2D and 3D Sediment Transport and Morphological Modelling

Mitchell Smith, Ian Teakle and Shuang Gao

Australian Water School Webinar 16th December 2020

Introduction

Sediment transport overview

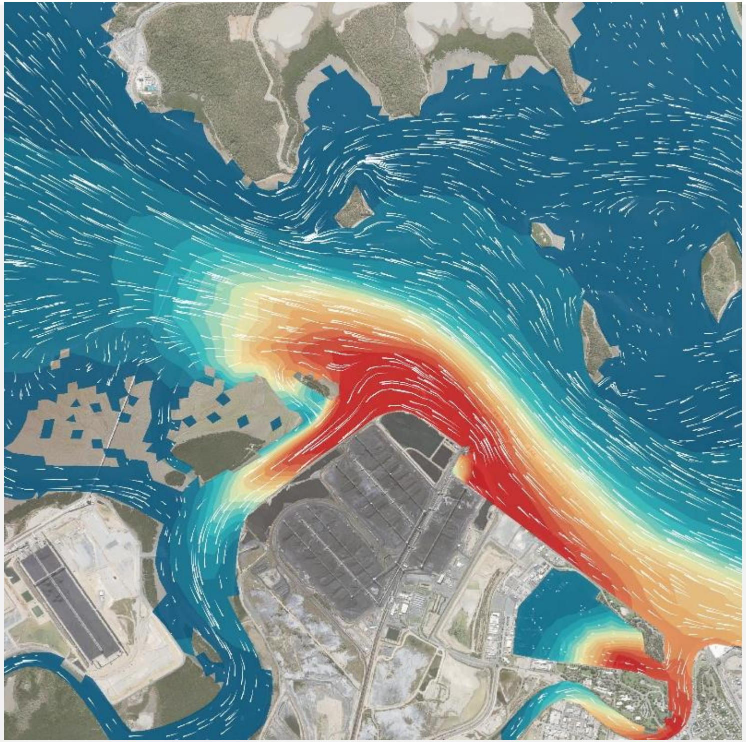
Choosing your hydraulic model

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

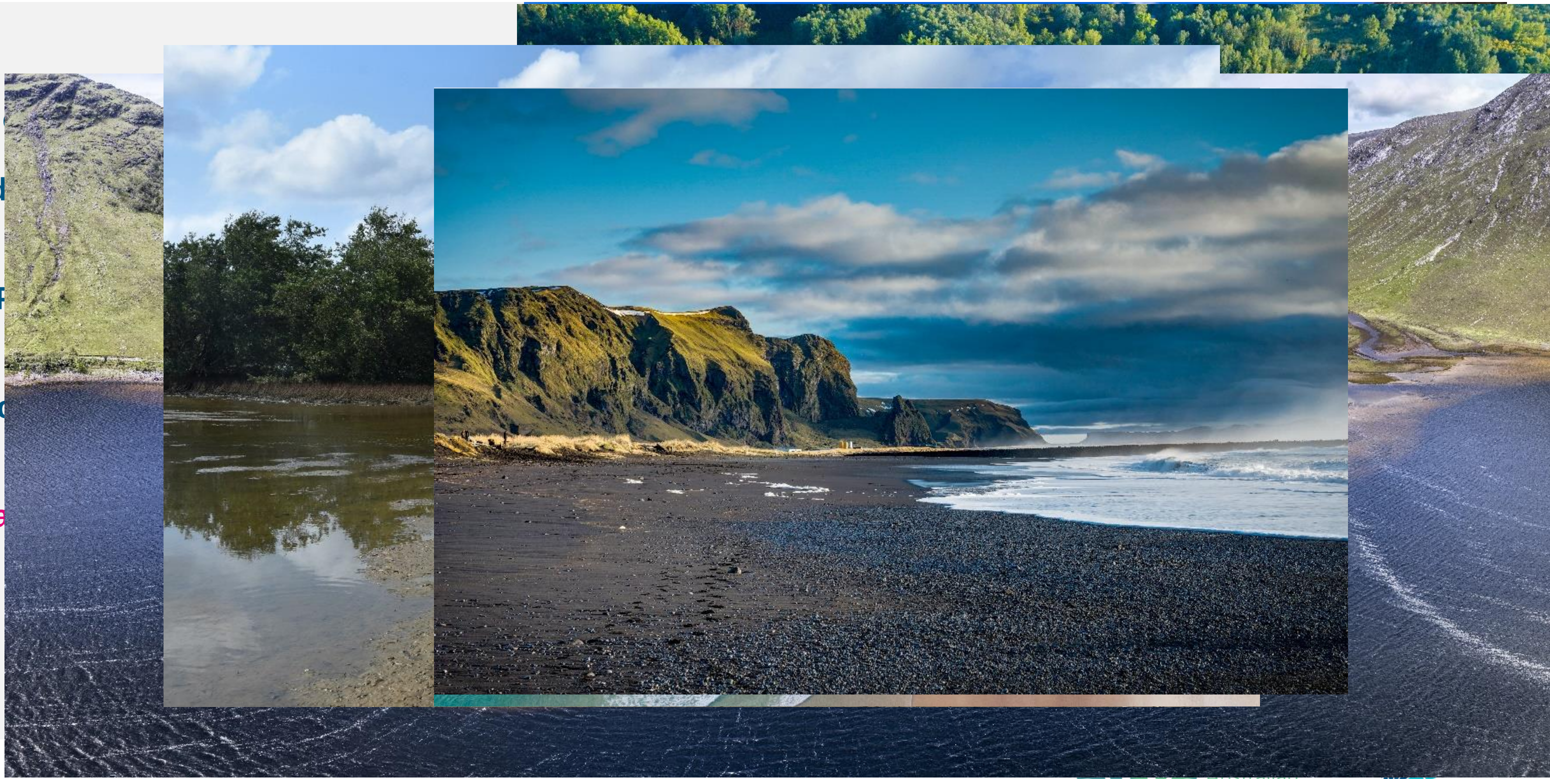
High energy to low

Erosion and degrad
aggrading

Constant change - F
and relative calm

Sediment distributio
environment

Winds, currents, wa



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Sediment Types

Sediment Grain Size – Classified by Diameter

Cohesive – Influenced by biological and electrical forces

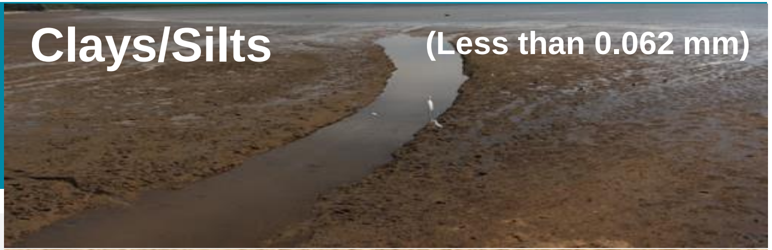
Clays and silts

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 / m^2)

As velocity increases reach a critical stress

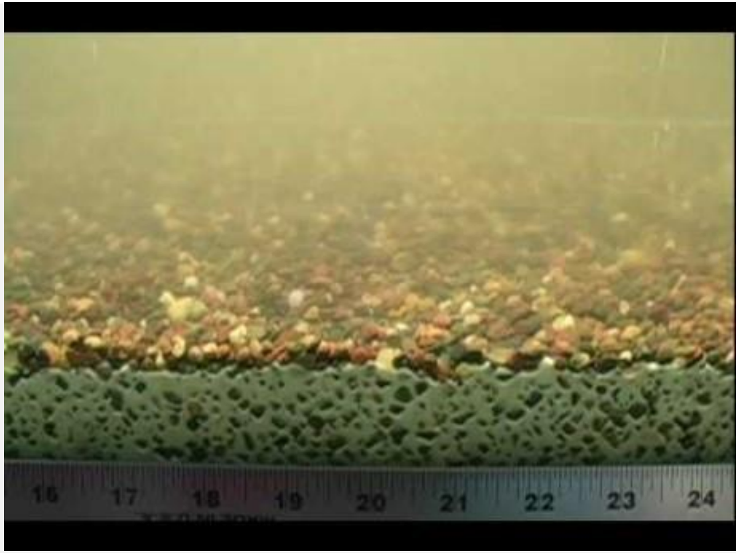
Grains start to roll, slide

Bounce or jump (saltation)

Lifted into suspension

Turbulence

More Energy



https://youtu.be/RJxOI0uUIAw

Bed Load + Suspended Load = Total Load

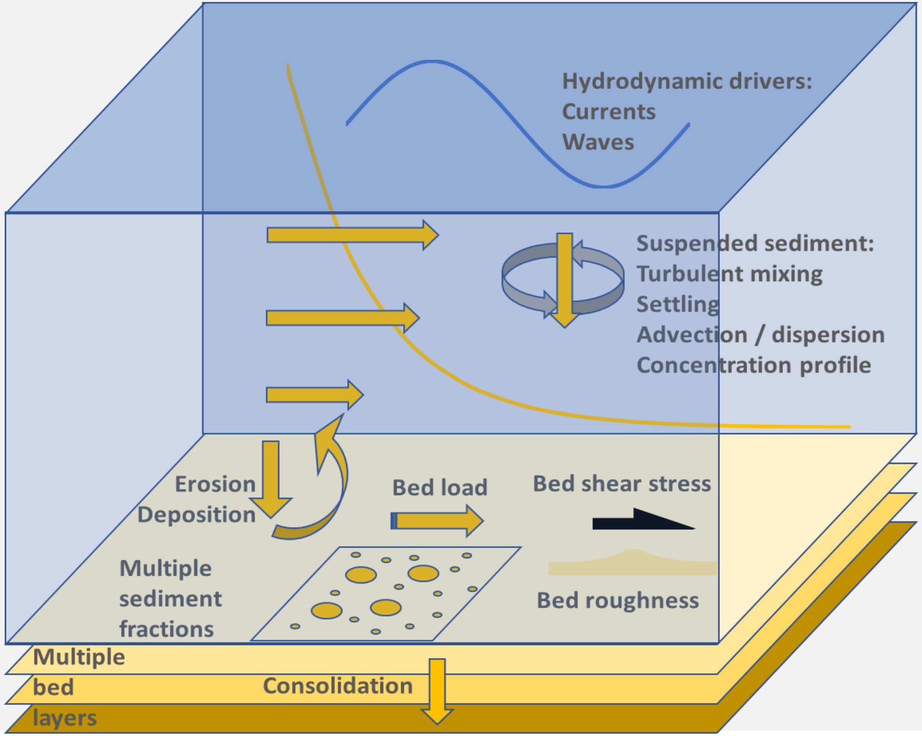
Components of a Sediment Transport Model

