Deltares

Enabling Delta Life

Towards prediction of fines captures

over the wide range of depositional environments occurring simultaneously in a typical facility

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+ Predicting Fines Capture

- No existing models can predict fines capture over the wide range of depositional environments occurring simultaneously in a typical facility
- Typical operational variability of an oil sands extraction plant plays a dominant role that would be difficult, if not impossible, to model
- Tailings planning has often made use of a pore capture model to estimate fines capture (developed by Mr. C. Marsh, at Syncrude)
  - Assumes that all sand settles out as beach, forming a sand skeleton at an assumed dry density. A portion of the fines and water slurry is trapped in the voids of the sand skeleton and the remainder reports to the pond.
  - Not applicable to BBW, given the different depositional mechanisms at play (slope instabilities, turbidity currents, etc.)
  - May give reasonable results for BAW, but inspections often indicate layers of concentrated fines within BAW that are not predicted by the model. Furthermore, open ended BAW deposits, with no containment, likely have sand captures that are less than 100%, thus reducing fines capture.

Predicting Fines Capture

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Beaches and deltas – scales and types

Kachemak Bay in Alaska. Source Flickr - NOAA

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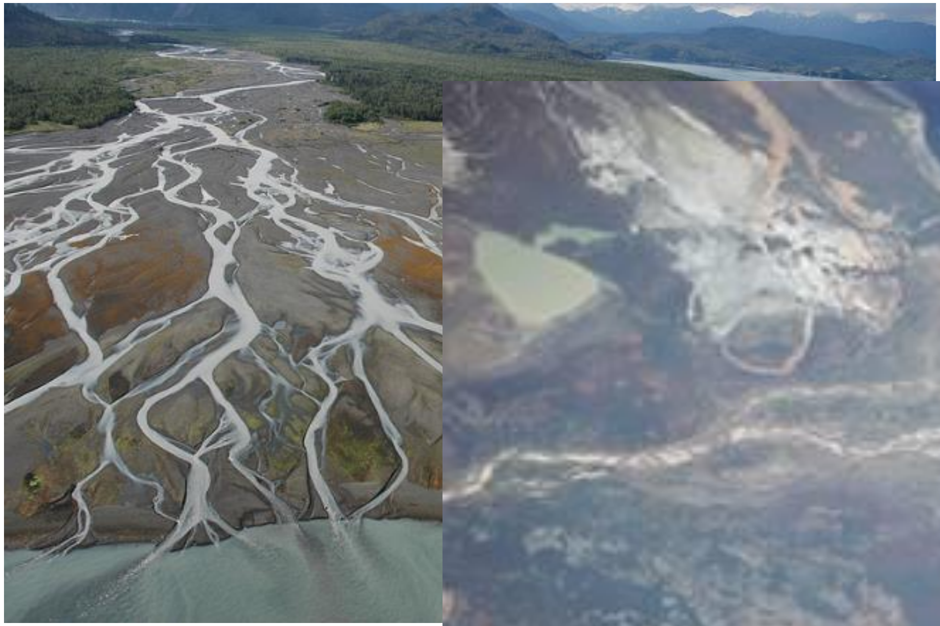
Beaches and deltas – scales and types



Kachemak Bay in Alaska. Sou

Mangoky River, Malagasy Republic. Source: internet

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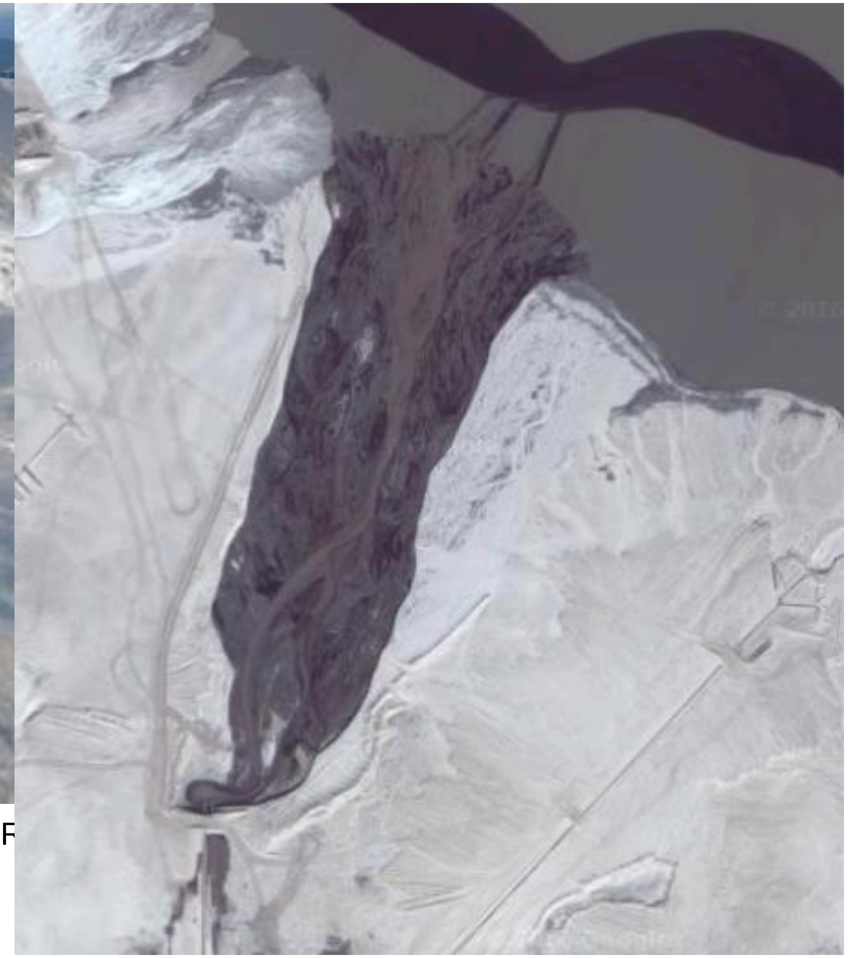
Beaches and deltas – scales and types

Kachemak Bay in Alaska. Sou

Mangoky River, Malagasy R



Shell Beach. Source: Google Maps

Beaches and deltas – scales and types

Source: Google Maps

Runoff from cultivated field near Pigeon Point, CA. Source: Gary Parker e-book morphodynamic

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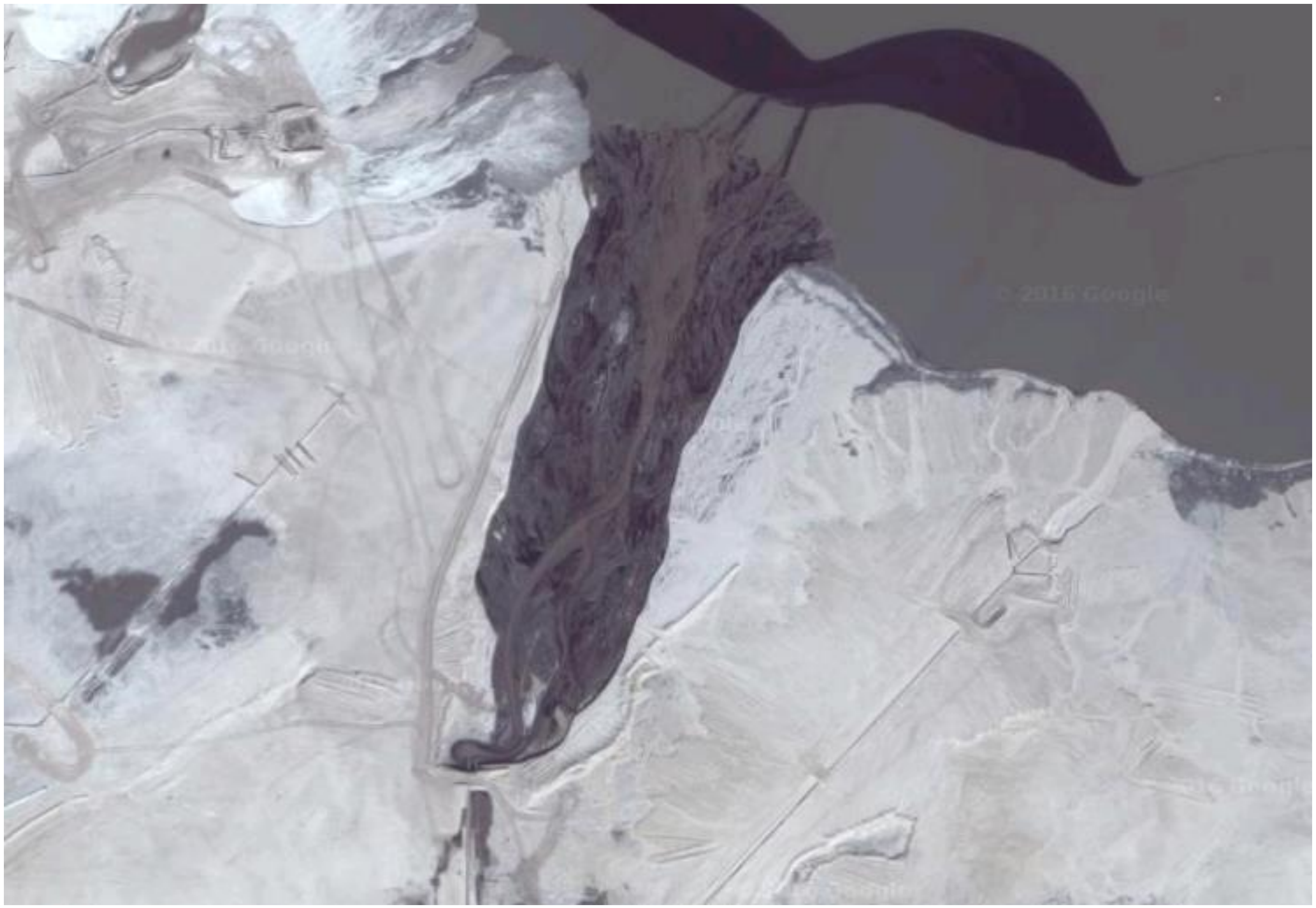
Beaches and deltas – scales and types

Sand dominated beaches



Shell Beach. Source: Google Maps

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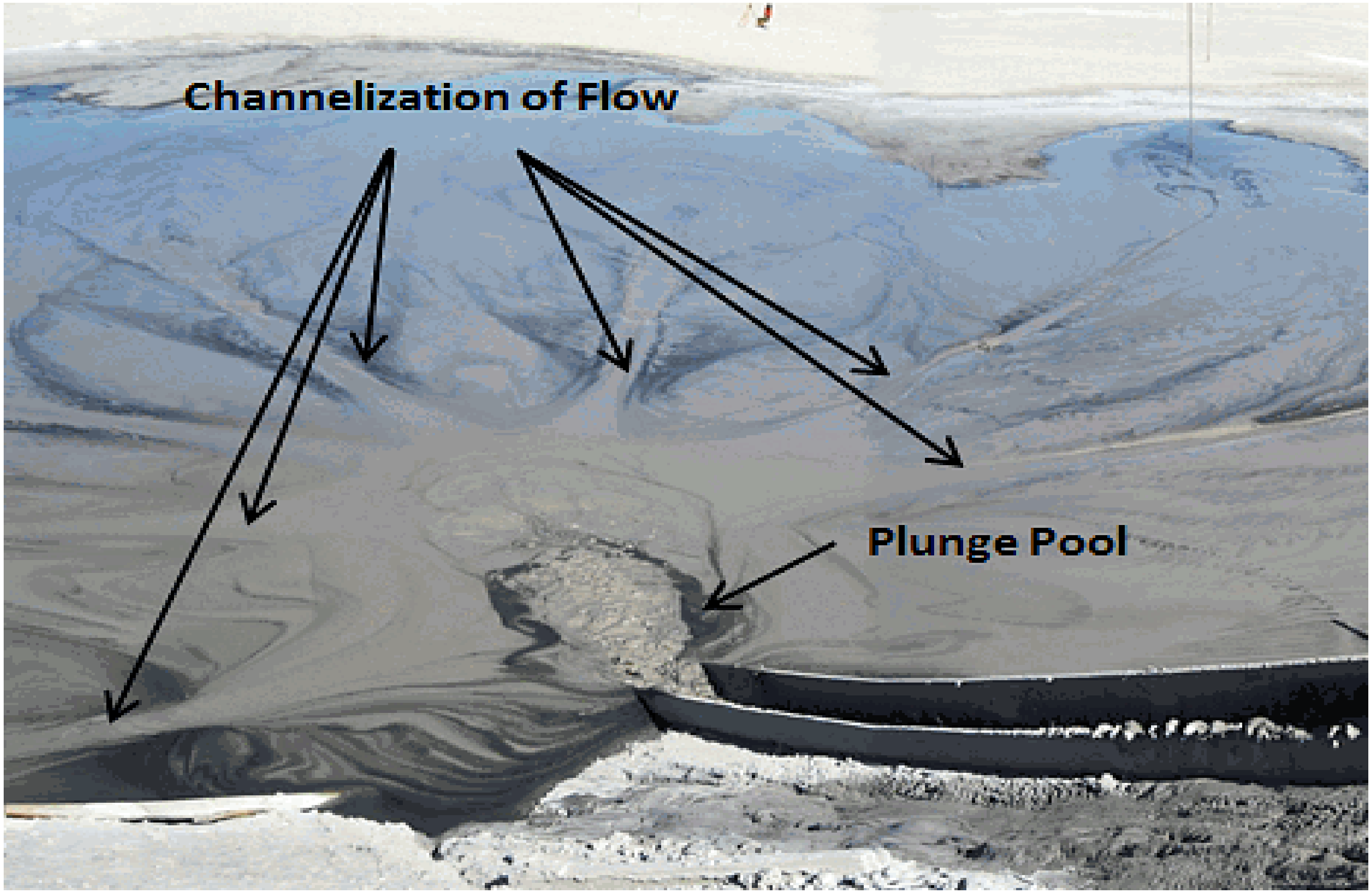
Beaches and deltas – scales and types

Fines dominated beaches



From B. Pirouz, ACT Williams, Australia

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Beaches and deltas – scales and types

Fines dominated beaches

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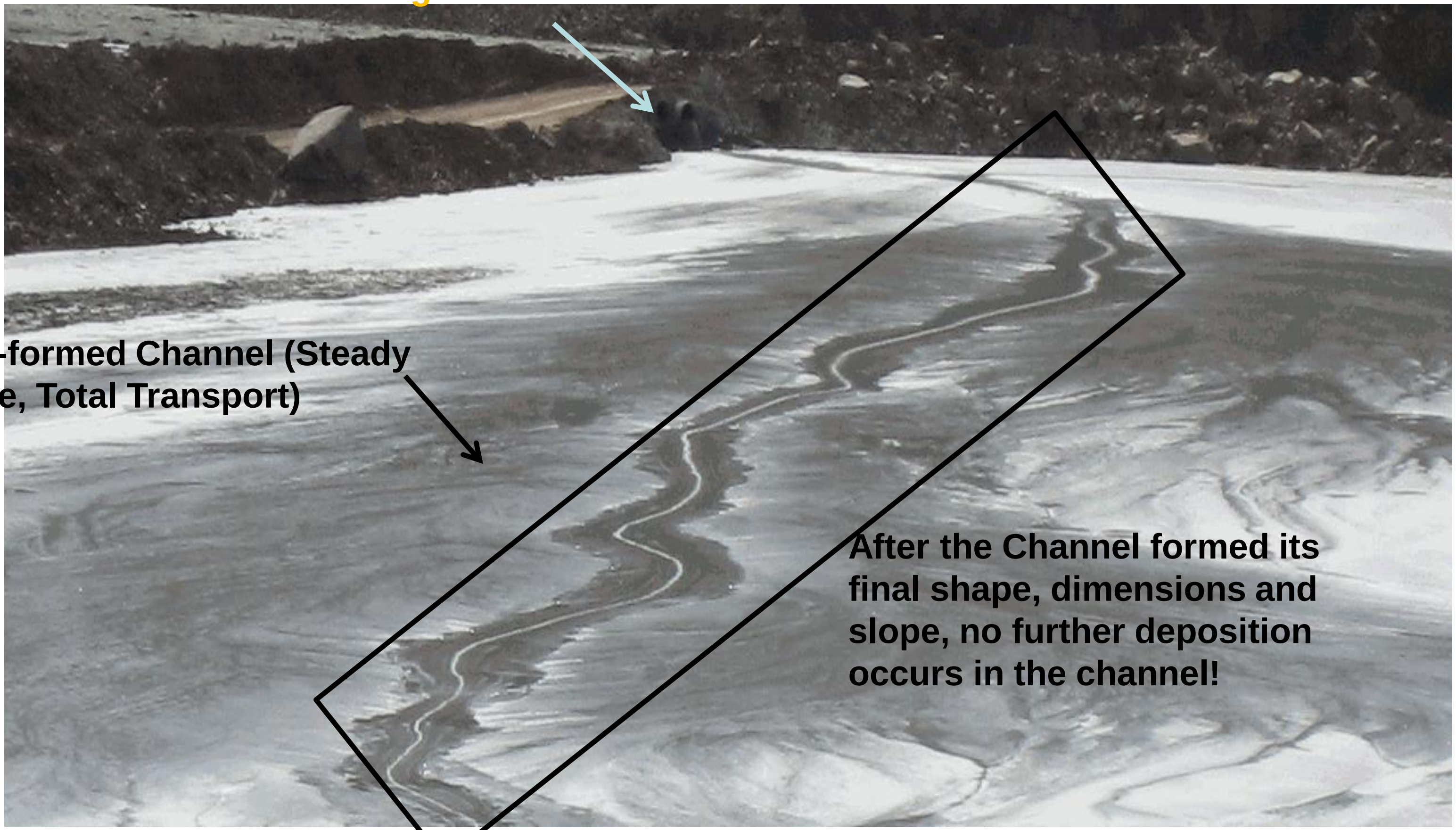
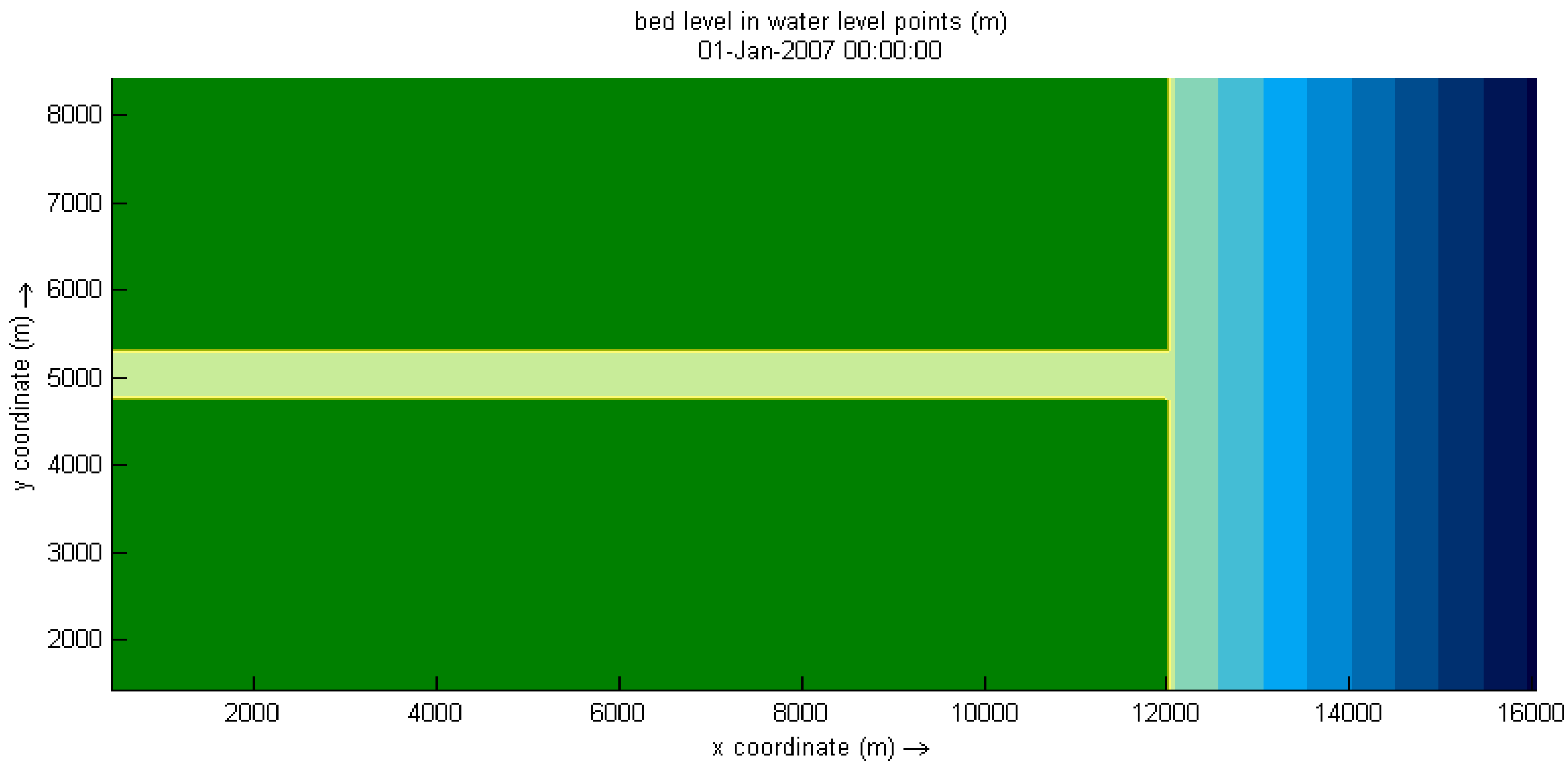


From B. Pirouz, ACT Williams, Australia

Existing model – Wax Lake Delta



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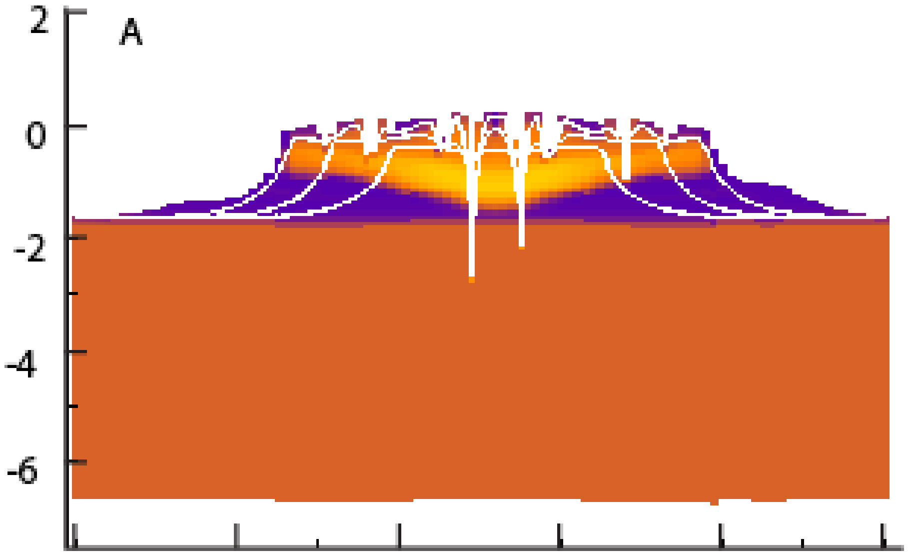
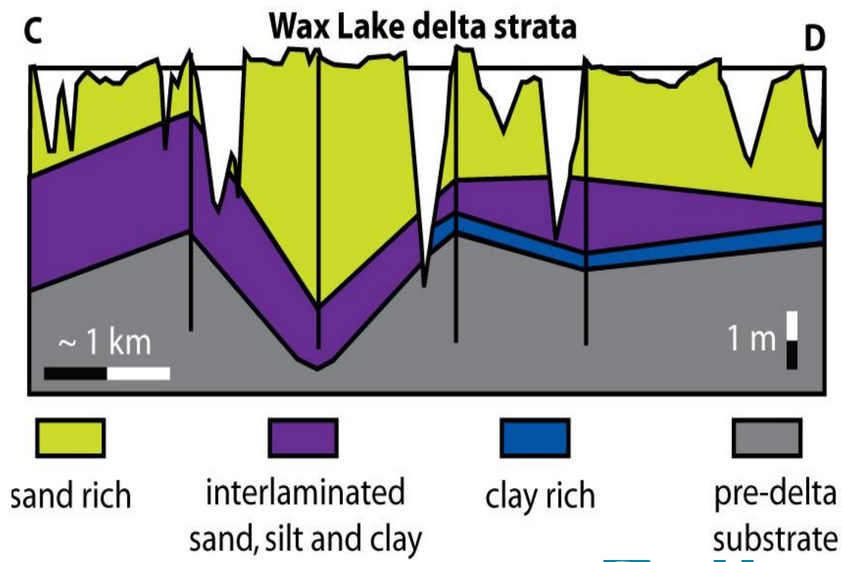
Existing model – Wax Lake Delta

