2D and 3D Sediment Transport and Morphological Modelling
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Introduction

Sediment transport overview

Choosing your hydraulic model

Sediment transport and morphological modelling

Example case studies
  Gravel bed sediment armouring and sorting
  Breakwater design at a river mouth
Sediment Transport Overview
Sediment and Geomorphology

Source material
High energy to low energy
Erosion and degrading, aggrading
Constant change - Periods of high energy and relative calm
Sediment distribution influenced by environment
Winds, currents, waves, gravity, ice
Sediment Types

Sediment Grain Size – Classified by Diameter

**Cohesive** – Influenced by biological and electrical forces
- Clays and silts

**Non-Cohesive** – Submerged weight
- Sands, gravels, cobbles, boulders

**Mixed sediments** > 10% of fines can be affected by cohesion
- Sands, gravels etc. with clays and silts
Sediment Transport

Currents and waves exert a drag force on the bed

Bed shear stress – Drag force per unit area (N/m²)

As velocity increases reach a critical stress
Grains start to roll, slide
Bounce or jump (saltation)
Lifted into suspension
Turbulence

Bed Load + Suspended Load = Total Load

https://youtu.be/RJxO10uU1Aw
Components of a Sediment Transport Model

**Sediment Transport Functionality**

- Multiple fractions – Capture the distribution
- Cohesive and non-cohesive
- Suspended sediment and bed load
- Have equations that suit each of these processes

*Why do we want this? Because nature has it.*

*Muddy banks, next to gravel channels, sandy beach next to mangroves…*
Applications

- Capital and operational dredging
- Navigation
- Port development
- Scour
- Sand bar accretion and erosion
- Water quality interactions – sediment biogenesis
- Beach nourishment, coastal erosion, beach restoration
- Alluvial fans
Choosing your Hydraulic Model
Choosing your hydraulic model

Picking the best tool for the job - Different models for different problems

1D - long time scales, large systems river reaches, difficult to capture changes at cross sectional scale and discrete events. Refer: https://awschool.com.au/resources/webinar-sediment-transport-modelling-too-hard-for-einstein/

2D – Velocity variation, flow splitting, overbank and floodplains

3D - Helicoidal currents, stratified flows, counter-currents with depth

3D – Non-Hydrostatic – Fine scale structure interaction, fine scale turbulence and scour
2D Model – Flow Distribution
3D Modelling – Secondary Flows

- Finite volume method on unstructured mesh
- 3D sigma-coordinates
- Vertical turbulence model: the standard $k$-$\varepsilon$ closure in GOTM
3D Hydrodynamics and Vertical Mixing in a stratified estuary
2D vs 3D

Suspended sediment fate

Limited mixing

Implications for disposal

3D Hydrodynamics and Vertical Mixing in a stratified estuary
Non-hydrostatic

Where vertical accelerations are significant
Fine scale turbulence and structure interactions
CFD models
Pier scour
Sediment Transport and Morphological Modelling
Sediment Transport and Morphology - Process

No 1 – A calibrated hydraulic/wave model

Sediment data

Discretise

- Sediment types
- Sediment size (d50)

Choose fraction models/equations

Estimate the spatial distribution and thickness of sediment

Bed ‘warm-up’ – Can I reproduce real conditions?

Ambient vs. Design
Sediment Data

For sediment model boundary conditions and calibration

Sediment samples
Particle Size Distributions
Composition
Parameters
Spatial distribution and depth (boreholes or bed samples)
Suspended sediment rating curve

ADCP – sediment backscatter

Bed load rates - Bed load traps or trench

Bathymetric surveys i.e. pre and post event.
### Sediment Transport and Morphology

#### Choose equations that suit cohesive or non-cohesive sediment for each fraction

<table>
<thead>
<tr>
<th>Settling</th>
<th>Erosion</th>
<th>Deposition</th>
<th>Bed load</th>
<th>Critical Stress</th>
<th>Consolidation</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

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**Settling**
- None

**Erosion**
- None

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**Partitioning of sediment fractions**

- **Fines**
  - Particle density: 2650 kg/m³
  - Median diameter: 5.0e-5 m
- **Sediment fraction commands**
  - Number of sediment fractions that are to be modelled.

```plaintext
Fraction == fines
  particle density == 2650.
  d50 == 5.0e-5
  settling model == constant
  settling parameters == 1.0e-03
  deposition model == krone
  deposition parameters == 0.18
  erosion model == mehta
  erosion parameters == 0.001, 0.2, 1.5
  critical stress model == none
  bed load model == none

End Fraction
```

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**Related readings**
- Soulsby - vanRijn
- Bijker
- Wilcock - Crowe
- Krone
- Mehta
- Soulsby - Egiazaroff
- Meyer - Peter
- MPM - Shimizu
- VanRijn (1984)
- VanRijn (2004)

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**Notes**
- Choose equations that suit cohesive or non-cohesive sediment for each fraction.
Initial estimate of spatial, layer thickness and depth
Run for extended period of ambient conditions
Outcome should represent reality

Bed Warmup
Ambient vs. Design

3D model

Offshore ocean circulation

Ambient only

Ambient plus dredge

Moving dredge head

Wind/wave inputs

Erosion/deposition

Navigation, suspended sediment and siltation
Case Studies
Bed Armouring and Sorting
Mixed Sand/Gravel River
Challenges of Modelling Bedload Transport

1. Sediment mixtures of different grain sizes

2. Meandering river:
   - Faster/slower flow
   - Helical (Secondary) flow
1. Sediment mixtures of different grain sizes

2. Meandering river:
   • Faster/slower flow
   • Helical (Secondary) flow
Background
Challenges of Modelling Bedload Transport