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

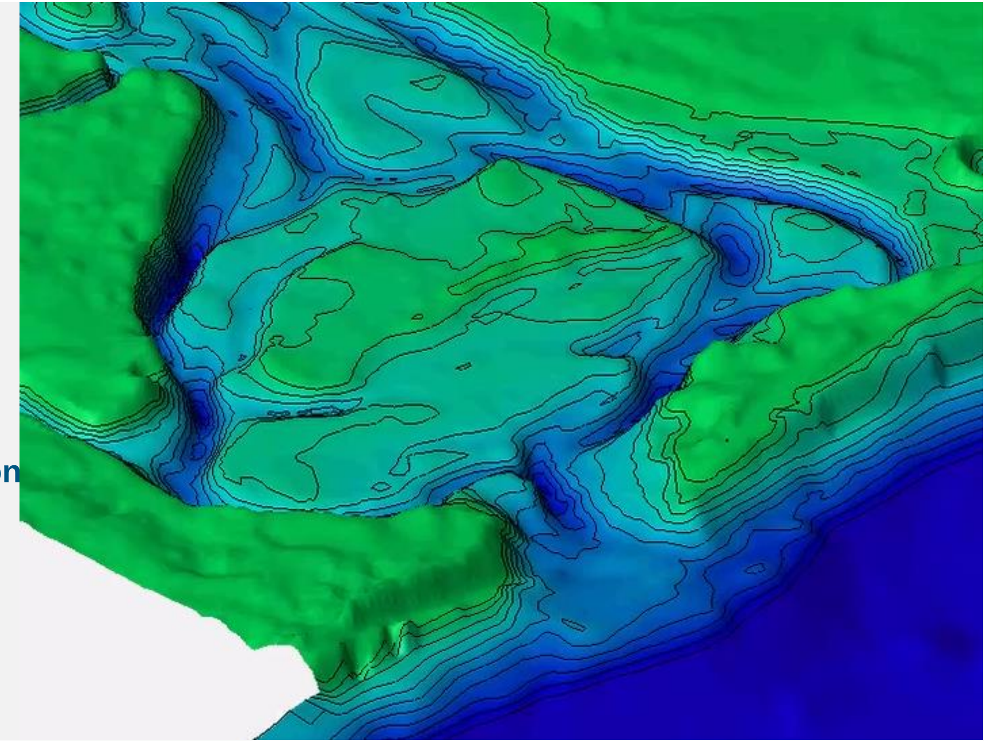
Scour

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

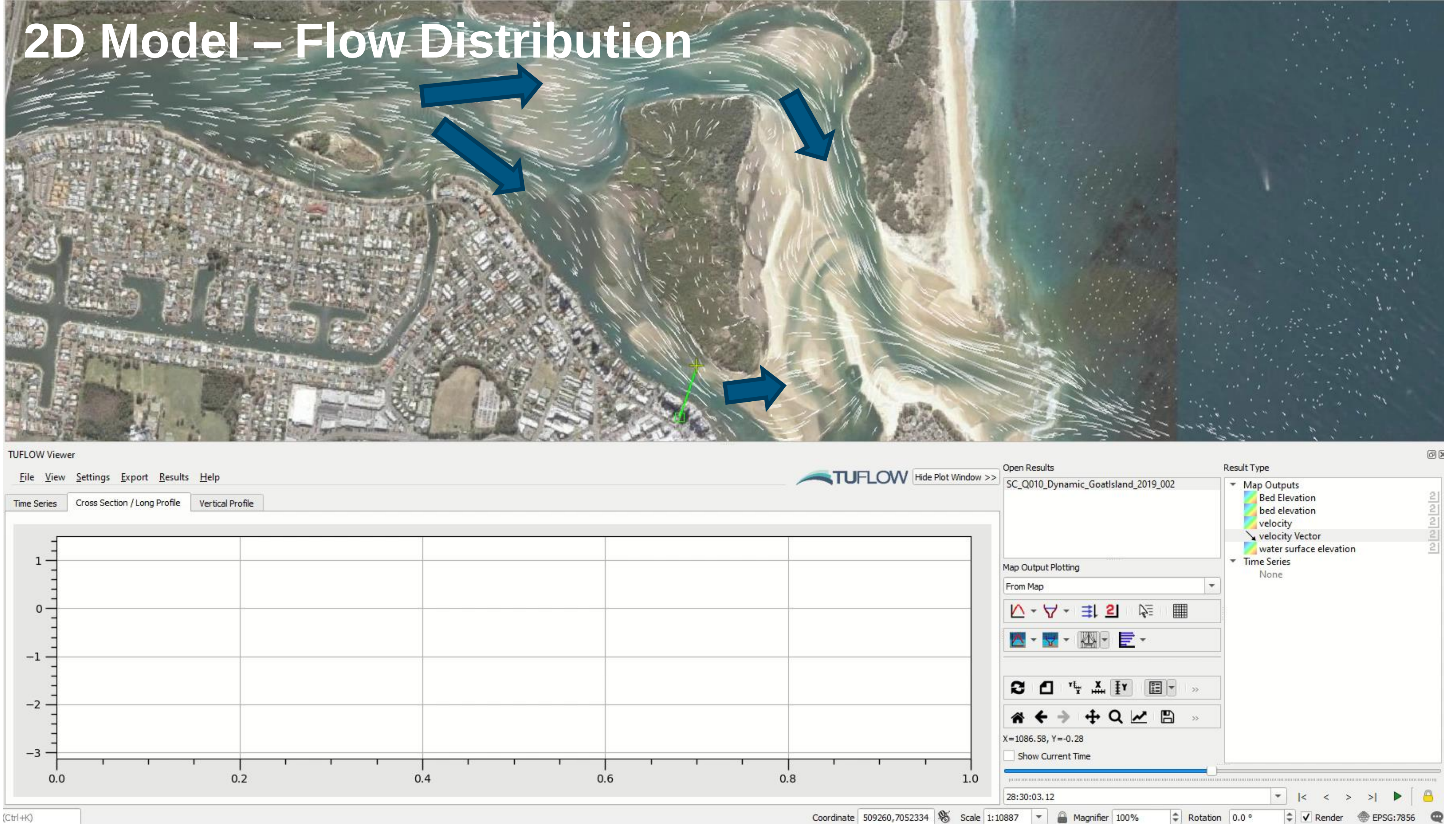
1D - long time scales, large systems river reaches, difficult to capture changes at cross sectional scale and discrete events. Refer: https://awschool.com.au/resources/webinar-sediment-transport-modelling-too-hard-for-einstein/

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

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

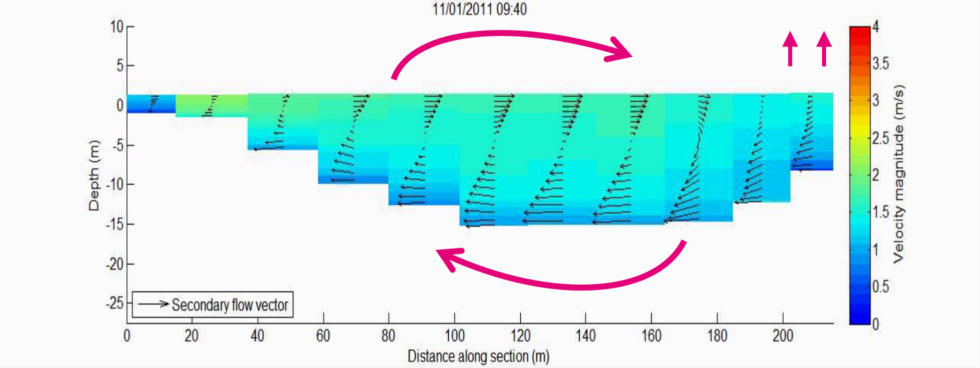
3D – Non-Hydrostatic – Fine scale structure interaction, fine scale turbulence and scour

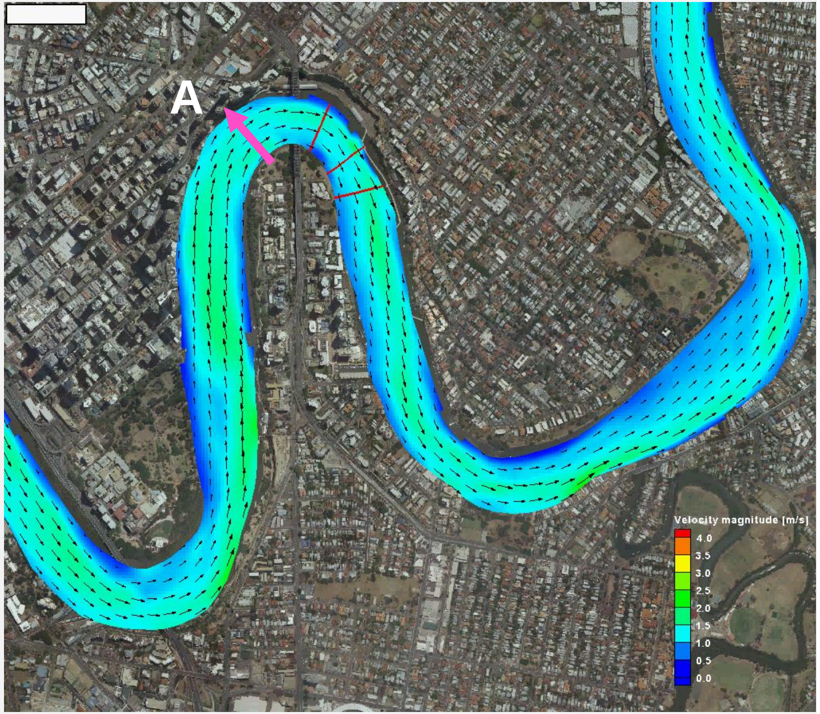
2D Model – Flow Distribution



3D Modelling – Secondary Flows

- Finite volume method on unstructured mesh
- 3D sigma-coordinates
- Vertical turbulence model: the standard *k-ε* closure in GOTM





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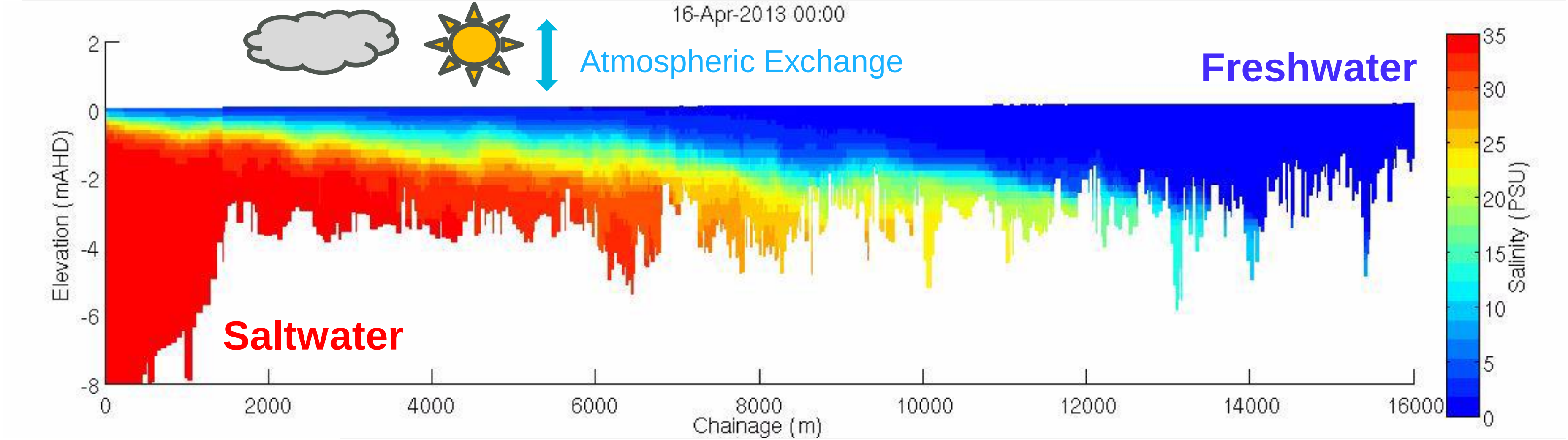
3D - Stratified flows

Ocean boundary saltwater

River and stormwater freshwater



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3D Hydrodynamics and Vertical Mixing in a stratified estuary

Jovanovic, D., Barnes, M.P., Teakle, I.A.L., Bruce, L.C. and McCarthy, D.T (2015).

