Deltares
Enabling Delta Life

INSTREAM WETLANDS IN SINGAPORE: OPTIMIZING PARTIALLY VEGETATED FLOWS FOR BIOREMEDIATION IN A TROPICAL URBAN CONTEXT

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NUS National University of Singapore

About Singapore

Island with limited water resources

Population 5.3 million

716 km^2

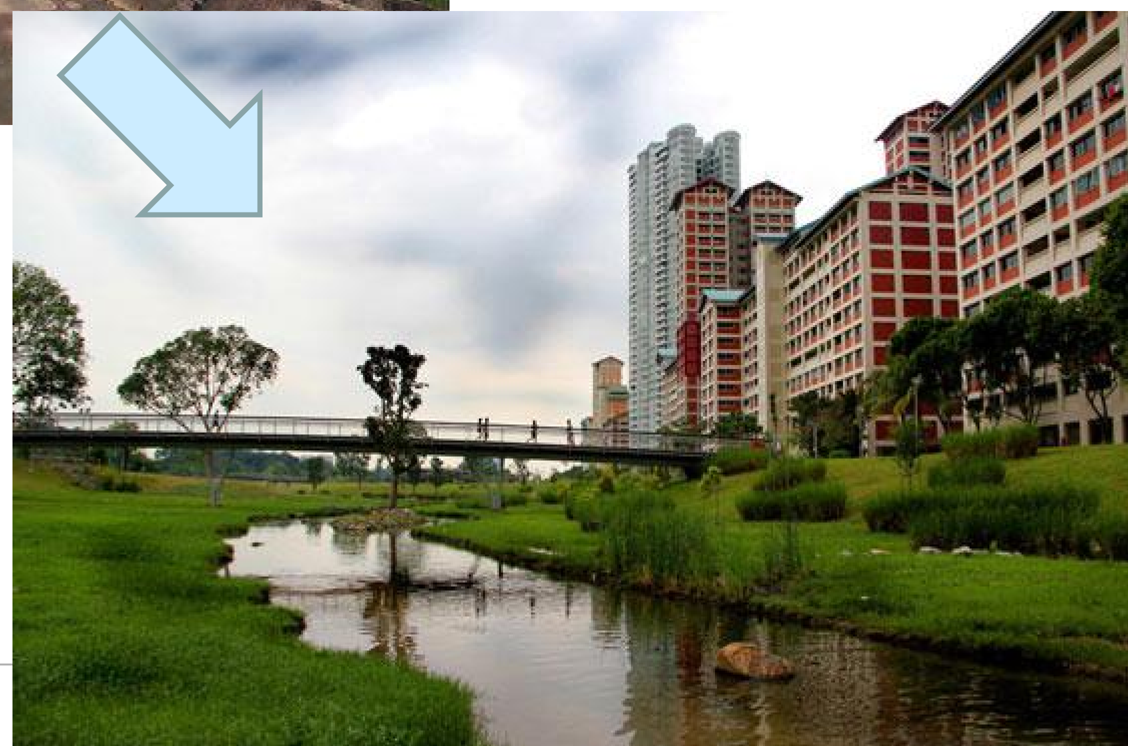
Every drop counts

4 taps strategy:

1. Local catchment water (20%, 2340 mm of rainfall a year)
2. Imported water (40%; agreement with Malaysia to 2016)
3. NEWater (30% => 55% in 2060)
4. Desalinisation (10% => 25% in 2060)

Singapore ABC waters

- Active
- Beautiful
- Clean



* Bishan Park, Ang Mo Kio

'A City in a Garden'

Instream wetlands

Can you construct a bioremediation wetland in a stormwater drainage channel?

Bioremediation wetland must:

- Reduce nitrogen, phosphorus and TSS concentrations of base flow
- Add aesthetic value
- Not pose additional flood risk
- Serve as pilot for future projects

=> Design faces a number of challenges

Tropical urban stormwater drainage channels

Test site = ‘average drainage channel’
Heavy downpoor on a daily/weekly basis (approx. 1 hour event)
Quick drainage is essential, space is limited

T = 0 min

T = 10 min

T= 30 min

Base flow Q=60 L s^{-1}

High flow Q = 20 m^3 s^{-1}
Design flow Q = 63 m^3 s^{-1}

Challenges for instream wetlands

Create sufficient residence time for adequate TSS and nutrient removal during base flow

- Plant selection
- Substrate selection
- Flow design

No increased risk of upstream flooding during high flow

Avoid risk of damage to the wetland

- Forces on during high flow plants
- Clogging

Virtually no data at the start of the project

Wetland must not exceed 4x50x1m dimensions

Approach

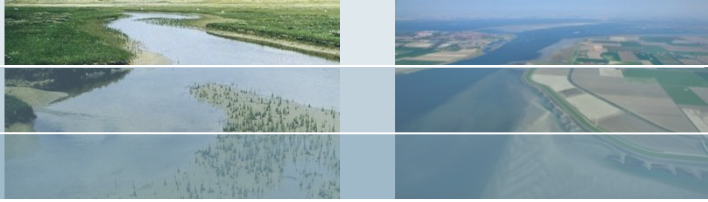
Interdisciplinary study

- Field measurements during base flow and high flow of the basics (water quality, water quantity, bathymetry)
- Flume experiments for base flow and high flow situations
- 1D and 2D modelling (SOBEK and 2d D-FM)

