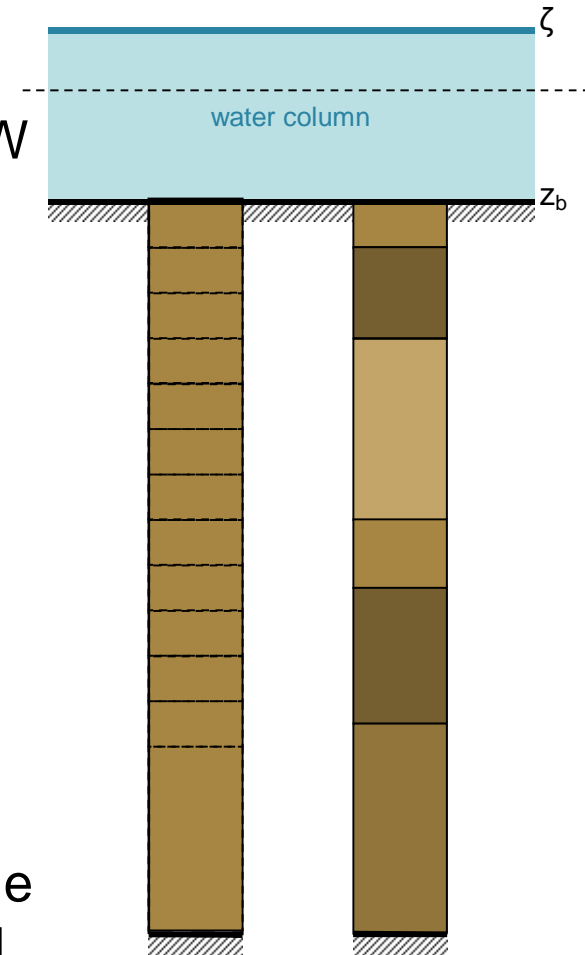
- the sediment amounts specified in the FLOW GUI (i.e. .sed file), or

- on a more detailed specification via the

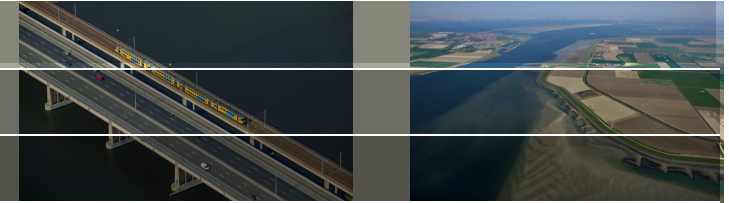
```
IniComp = #bedcomp.inb#
```

keyword in the [UnderLayer] block in the .mor file, or

- the bed composition is read from the map-file from which the model is restarted (note: bed number of underlayers may change).



Features: initial condition file

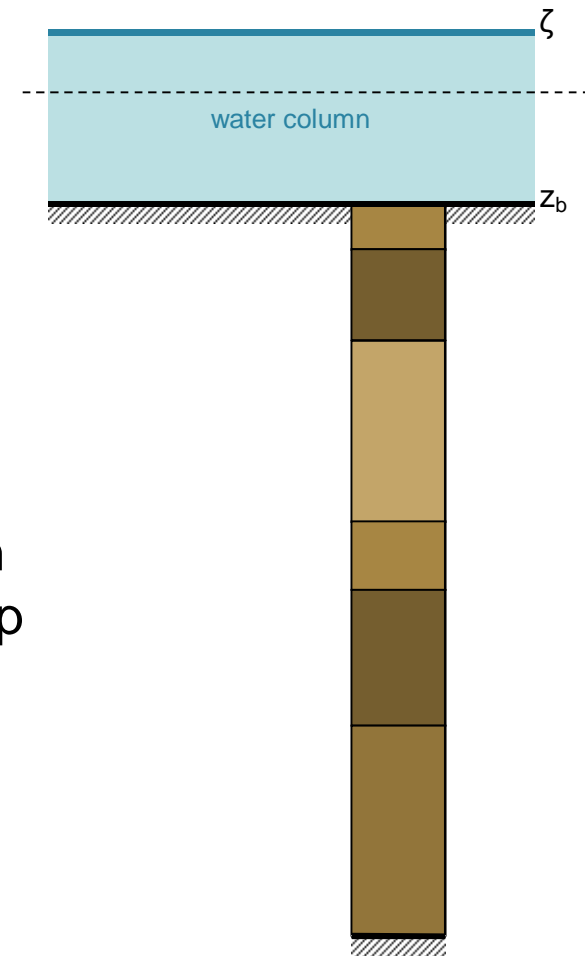


The initial bed composition file should contain one or more **[Layer]** blocks.