Start movie





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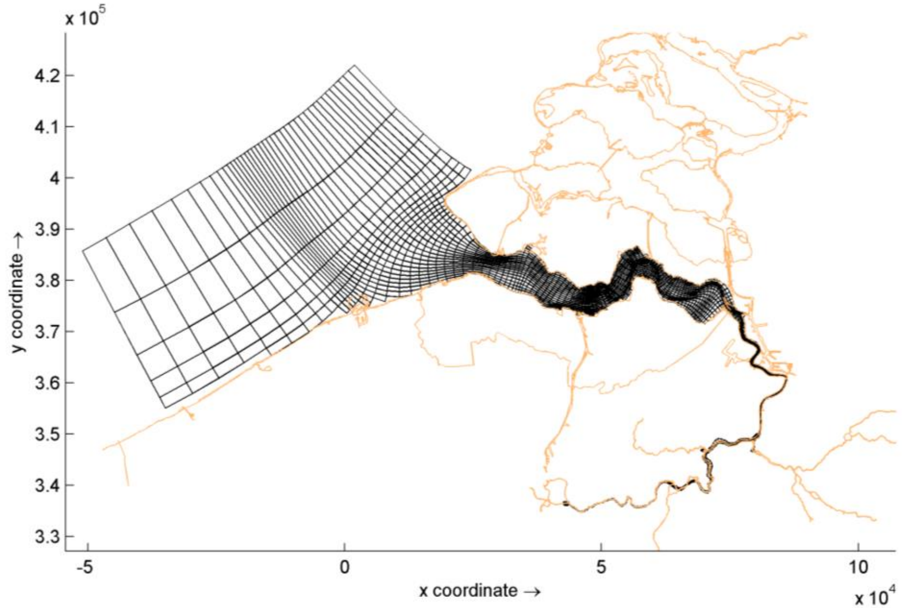
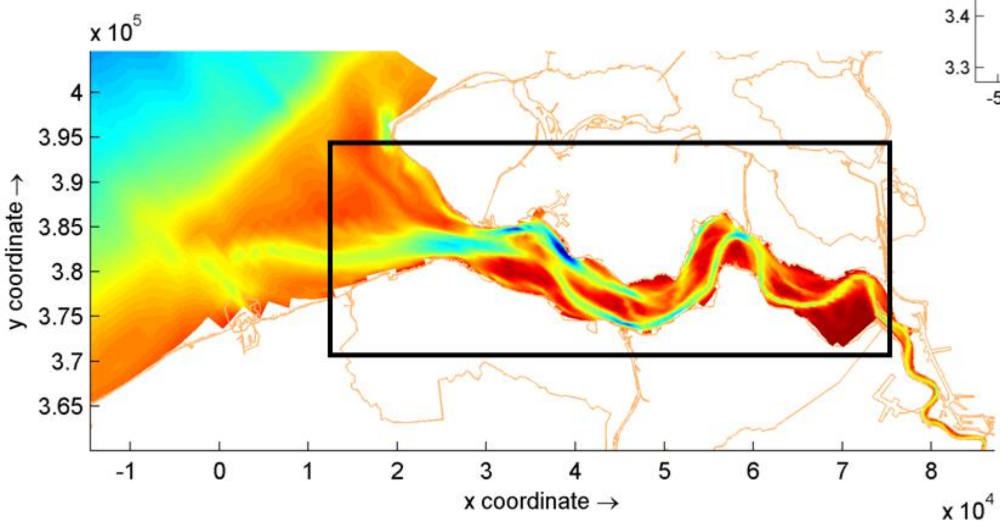
Existing model – Western Scheldt example

Evaluate capability of model to create morphology from flat-bed

Given tide and landboundaries

Example: Western Scheldt





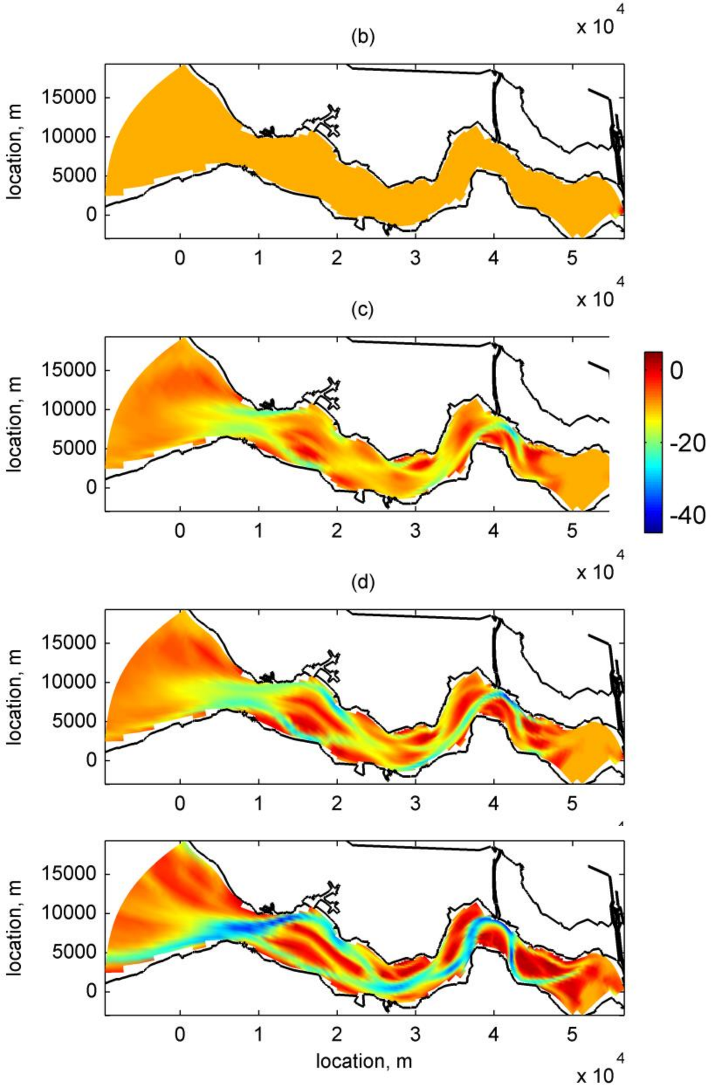
Existing model – Western Scheldt example

Initial flat bathymetry

Modelled, 15 yrs

Modelled, 30 yrs

Modelled, 200 yrs



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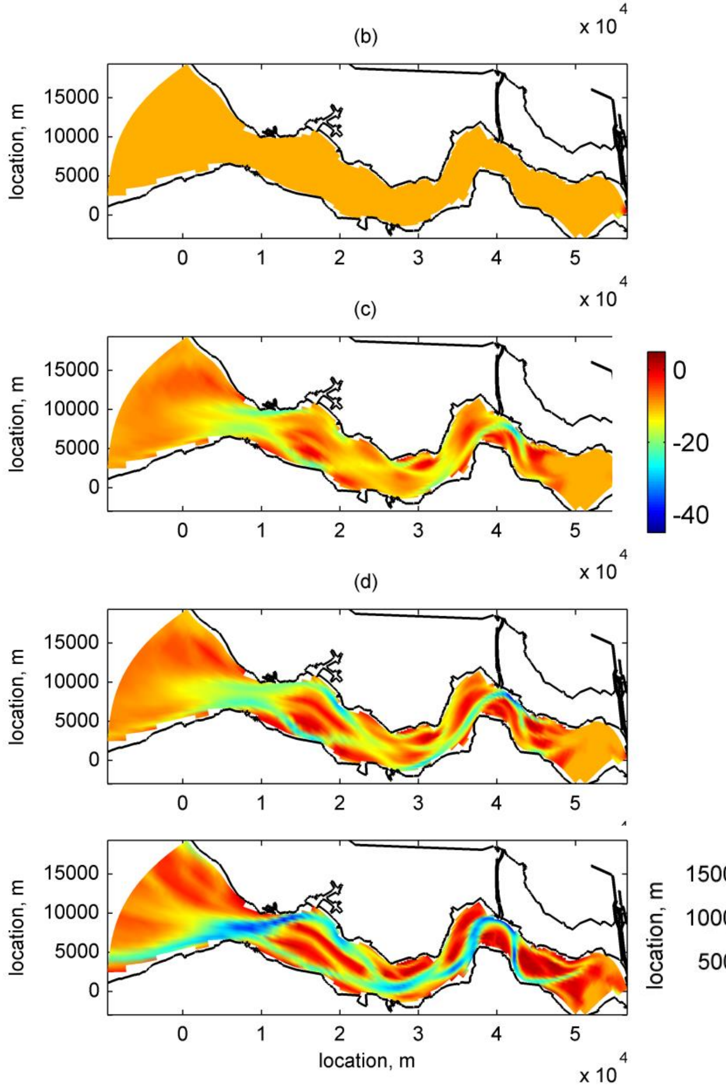
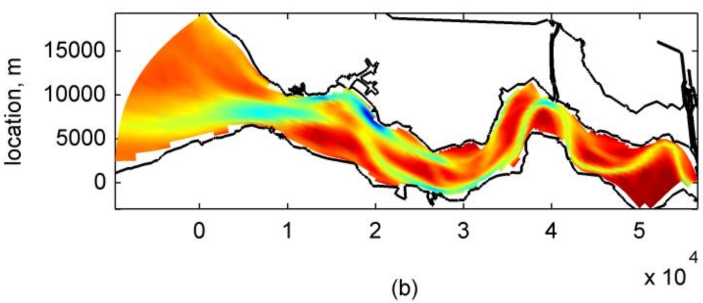
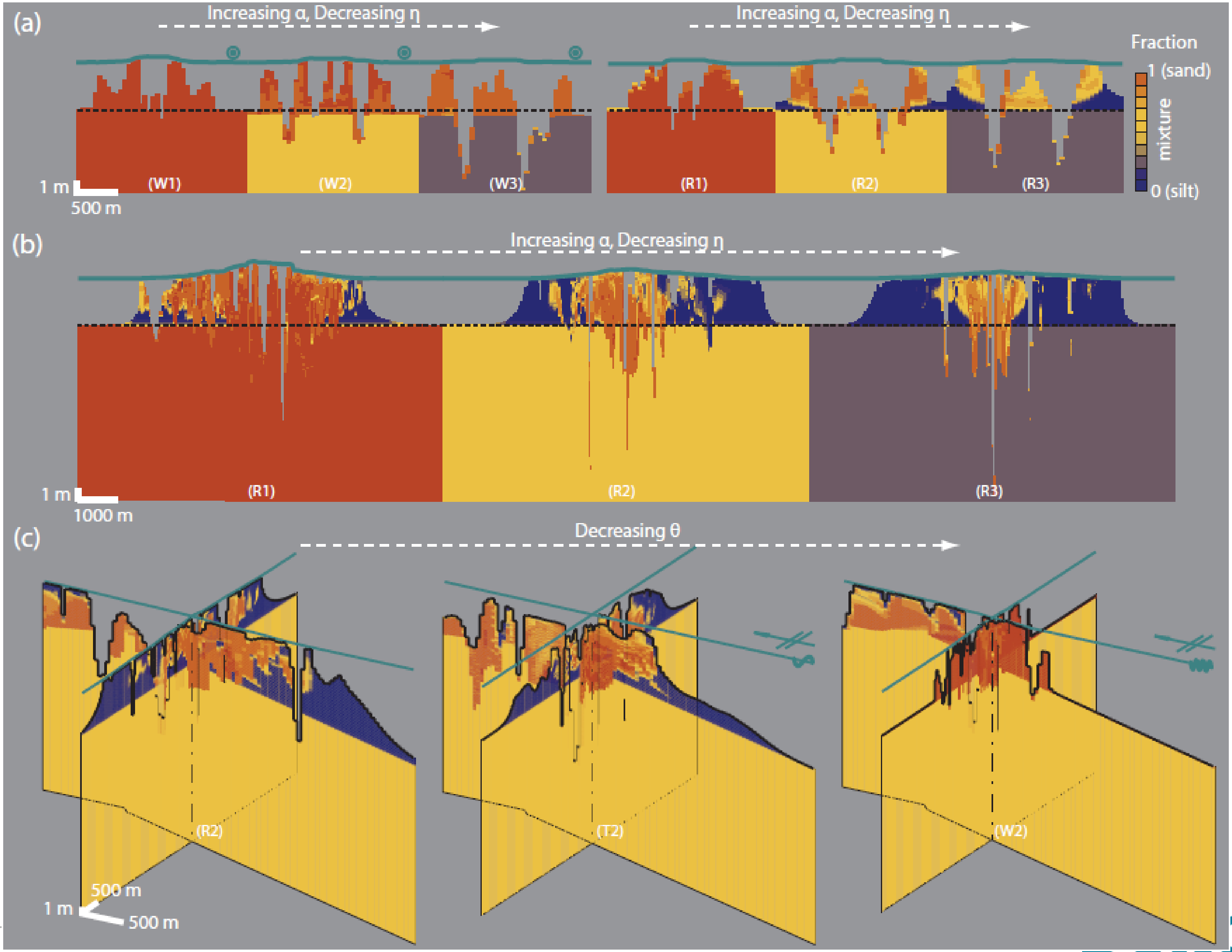


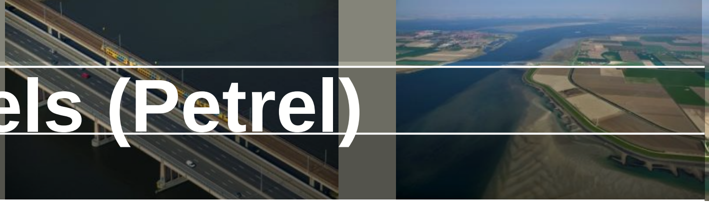


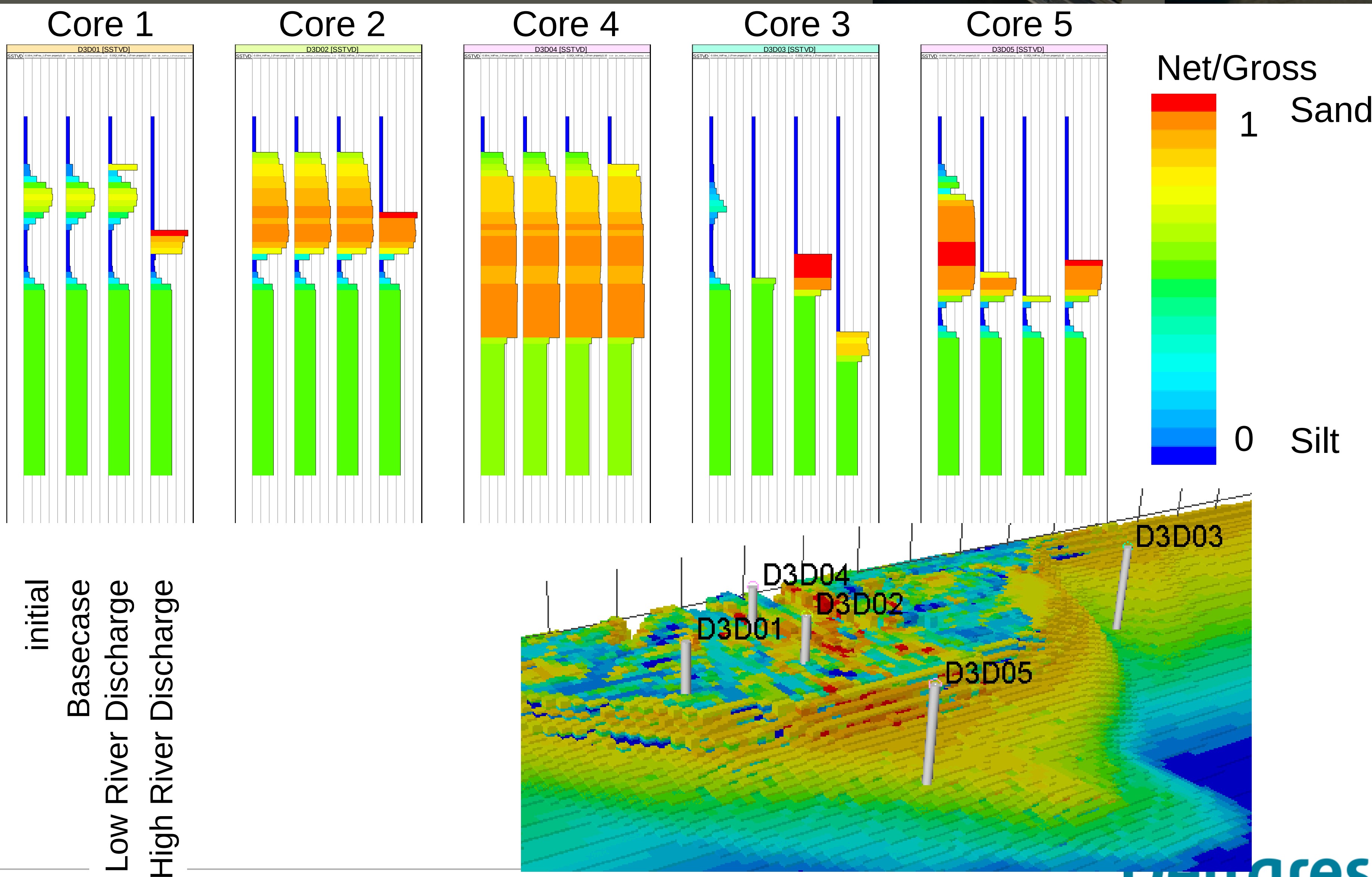
Simulated stratigraphy – alluvial beaches / deltas



Geleynse et al., 2011

Coupling to Sub-surface models (Petrel)





Courtesy of J.E.A. Storms

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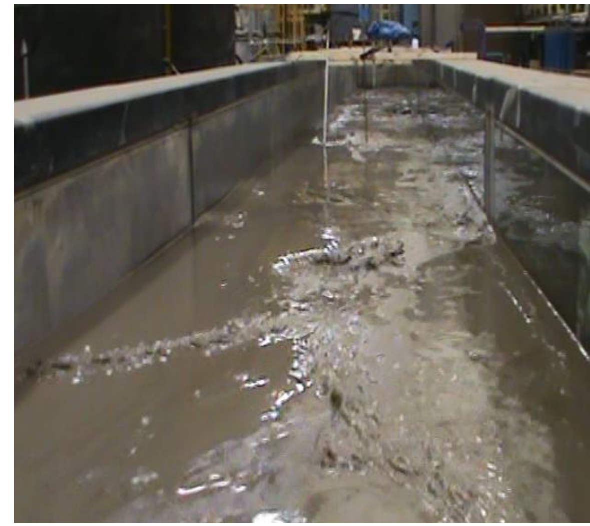
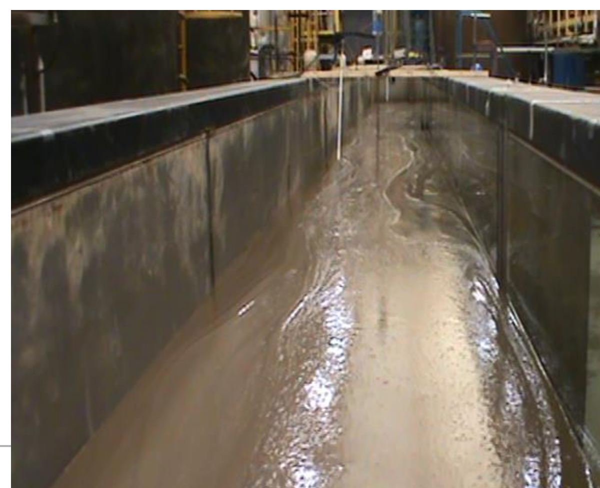
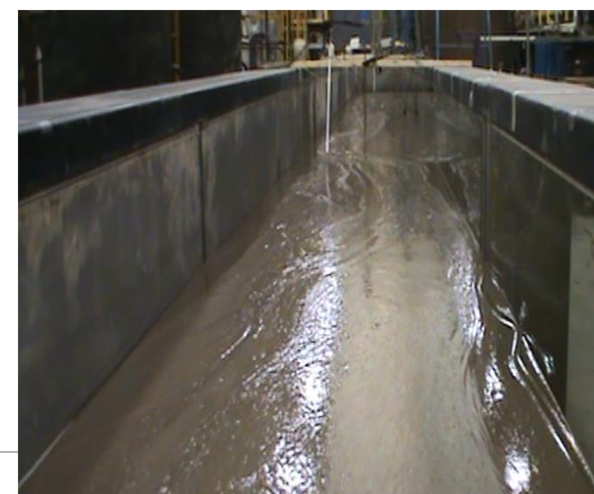
Different environments / tailings characteristics

Whole Tails t ~ 0 | t ~ 30 m | t ~ 4 h



(Weak) NST





Tailings vs processes

FFT ADW

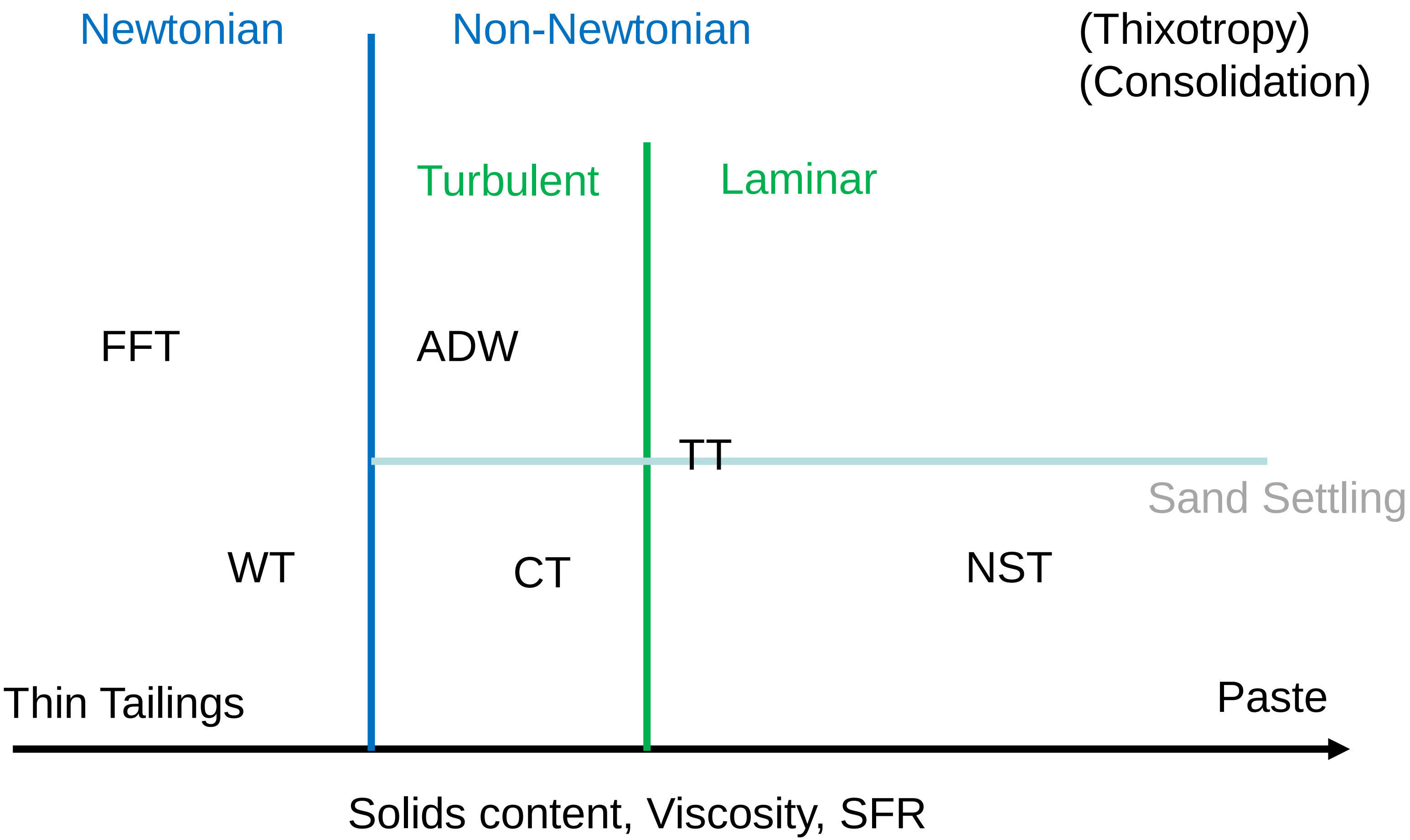
TT

WT CT NST

Thin Tailings → Paste

Solids content, Viscosity, SFR

Tailings vs processes



Deltares

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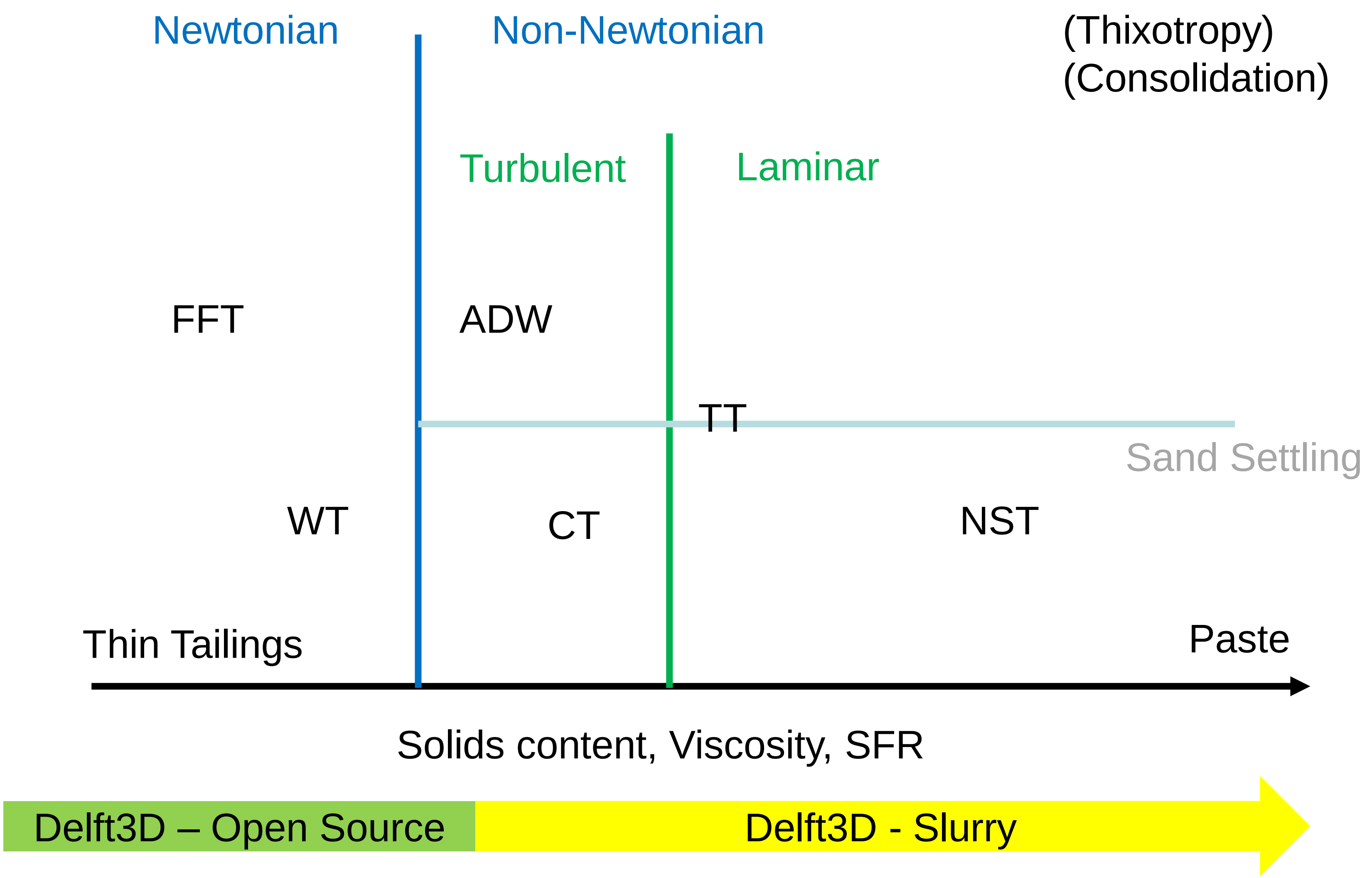