Integration of above in an optimal design

Automated WQ sampling

Catchment identification



Field measurements

Baseflow is ~ 7000L/day
Water quality is of ‘average-to-good quality’ in Singapore standards

	Base flow	High flow
Total Nitrogen (mg L-1)	0.72	1.41
Total Phosphorus (mg L-1)	0.05	0.17
Total Suspended Solids (mg L-1)	49	126

⇒ The wetland needs to deal with low concentrations yet high daily loads
⇒ Affects the choice of substrate for the wetland body

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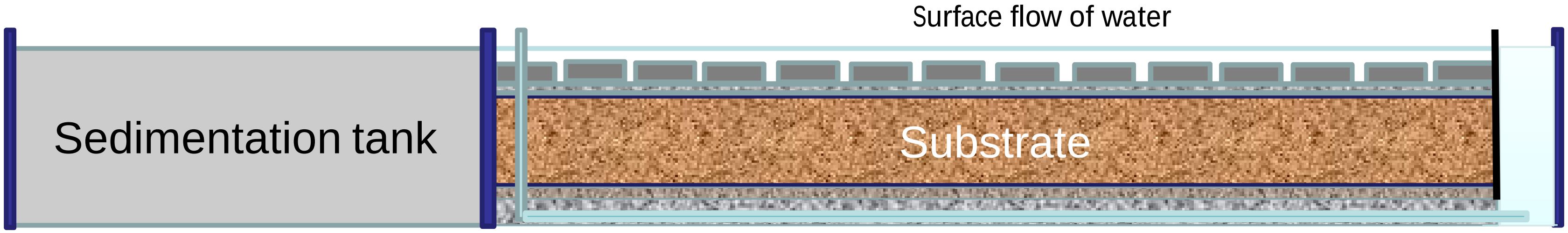
Remediation – Bioflume Experiments