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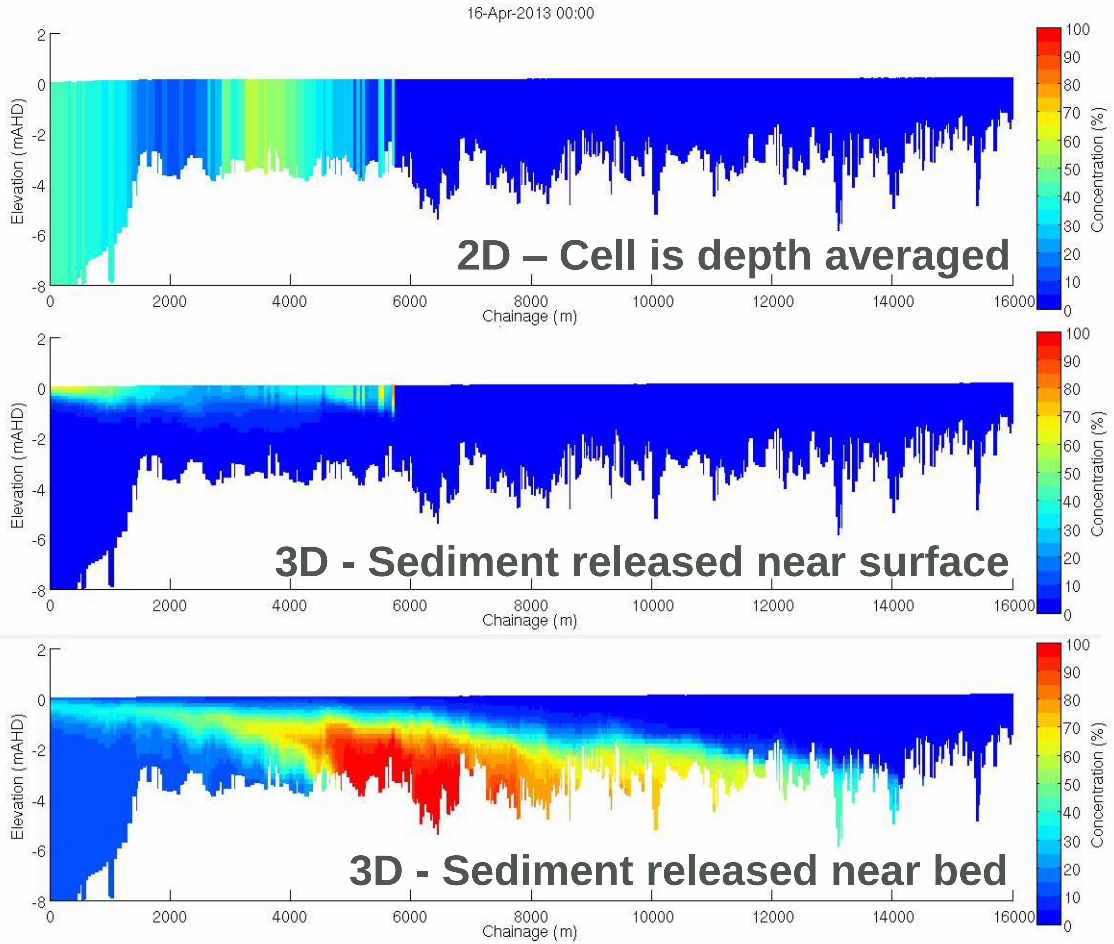
2D vs 3D

Suspended sediment fate

Limited mixing

Implications for disposal



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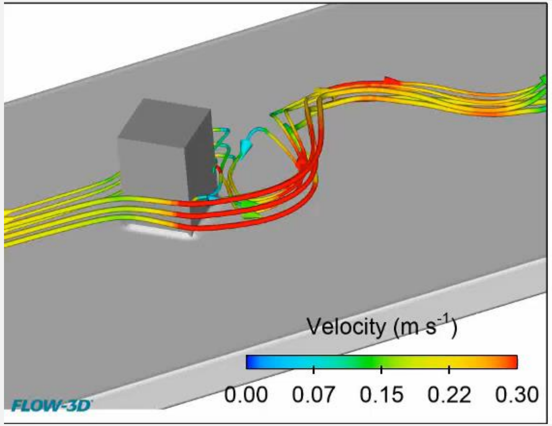
Non-hydrostatic

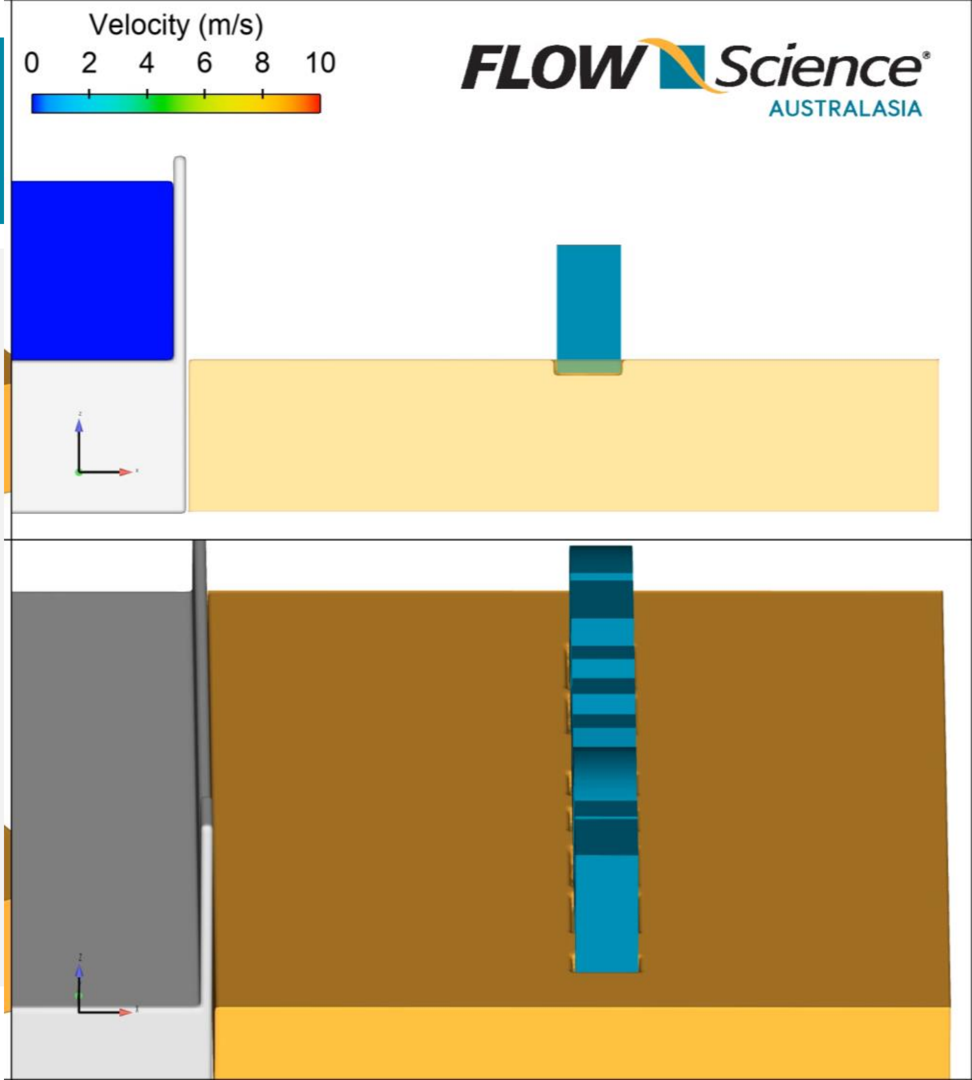
Where vertical accelerations are significant

Fine scale turbulence and structure interactions

CFD models

Pier scour





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Sediment Transport and Morphological Modelling

Sediment Transport and Morphology - Process

No 1 – A calibrated hydraulic/wave model

Sediment data

Discretise

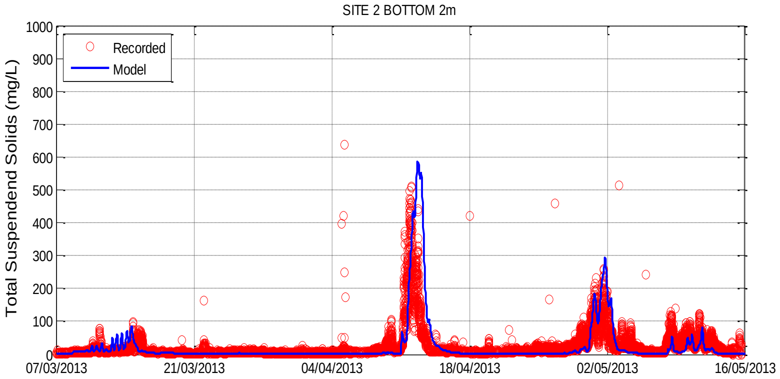
- **Sediment types**
- **Sediment size (d50)**

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)

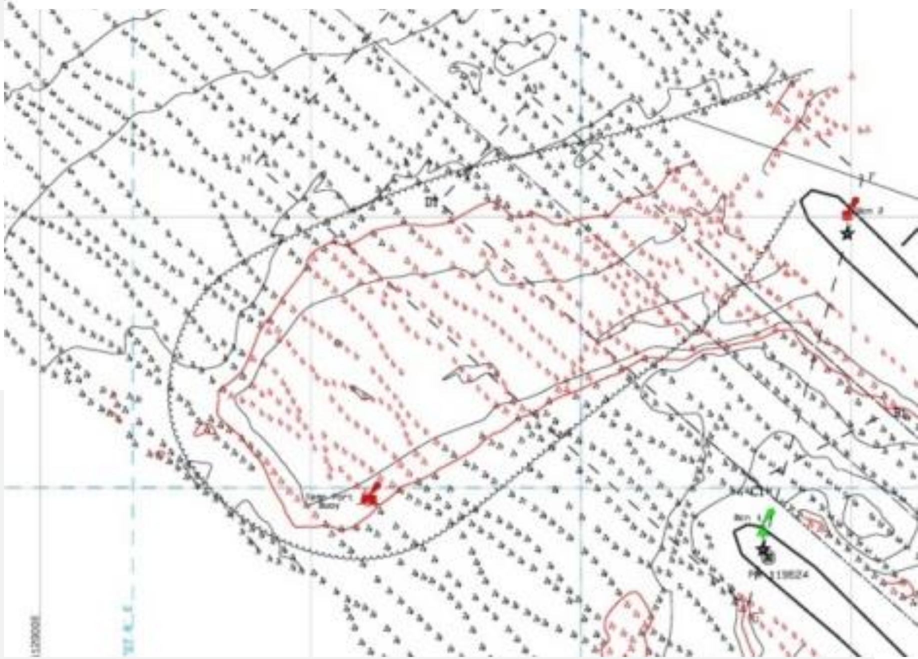
Suspended sediment rating curve

ADCP – sediment backscatter

Bed load rates - Bed load traps or trench

Bathymetric surveys i.e. pre and post event.