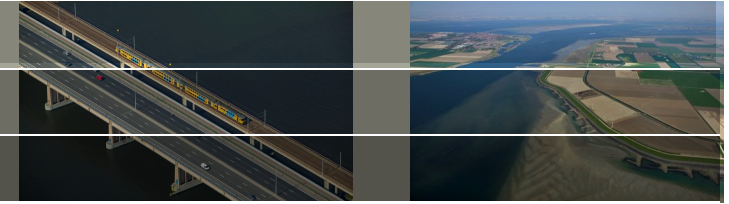
```
[Layer]
Type = mass fraction
Thick = layer1.thk
Fraction1 = 0.3
Fraction2 = 0.7
```

Every block adds a sediment layer to the bed in the order specified in the file (first block = top of sediment column, last block = bottom of sediment column).

See Appendix B.9.9 for details.



Features: initial condition file



Notes:

- Initial layer thicknesses not limited to thickness of transport or under layers.
- Layer thickness may be constant or spatially varying

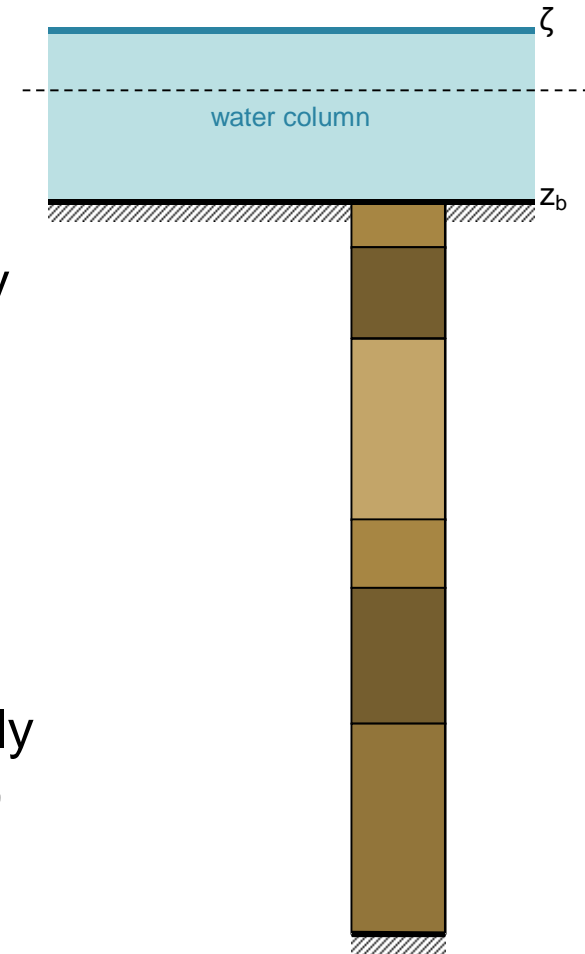
`Thick = 0.8`

`Thick = QNfile.thk`

- Bed composition may be constant or spatially varying (fractions must sum to 1.0 per point)