- **Plants acclimatized in waterlogged conditions for one month**

  1) Pandanus amaryllifolius

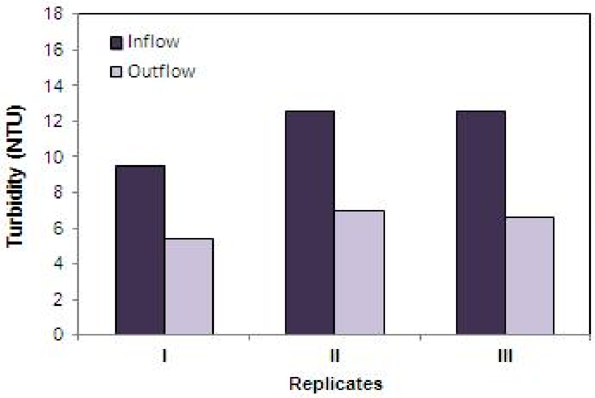
  2) Echinodorus palaefolius

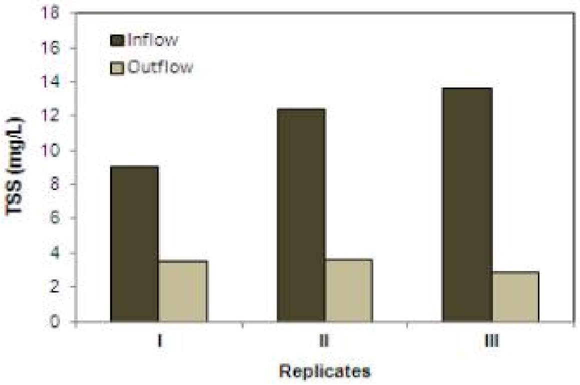
  3) Hymenocallis speciosa

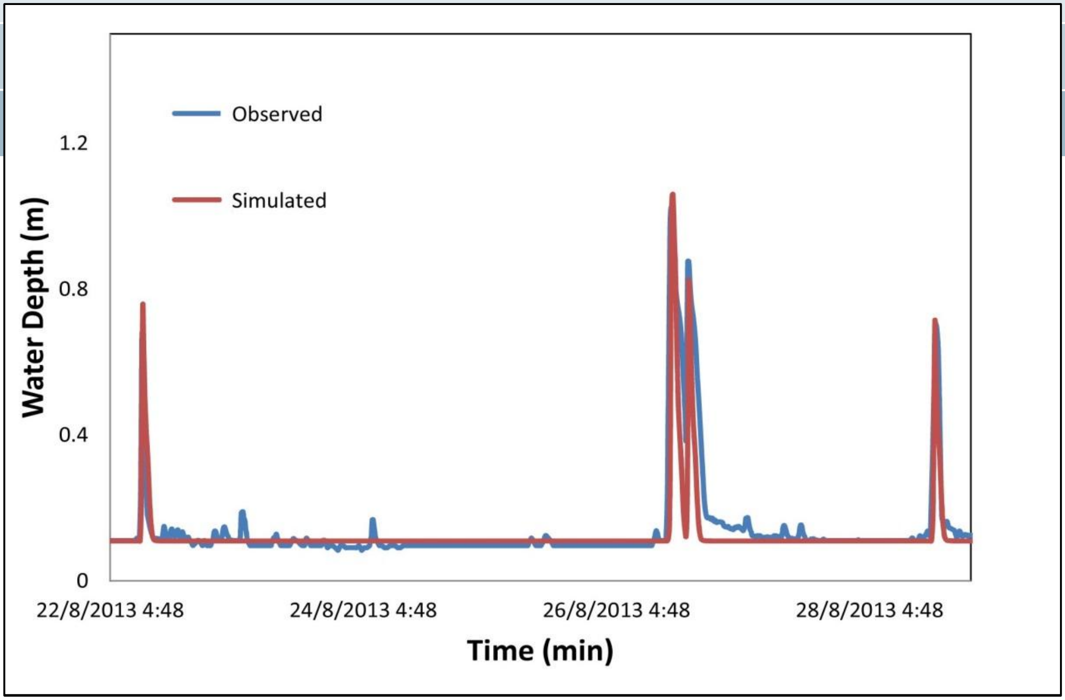
  4) Acorus gramineus

  5) Cyperus haspan

- Influent from canal water @ Sungei Ulu Pandan (non-rain event)
- Turbidity reduction –av. 45%
- TSS reduction – av. 70%
- Nutrient reduction - *Pending*