Regular Bed Survey



Sediment Transport and Morphology

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

- Settling
- Erosion

Settling	Erosion	Deposition	Bed load	Critical Stress	Consolidation
None	None	None	None	None	None

```
!________________________________________________________________________
!SEDIMENT FRACTION COMMANDS
! Number of sediment fractions that are to be modelled.

Fraction == fines
    particle density == 2650.          ! (kg/m^3) ! Density, used for erosion/deposition
    d50 == 5.0e-5                       ! Median diameter (m)
    settling model == constant          ! Constant settling velocity (Constant | Flocculation | Flocculation-hindered | vanRijn84 | vanRijn04)
    settling parameters == 1.0e-03      ! Parameters for Constant model Settling velocity (m/s)
    deposition model == krone           ! (None | ws0 | Krone)
    deposition parameters == 0.18       ! Parameters for Krone - Taucd
    erosion model == mehta              ! Erosion model (Mehta | vanRijn84 | Soulsby_vanRijn | Bijker | vanRijn04)
    erosion parameters == 0.001, 0.2, 1.5   ! Parameters for Mehta - Er, taucr, alpha
    critical stress model == none       ! Optional critical shear stress model
    bed load model == none              ! No bed load for fines.
End Fraction
```

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Bed Warmup

Ambient vs. Design

3D model

Offshore ocean circulation

Ambient only

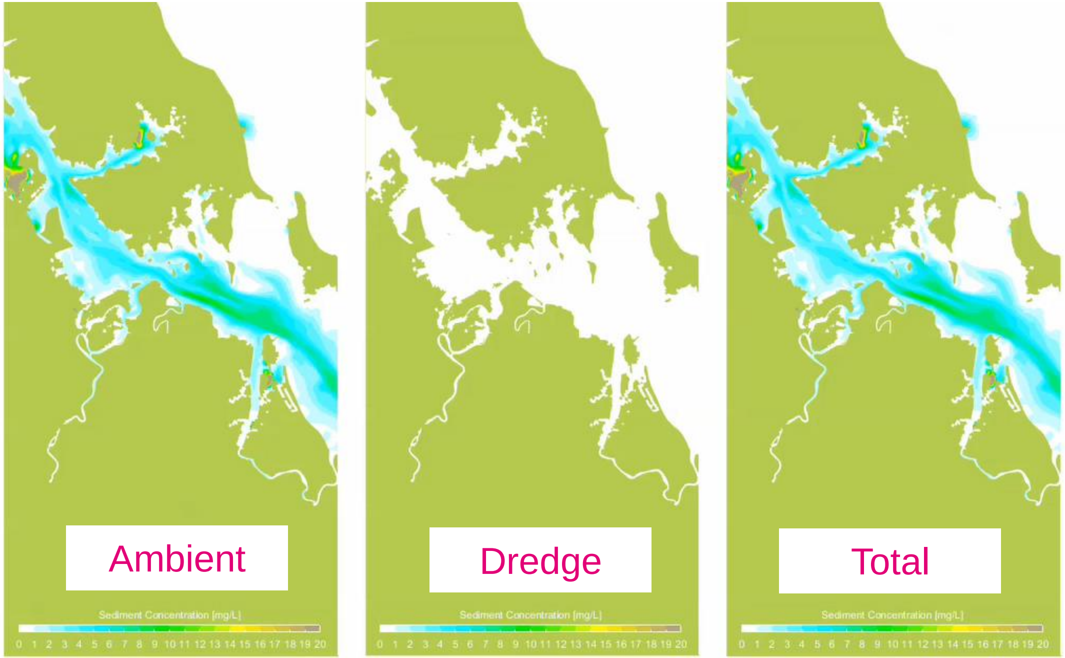
Ambient plus dredge

Moving dredge head

Wind/wave inputs

Erosion/deposition

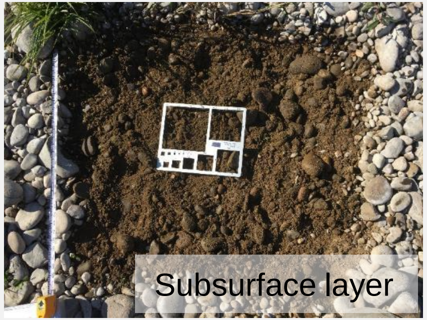
Navigation, suspended sediment and siltation



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



Background
Challenges of Modelling Bedload Transport

1. **Sediment mixtures of different grain sizes**

2. **Meandering river:**
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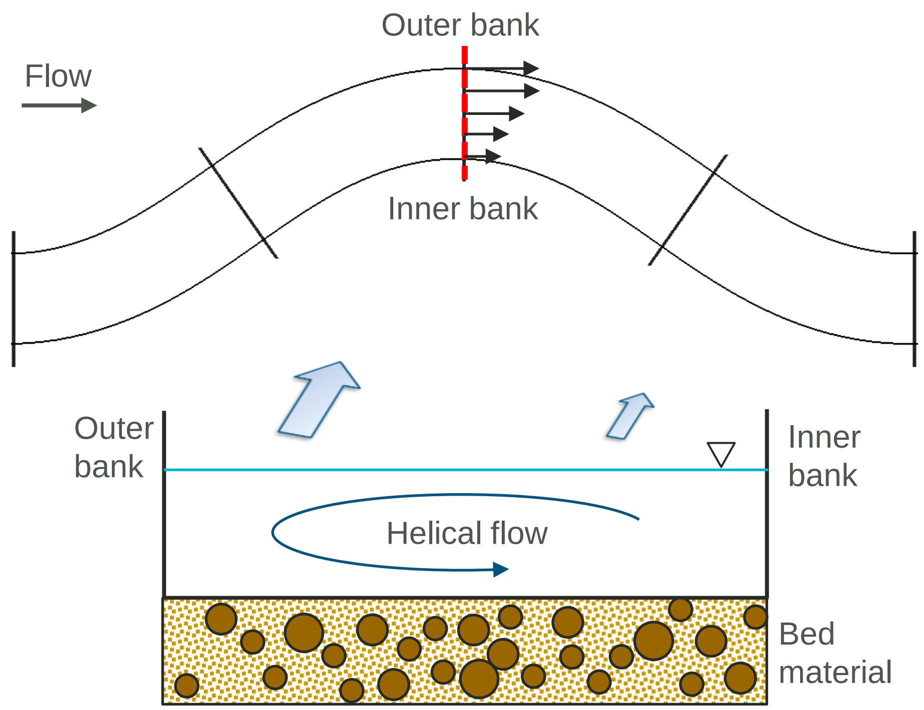


Background

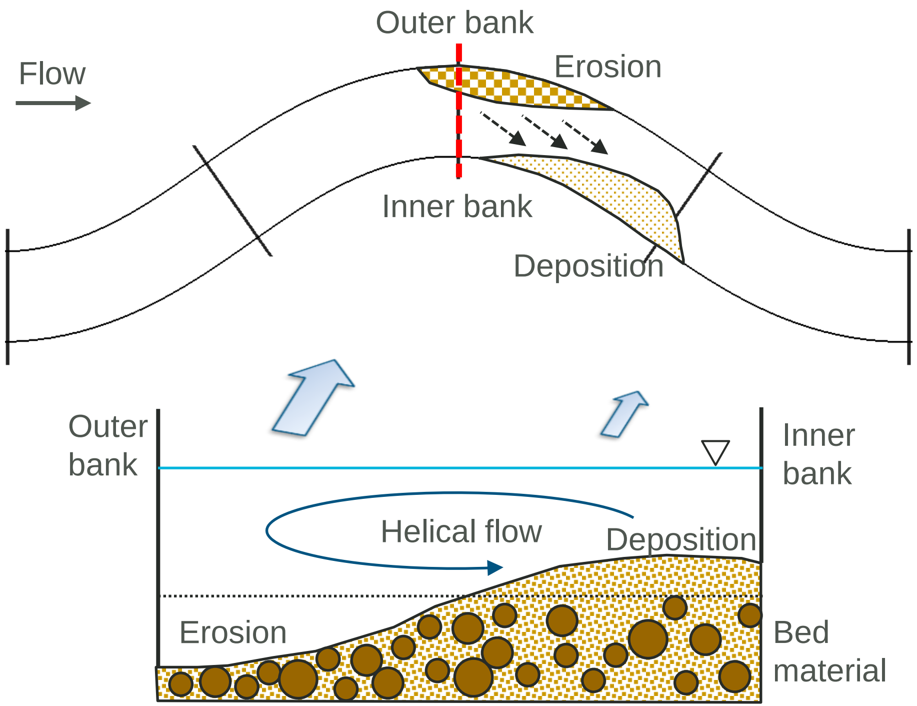
Challenges of Modelling Bedload Transport

1. **Sediment mixtures of different grain sizes**

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

3. **Erosion/deposition**

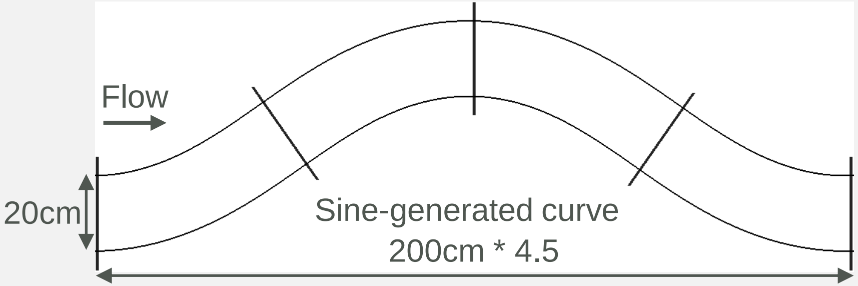
   → bed armouring/sorting



Armouring

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

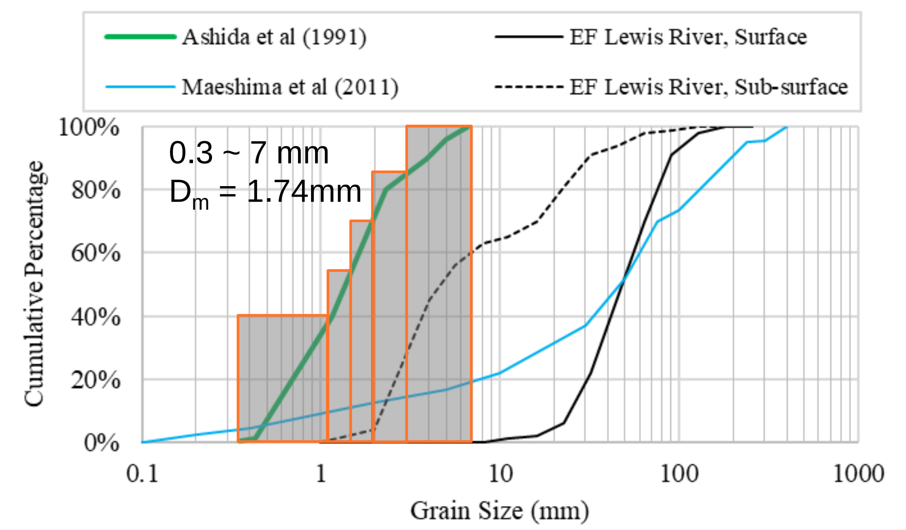
Hydraulic condition



Case	Flow Rate (l/s)	Depth (cm)	Cell Size (cm)
A1	1.2	1.65	3 * 2
A2	3.6	4.26	3 * 2

Gao, S., Smith, M., Teakle, I., Marcoe, K. and Kolp, P. (2019): "Numerical Modelling of Bed Sorting and Armouring in Meandering Channels Applications from the East Fork Lewis River - Ridgefield Pits Area, USA", 14th River Sedimentation, Sep 2019, Chengdu, China