Main processes in Delft3D


Delft3D – Open Source

Relevant to tailings beaches…

- Shallow water, quasi 3D
- Coupled hydrodynamic, sediment transport and morphology
- Track bed changes and composition
- Multiple grain size (up to 99?), different equations for fines (cohesive) and sand (non-cohesive)
- Variable input in time series, liquid and solids discharge, sediment composition, number of discharges
- Density driven flow, i.e. turbidity currents
- Non-Newtonian
- Open source

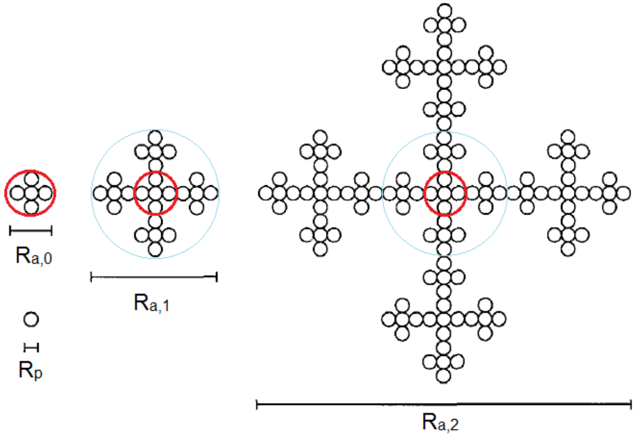
Delft3D - Slurry

Upgrade to Delft3D-slurry

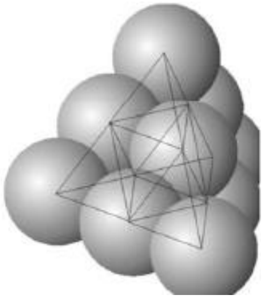
- Specific tailings / slurry rheology
- Sheared-induces sand settling
- Laminar – turbulent transition
- Consolidation
- Thixotropy

Tailings rheology, function of sand & clay

- Clay: built from aggregates
  - Water content to fines
  - Self-similar (fractal dimension)
  - Depending on type of clays



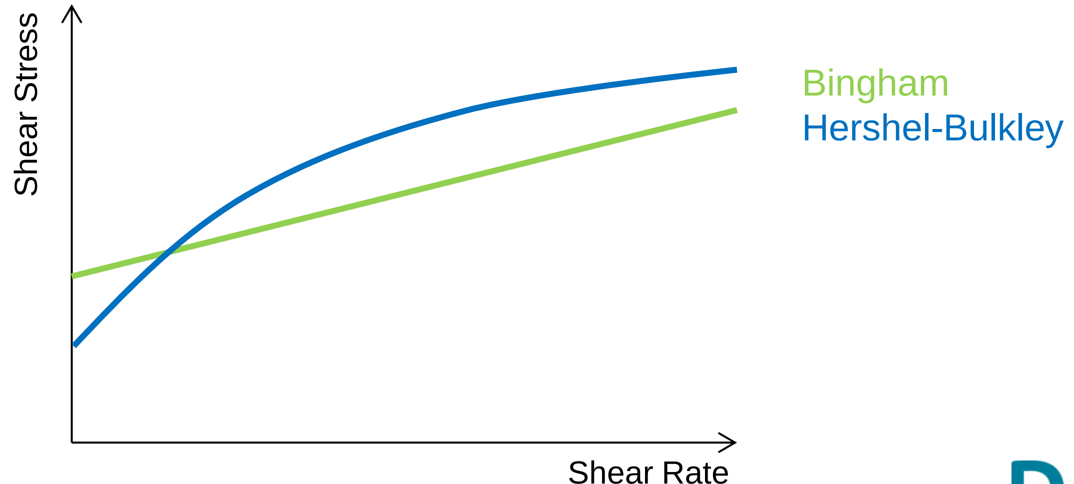
- Granular material
  - Sand and/or silt
  - Enhances friction in fluid → viscous
  - linear concentration concept (Bagnold)



Tailings rheology, function of sand & clay

- Models developed in different fields (natural muds, mining)

Rheological Model	Discipline	Authors	Fluid type	Solids effect
1	Nature: mud flats / siltations	C. Kranenburg J.C. Winterwerp	Hershel-Bulkley	exponential with Bagnold type linear concentration
2	Oil sands tailings	W. Jacobs W.G.M. van Kesteren	Bingham	exponential with Bagnold type linear concentration
3	Thick slurries	A.D. Thomas	Bingham	Krieger-Dougerty type



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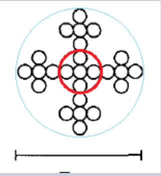
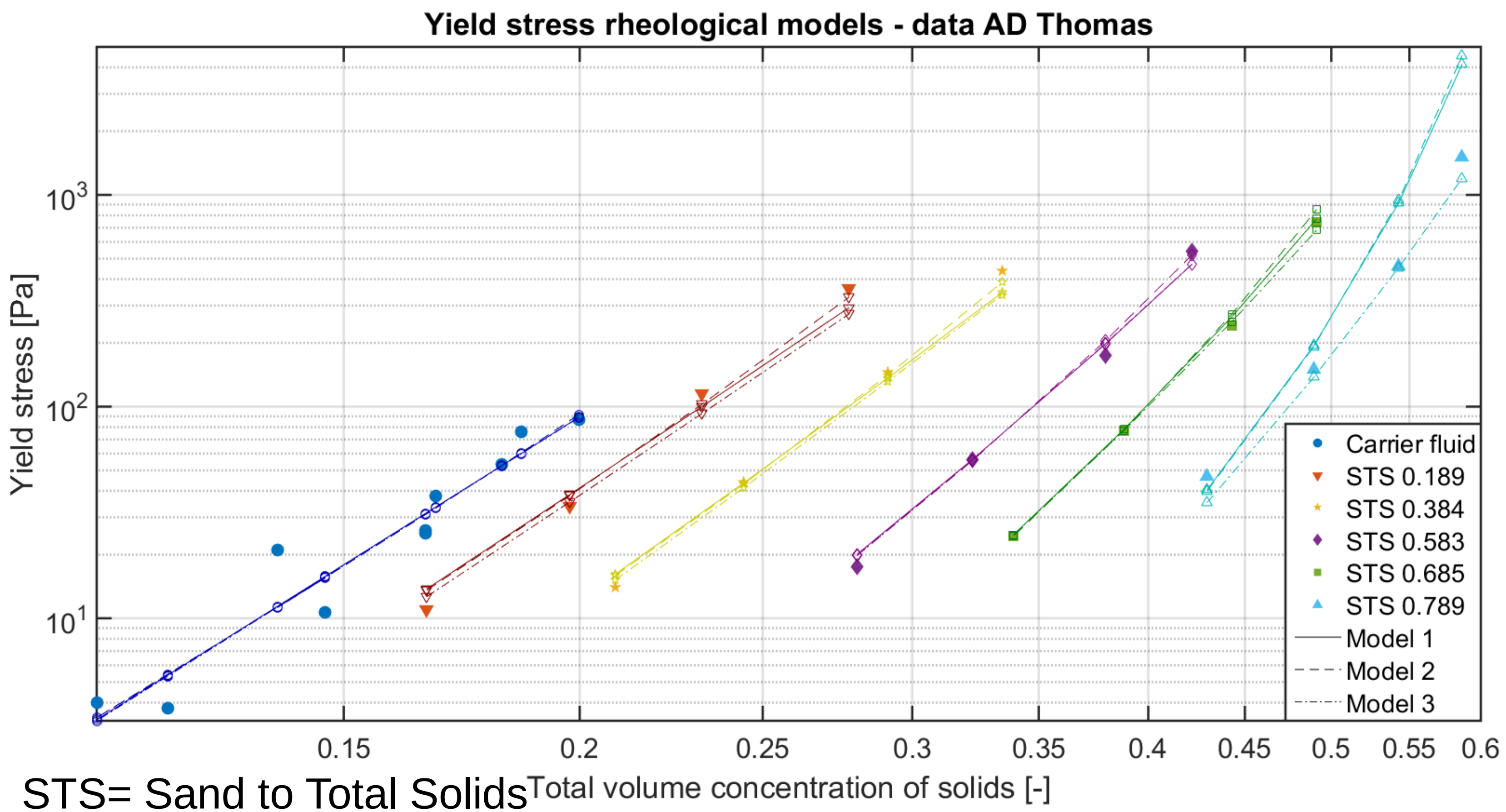
Tailings rheology, function of sand & clay

Rheological Model	Shear Stress and viscosity
1 **Fractal dimension theory**	$\tau_y = A_y \left(\frac{\phi_{clay}}{\phi_{water} + \phi_{clay}} \right)^{2/(3-n_f)} \exp(\beta\lambda)$ $\mu = \left[\mu_w + A_\mu \left(\frac{\phi_{clay}}{\phi_{water} + \phi_{clay}} \right)^{\frac{2(a+1)}{3}} \left[\frac{1}{\dot{\gamma}} \right]^{\frac{(a+1)(3-n_f)}{3}} \right] \exp(\beta\lambda)$ 
2 **water content to the fines (W/PI)**	$\tau_y = K_y \left(\frac{W}{PI} \right)^{B_y} \exp(\beta\lambda)$ $\mu = \left[\mu_w + K_\mu \left(\frac{W}{PI} \right)^{B_\mu} \right] \exp(\beta\lambda)$ $\frac{W}{PI} \approx \frac{W_{clay}}{A_{clay\ activity}}$
3 **Viscosity enhancement and empirical fit**	$\tau_y = C_y \left(\frac{\phi_{fines}}{\phi_{water} + \phi_{fines}} \right)^{p} \left[1 - \frac{\phi_{sa}}{k_{yield} \phi_{sa\max}} \right]^{-2.5}$ $\mu = \exp\left(D \frac{\phi_{fines}}{\phi_{water}} \right) \left[1 - \frac{\phi_{sa}}{k_{visc} \phi_{sa\max}} \right]^{-2.5}$

Tailings rheology, function of sand & clay

- Suitability of the 3 models tested with AD Thomas 1999 data



STS= Sand to Total Solids

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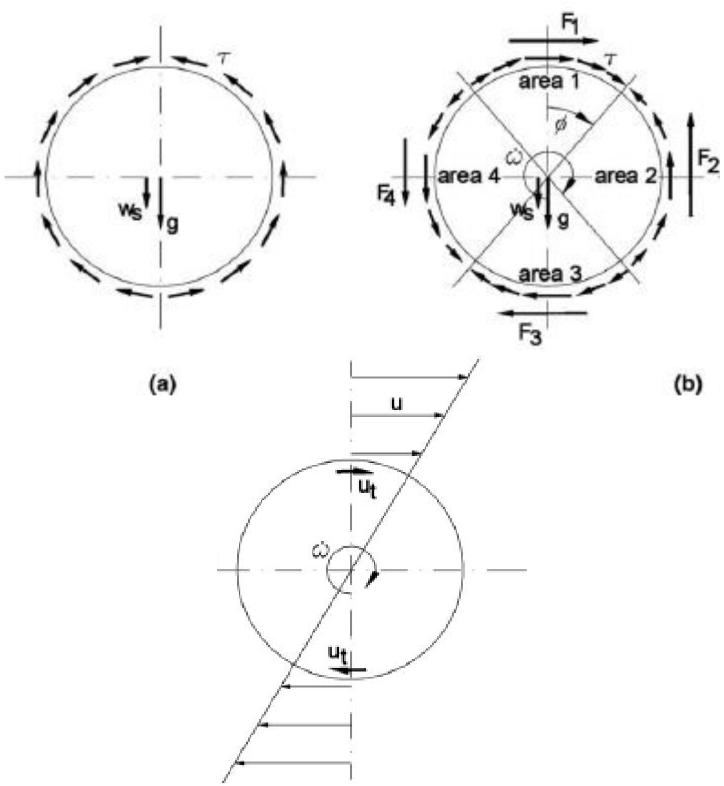
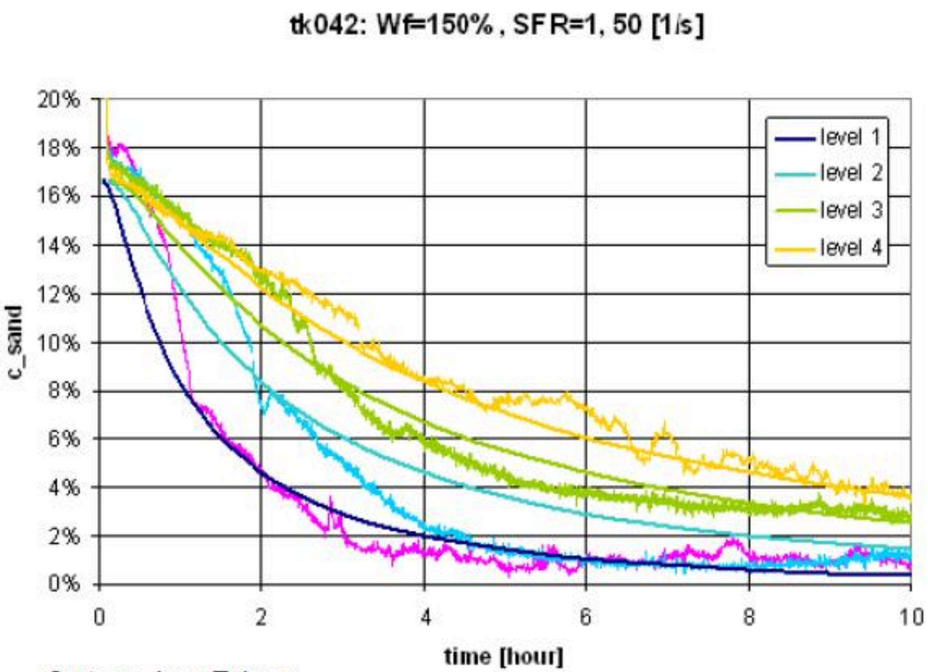
Sheared-induced sand settling





Curtesy: Arno Talmon

$$w_{s,eff} = w_{s,0}(1 - k\phi_{sol})^n = \alpha \frac{(\rho_s - \rho_{cf})gd^2}{18\mu_{apparent-cf}}(1 - k\phi_{sol})^n$$

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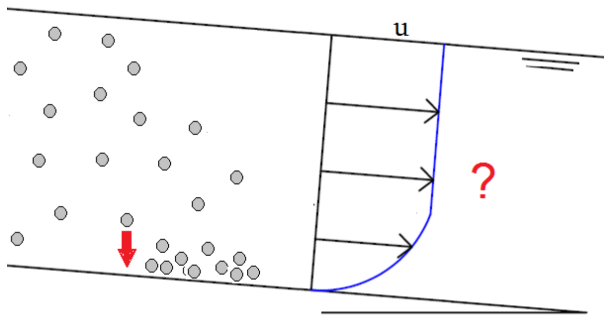
Model testing in 1DV-mode

- Constant slurry discharge down a 1% beach
- Uniform fines and sand composition at discharge
- Fines are not allowed to settle (carrier fluid remains constant)
- Sand settles depending on shear rate
- Current testing in laminar regime

Feedback loop:

- Slurry (sand + fines) rheology influence flow regime and shear rate
- Shear rate influence sand settling
- Sand settling influence slurry rheology

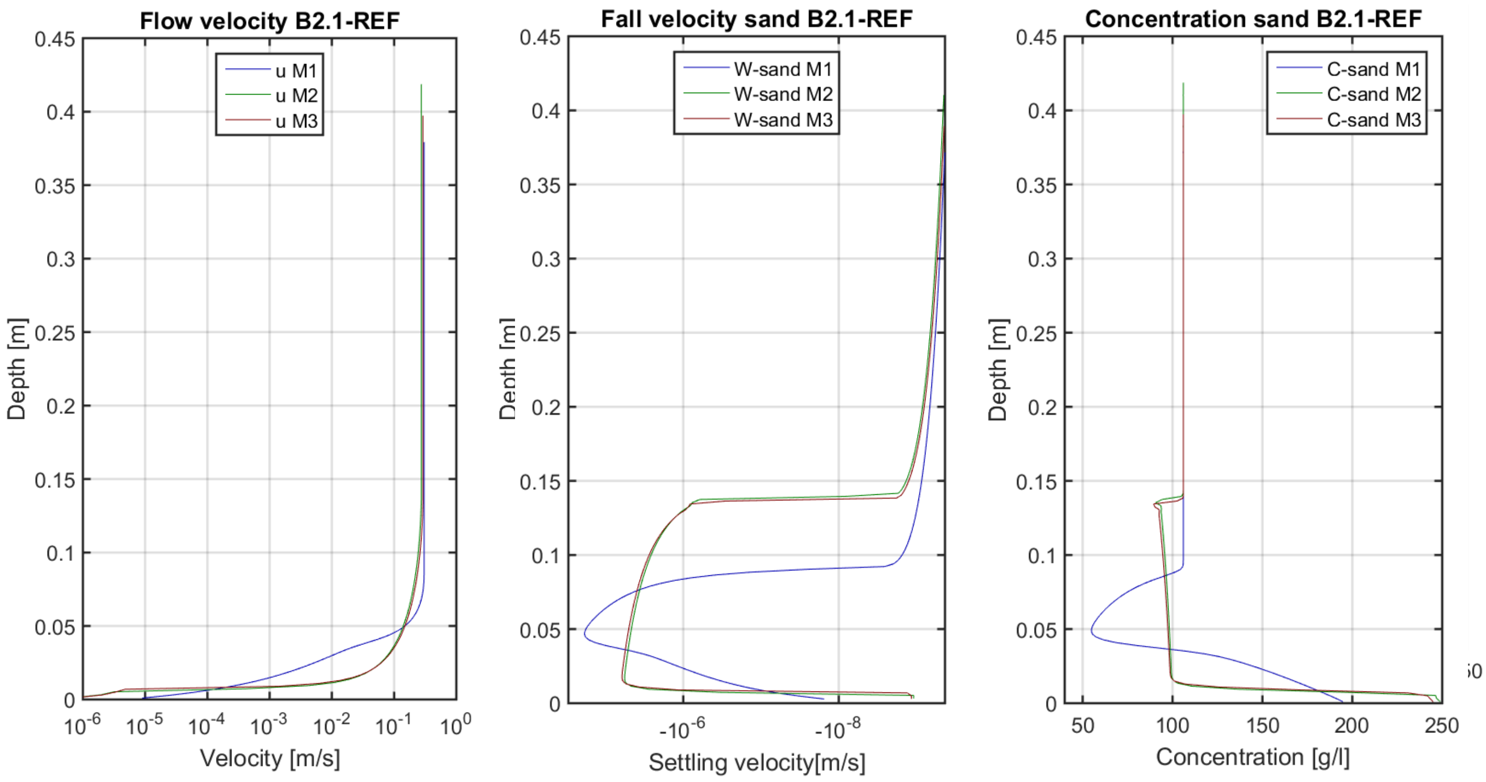
Interested in flow field and sand concentration (or SFR) distribution



1DV model verification

- Cs_w = 40 %; SFR = 0.25; Ty = 40 Pa; rho = 1330 kg/m³ – TT?

Ca 1,000 m down the slope



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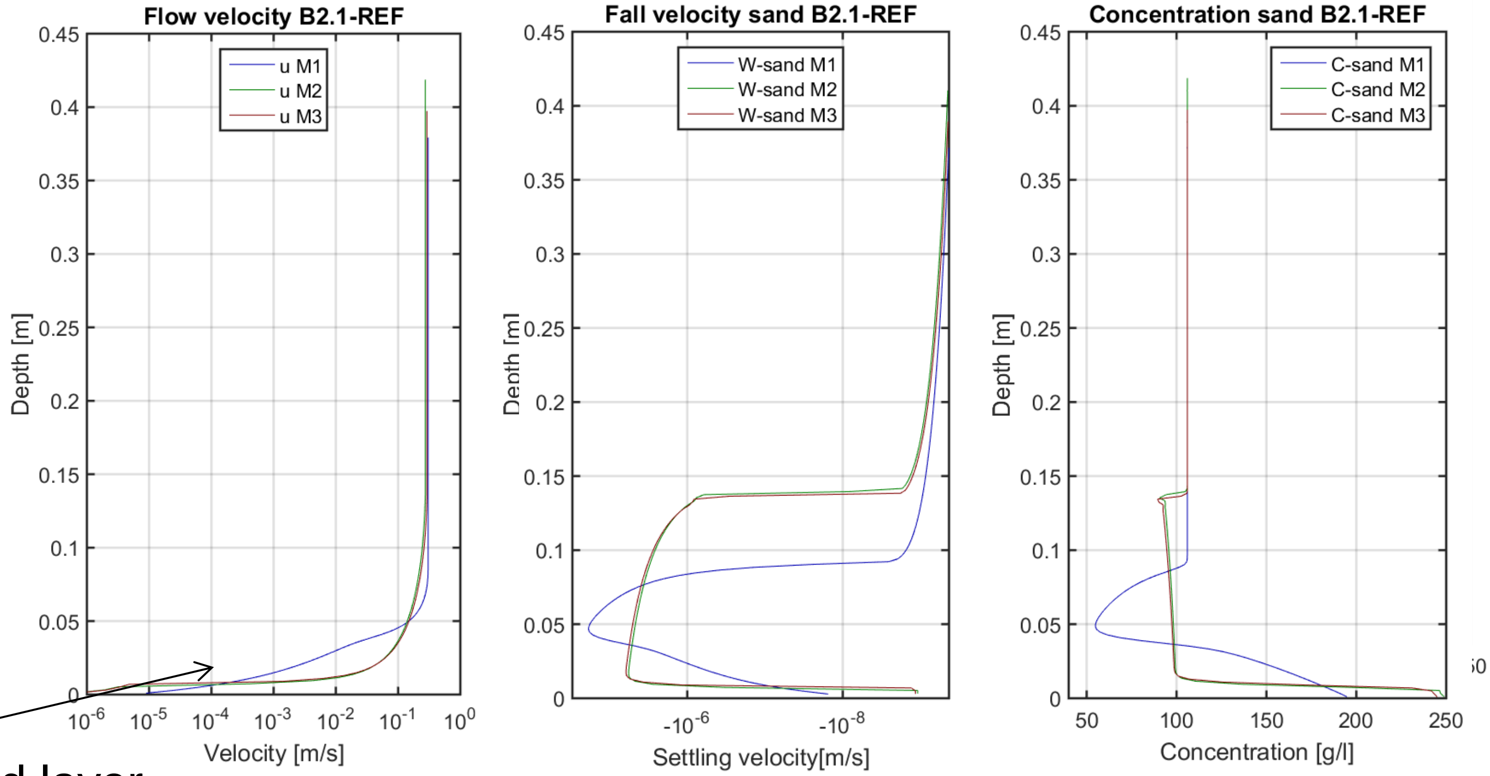

Gelled bed layer

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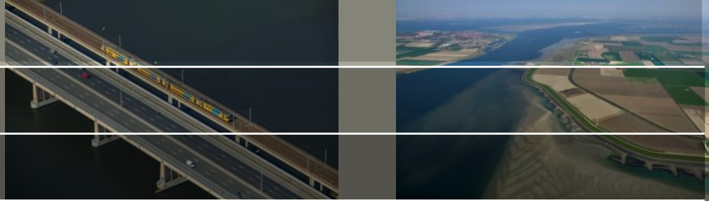
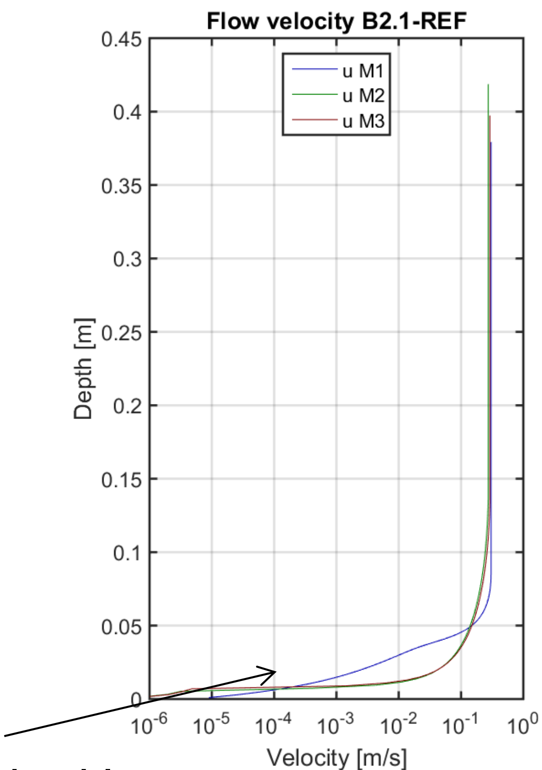
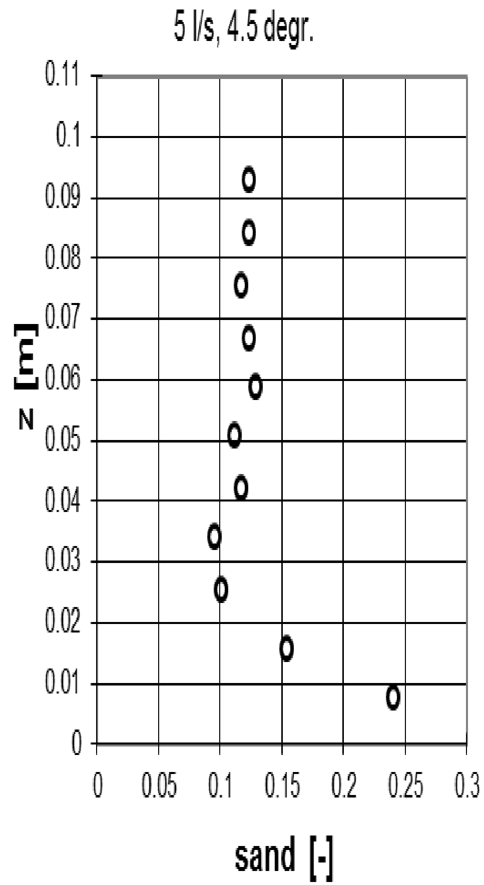
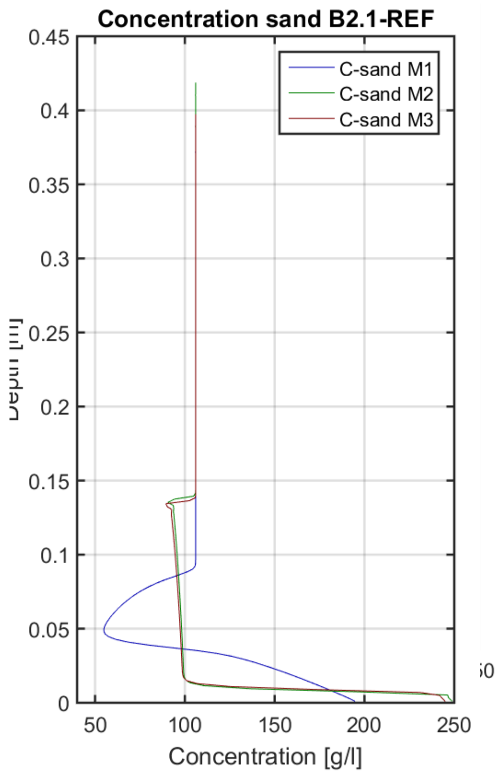
1DV model verification