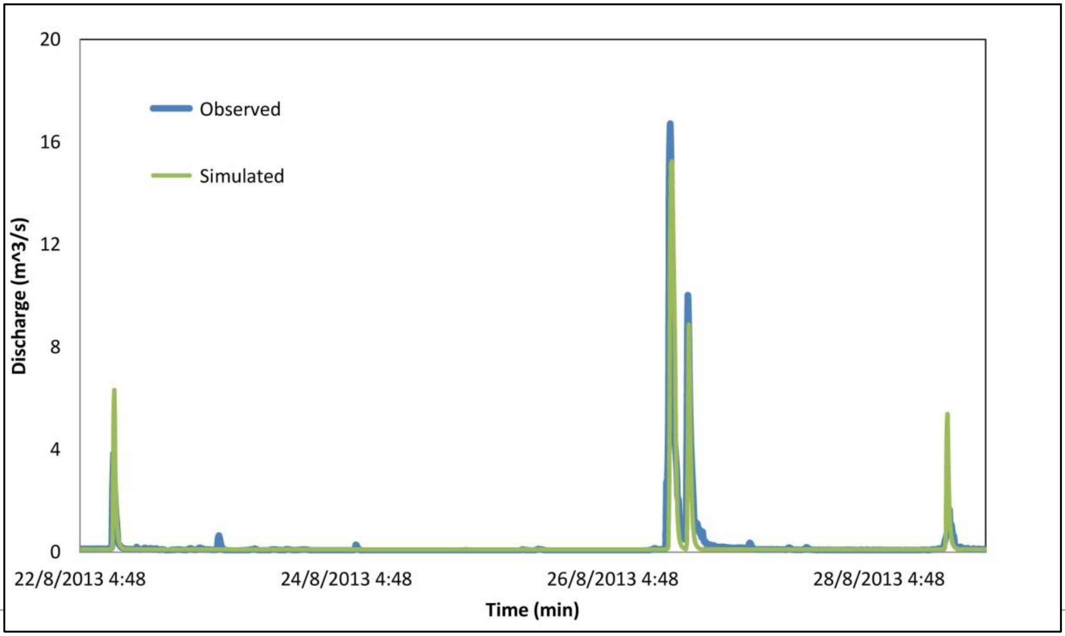


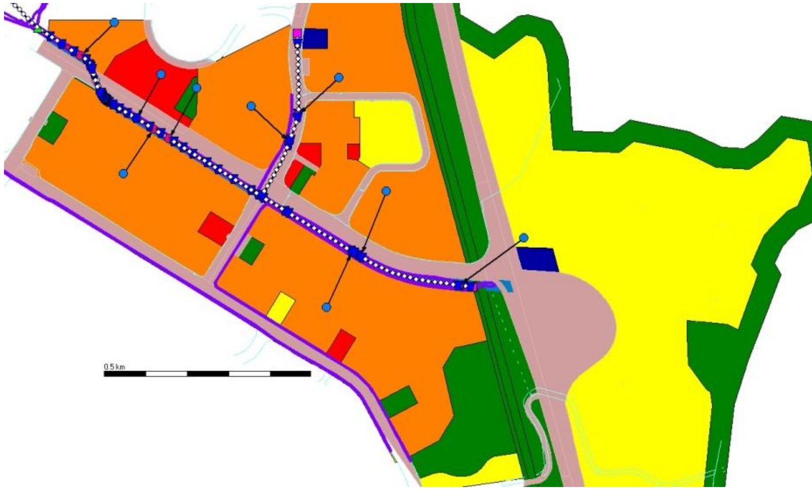




SOBEK 1D model for catchment analysis

- 70 ha paved
- 80 ha unpaved





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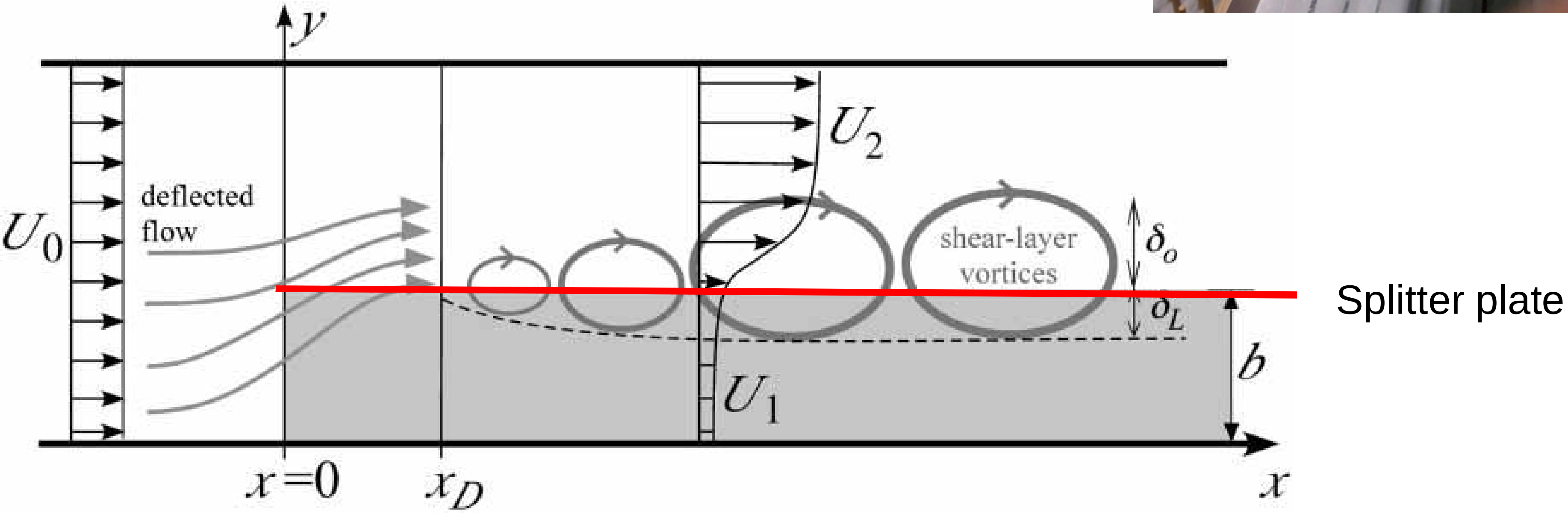
Lateral exchange

- Flow through vegetation slows
- Flow in open channel becomes faster
- Velocity difference between channels causes formation
- of shear layer
  - Rotation of fluid in 2D turbulent eddies
  - Mixing layer width = $\delta_I + \delta_O$