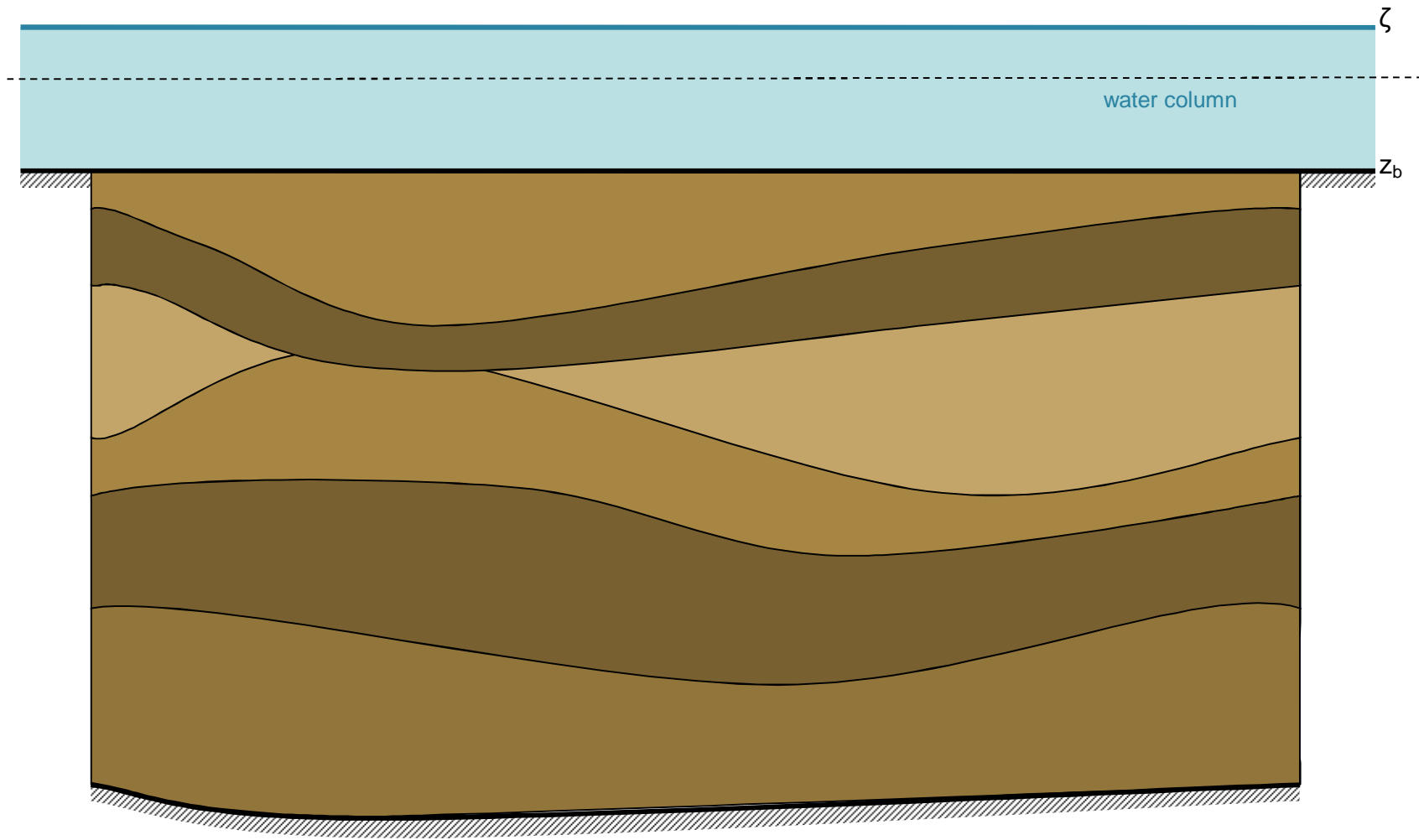
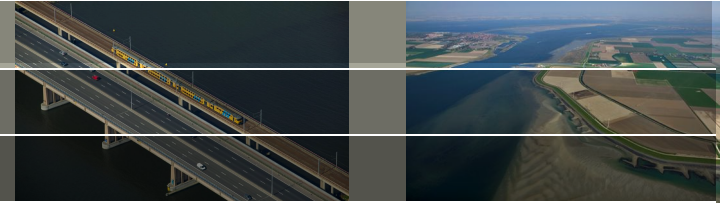
`Fraction1 = 0.3`