Phemenological similar to Sanders and Spelay open channel tests







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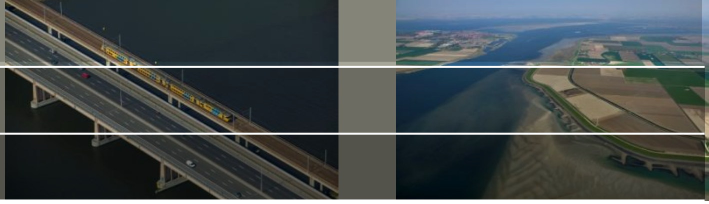
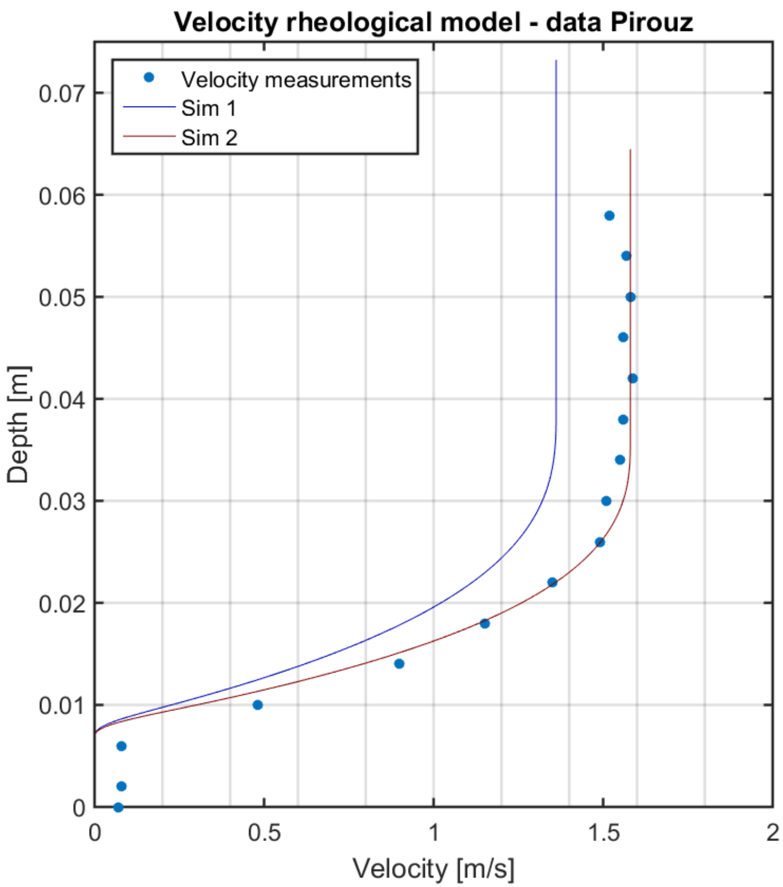
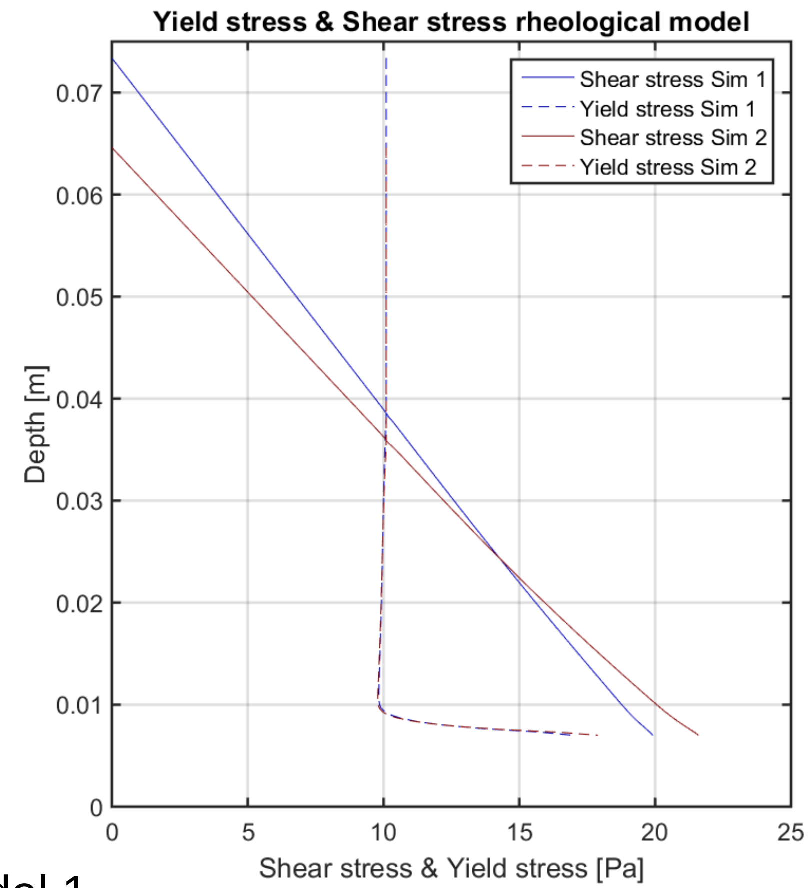


1DV model verification

- Comparison with field flume Pirouz et al. 2013





Model 1

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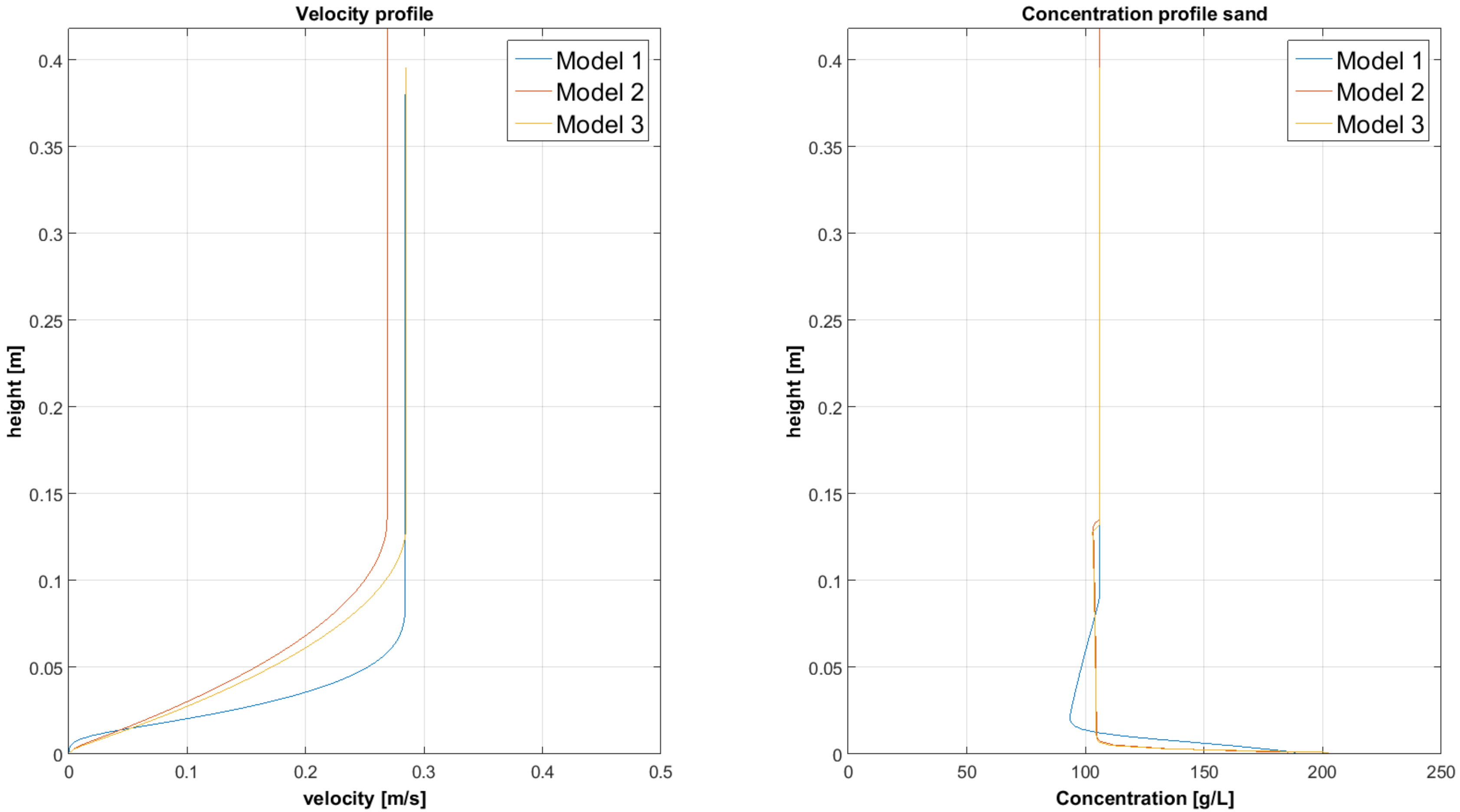
Implementation of 1DV model to different tailings types

1. Cs_w = 40 %; SFR = 0.25; Ty = 40 Pa; rho = 1330 kg/m^3 – TT
2. Cs_w = 67.5 %; SFR = 5, Ty = 30 Pa; rho = 1725 kg/m^3 – NST

Testing TT – strong rheology, low sand



100 m

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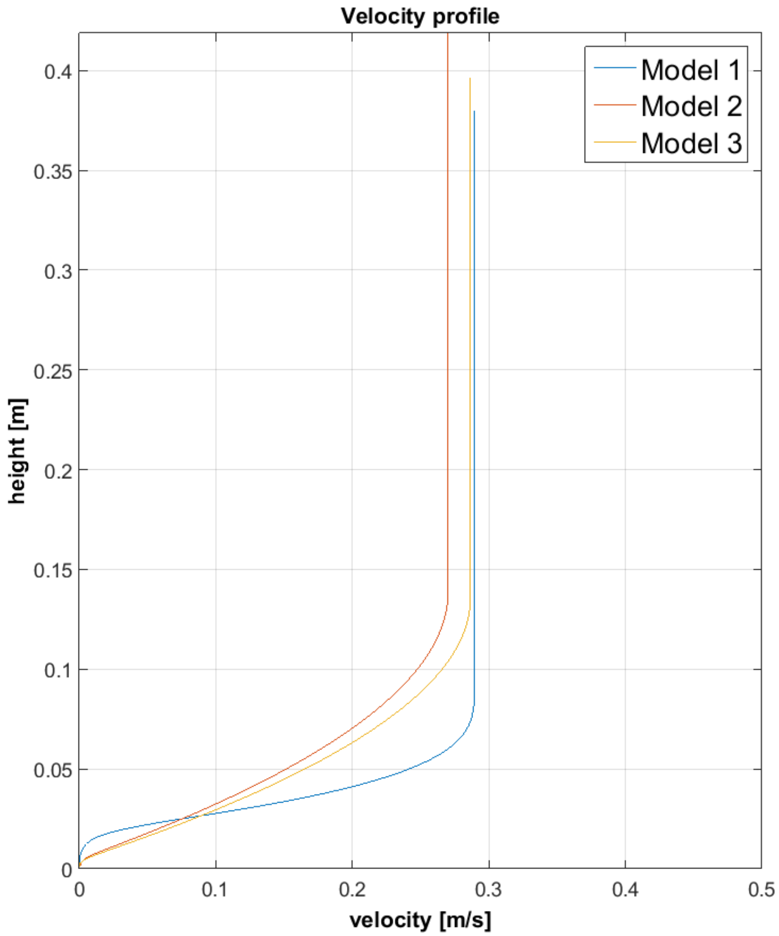
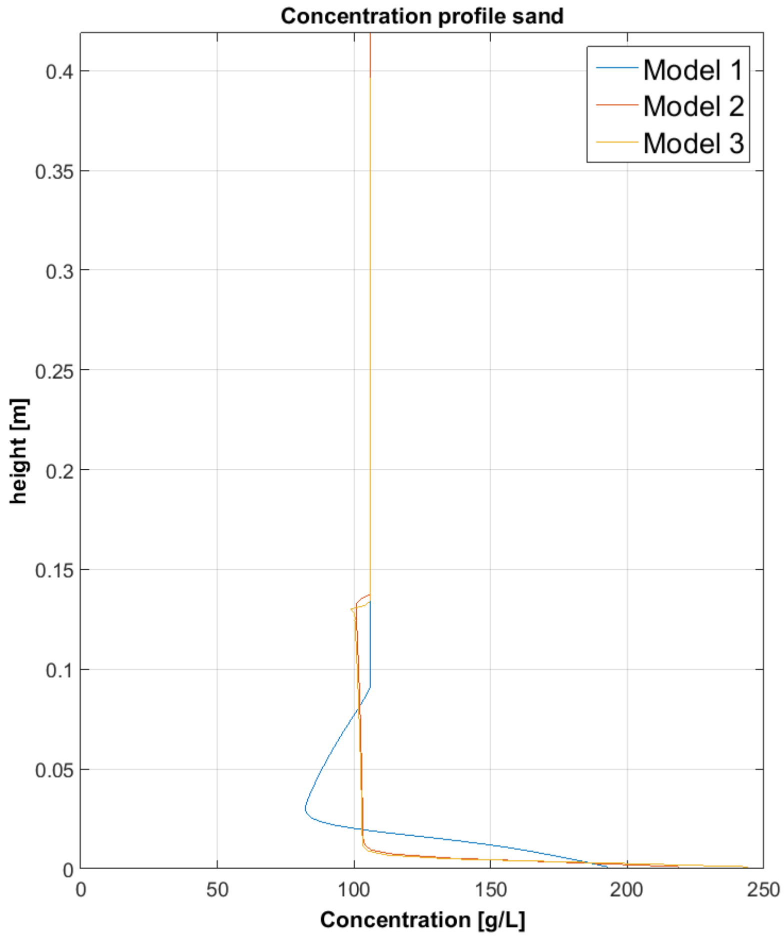
Testing TT





200 m

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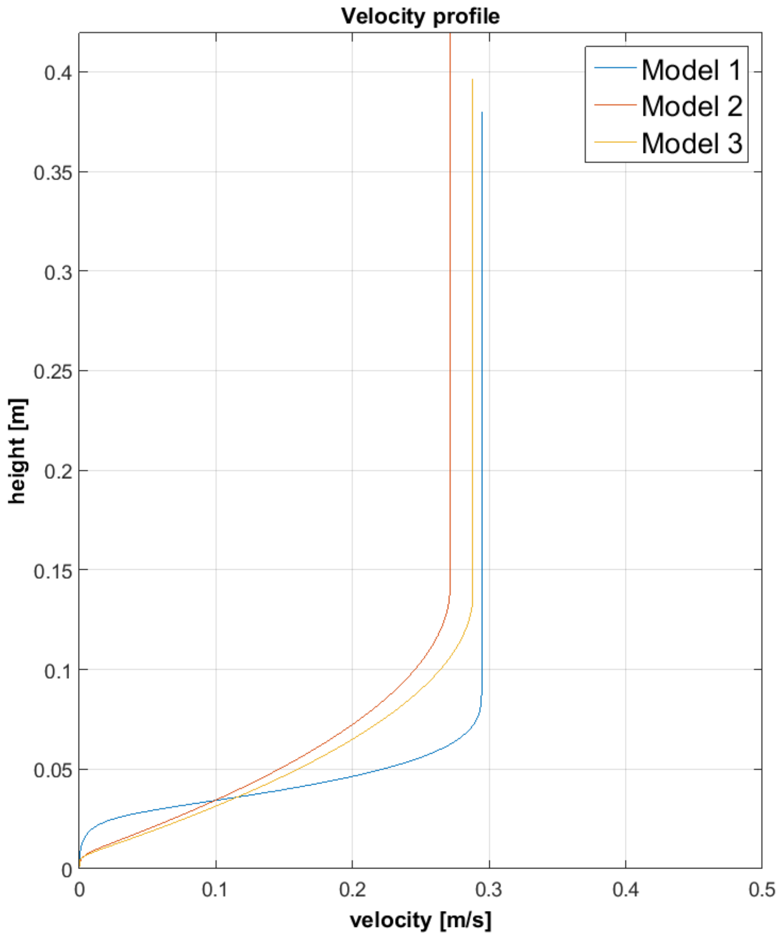
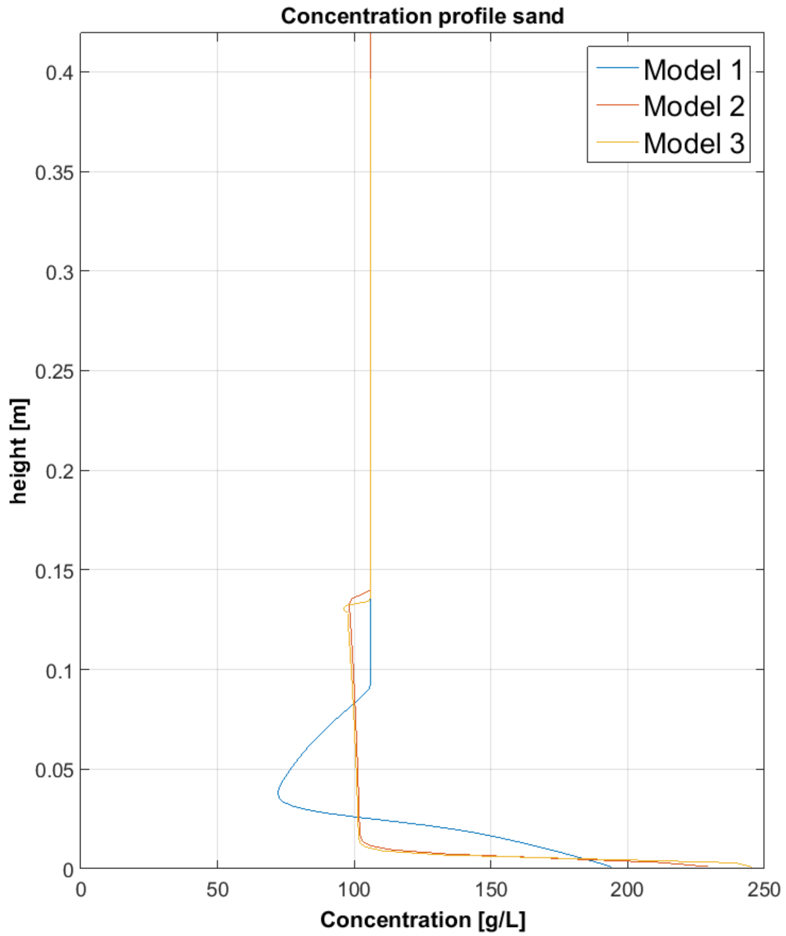
Testing TT





300 m

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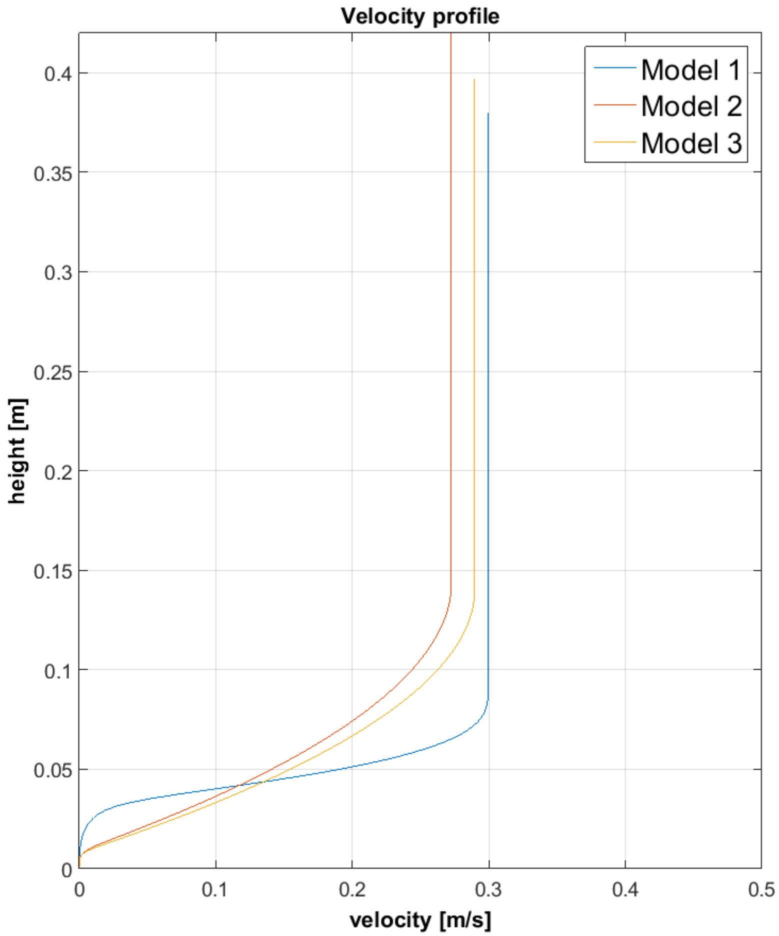
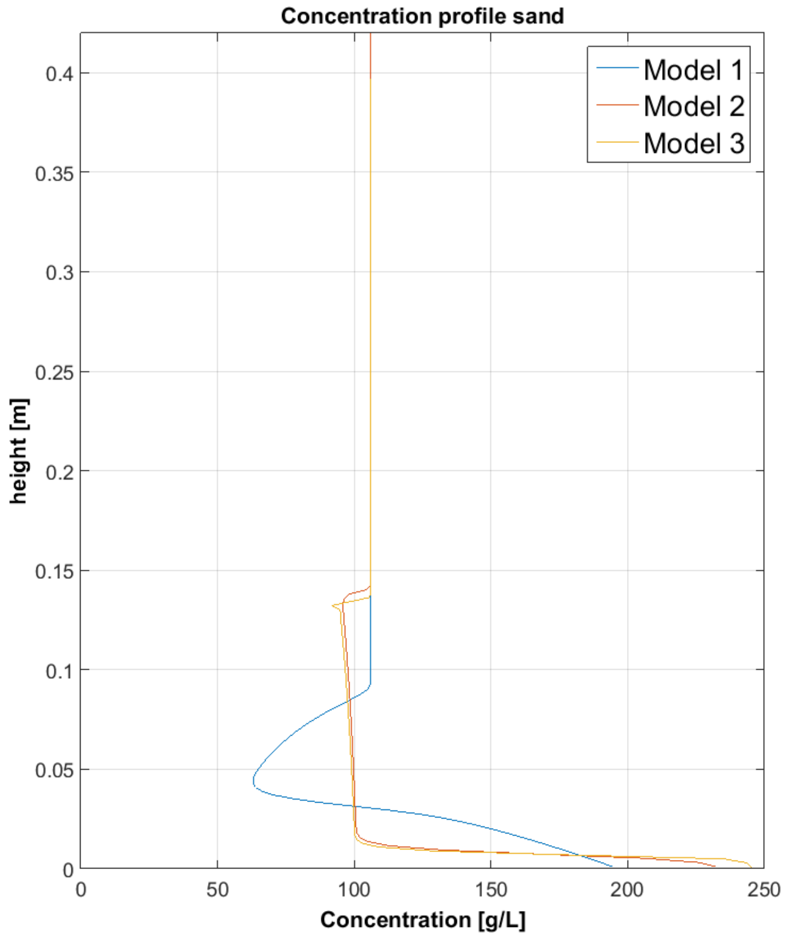
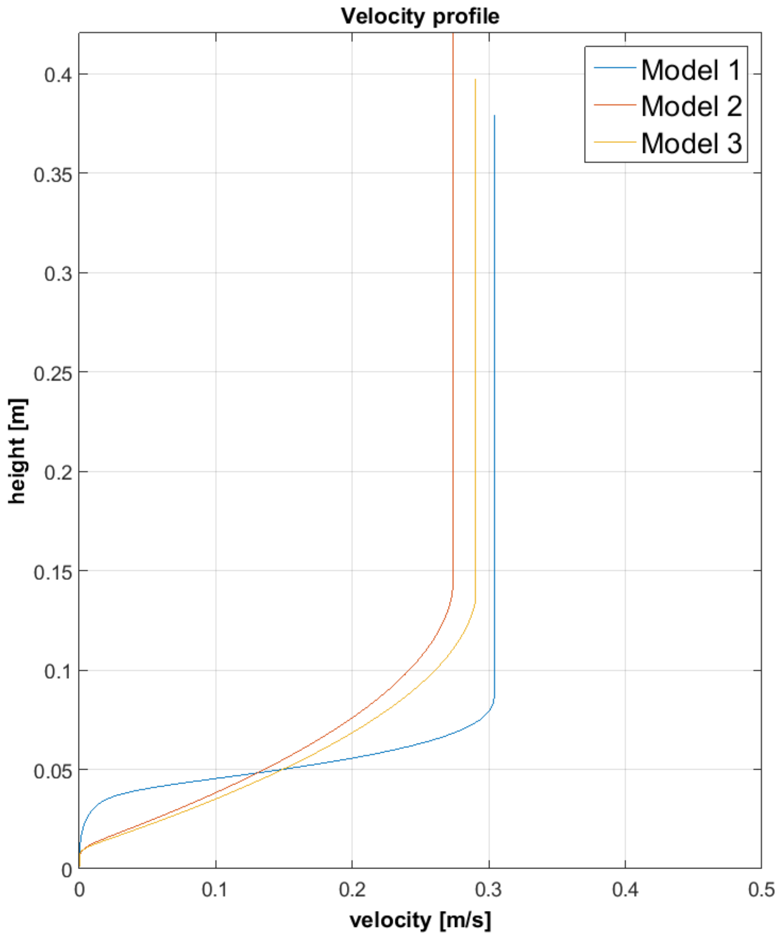
Testing TT

