A New Sediment Transport Model for Western Scheldt

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The Scheldt Estuary

(from Fettweis et al., 1998)
Hydrodynamic Model

(Mesh and bathymetry of the Scheldt model)
Hydrodynamic Model

Upstream: constant fresh water inflow from tributaries

Downstream: imposed tidal elevations and salinity data

(Liquid boundaries)
Hydrodynamic Model

Salinity in Western Scheldt (ppt)

(Initial salinity)
Hydrodynamic Model

Other settings

• Law of bottom friction: Chézy formula
• Turbulence model: k-epsilon model
• Treatment of tidal flats: equations solved everywhere with correction on tidal flats
• Coriolis force considered
• Coupled with SISYPHE
(mixed-sediment: sand faction distribution map)
Sediment Transport Model

Sediment properties (two-layer bed model)

<table>
<thead>
<tr>
<th>Type of Sediment</th>
<th>Diameter</th>
<th>Density</th>
<th>Settling Velocity</th>
<th>Critical Shear Stress for Erosion (first layer)</th>
<th>Critical Shear Stress for Erosion (second layer)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-cohesive (Sand)</td>
<td>300 µm</td>
<td>2560 kg/m³</td>
<td>1.0E-02 m/s</td>
<td>0.6 Pa</td>
<td>0.6 Pa</td>
</tr>
<tr>
<td>Cohesive (Mud)</td>
<td>60 µm</td>
<td>1600 kg/m³</td>
<td>1.0E-03 m/s</td>
<td>0.5 Pa</td>
<td>0.8 Pa</td>
</tr>
</tbody>
</table>

(Waeles, 2005)
Sediment Transport Model

- The new bottom friction Law based on GML theory
  - General case (laminar – transient – turbulent):
    \[
    u_*^2 = f_A^2 u_{*turb}^2 + u_{*lam}^2
    \]
    \[
    u_*^2 = f_A \left( \frac{\kappa U}{\ln(h/z_0) - 1 + z_0/h} \right)^2 + \left( \sqrt{\left( z_0 \frac{U}{h} \right)^2 + 2 \frac{U}{h} \nu - z_0 \frac{U}{h}} \right)^2
    \]
  - with: \( z_0 = \frac{k_s}{30} + \beta \phi h \)
Sediment Transport Model

(Chézy coefficient obtained from the new bottom friction law)
Sediment Transport Model

• Advantages of the new bottom friction law
  o More physically based, more accurate
  o Allows reduction of inundation threshold to roughness height (1mm in current model)
  o Improves bed shear stress computation in very shallow areas (intertidal flats)
In dry areas, velocity $U$ tends to be zero \( \Rightarrow u_\ast = \sqrt{C_D / 2U} \)
In dry areas, $u^*$ is limited to zero by the new friction law.
Sediment Transport Model

Non-cohesive sediment

Bed-load computation

Suspended load computation

Erosion flux
Deposition flux

Cohesive sediment

Suspended load computation
Sediment Transport Model

- **Bed-load:**  
  the formula from Van Rijn (1984)  
  \[ q^* = \frac{0.053}{d^{0.3}} \left( \frac{\tau^*}{\tau^*_{\text{crit}}} - 1 \right)^{2.1} \]

- **Suspended load:** depth-averaged advection-diffusion equation

\[ \frac{\partial hC}{\partial t} + \frac{\partial (hUC)}{\partial x} + \frac{\partial (hVC)}{\partial y} = \frac{\partial}{\partial x} \left( h\varepsilon_s \frac{\partial C}{\partial x} \right) + \frac{\partial}{\partial y} \left( h\varepsilon_s \frac{\partial C}{\partial y} \right) + E - D \]

- **Erosion:** Waeles (2005)

  **Non-cohesive regime** \( f_m < 30\% \)
  \[
  E_s = (1 - f_m) \cdot E_{0s} \cdot T^a \\
  E_m = f_m \cdot E_{0s} \cdot T^a
  \]

  **Cohesive regime** \( f_m > 50\% \)
  \[
  E_s = (1 - f_m) \cdot E_{0m} \cdot T \\
  E_m = f_m \cdot E_{0m} \cdot T
  \]

**linear interpolation**
Sediment Transport Model

• The new deposition criterion
  Critical shear stress for deposition:

\[
\tau_{cd,s} = \left(1 - \frac{\rho_w}{\rho_s}\right) gh \frac{w_s C_s}{Rf_L} \quad \tau_{cd,m} = \left(1 - \frac{\rho_w}{\rho_m}\right) gh \frac{w_m C_m}{Rf_L}
\]

Deposition probabilities

\[
p_s = \max\left[1 - \frac{C_s}{C_s + C_m} \frac{\tau}{\tau_{cd,s}}, 0\right] \quad p_m = \max\left[1 - \frac{C_m}{C_s + C_m} \frac{\tau}{\tau_{cd,m}}, 0\right]
\]

• Krone’s deposition law

\[
D_s = (w_s C_s) \cdot p_s \quad D_m = (w_m C_m) \cdot p_m
\]
Model Performance

Suspension concentration at step 7000
Model Performance

Suspension concentration at step 7000

Suspension Concentration - ConR (g/L)
Model Performance

Suspension concentration at step 7000
Model Performance

sediment exporting to the North Sea

Accumulated Sediment Flux (MT)

Sediment Flux ConR
Sediment Flux DepR
Sediment Flux DepCsR
Costal Waves

- Stationary wind towards the coast
- Boundary significant wave height = 1.5m
- Boundary peak frequency = 0.125

- Three-way coupling
- Wave-current interactions
Costal Waves
Costal Waves

Suspension Concentration (g/L) at Time Step 700

(without costal waves)
Costal Waves
Thanks for your attention!