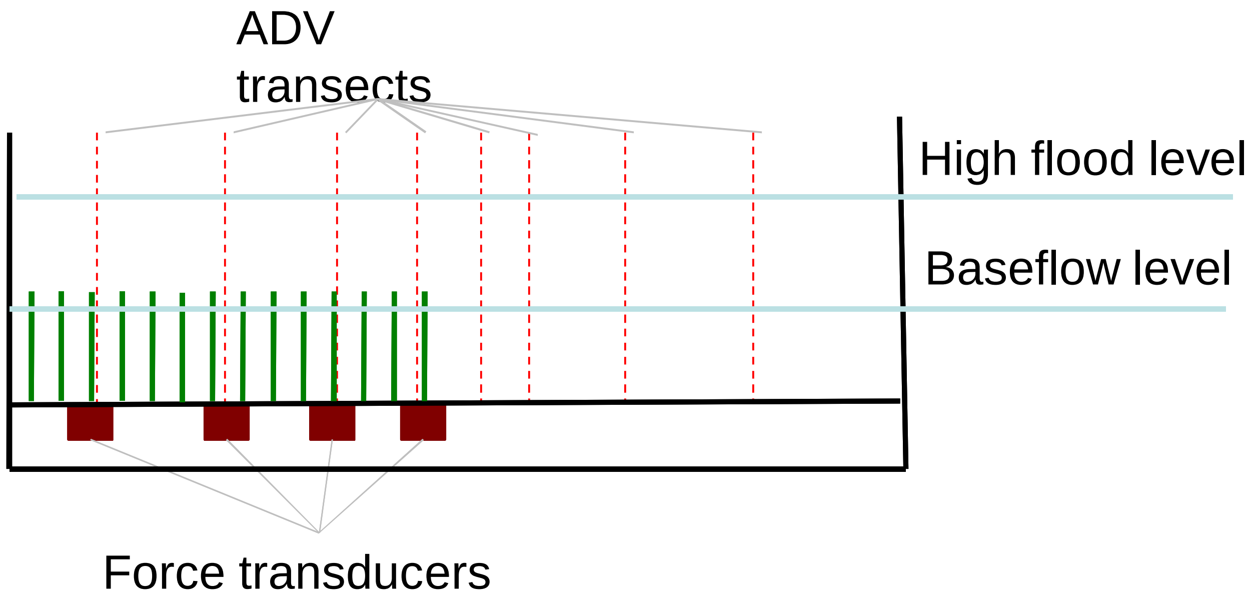


Top view (*source: Zong & Nepf, 2010*)

Methods

Direct force measurement using force transducers

Direct velocity measurement using acoustic doppler velocimetry (ADV)