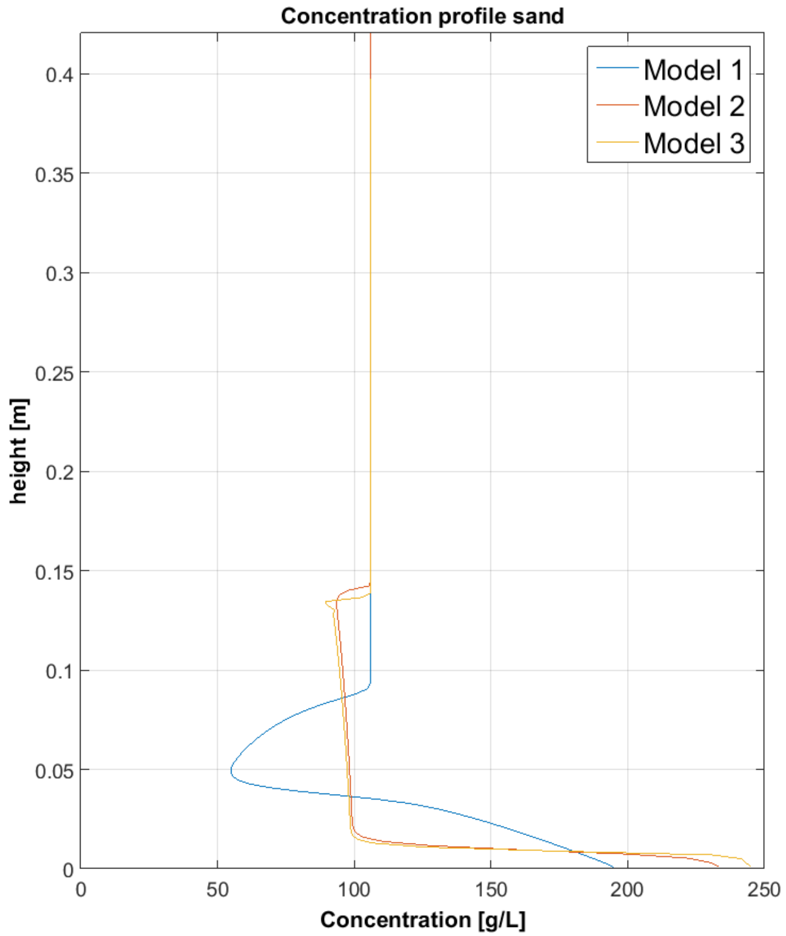




400 m

Testing TT





500 m

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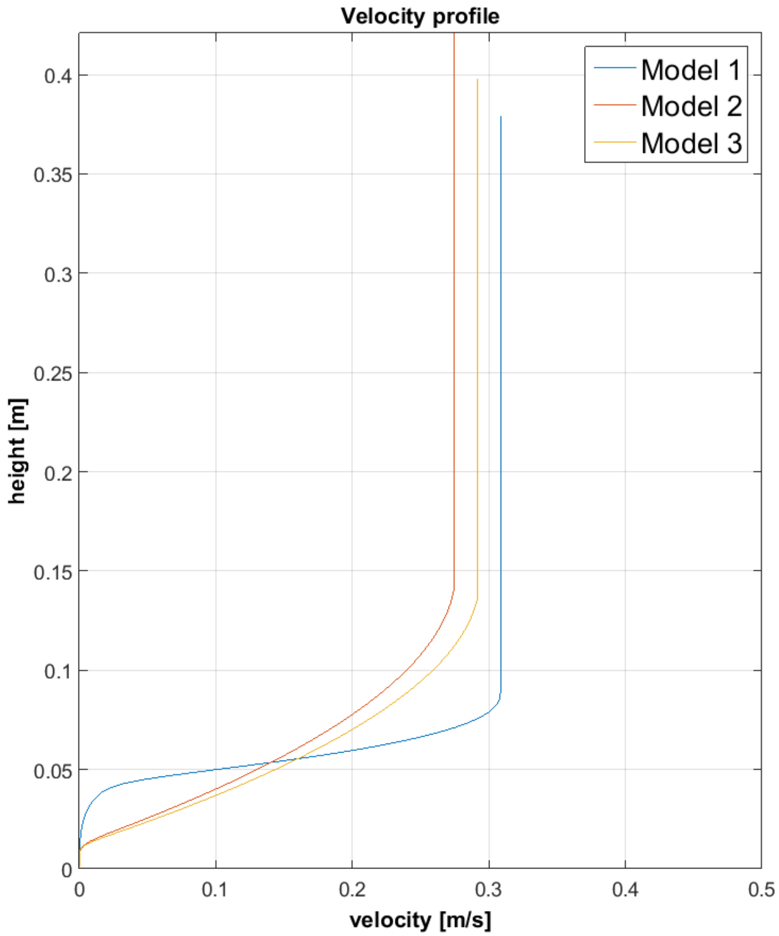
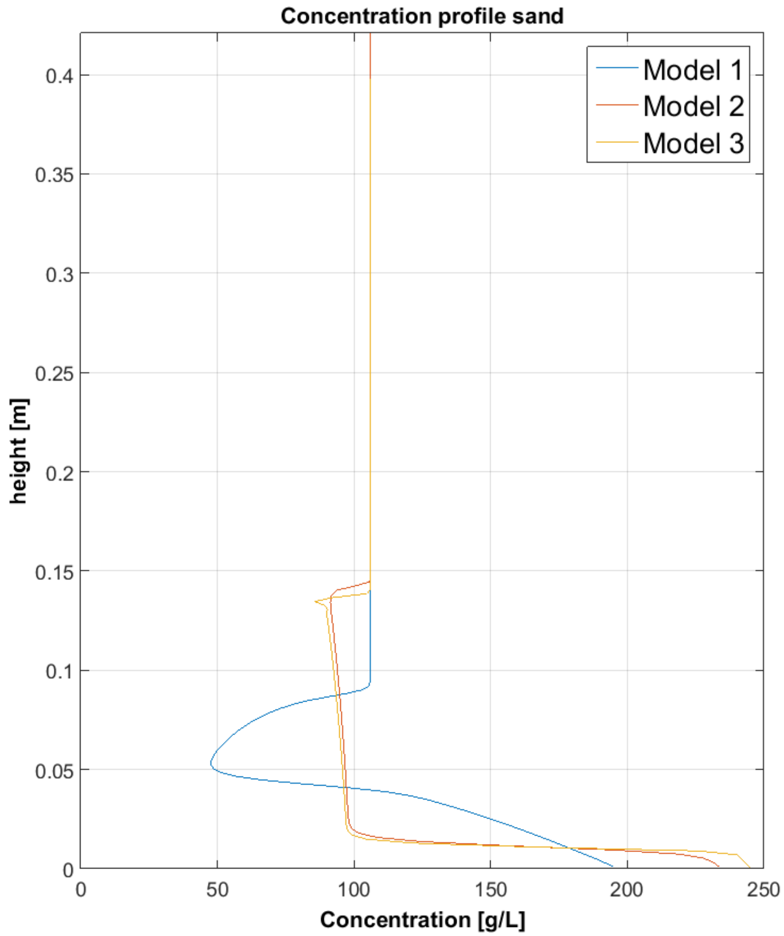
Testing TT





600 m

Deltares

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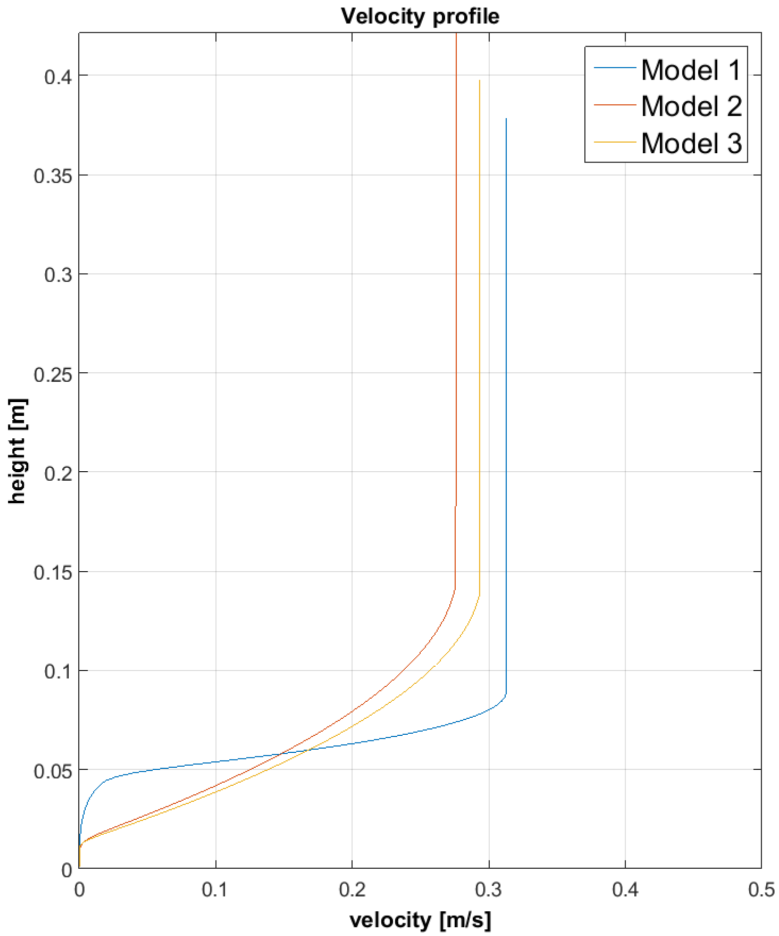
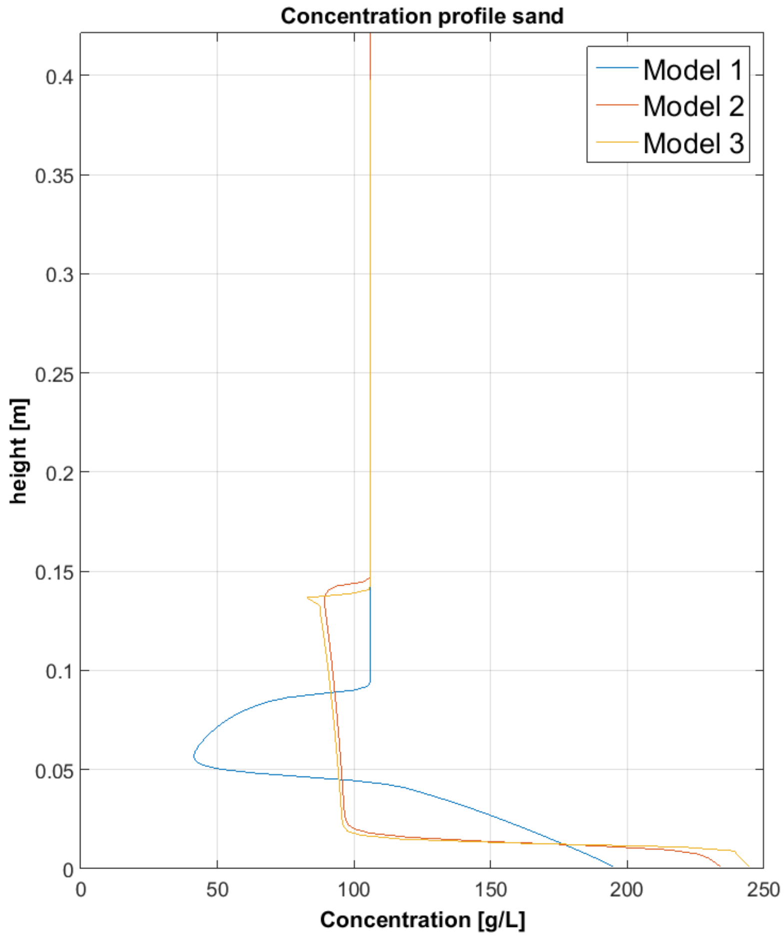
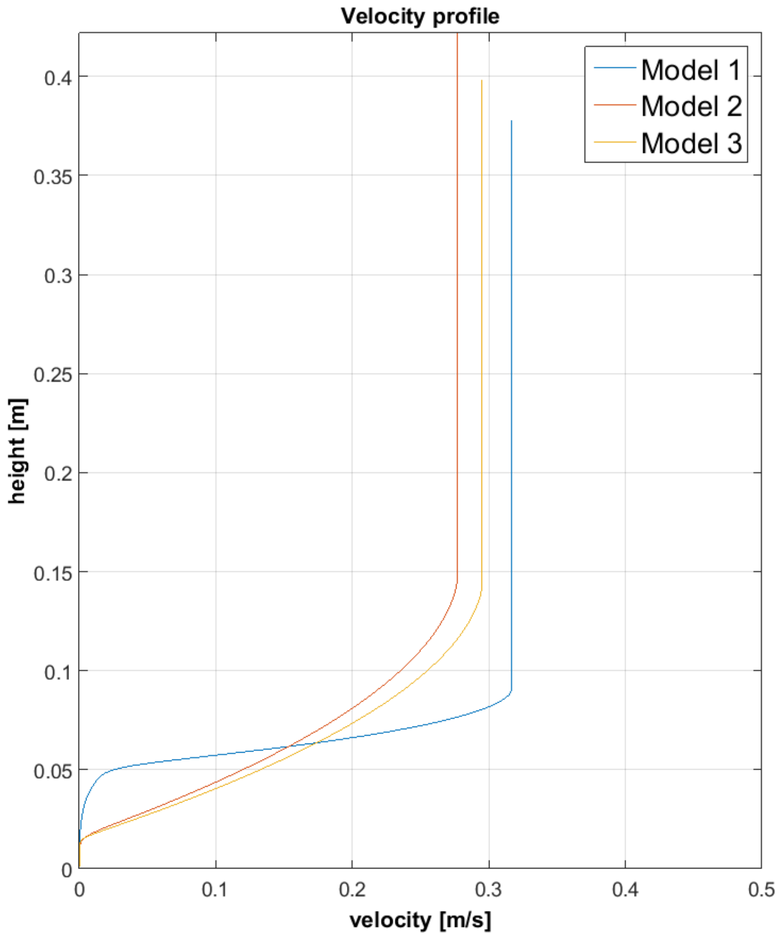