`Fraction1 = QNfile.thk`

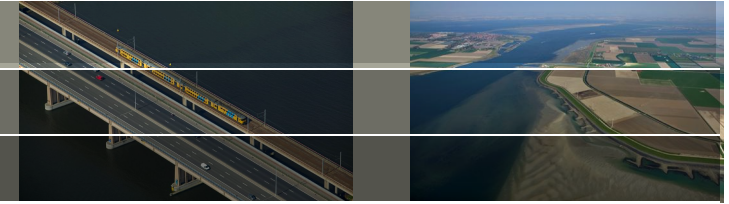


Deltares

Features: initial condition file



Behaviour: initial condition

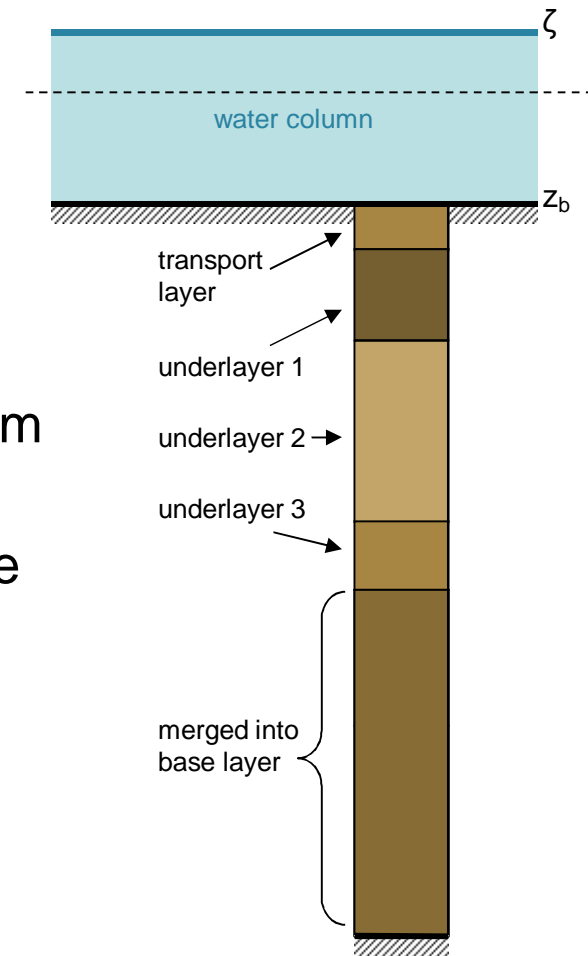


So how does it actually work?

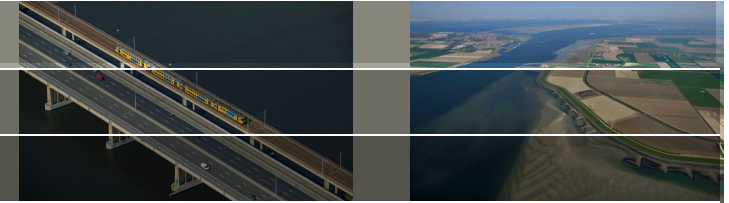
Let's assume we use 3 underlayers and the transport layer thickness matches the thickness of layer 1.

The initial condition will be used to fill layers from top to bottom

The remaining layers will be merged in the base layer, but generally you will define initially less layers than you'll use in the simulation.