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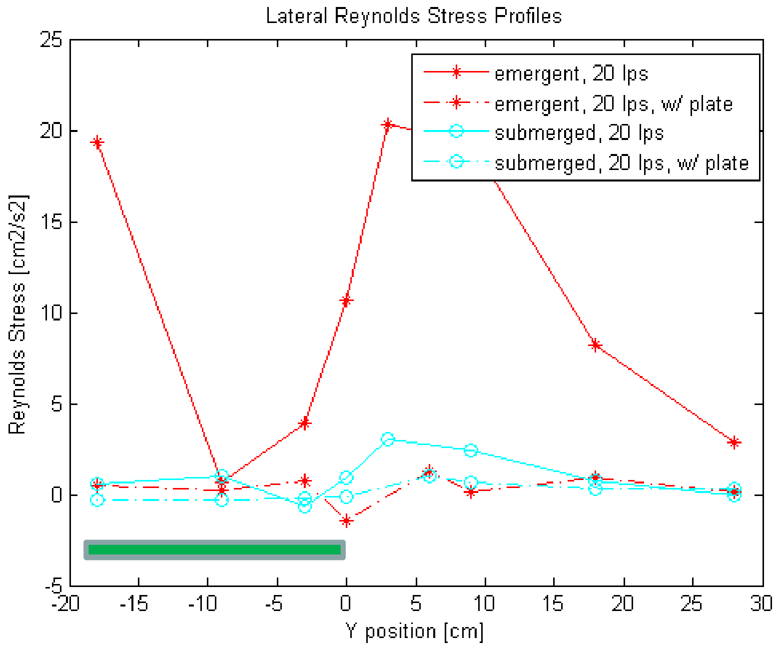
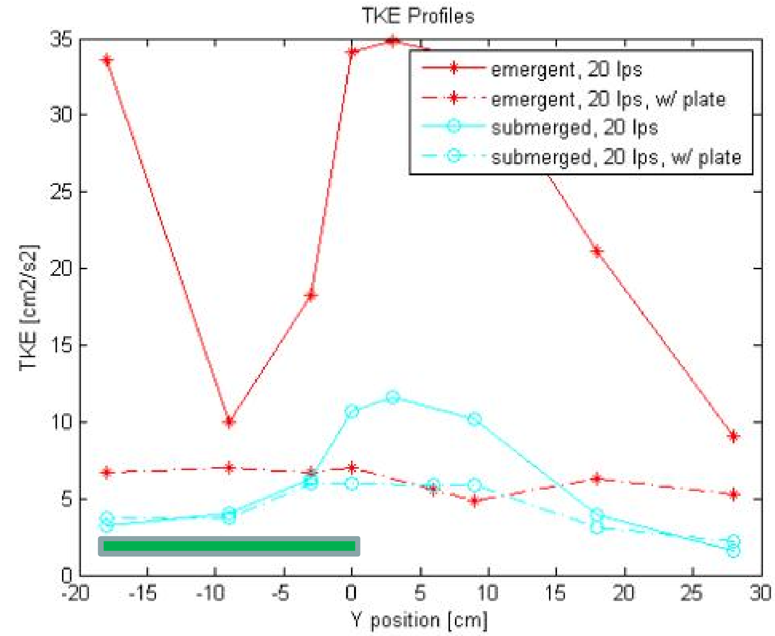
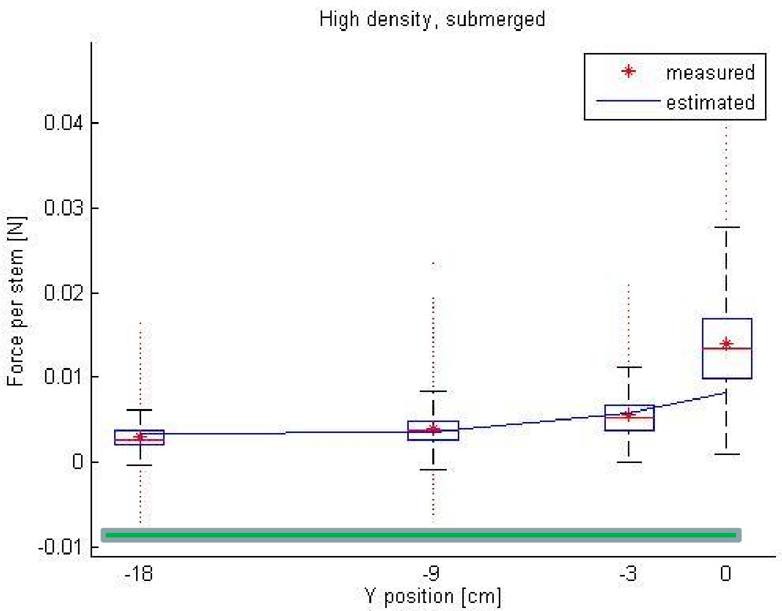
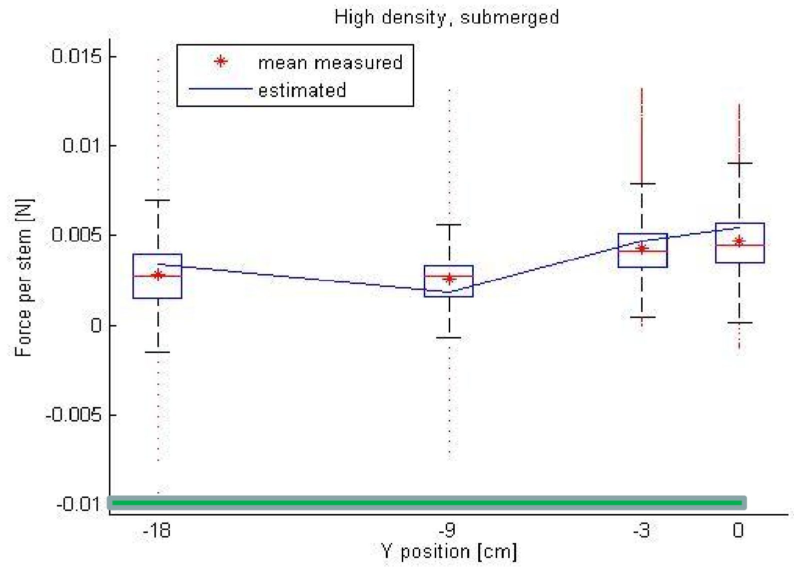
Adding a splitter plate helps reduce max. force