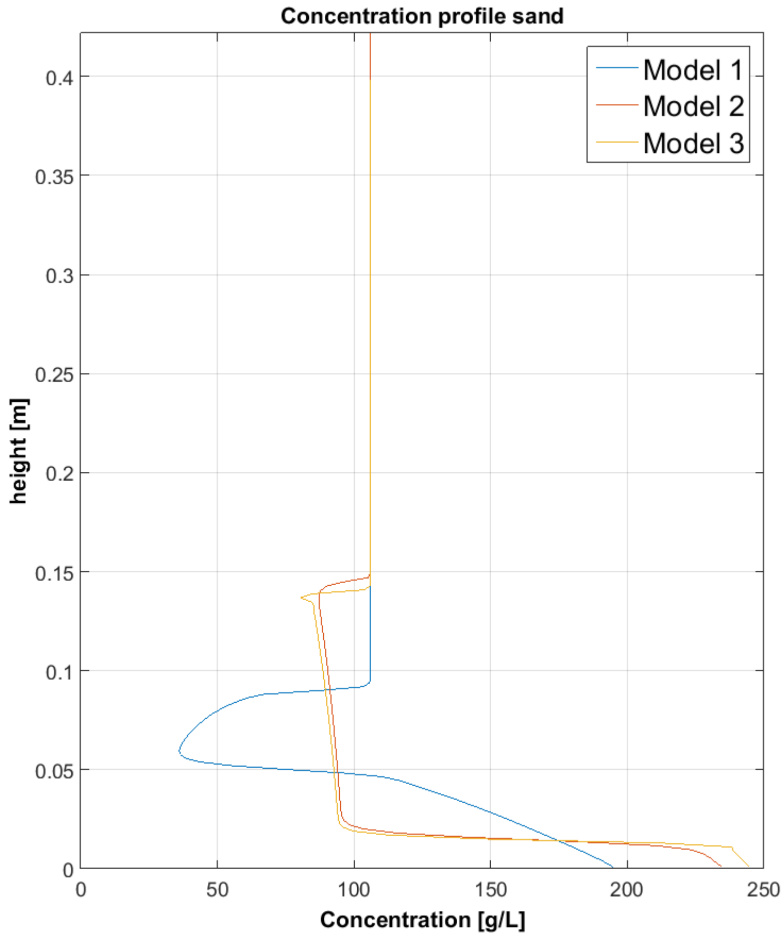


700 m

Deltares

Testing TT

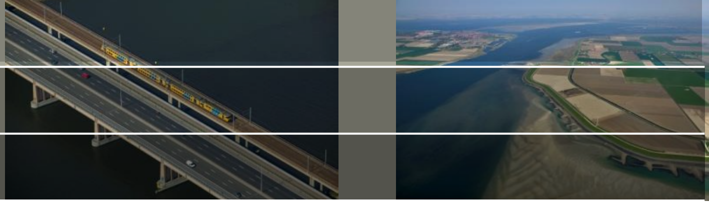


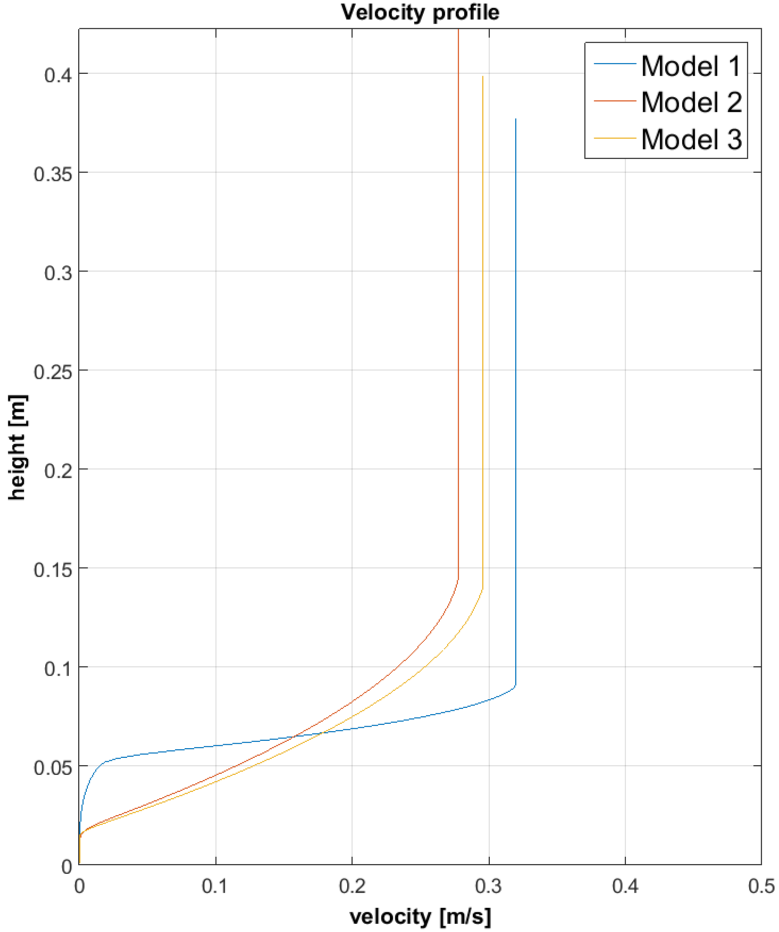


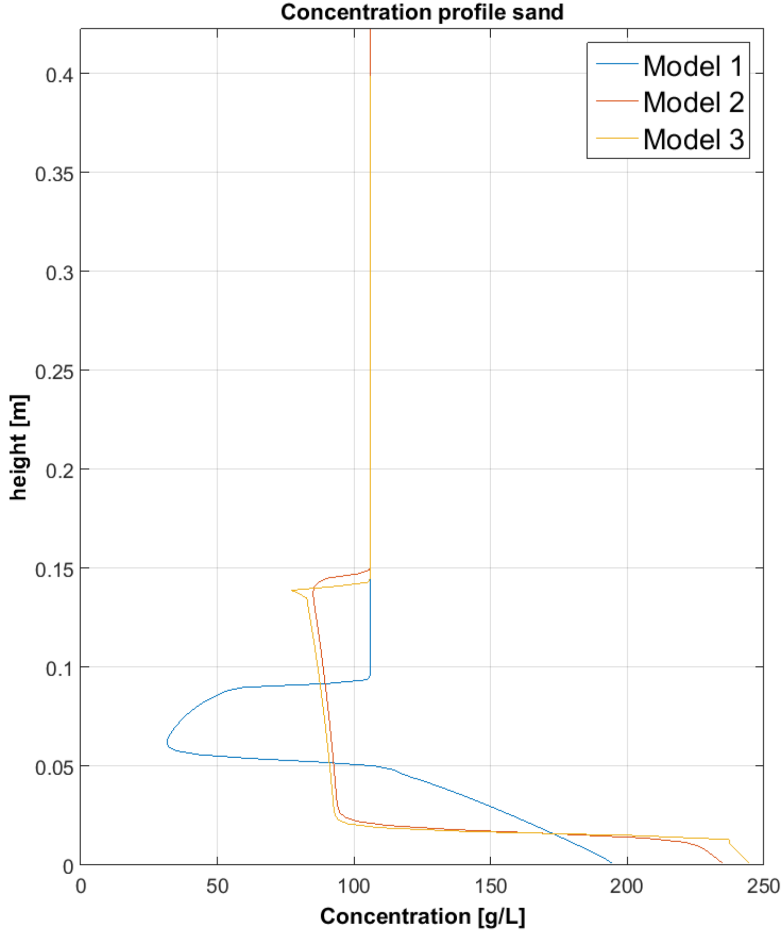
800 m

Deltares

Testing TT



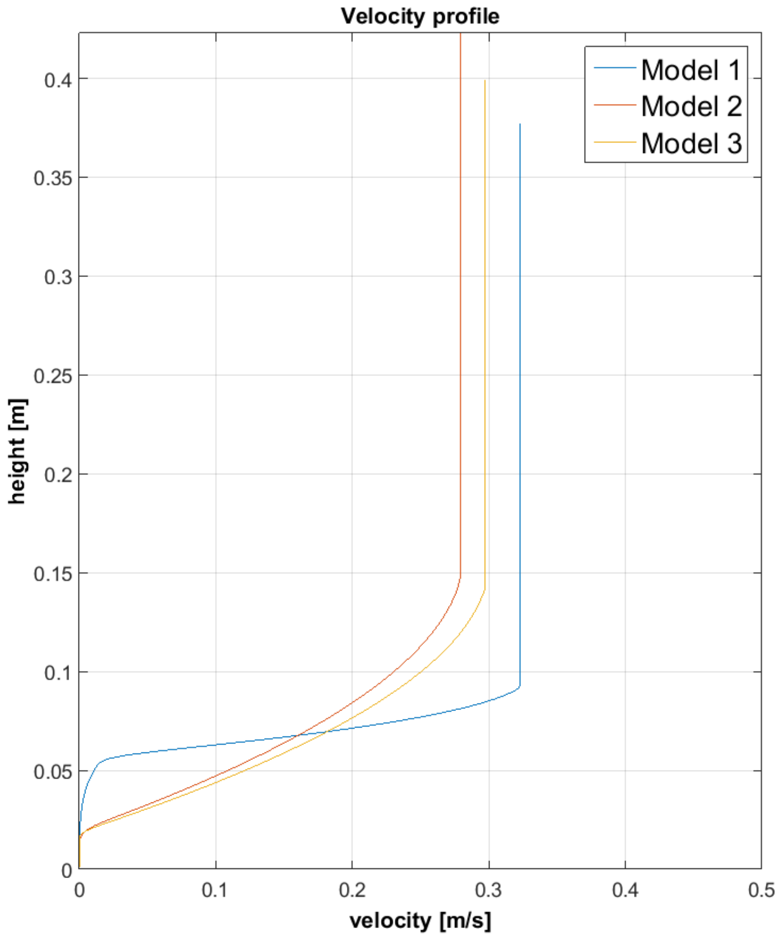


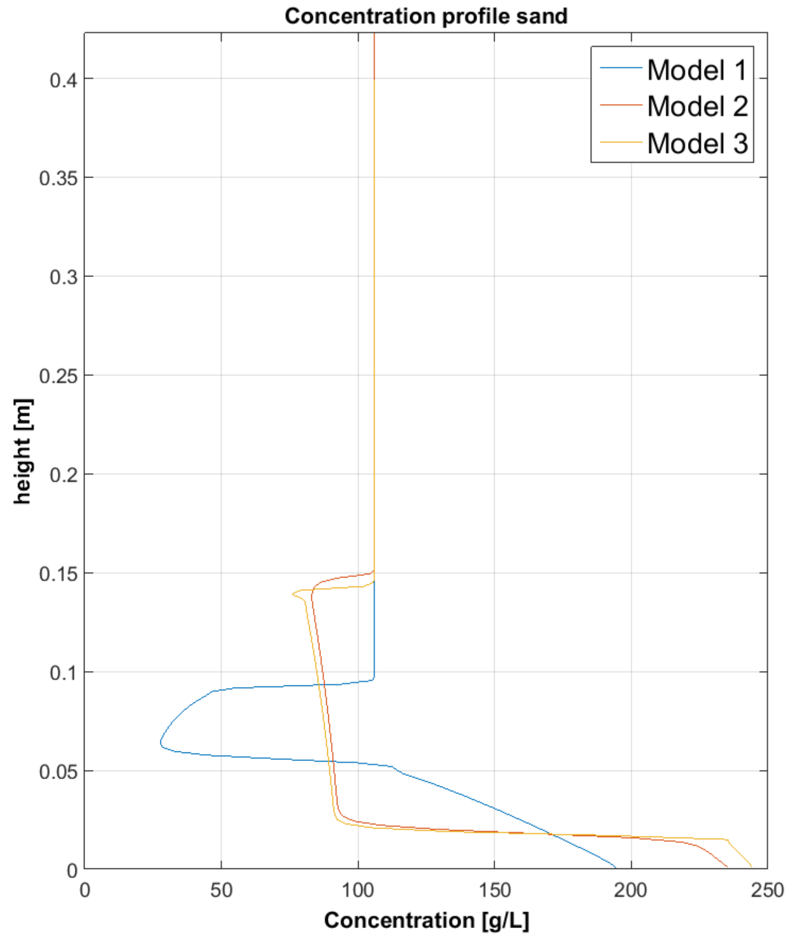


900 m

Deltares

Testing TT

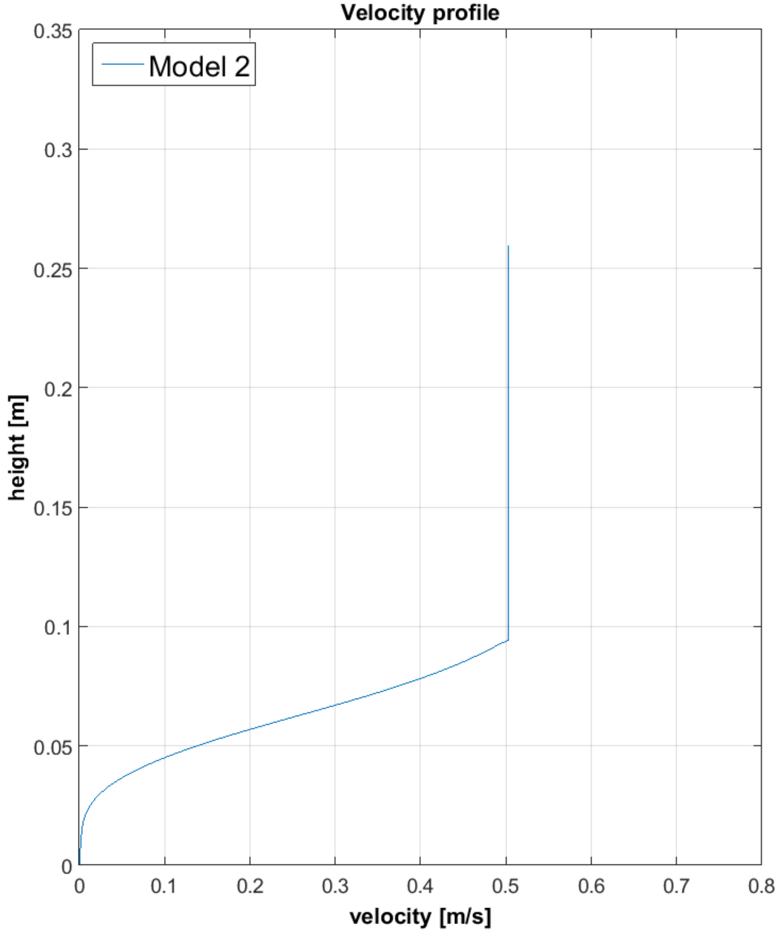


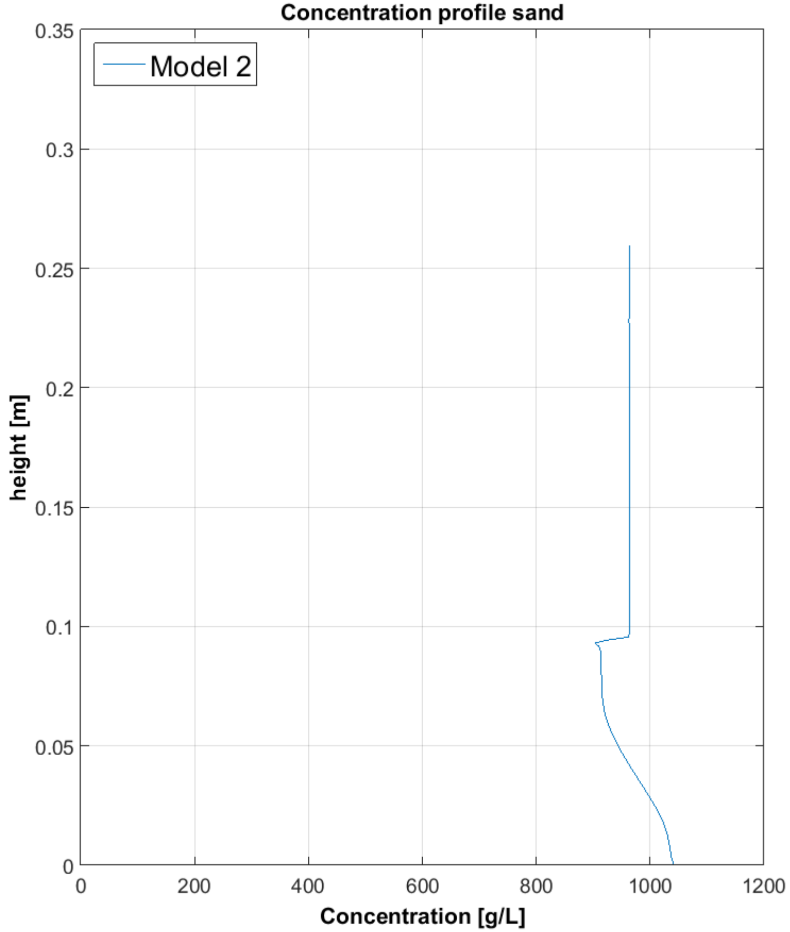


1000 m

Deltares

Testing NST – weaker rheology, high sand

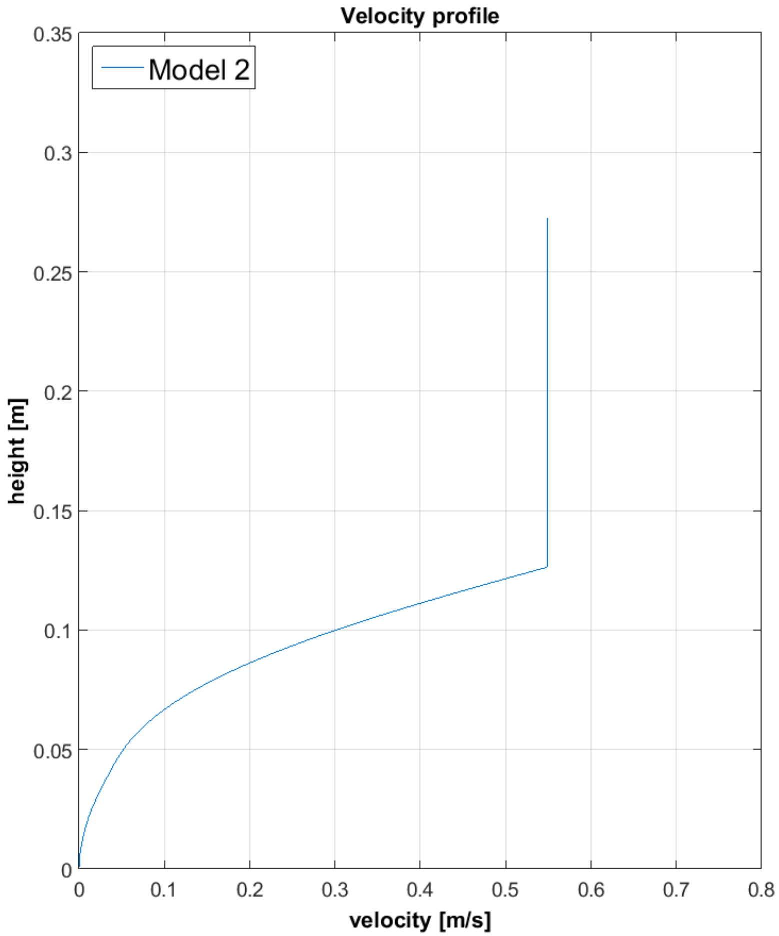


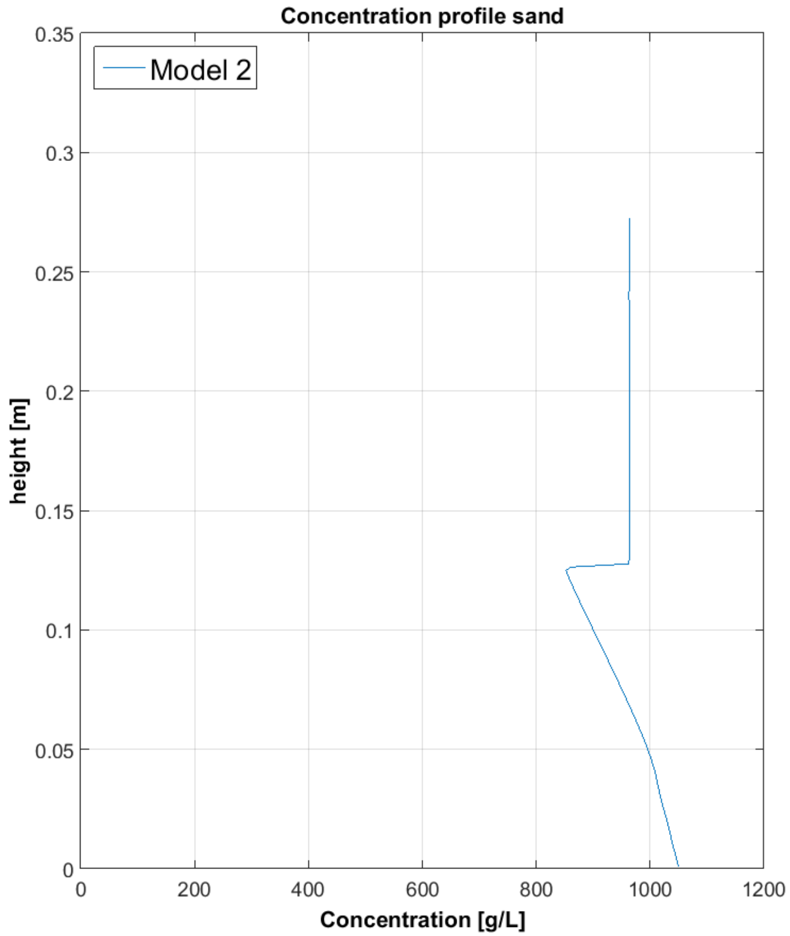


100 m

Deltares

Testing NST

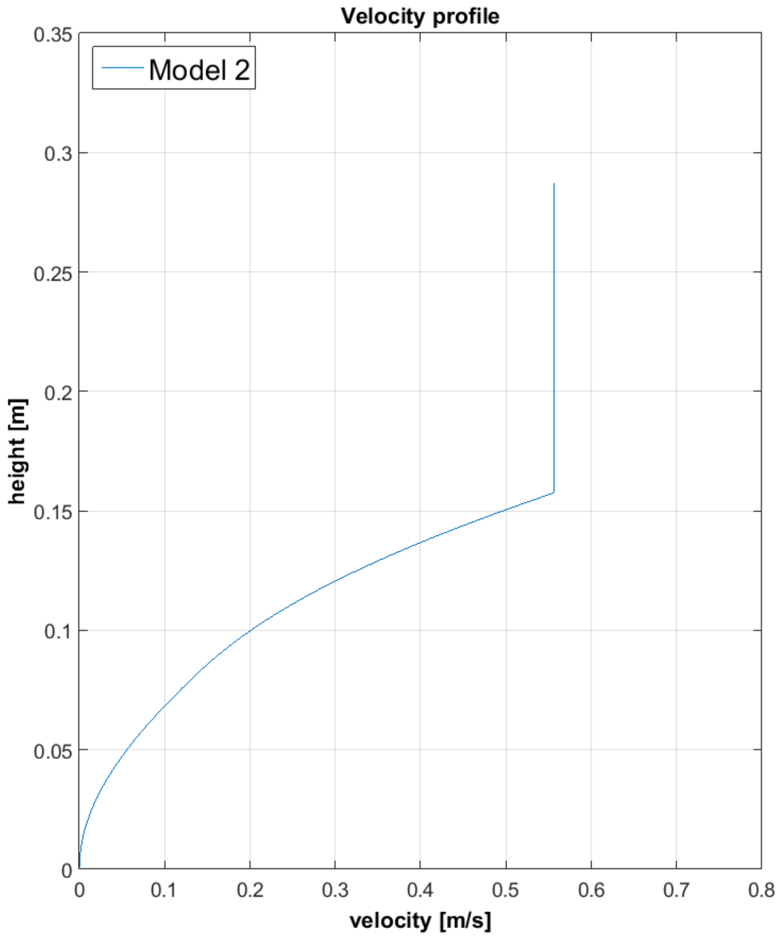


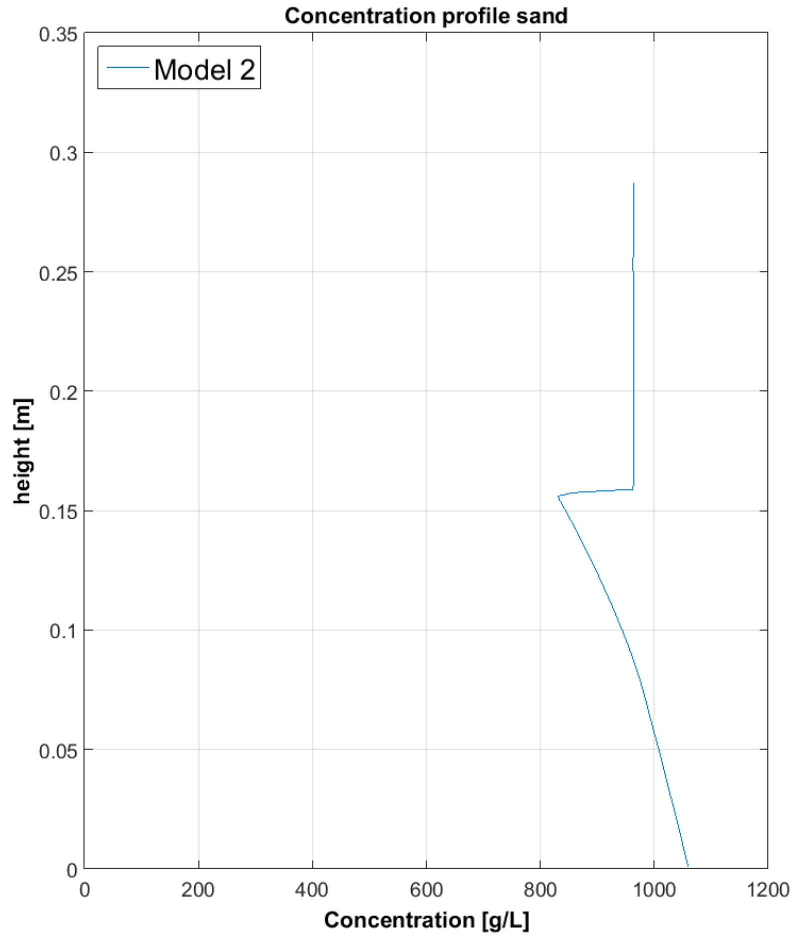


200 m

Deltares

Testing NST

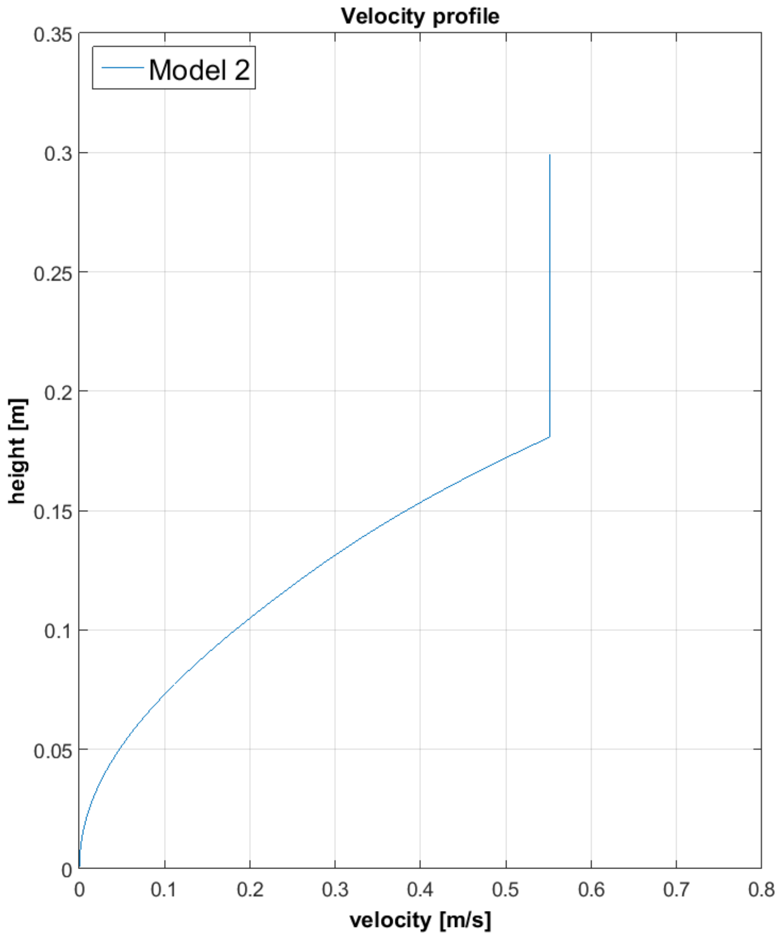


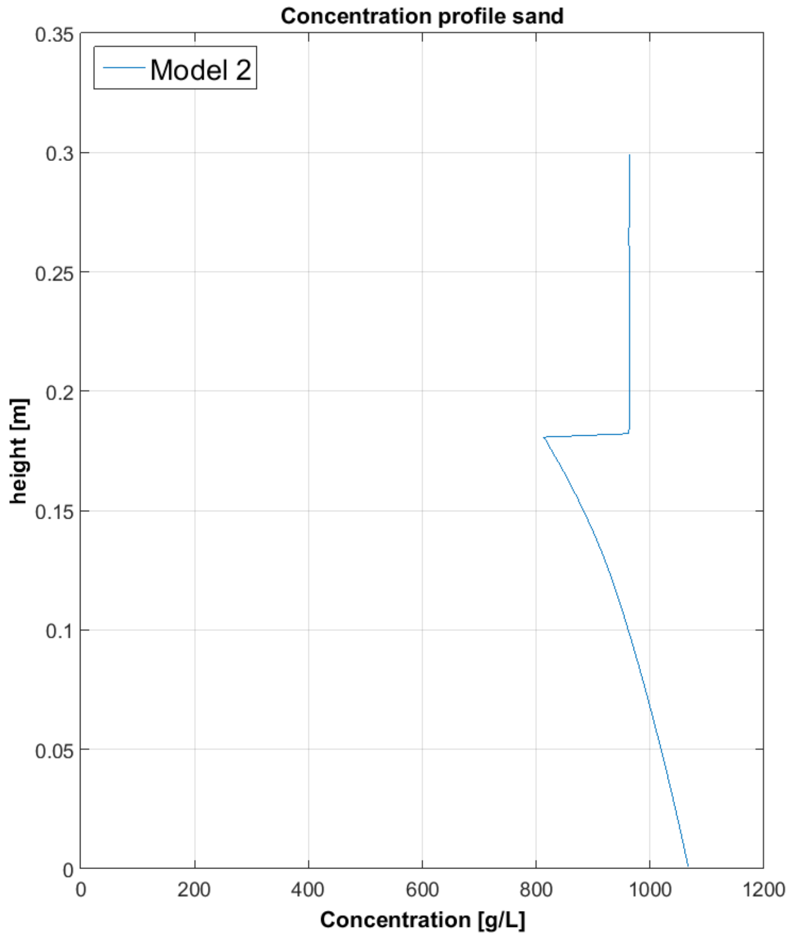


300 m

Deltares

Testing NST

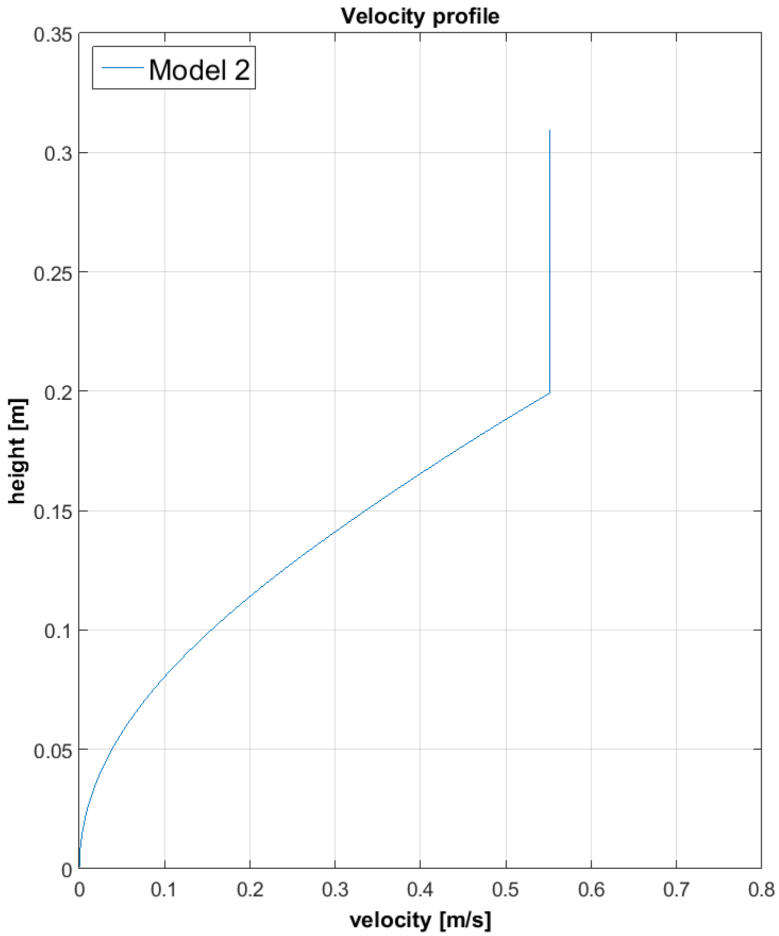


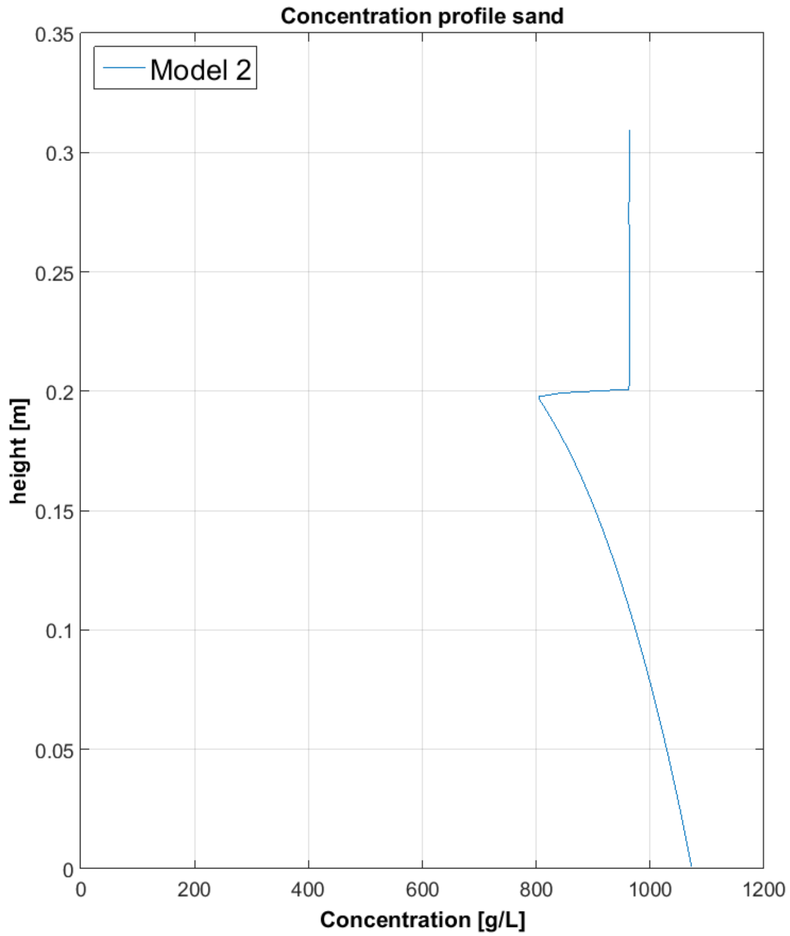


400 m

Deltares