Sediment property

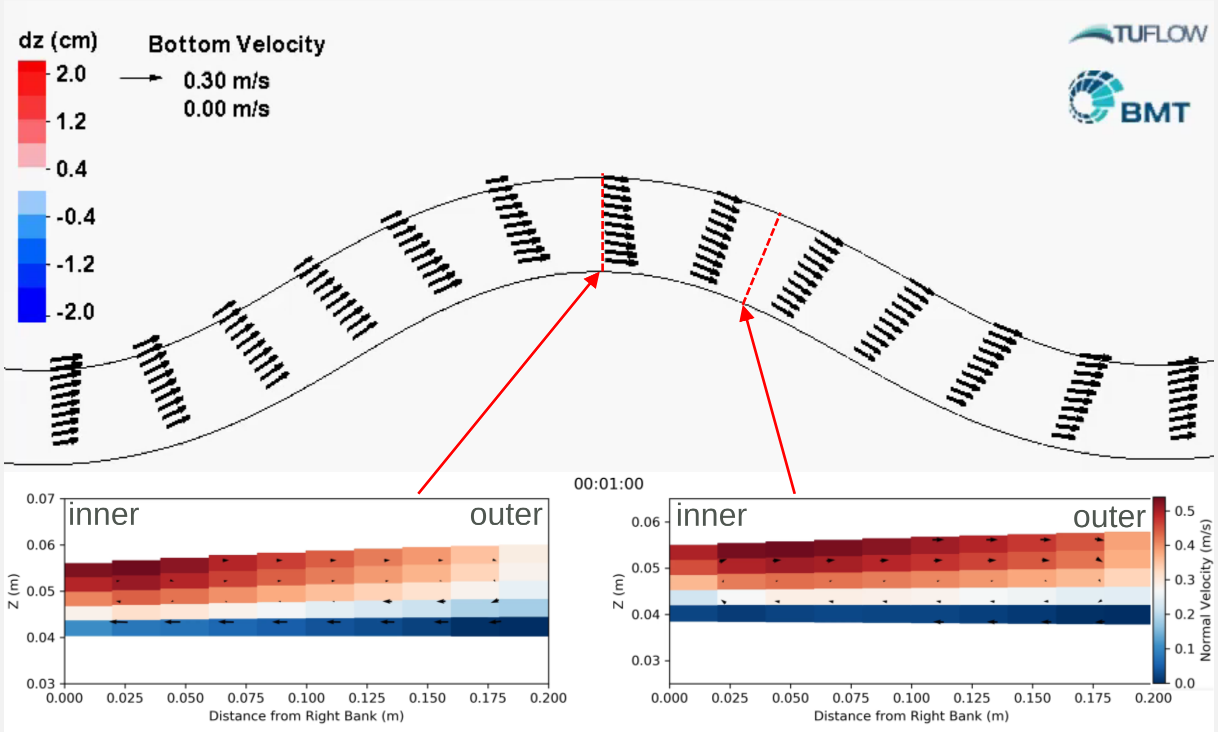


Size (mm)	0.7	1.3	1.74	2.5	4
Distribution (mm)	< 1.1	1.1 - 1.5	1.5 - 2.0	2.0 - 3.0	> 3.0

Model Verifications

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

Result:

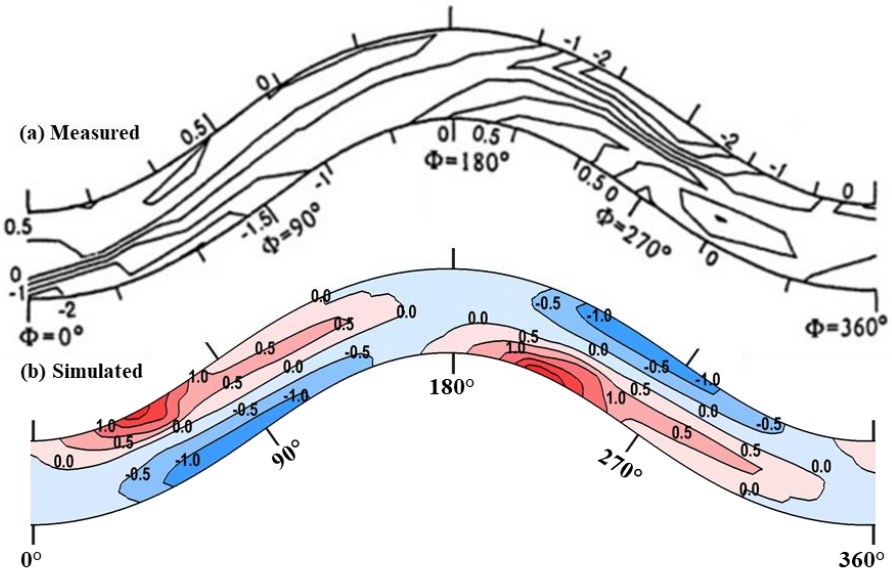


Model Verifications

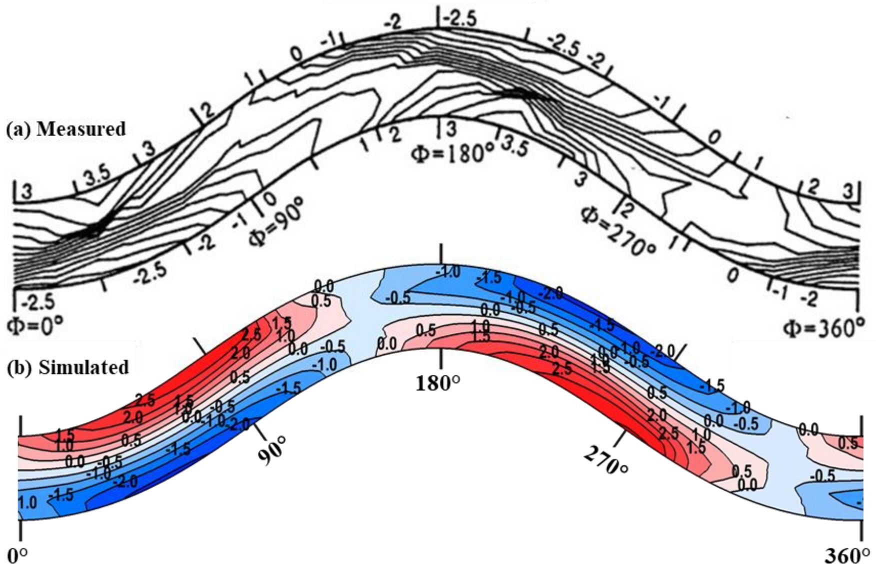
Bed Sorting in a Meandering Channel - Ashida et al (1990)

Result:

Case A1



Case A2



Model Verifications

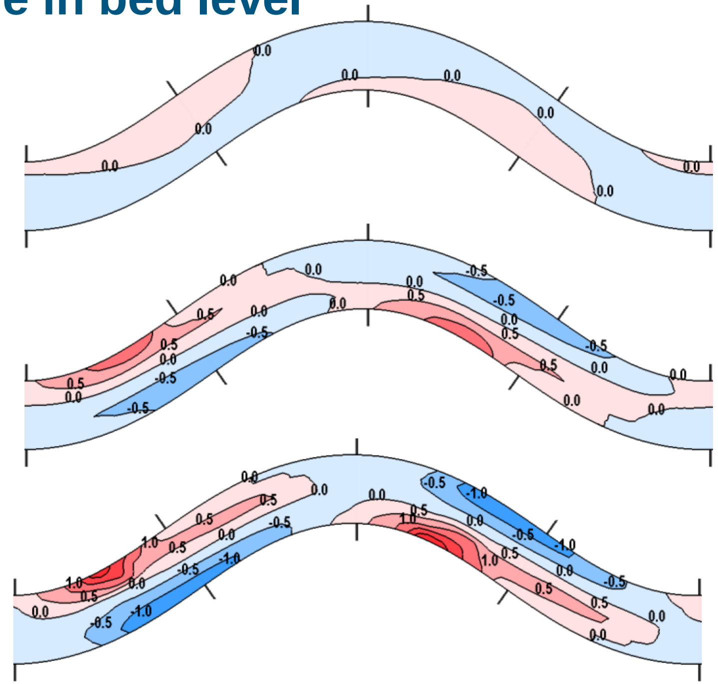
Bed Sorting in a Meandering Channel - Ashida et al (1990)

Change in bed level

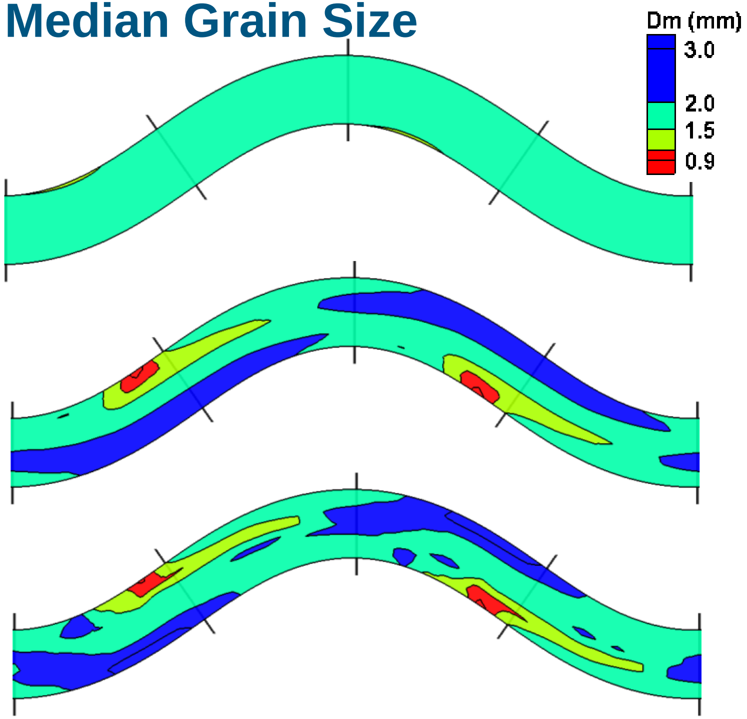
1 min

15 min

60 min



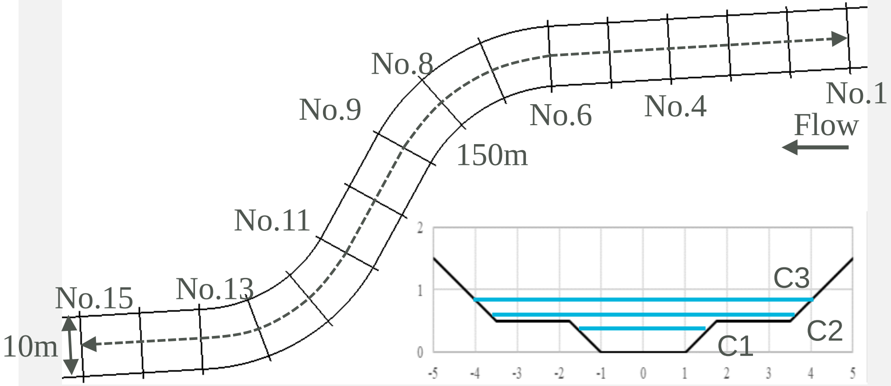
Median Grain Size



Model Verifications

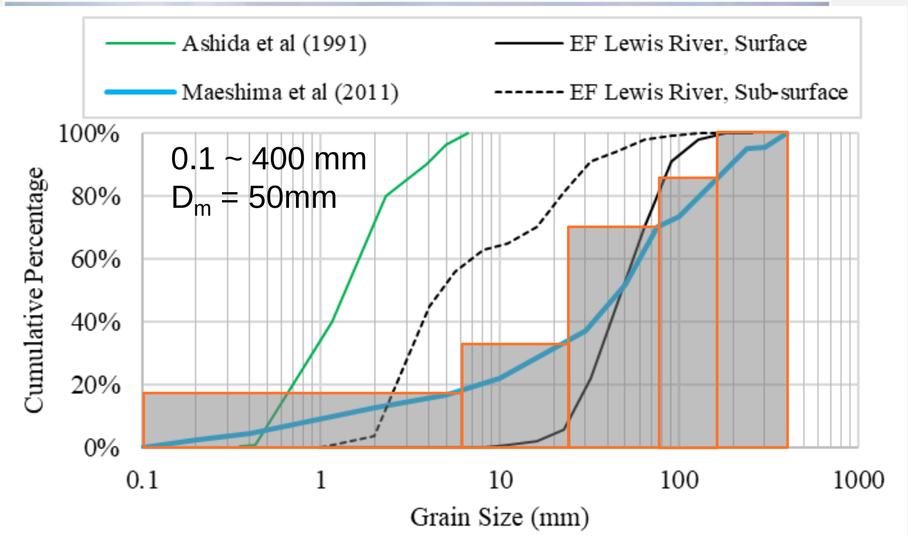
Field scale experiment - Maeshima et al (2011)