Behaviour: erosion



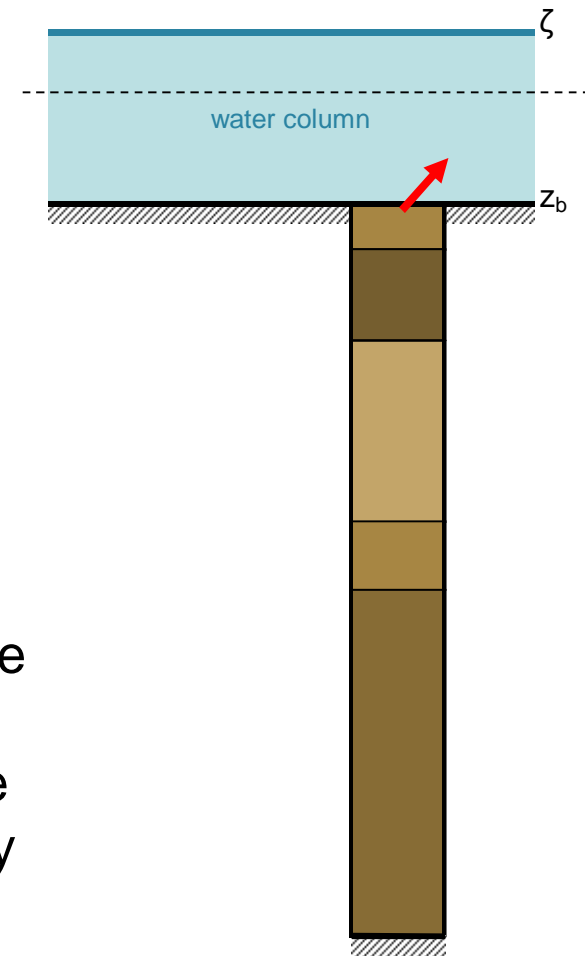
Now some erosion occurs.

The sediment is removed from the transport layer.

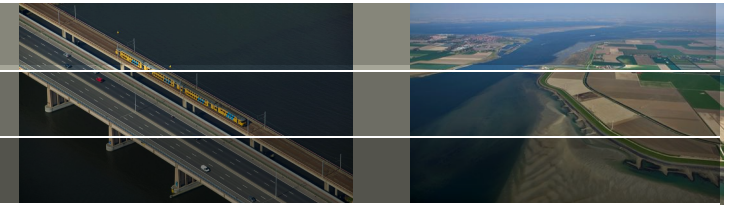
Now transport layer is too thin and the layer is replenished from the underlayers.

The other layers are not adjusted.

This process continues until erosion stops or the rock level is reached. At that time the transport layer is reduced in thickness to the amount of sediment available and eventually it becomes empty.



Behaviour: sedimentation



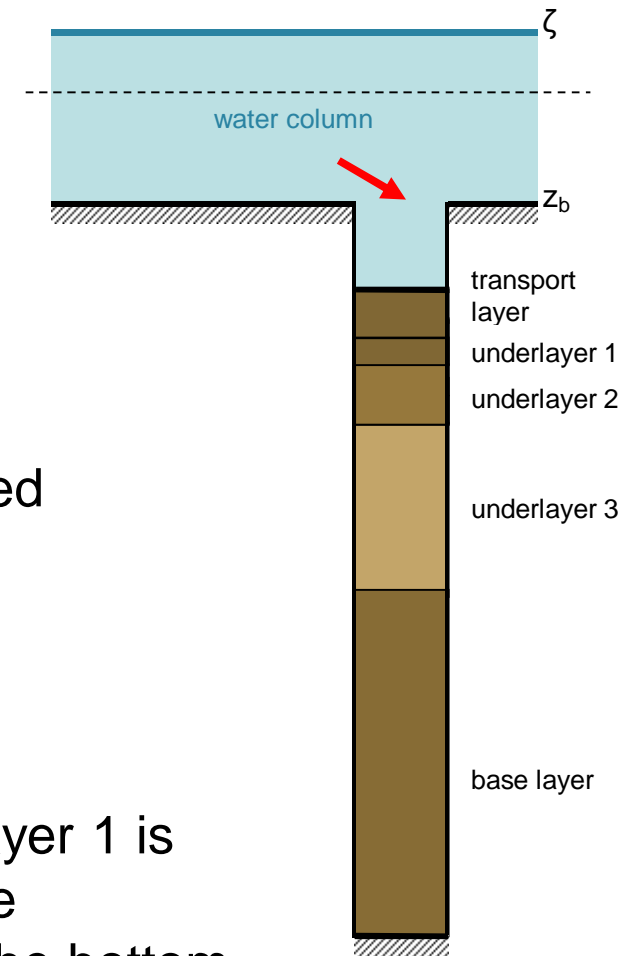
Let's restart somewhere in the middle and assume that some sedimentation occurs.

The sediment is added to the transport layer.