Testing NST

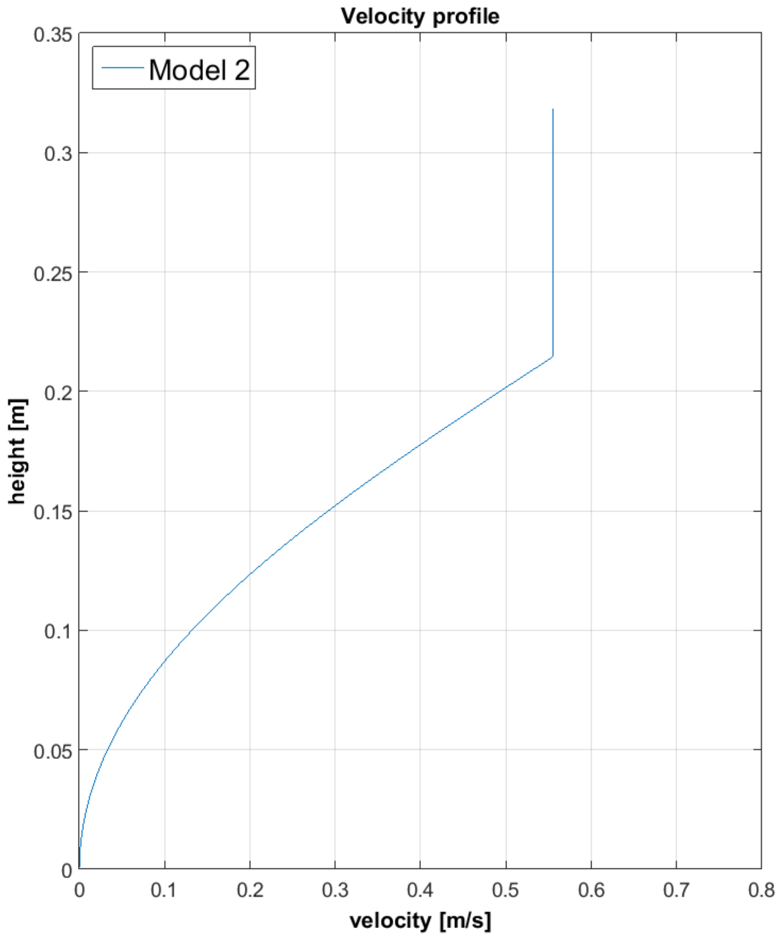


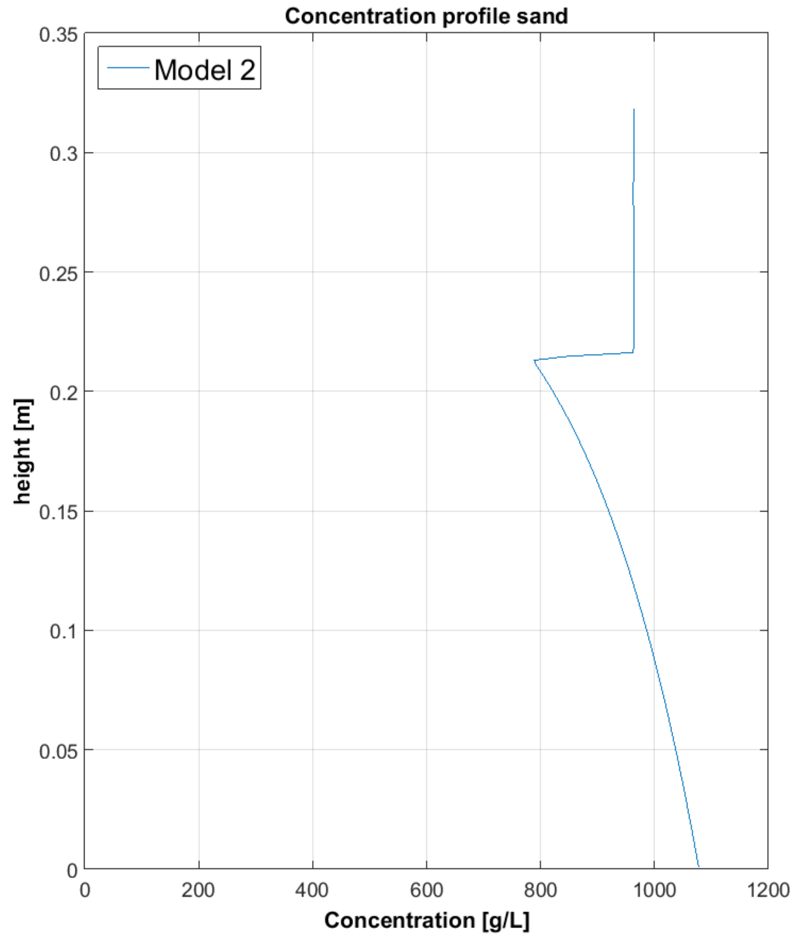


500 m

Deltares

Testing NST

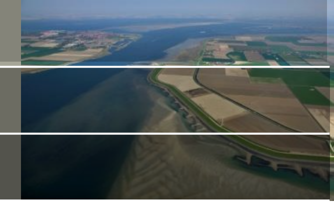


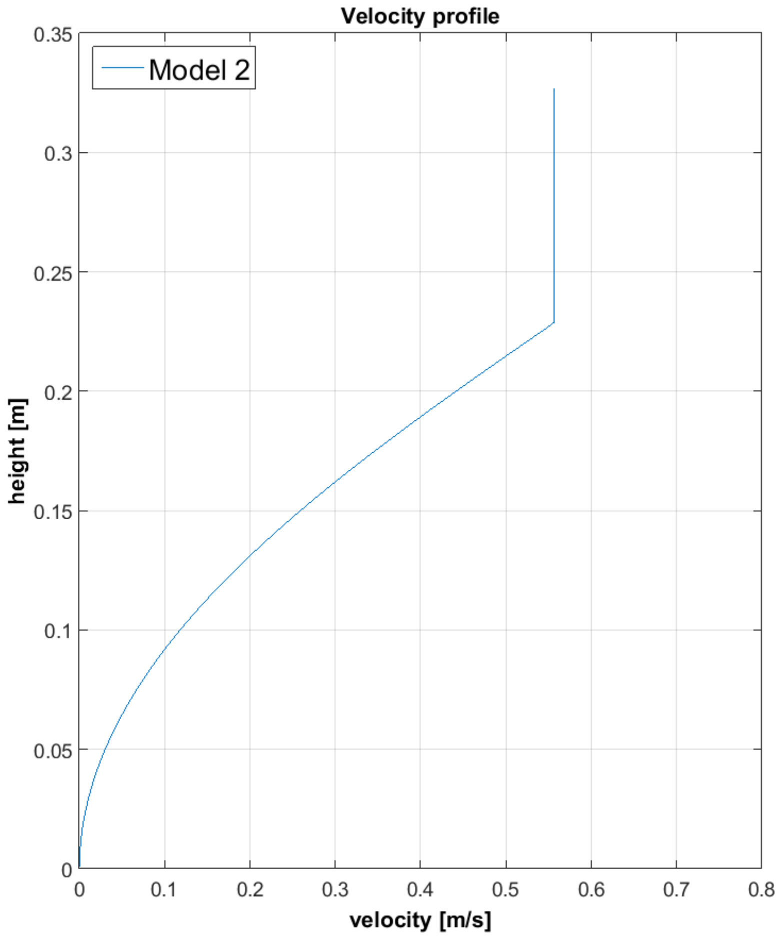


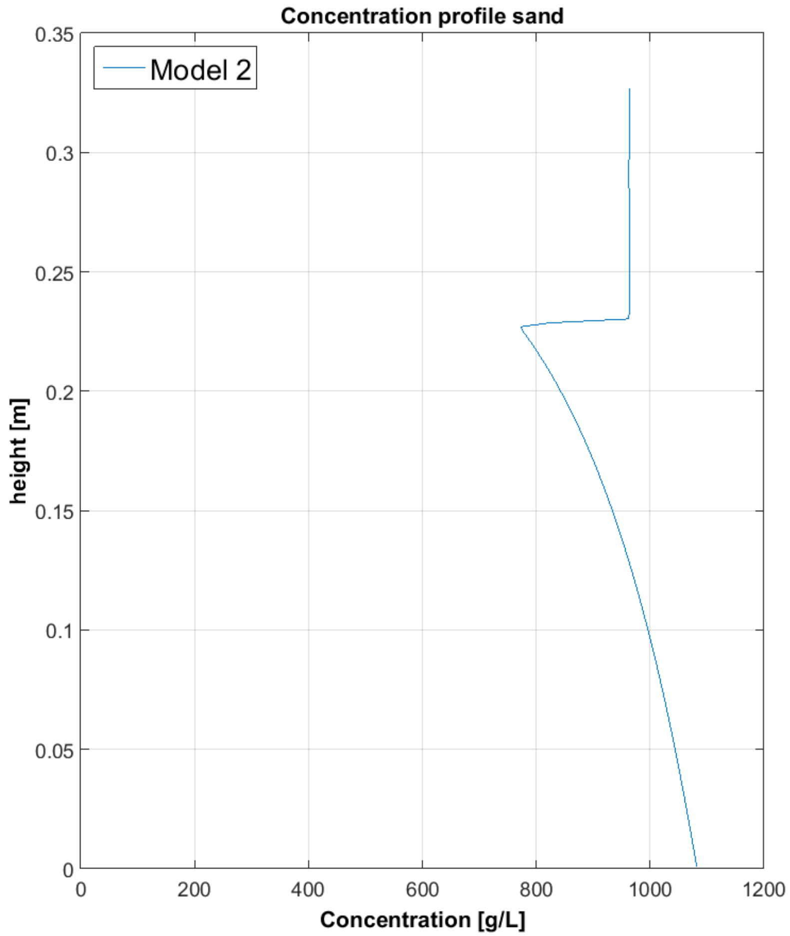
600 m

Deltares

Testing NST

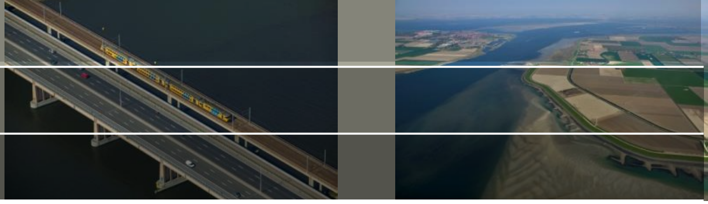





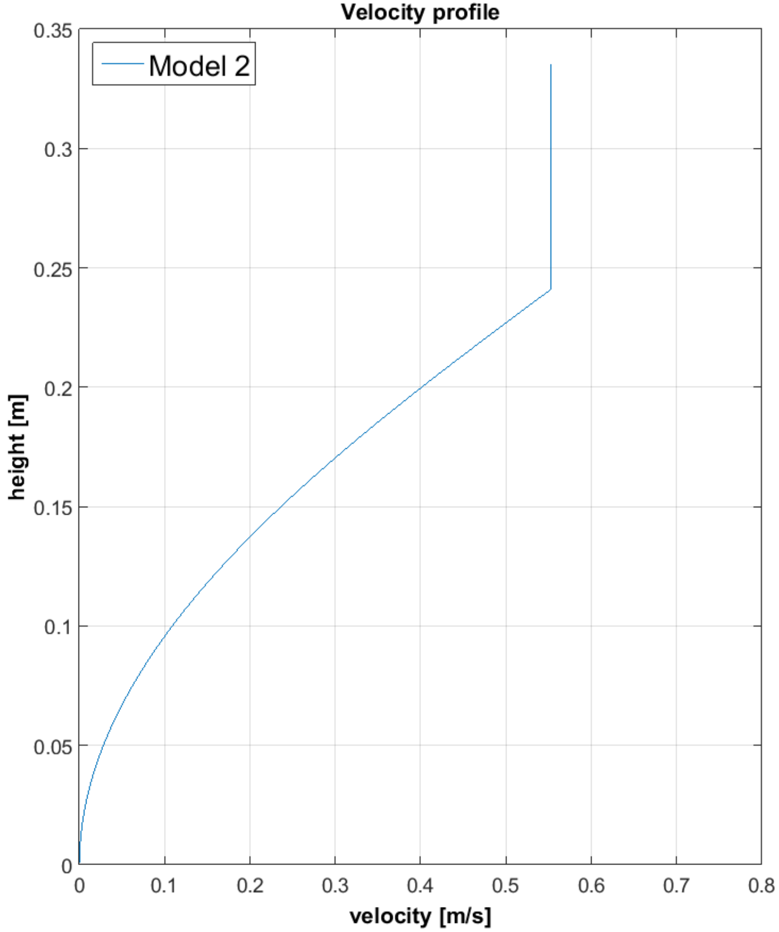


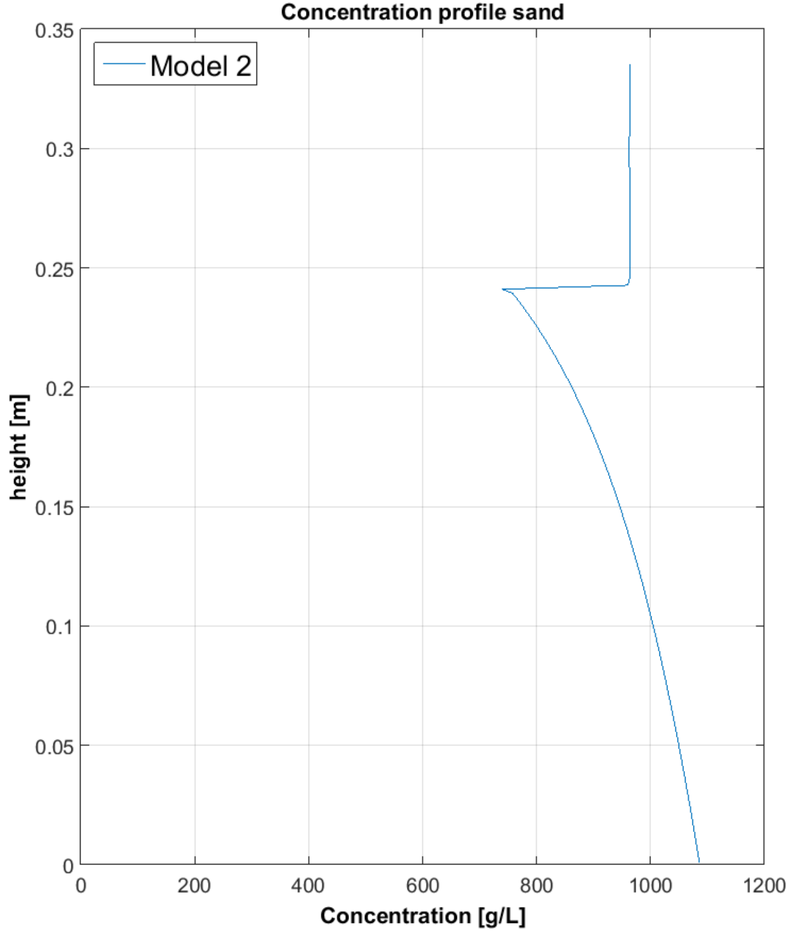
700 m

Deltares



Testing NST

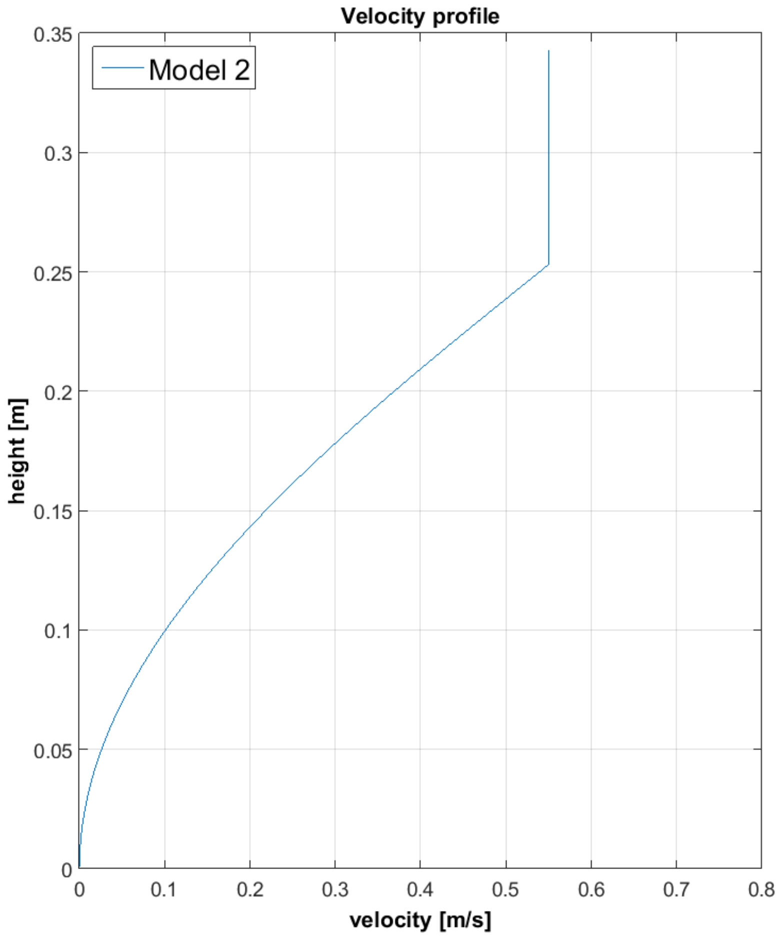


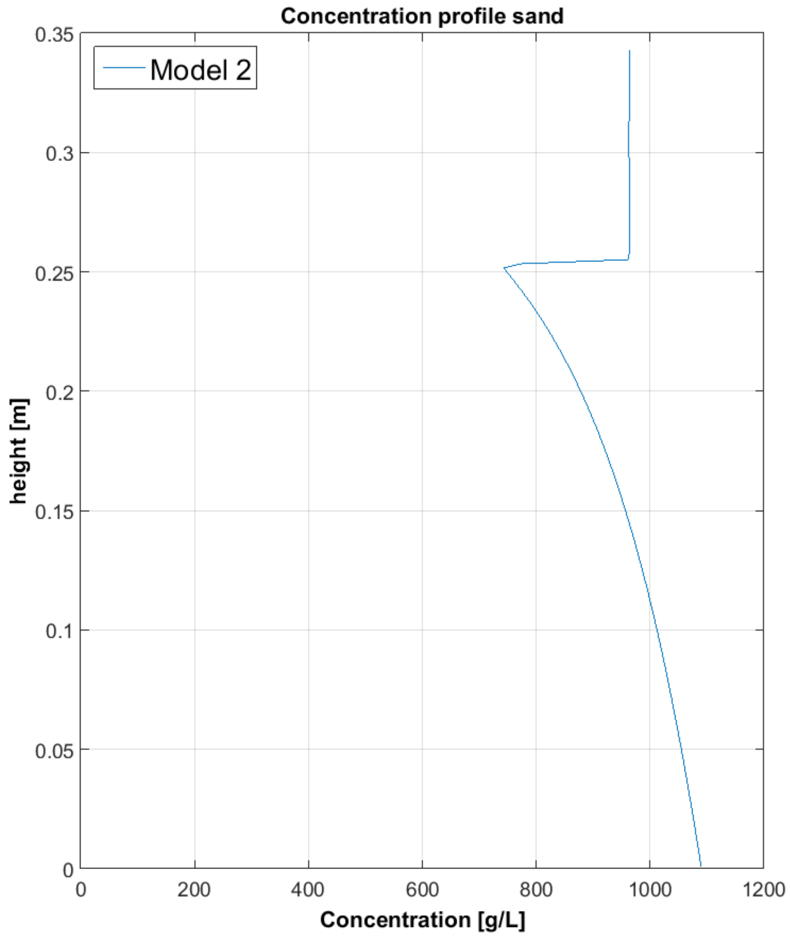


800 m

Deltares

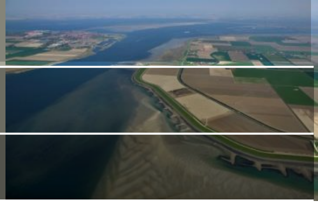
Testing NST



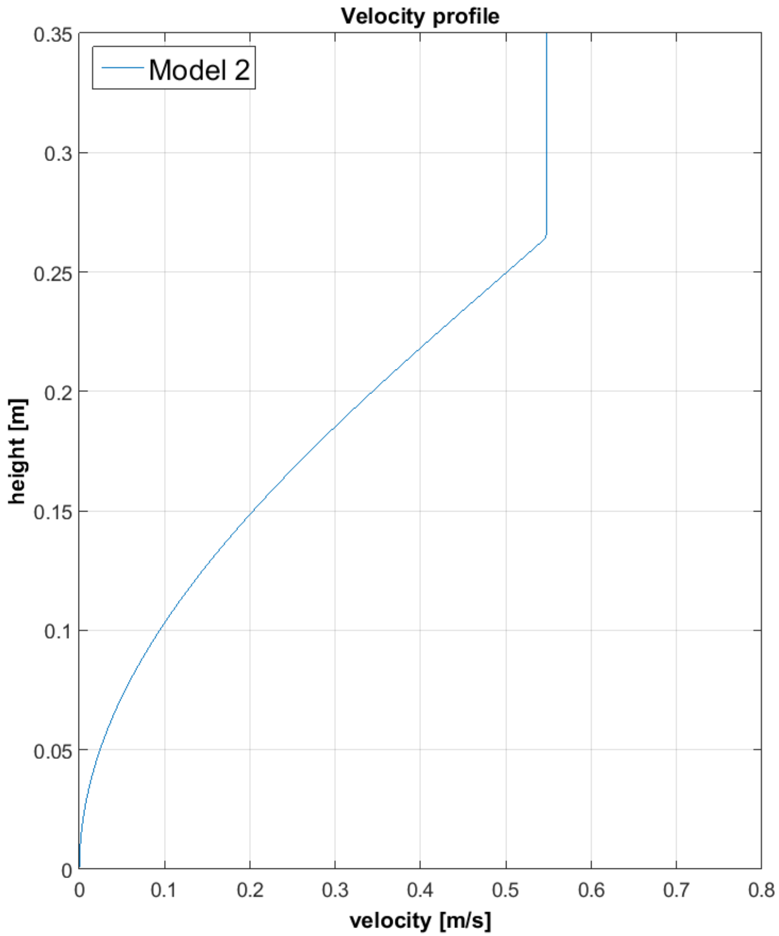


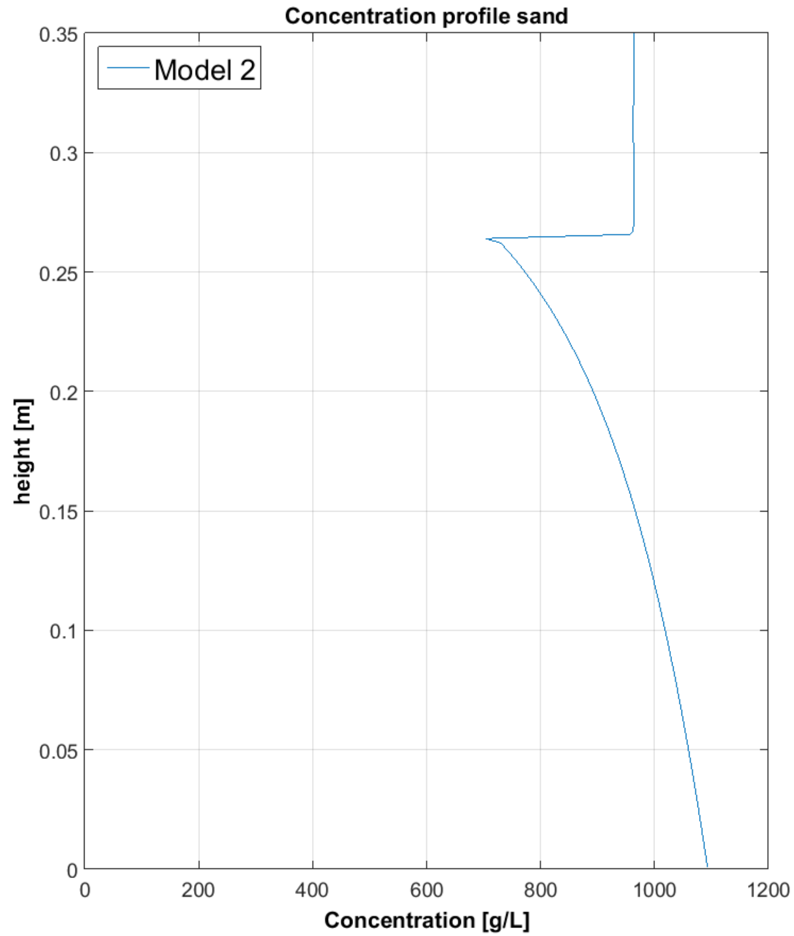
900 m

Deltares

Testing NST



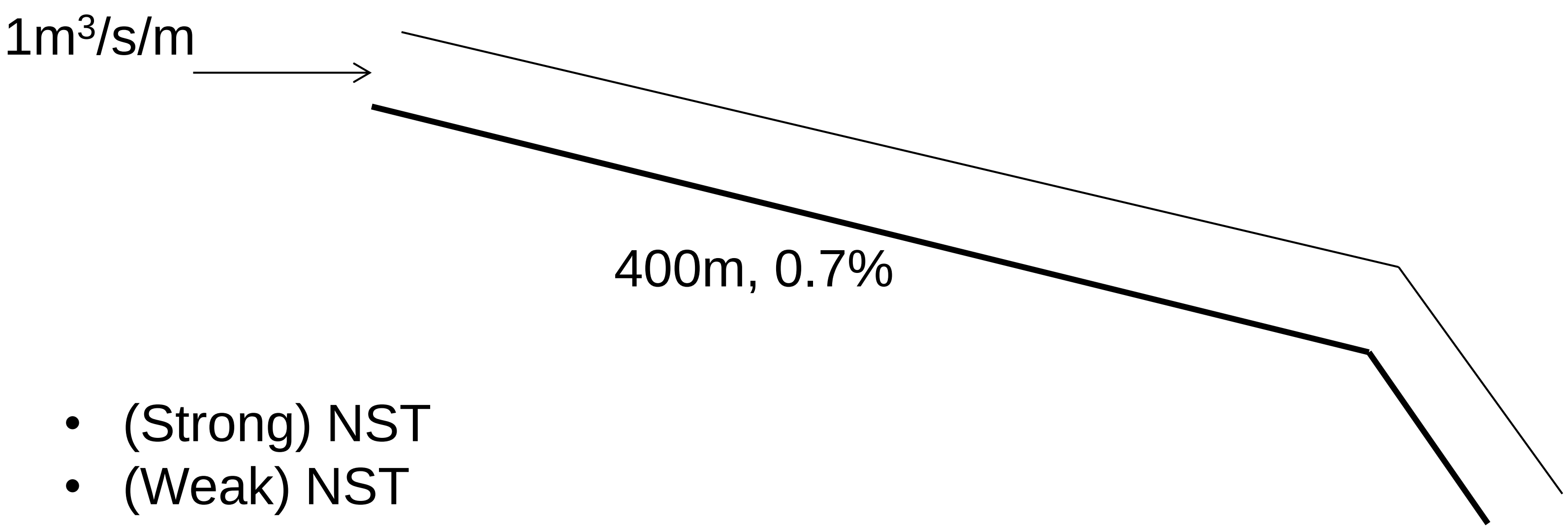


1000 m

Deltares

Test in 2DV (older version of Delft3D – slurry)

2DV simulations on beach slope (a long flume test!), constant $1m^3/s/m$ slurry flow rate. 40 mins of beach deposition.