Modelling the effect of the wetland on high flow

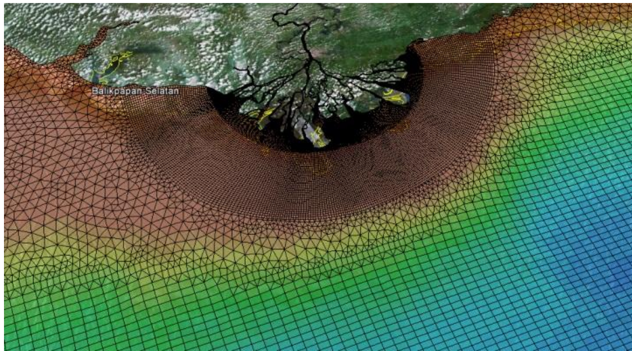
Choice of model:

1. A realistic representation of vegetation in the hydrodynamic model;
2. A realistic representation of altered channel cross-sections;
3. A set of equations and a numerical scheme that can simulate the flow in a steep channel with transcritical flow.

1+2: Delft3D OK, but was not intended for extreme situations like our channel

2+3: new Flexible Mesh model (2D, no vegetation included, only altered roughness, yet validated for alike channels in Hong Kong)

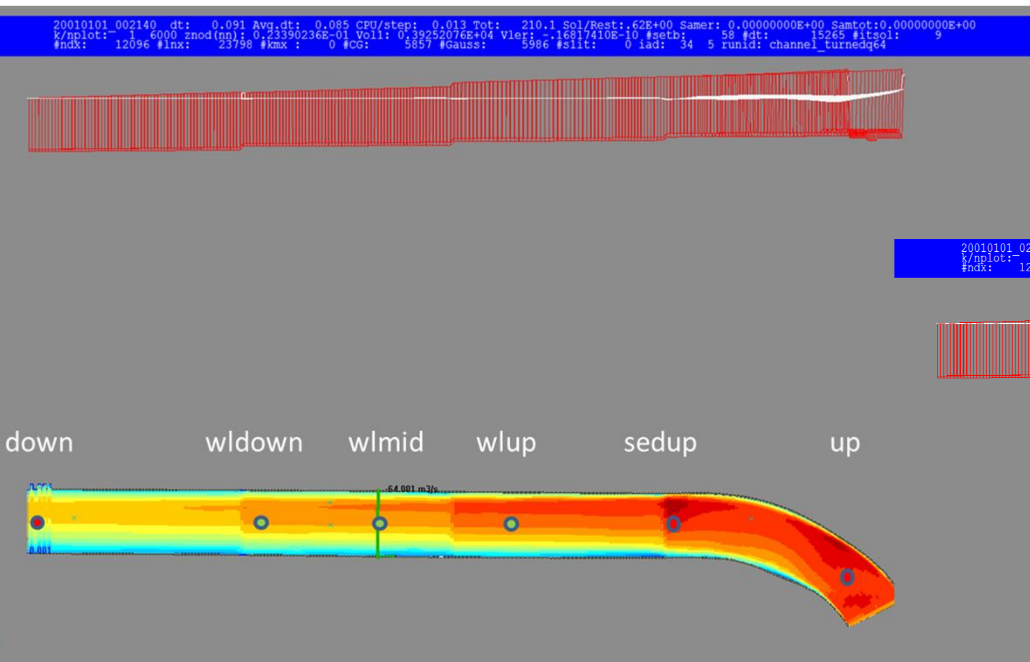
http://oss.deltares.nl/web/delft3d/d-flow-flexible-mesh

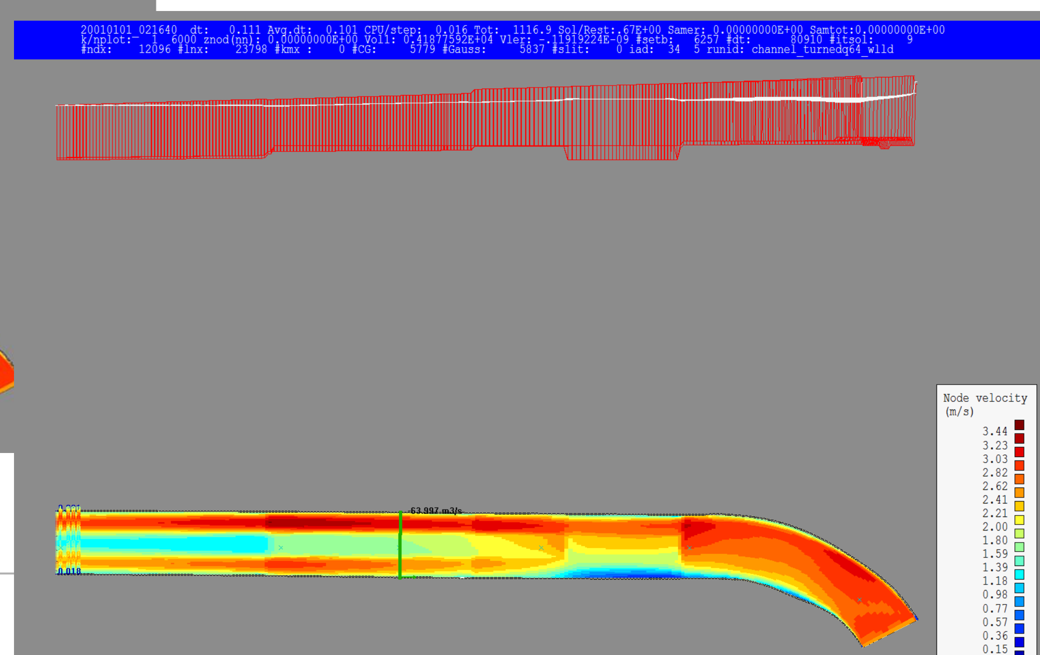


2D Delft-Flow Flexible Mesh modelling

- Empty channel validated with measured high discharges and water levels (Q=20 m3/s)
- Vegetation parameters from selected plants included via trachytope approach *(Baptist et al 2007)*
- Used for the design discharge of Q = 63 m3/s