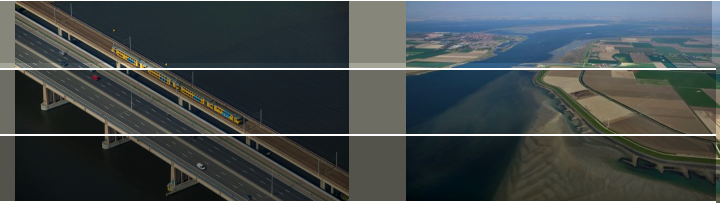
Now transport layer is too thick and the superfluous material has to move to the underlayers. The first underlayer has reached its maximum thickness, so a new layer is created.

More sediment ... still fits in underlayer 1 (less than Th_{UnLyr}).

More sediment ... doesn't fit anymore. A new layer 1 is created and all layers are renumbered. If the maximum number of layers were reached, the bottom most layer would be merged with the base layer.

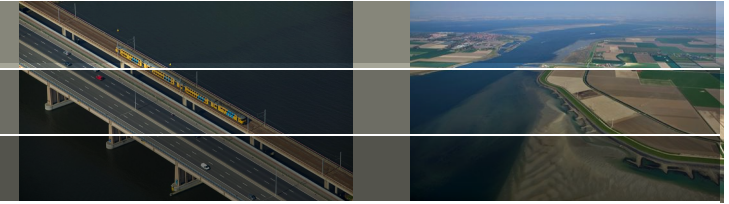


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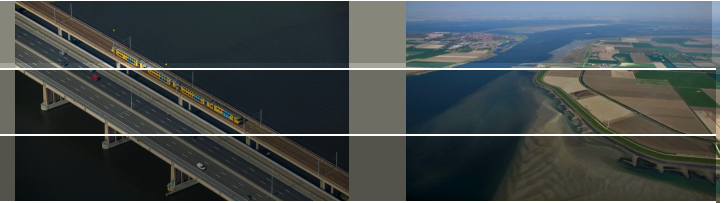
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Domain decomposition