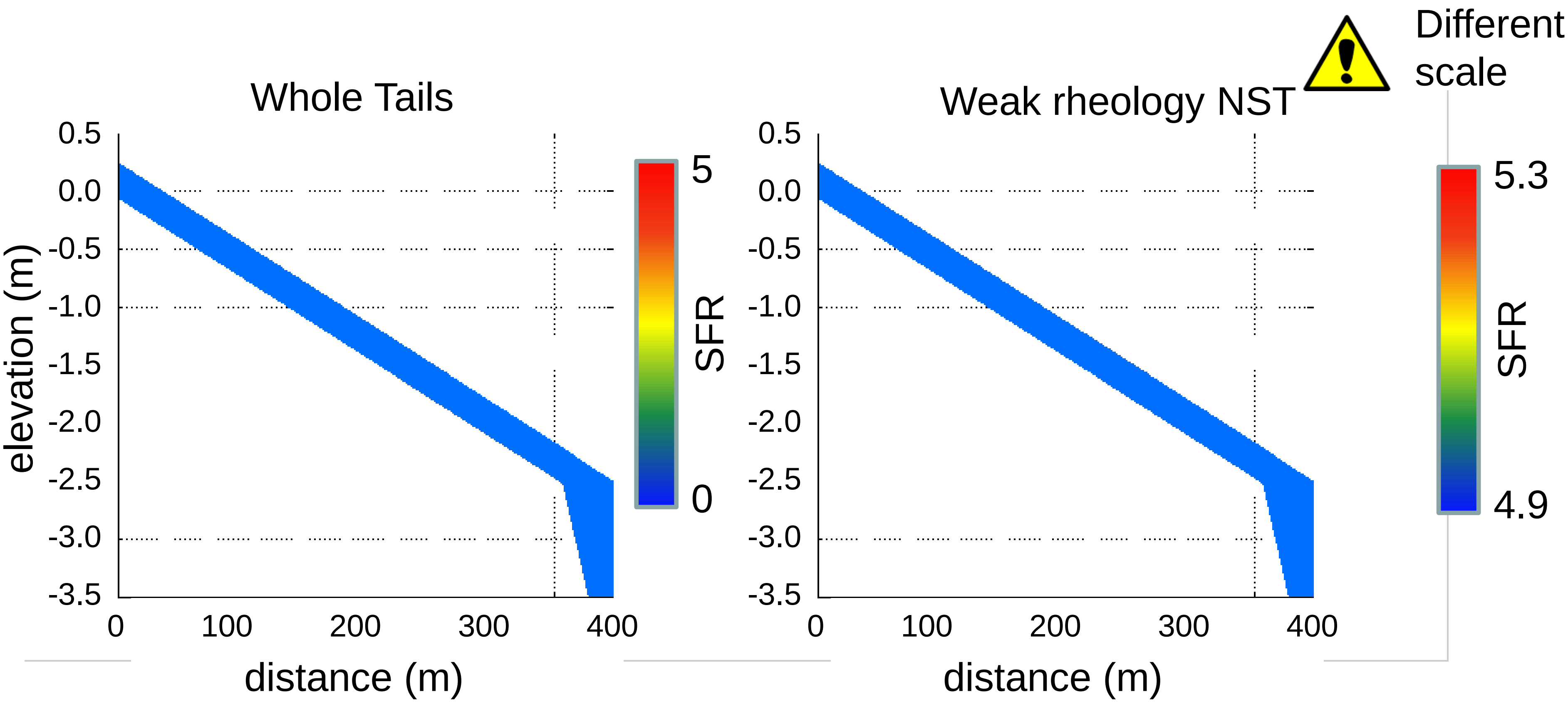


- (Strong) NST
- (Weak) NST
- Whole Tails

Test in 2DV (older version of Delft3D – slurry)

Whole Tails-like: SFR 1.1; Density = 1,251 kg/m^3; 32 % Cw

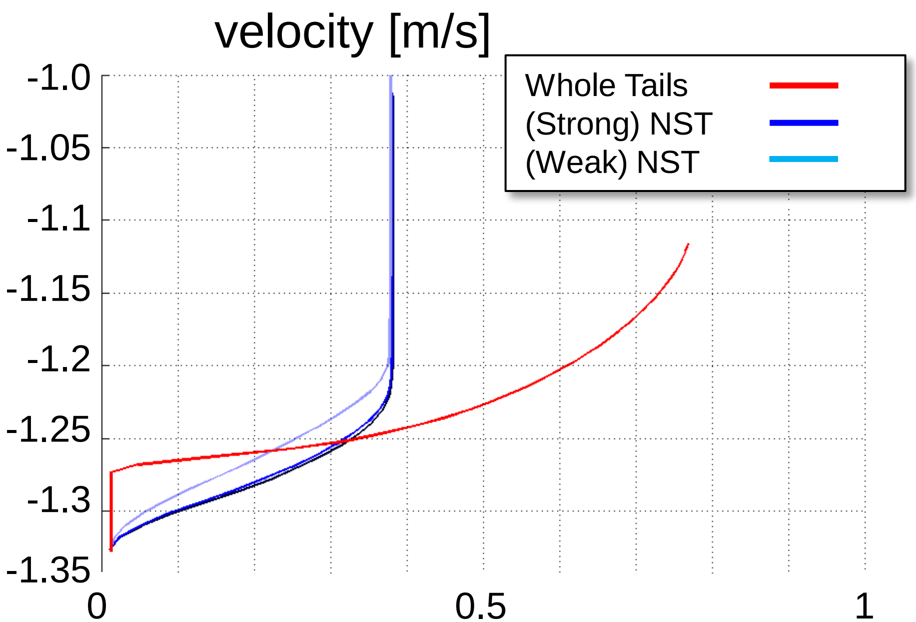
NST-like: SFR 5; Density = 1,725 kg/m^3; 67.5% Cw

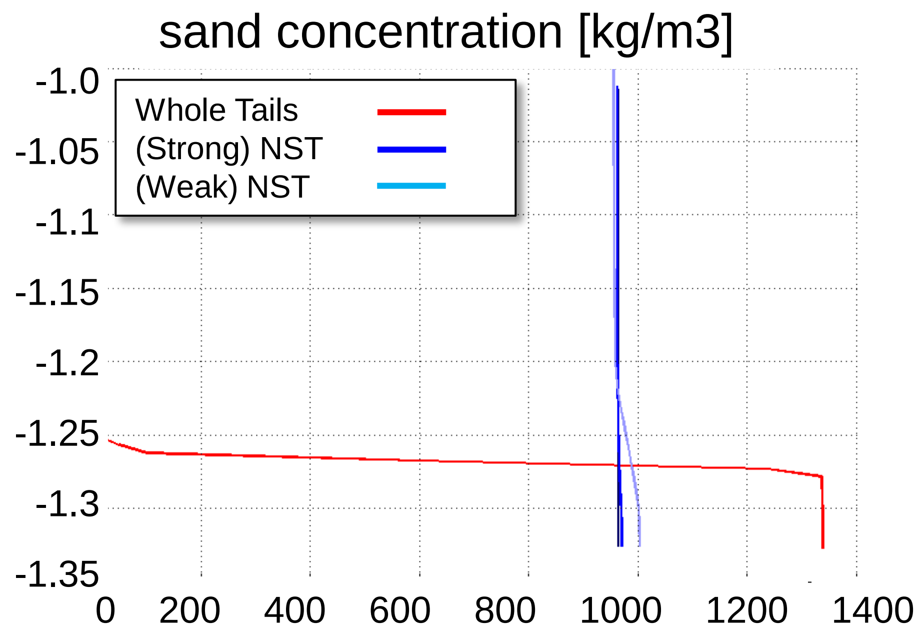


Test in 2DV (older version of Delft3D – slurry)

Sand Concentration and Velocity Profiles:

- note ‘plug’ velocity structure in NST slurries (contrast with Whole Tails)
- nearly all sand in Whole Tails settles out and forms immobile bed layer
- modest increase in sand content near base of weaker NST flows – not sufficient for bed formation

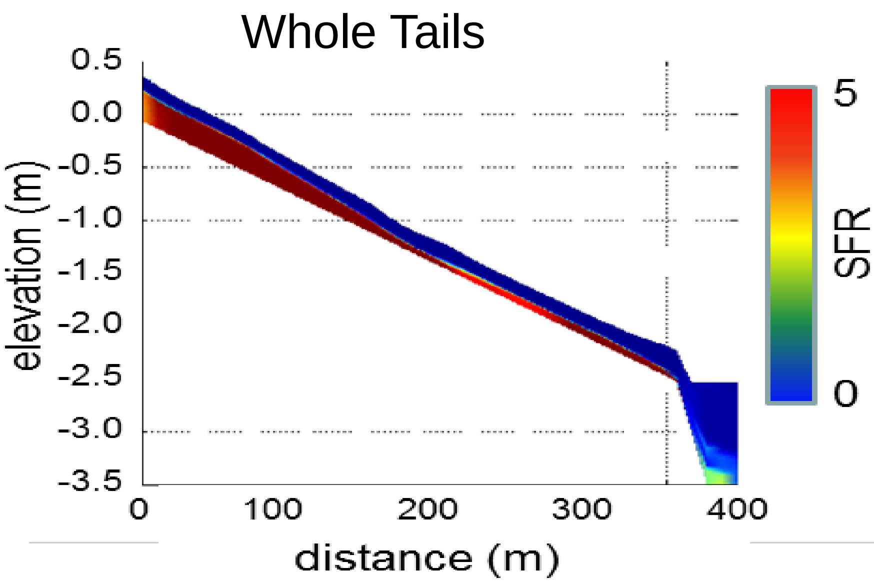


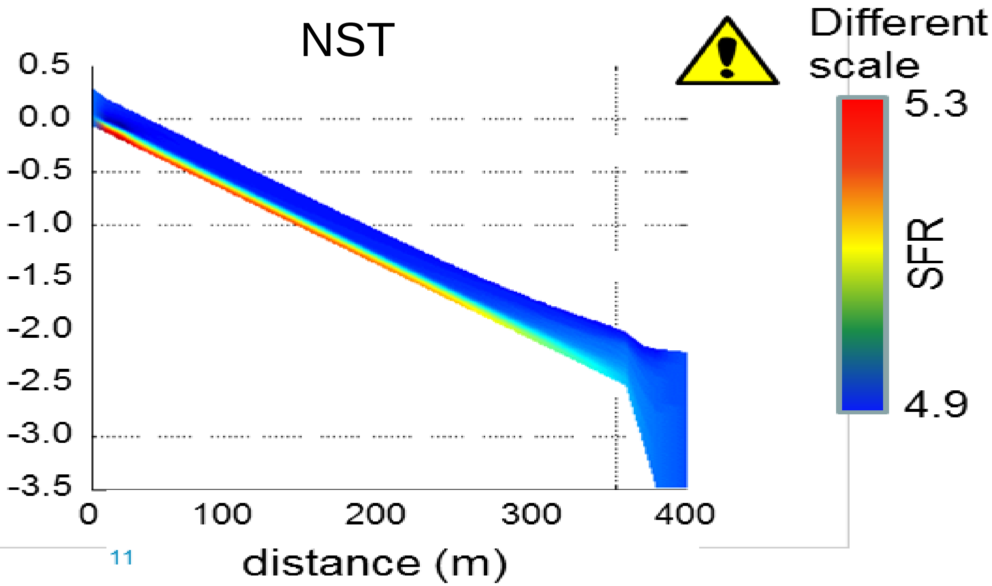


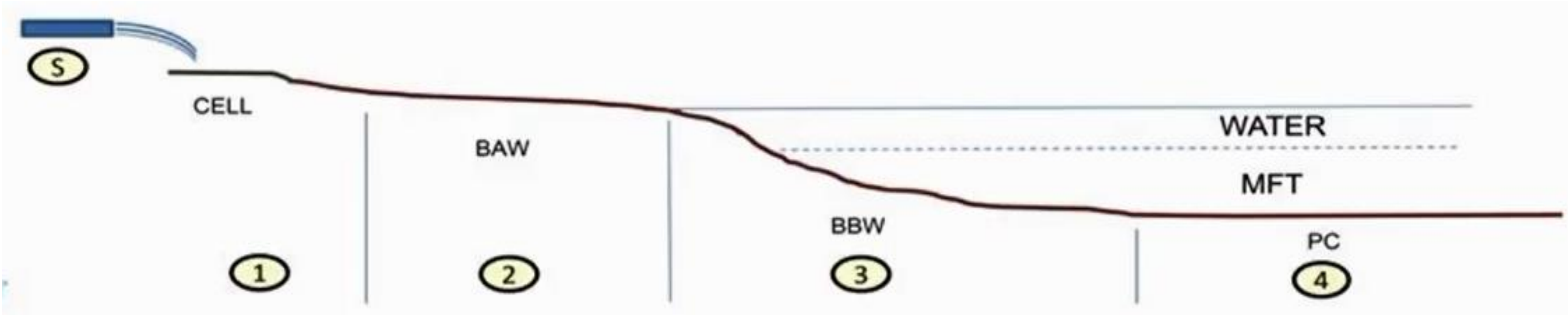
Today

Next Steps

New model in 2DV and calcs of Fine Captures – 2016







Deltares

Comparison with COSIA 2014

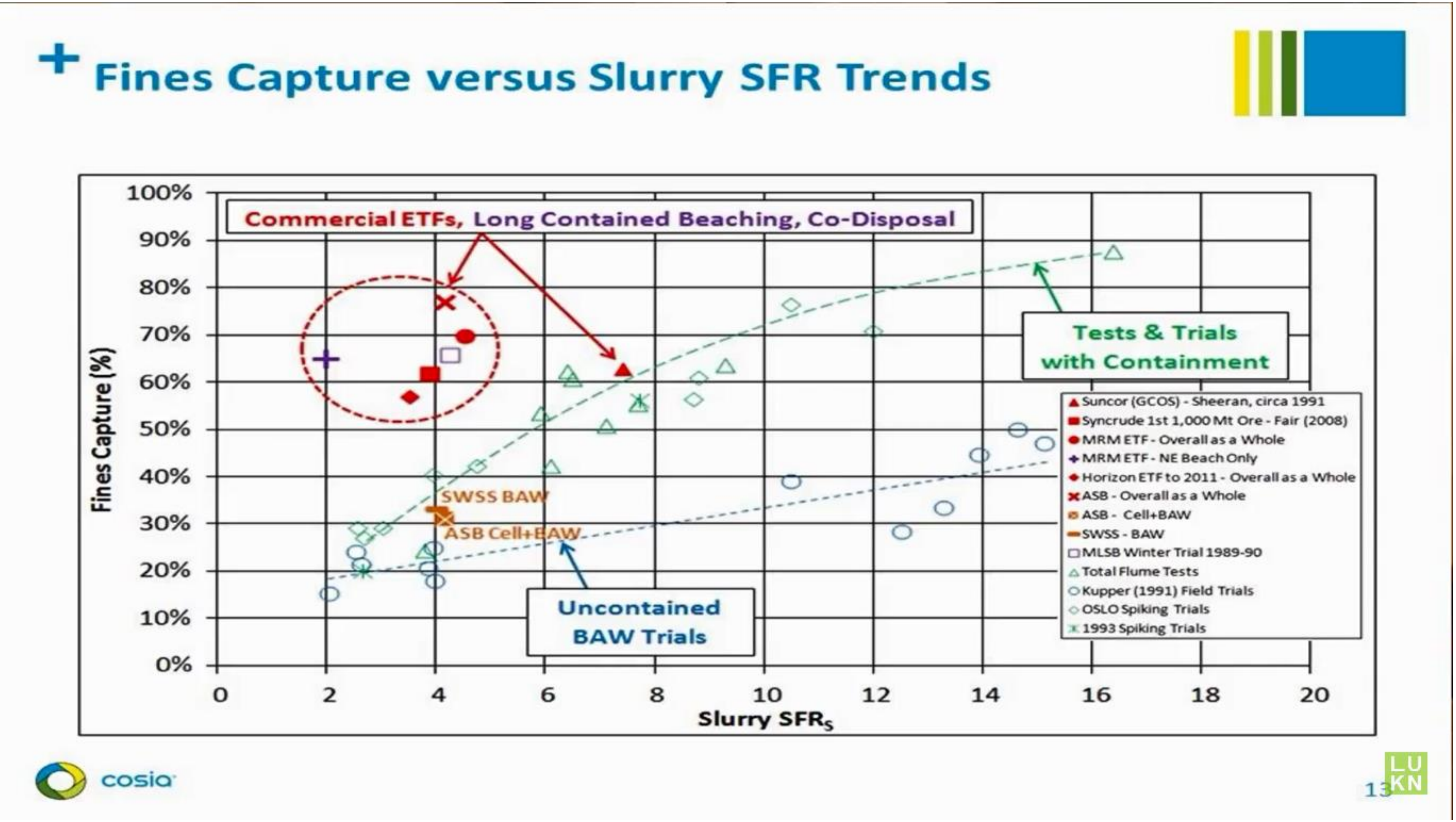
Fines Capture Summary

Operator	Tailings Facility	Time Period	44 Micron Fines Capture
Commercial Scale ETFs			
Syncrude	Aurora Settling Basin (ASB)	2000 to 2009	77%
Shell	Muskeg River Mine (MRM) ETF	2003 to 2011	70%
Suncor	Tar Island Pond (Pond 1)	Up to early 1990's	63%
Syncrude	Mildred Lake Settling Basin (MLSB)	1st 1,000 Mt Ore	62%
CNRL	Horizon Mine ETF	2008 to 2012	62%
Commercial Scale Co-Disposal			
Shell	MRM ETF – NE Beach Only	2008 to 2011	65%
Field Monitoring, Flume Tests and Field Trials			
Syncrude	1200 m Long Contained Beaching Berm	1989/90	66%
Syncrude	Southwest Sands Storage (SWSS) Field Monitoring of Uncontained Beaches Above Water (BAW)	2004	37%
OSLO	Contained 100 m Long Beaching Trials	1991	30 to 40%
Syncrude	ASB Cell & BAW Only	2000 to 2009	31%
Syncrude	Contained 300 m Long Spiking Trials	1993	20 to 30%
Total	Contained 8 m Long Flume Tests	2011	25%
Syncrude	Uncontained Beaching Trials	1988	≤ 21%

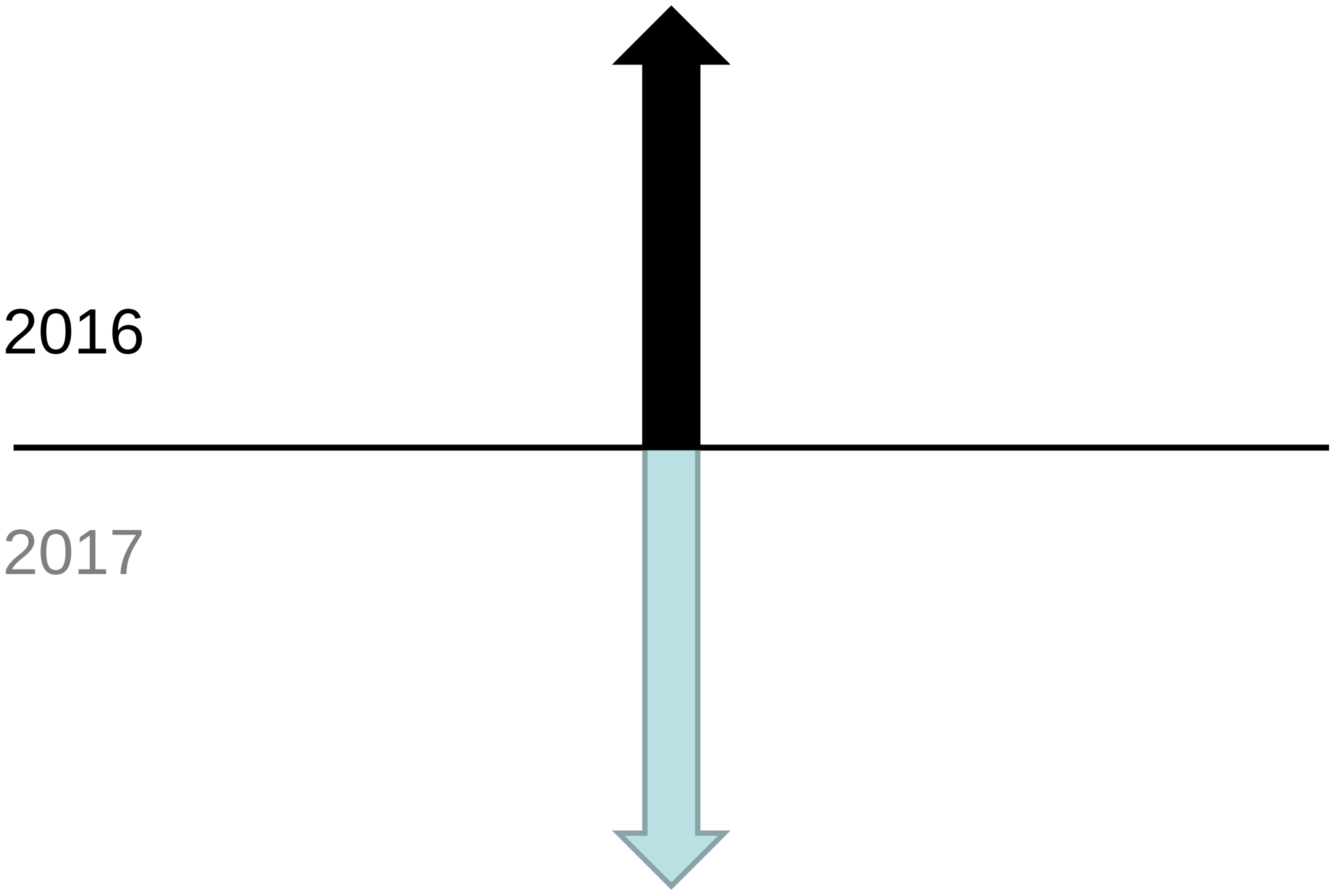
cosia

The fines capture reported for each set of flume tests or field trials is for the test or trial that had a slurry fines content closest to the overall averages for the commercial operations, for direct comparison.

Comparison with COSIA 2014



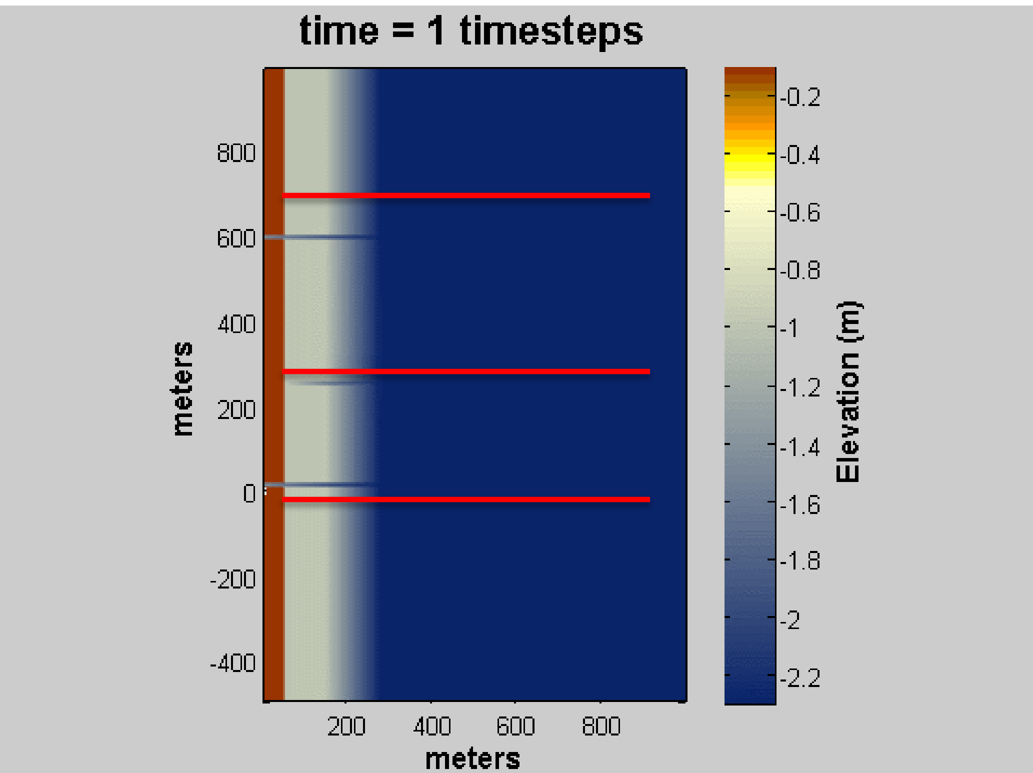
Deltares

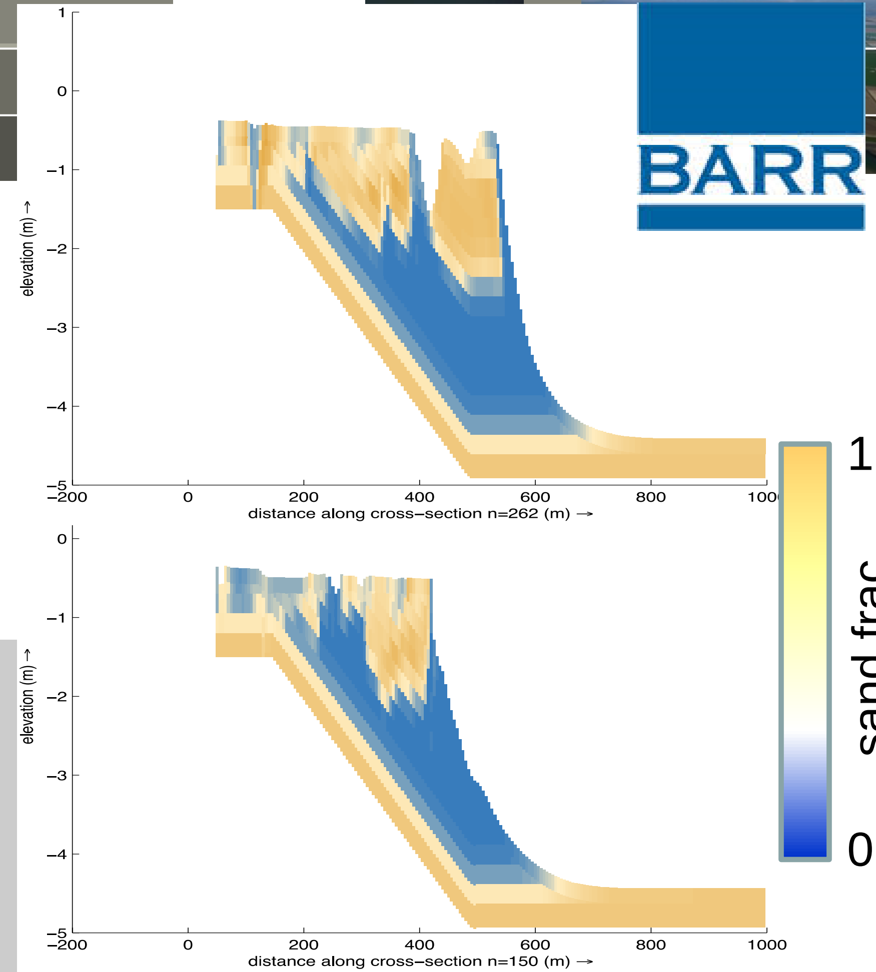

2016
2017

3D Newtonian Tailings Delta

General trends:

- sandier discharge → sandier deposit
- finer grained deposits away from channels





But are all the process in there?

AFD and Tailings beaches

Drone survey

Photos analysis, Photo by Photosat Canada

Predicting Fines Capture

- Delft3D may be able to predict fines capture over the wide range of depositional environments occurring simultaneously in a typical facility
- Typical operational variability of an oil sands extraction plant plays a dominant role that would be difficult, if not impossible, to model
- Tailings planning has often made use of a pore capture model to estimate fines capture (developed by Mr. C. Marsh, at Syncrude)
  - Assumes that all sand settles out as beach, forming a sand skeleton at an assumed dry density. A portion of the fines and water slurry is trapped in the voids of the sand skeleton and the remainder reports to the pond.
  - Not applicable to BBW, given the different depositional mechanisms at play (slope instabilities, turbidity currents, etc.)
  - May give reasonable results for BAW, but inspections often indicate layers of concentrated fines within BAW that are not predicted by the model. Furthermore, open ended BAW deposits, with no containment, likely have sand captures that are less than 100%, thus reducing fines capture.

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