1. Sediment mixtures of different grain sizes

2. Meandering river:
   • Faster/slower flow
   • Helical (Secondary) flow

3. Erosion/deposition
   → bed armouring/sorting

Armouring
Model Verifications
Bed Sorting in a Meandering Channel - Ashida et al (1990)

Hydraulic condition

Sine-generated curve
200cm * 4.5

<table>
<thead>
<tr>
<th>Case</th>
<th>Flow Rate (l/s)</th>
<th>Depth (cm)</th>
<th>Cell Size (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>1.2</td>
<td>1.65</td>
<td>3 * 2</td>
</tr>
<tr>
<td>A2</td>
<td>3.6</td>
<td>4.26</td>
<td>3 * 2</td>
</tr>
</tbody>
</table>

Sediment property

Model Verifications
Bed Sorting in a Meandering Channel - Ashida et al (1990)

Result:
Model Verifications
Bed Sorting in a Meandering Channel - Ashida et al (1990)

Result:

Case A1

Case A2

(a) Measured

(b) Simulated
Model Verifications
Bed Sorting in a Meandering Channel - Ashida et al (1990)

Change in bed level

1 min

15 min

60 min

Median Grain Size

Dm (mm)

3.0
2.0
1.5
0.9
Model Verifications
Field scale experiment - Maeshima et al (2011)

Hydraulic condition

<table>
<thead>
<tr>
<th>Case</th>
<th>Flowrate (m$^3$/s)</th>
<th>Depth (m)</th>
<th>Cell Size (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>2.0</td>
<td>0.34</td>
<td>50 * 25</td>
</tr>
<tr>
<td>C2</td>
<td>3.2</td>
<td>0.56</td>
<td>50 * 25</td>
</tr>
<tr>
<td>C3</td>
<td>8.0</td>
<td>0.80</td>
<td>50 * 25</td>
</tr>
</tbody>
</table>

Sediment property

- **Case**
  - No.1
  - No.4
  - No.6
  - No.8
  - No.9
  - No.11
  - No.13
  - No.15

- **Flow**: 150m

- **No.1 ~ 400 mm**
  - **$D_m = 50mm$**

- **Cumulative Percentage**
  - 0% - 100%
  - 0.1 ~ 1000 Grain Size (mm)
  - Ashida et al (1991)
  - EF Lewis River, Surface
  - EF Lewis River, Sub-surface
  - Maeshima et al (2011)
Model Verifications
Field scale experiment - Maeshima et al (2011)

Result:
dZ before and after run M3

Cross-section 8 (meandering section)

Initial bed level
After C2
After C3

Elevation (m)
Transverse Distance (m)

ZB Initial, Measurement
ZB initial, Simulation
ZB after C2, Measurement
ZB after C2, Simulation
ZB after C3, Measurement
ZB after C3, Simulation
Model Verifications
Field scale experiment - Maeshima et al (2011)
Case Studies
River Mouth Navigation
River Mouth Entrance – Wave Current Interactions

- Base for the marine pilots, two commercial marinas and a large commercial fishing fleet
- Major launch point recreational vessels
- Periodic entrance shoaling requires maintenance dredging

2-way Coupled Modelling Approach

- Waves estimated using SWAN
- Passed to TUFLOW FV for a hydrodynamic and sediment transport calculation
- Bed morphology update passed back to SWAN
TUFLOW FV Model

- Capital works options incorporated into the mesh design
TUFLLOW FV Model Validation

- Existing ADCP transect data set
SWAN Model Validation

- Significant height
- Wave period
- Wave direction
Design Shoal Event Simulation

- December 2011 to May 2012
- Vectors show sediment transport flux
- Contours bed elevation
- Wave height time series
Unique morphology calibration dataset

- Operator required to identify navigable channel during the 2011-2013 shoaling event
- This resulted in a sequence of hydrographic surveys
- Converted to sequence of DEMs for shoal volume calibration
Design Shoal Event Validation

![Observed Shoal](image1)

![Predicted Shoal](image2)

- **Date**
- **Shoal Volume (m$^3$)**
  - **Observed Shoal**
  - **Predicted Shoal**

![Graph](image3)

- **Shoal Volume (m$^3$)**
- **Date**
  - 10/12/2011 00:00
  - 14/01/2012 00:00
  - 18/02/2012 00:00
  - 24/03/2012 00:00
  - 28/04/2012 00:00

- **x 10$^4$**
  - 0
  - 0.5
  - 1
  - 1.5
  - 2
  - 2.5

- **Bed Elevation (m BDT)**
  - -4.0
  - -3.5
  - -3.0
  - -2.5
  - -2.0
  - -1.5
  - -1.0
  - -0.5
  - 0.0
  - 0.5
  - 1.0
  - 1.5
  - 2.0
  - 2.5
  - 3.0
  - 3.5
  - 4.0
Options assessment

• Each capital works option maintains a navigation channel to -3 m LAT during the design shoal event

• Major impact to “natural” sand bypassing to Spit (downdrift beach)
Conclusions
Conclusions

Sediment Transport Overview
• Sediment source material
• Energy and hydraulic drivers
• Nonstationary – cycles of deposition and erosion
• Bed load and suspended load

Choosing your Hydraulic Model – The right tool for the job

Data and Calibration – can make the model a useful tool

Sediment fractions and equations - flexibility

Modelling process - Bed ‘warm up’, ambient and design

Many applications – validate and calibrate
Modelling with TUFLOW Flexible Mesh

Hydraulic Tutorial Modules

Sediment Transport Demo Models
• Please let me know if you’re interested and we can send through: support@tuflow.com

More info
www.tuflow.com
Thank you!!!