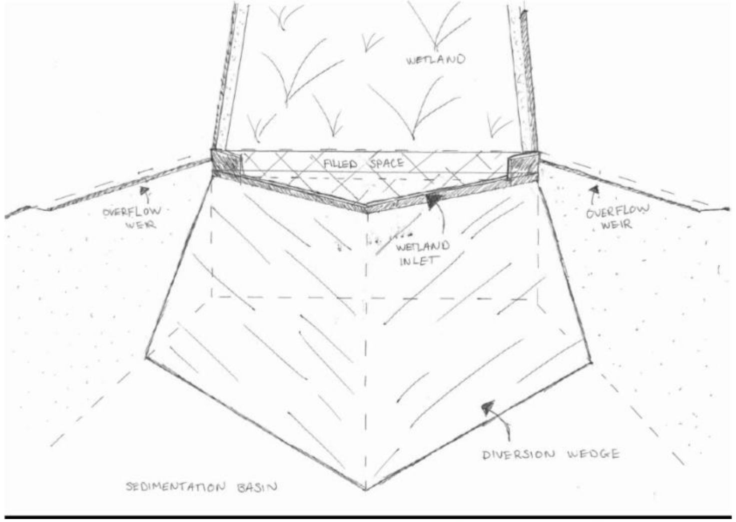
=> no additional flood risk





Final design

- Addition of a sedimentation pond with a wedge structure that is self cleaning during high flow
- 10 cm high wall along the wetland to reduce forces on plants
- Most robust plants on the outside shelter other plants
- Adjustable weirs at in- and outlet of wetland to optimize and adjust head if needed
- Pipe in lowest drainage layer for additional flushing in case of clogging



And now?

- Construction planned for this summer
- Monitoring of water quantity, water quality and plants when in place
- Guidelines on these types of instream wetlands for Singapore

Take-home message:

Interdisciplinary state-of-the- art research and monitoring equipment, and basic engineering helped to reach an optimized design

Knowledge gained from ecohydraulic research is being used for day-to-day water management even in urban tropical systems

Thank you!

Delft Software Days 2014 : 27 Oct. – 7 November

http://schedule.delftsoftwaredays.nl/

Mean Stem Drag Force, $\overline{f_d}$

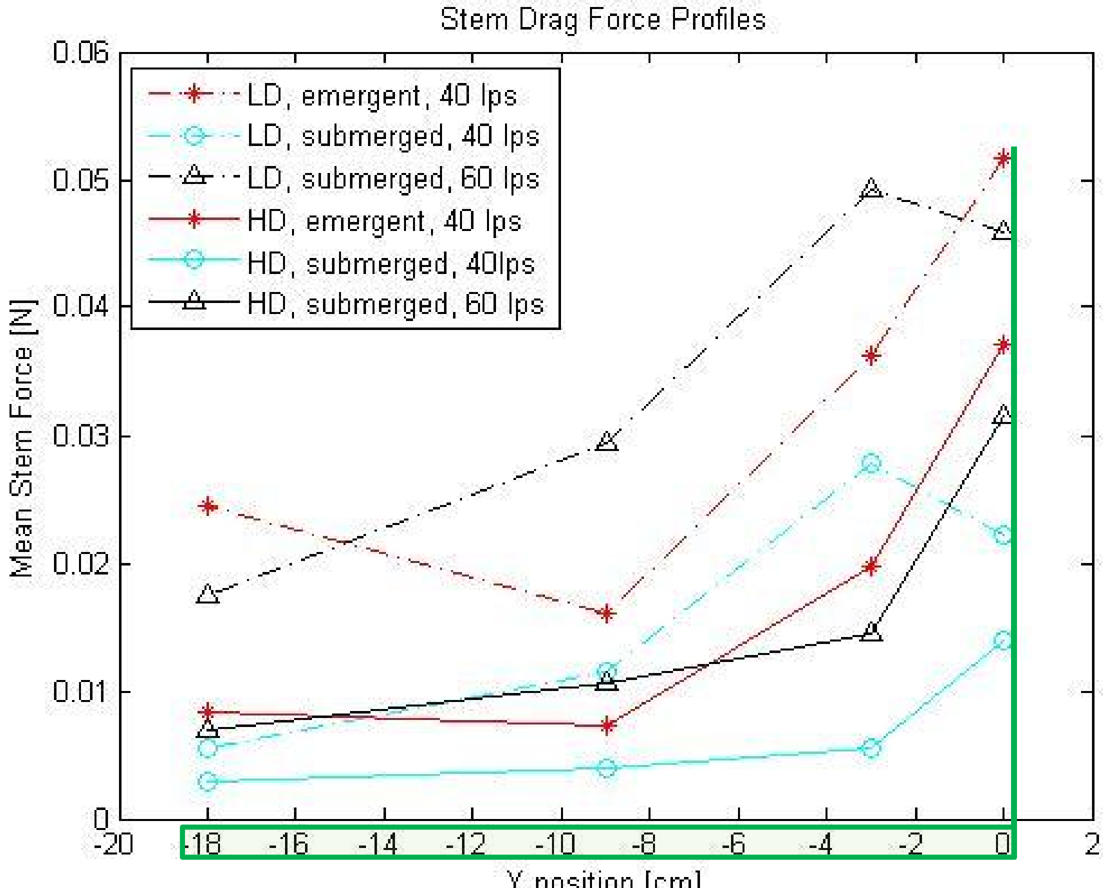
Introduction
- In-stream wetland
- Research Objectives
- Approach

Methods
- Experiments

Findings
- Flow characteristics
- **Stem drag forces**
- Effects of turbulence
- Estimation of stem force

Conclusions

- Estimations derived from momentum balance within standard error of the mean of the measurements



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