Hydraulic condition



Case	Flowrate (m³/s)	Depth (m)	Cell Size (cm)
C1	2.0	0.34	50 * 25
C2	3.2	0.56	50 * 25
C3	8.0	0.80	50 * 25

Sediment property



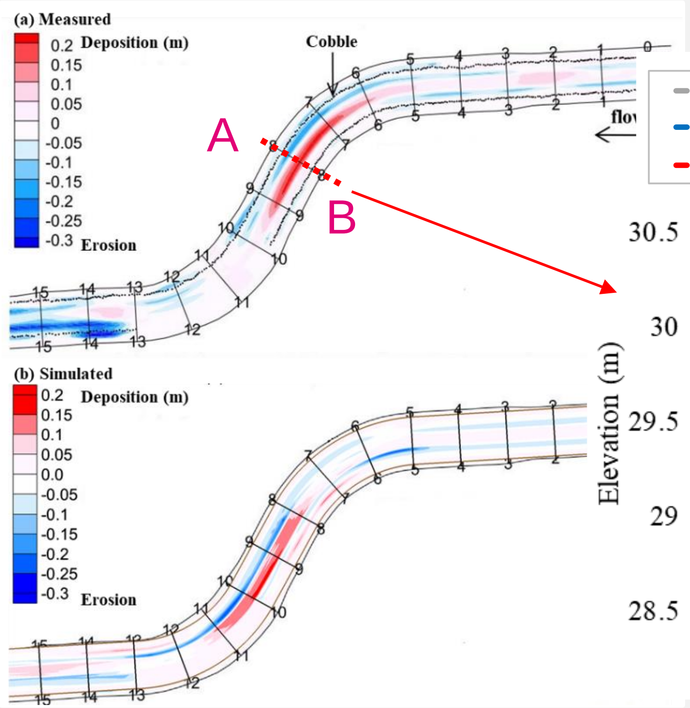
Size (mm)	2	10	50	100	200
Distribution (mm)	< 6	6 - 25	25 - 75	75 - 150	> 150

Model Verifications

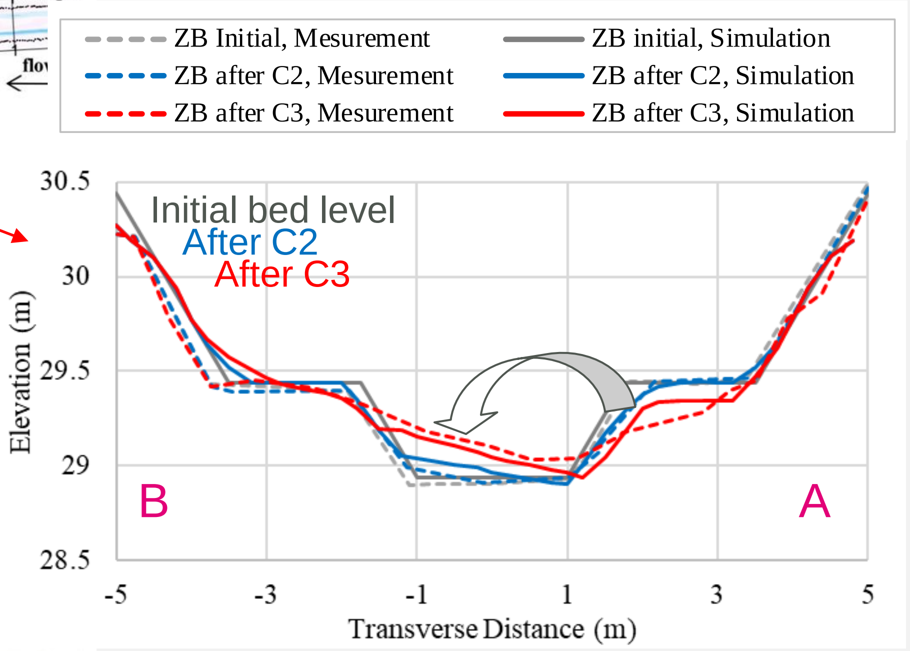
Field scale experiment - Maeshima et al (2011)

Result:

dZ before and after run M3

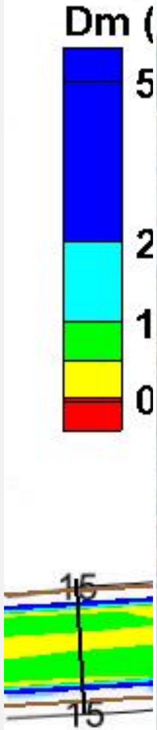


Cross-section 8 (meandering section)



Model Verific

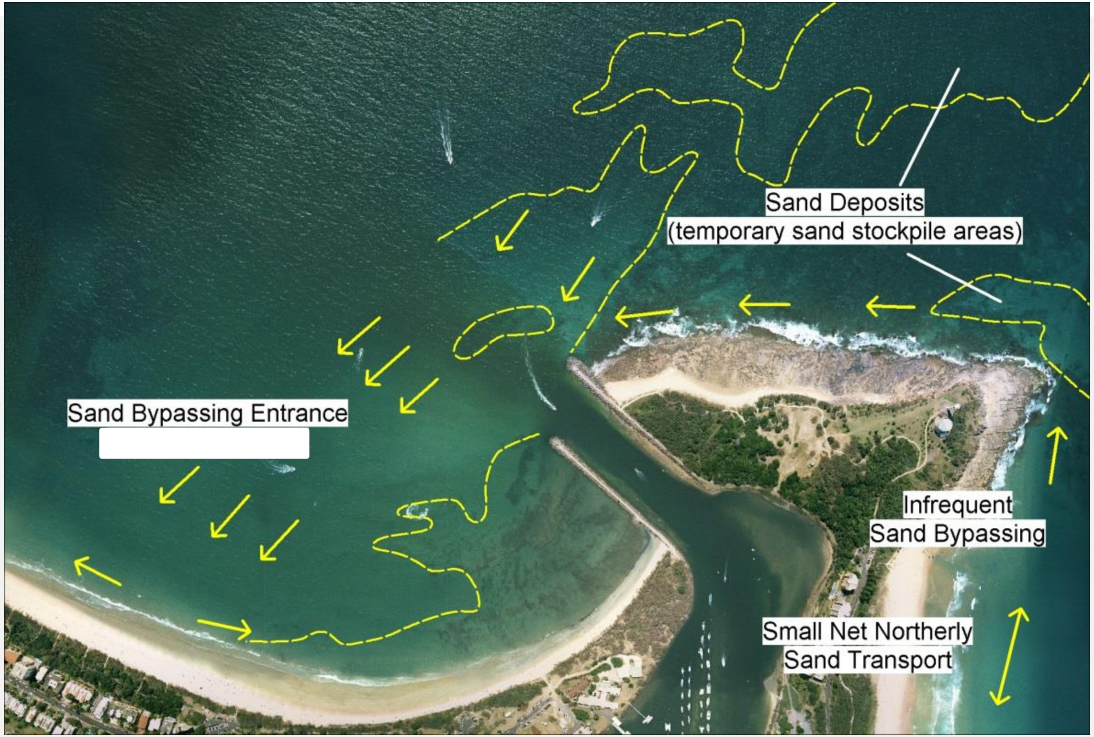
Field scale exp



Case Studies
River Mouth Navigation

River Mouth Entrance – Wave Current Interactions

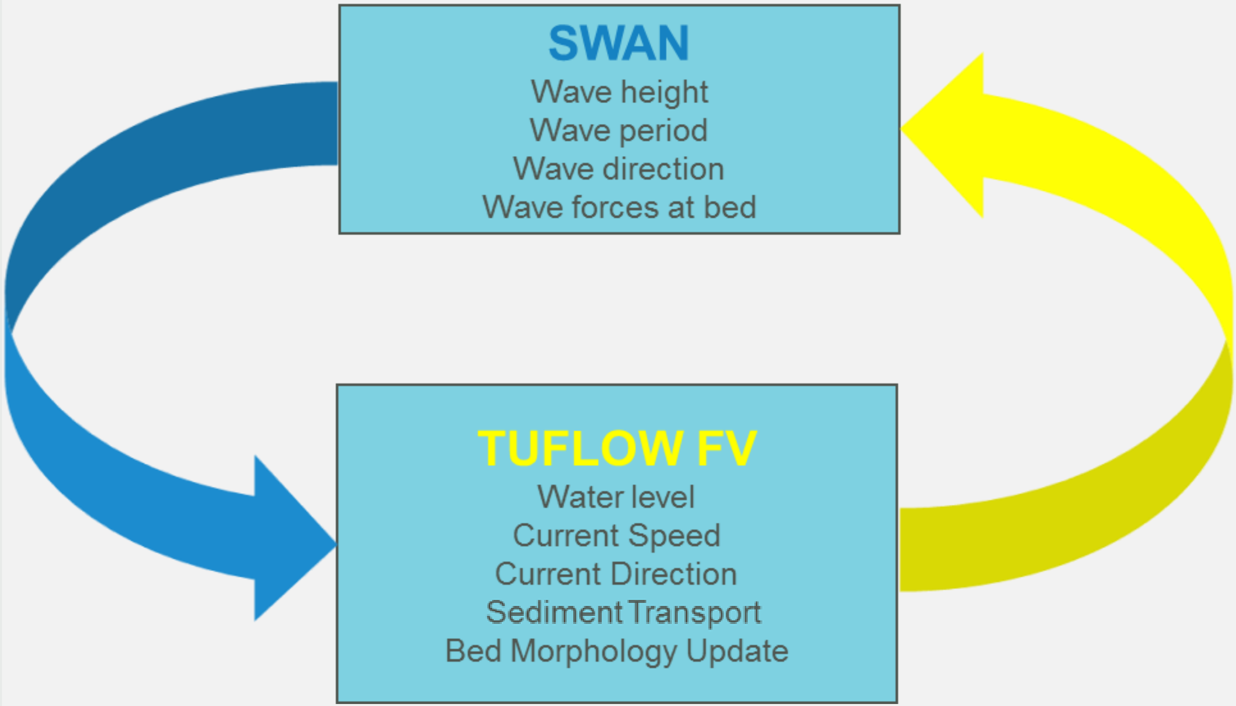
- Base for the marine pilots, two commercial marinas and a large commercial fishing fleet
- Major launch point recreational vessels
- Periodic entrance shoaling requires maintenance dredging



Assessment of Capital Works Options to Mitigate Shoaling at the Mooloolaba Harbour Entrance,
Barnes, M.P., Teakle, I.A.L., Wood, P. and Voisey, C Australasian Coasts and Ports (2015).