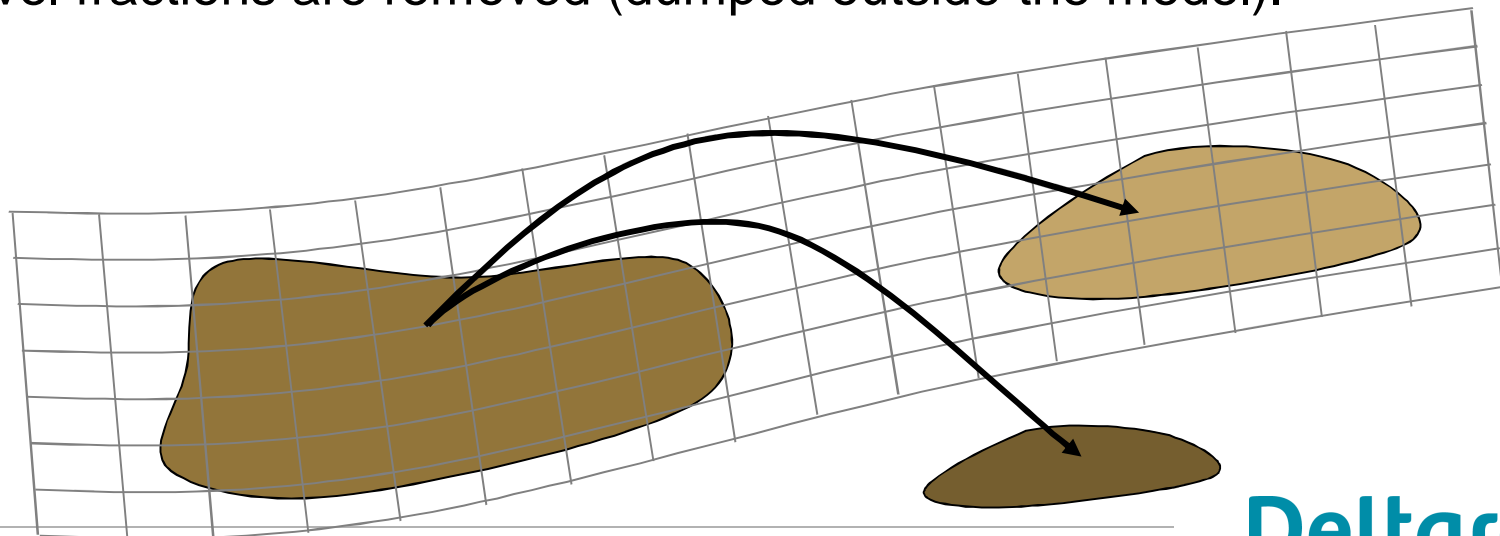


- Bed composition works together with domain decomposition.
- The number of sediment fractions and their types must be uniform across the domains.
- The sediment transport formulae may vary across domains.
- The bed composition model (and the settings such as number of layers and thicknesses) may vary across domains.
- However, note that changes in settings across domains may cause discontinuities in the sediment transport rates across domain boundaries and hence result in discontinuities in bed levels after morphological change.

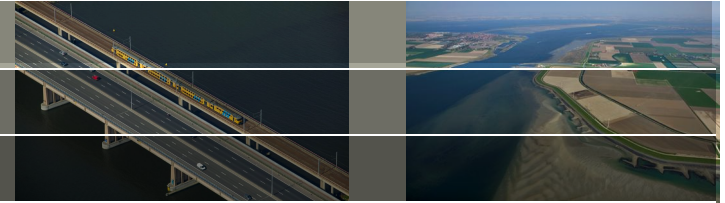
Dredging & dumping



- Dredging and dumping is mass conserving per sediment fraction.
- Note: if dredging reaches the “rock layer” it stops dredging by default, if in the dredging model `obeyCmp = false` is used then it continues dredging, but no sediment will be dumped since no sediment is actually removed.
- You may specify to treat fractions differently, e.g. in case of gravel mining, you may indicate that sand fractions are dumped back, but gravel fractions are removed (dumped outside the model).

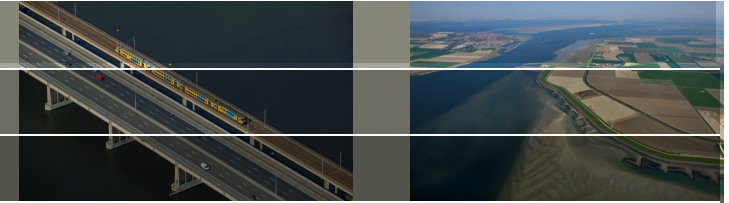


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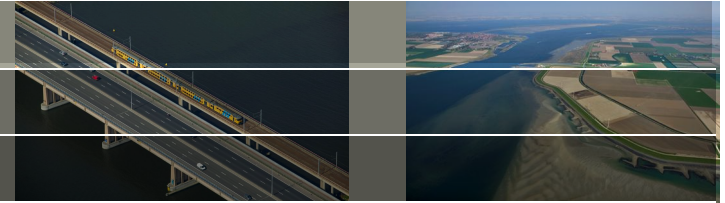
Lagrangian layers



- The default layers are called Eulerian layers because they stay in the same location during erosion and sedimentation.
- Some modeling concepts use Lagrangian layers: just like the transport layer they move up and down with the bed surface.
- You can set the number of Lagrangian layers using the keyword **NLaLyr = 2**
The number of Eulerian layers can be set using **NEuLyr = 3**
The keyword **NUnLyr** sets the total number of layers which are Eulerian by default.
- Note: the use of Lagrangian layers introduces additional numerical mixing. Lagrangian layers are located between the transport layer and the Eulerian layers.

This is an undocumented feature of the current trunk.

Consolidation



- The dry bulk density shouldn't be a fraction dependent quantity; it should be a property of the sediment mixture and the historical load.
- The trunk version now includes the undocumented feature to switch the porosity computation via the keyword **IPorosity** to
 0. combined porosity based dry bed density per fraction
 1. porosity computed from $-0.06 * S + 0.36$
 2. porosity computed from $0.45 * x / (1+x)$
where $x = 3.7632 * S^{-0.7552}$ (Beard & Weyl, 1973)where S is the log std of the sediment mixture.

End of presentation