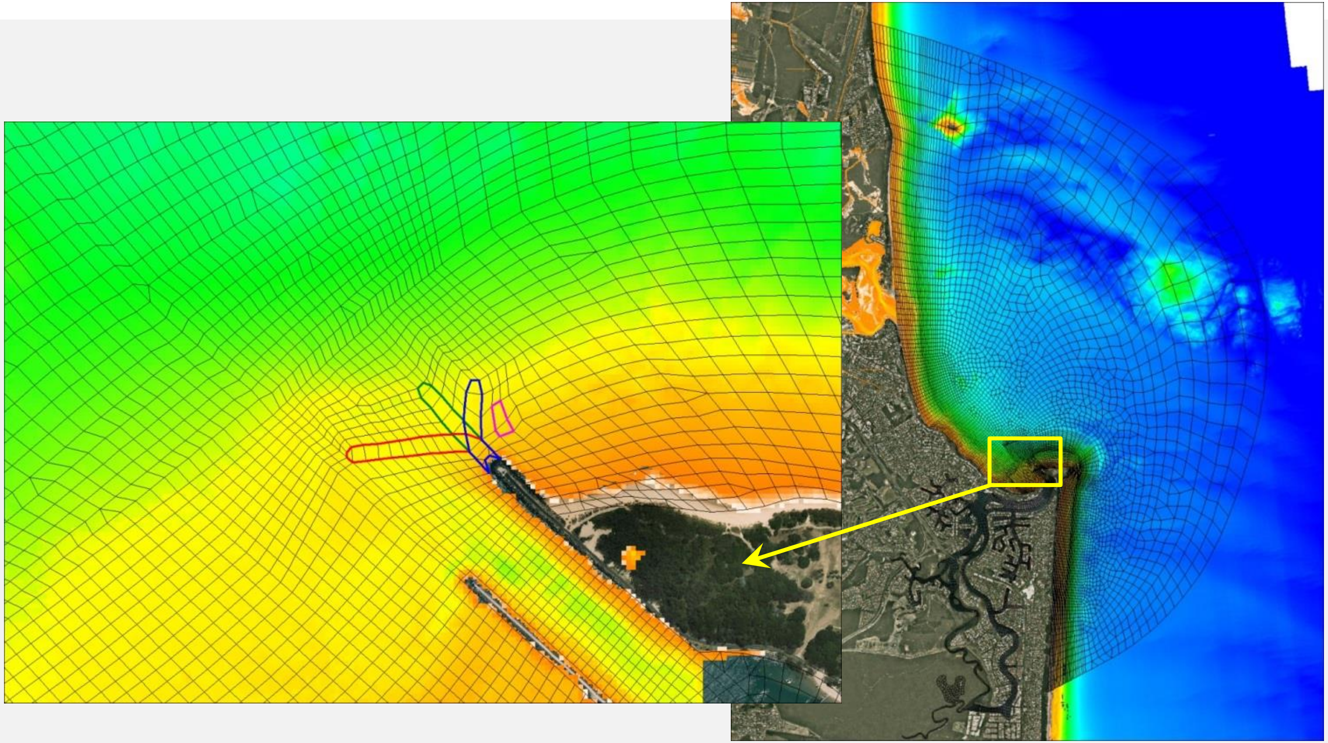
2-way Coupled Modelling Approach

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



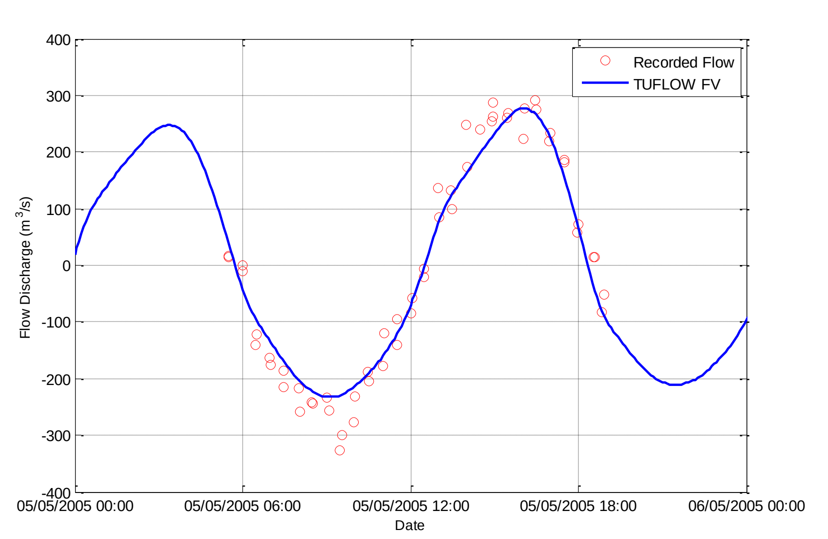
TUFLOW FV Model

- Capital works options incorporated into the mesh design



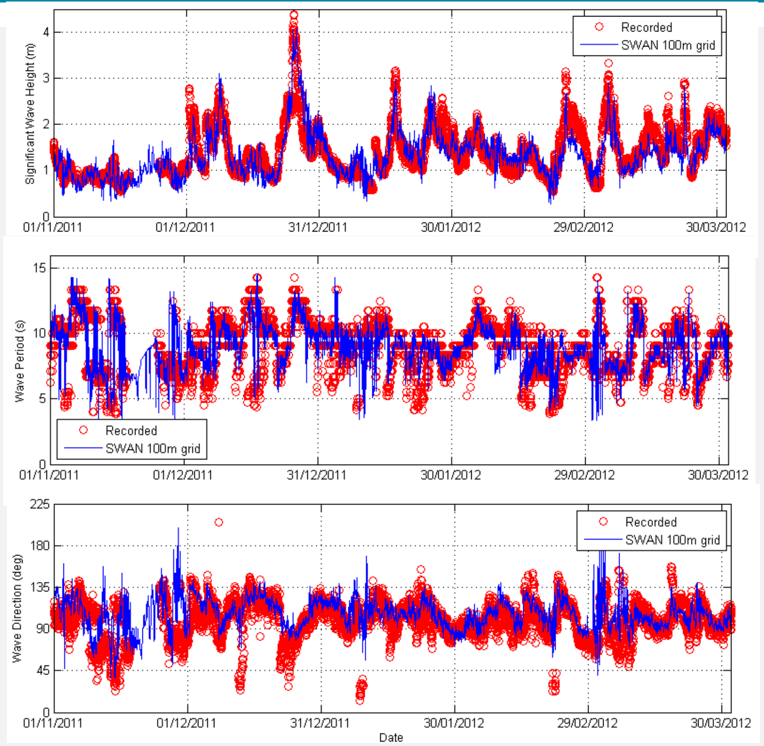
TUFLOW FV Model Validation

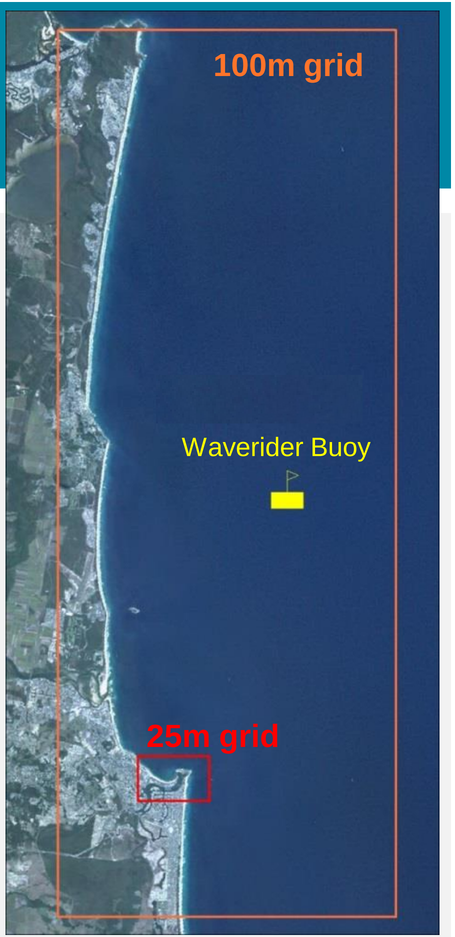
- Existing ADCP transect data set



SWAN Model Validation

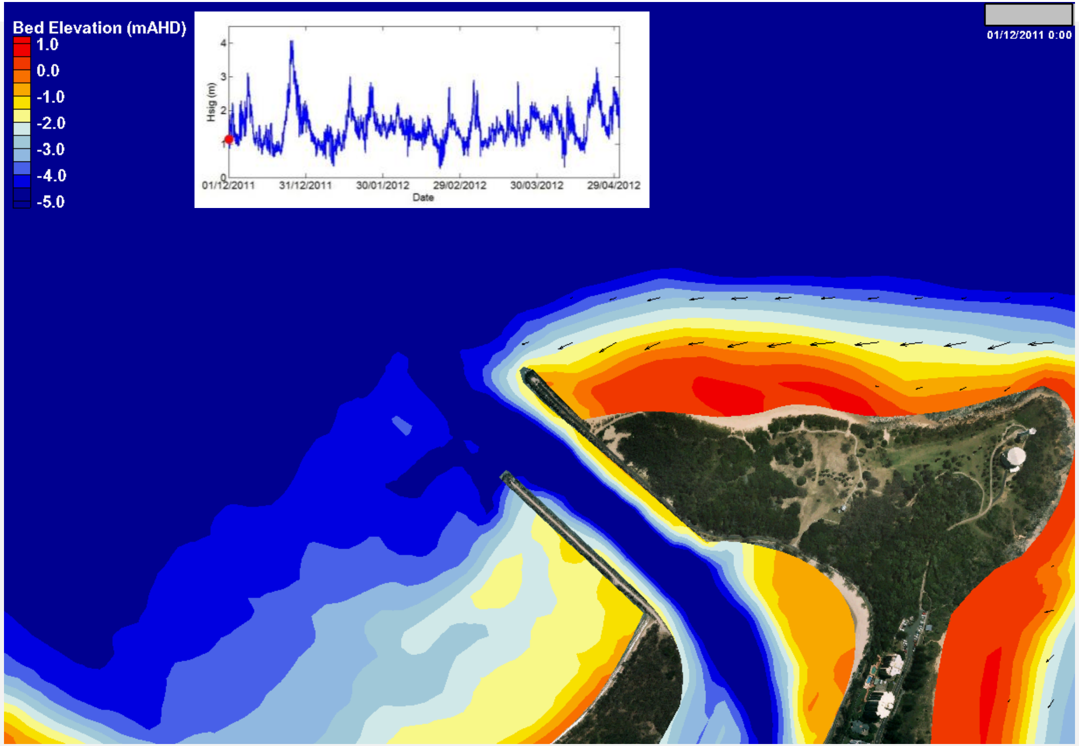
- Significant height
- Wave period
- Wave direction





Design Shoal Event Simulation

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



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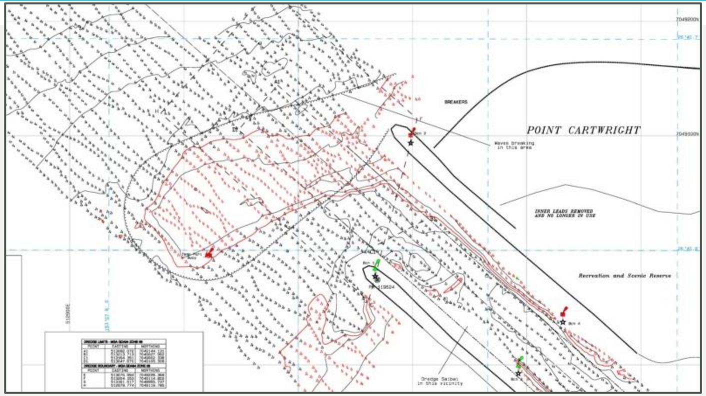
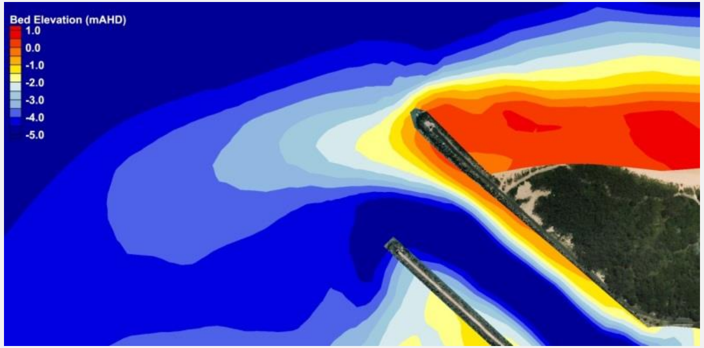
Design Shoal Event Validation

Unique morphology calibration dataset

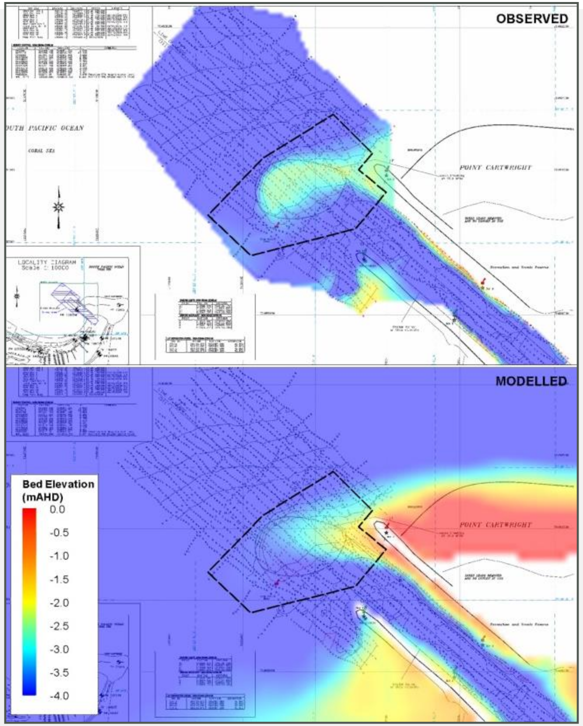
- Operator required to identify navigable channel during the 2011-2013 shoaling event
- This resulted in a sequence of hydrographic surveys
- Converted to sequence of DEMs for shoal volume calibration

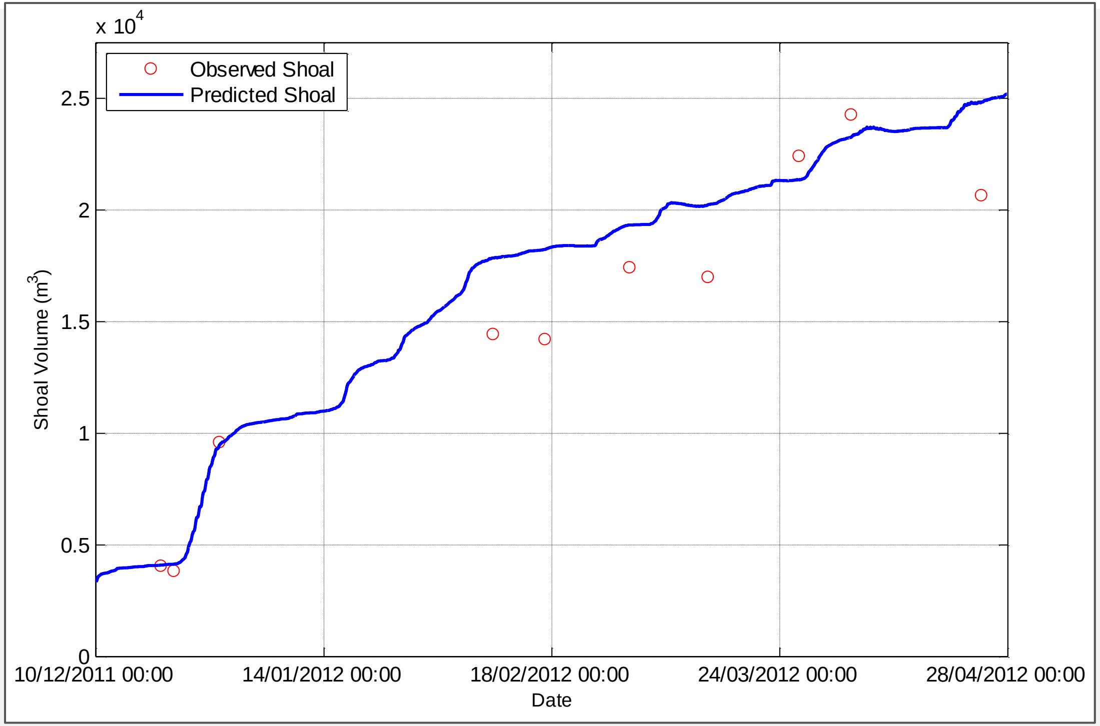




TUFLOW BMT

Design Shoal Event Validation

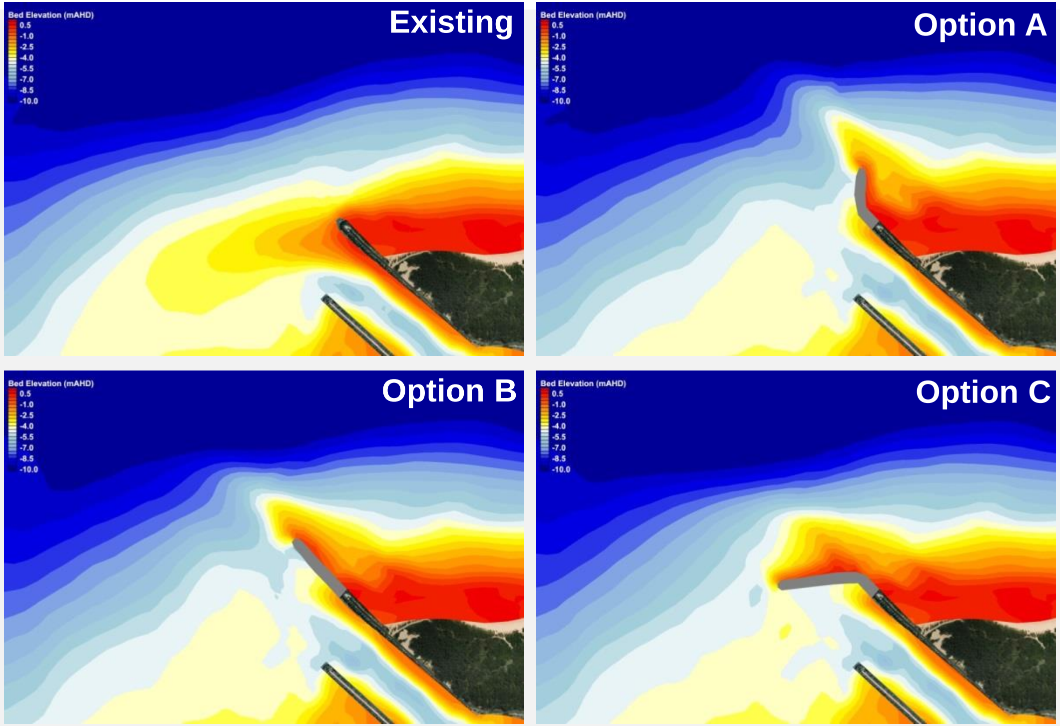




Design Event Options Assessment

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

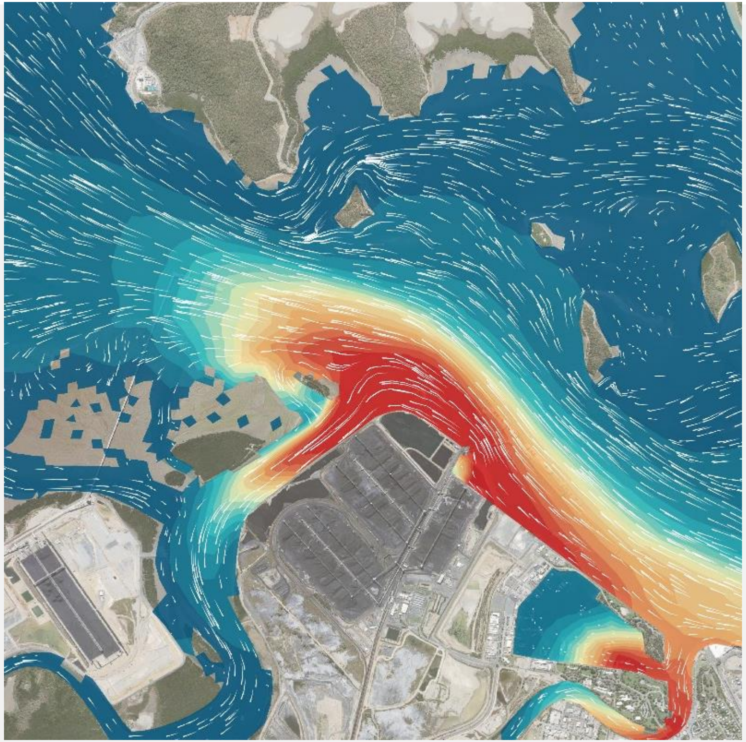
Choosing your Hydraulic Model – The right tool for the job

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

- https://fvwiki.tuflow.com/index.php?title=Main_Page
- https://fvwiki.tuflow.com/index.php?title=Tutorial_Model_Introduction

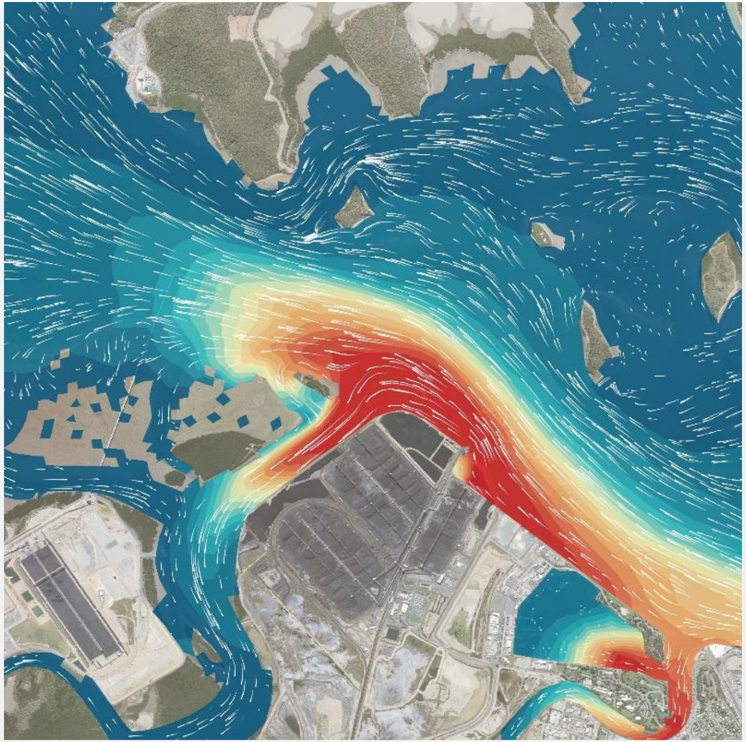
Sediment Transport Demo Models

- Please let me know if you're interested and we can send through: support@tuflow.com

More info

www.tuflow.com

https://downloads.tuflow.com/_archive/TUFLOW_FV/Manual/STM_PTM_User_Manual_2020.pdf



Thank you!!!