Rijkswaterstaat
Ministerie van Infrastructuur en Waterstaat

review on engineering aspects of dead wood in

the Dutch Rhine Branches and Meuse

May 15 2024
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Meuse Wellerlooi km 131-132

erodible, mild-sloped bank with submerged trees

specifications

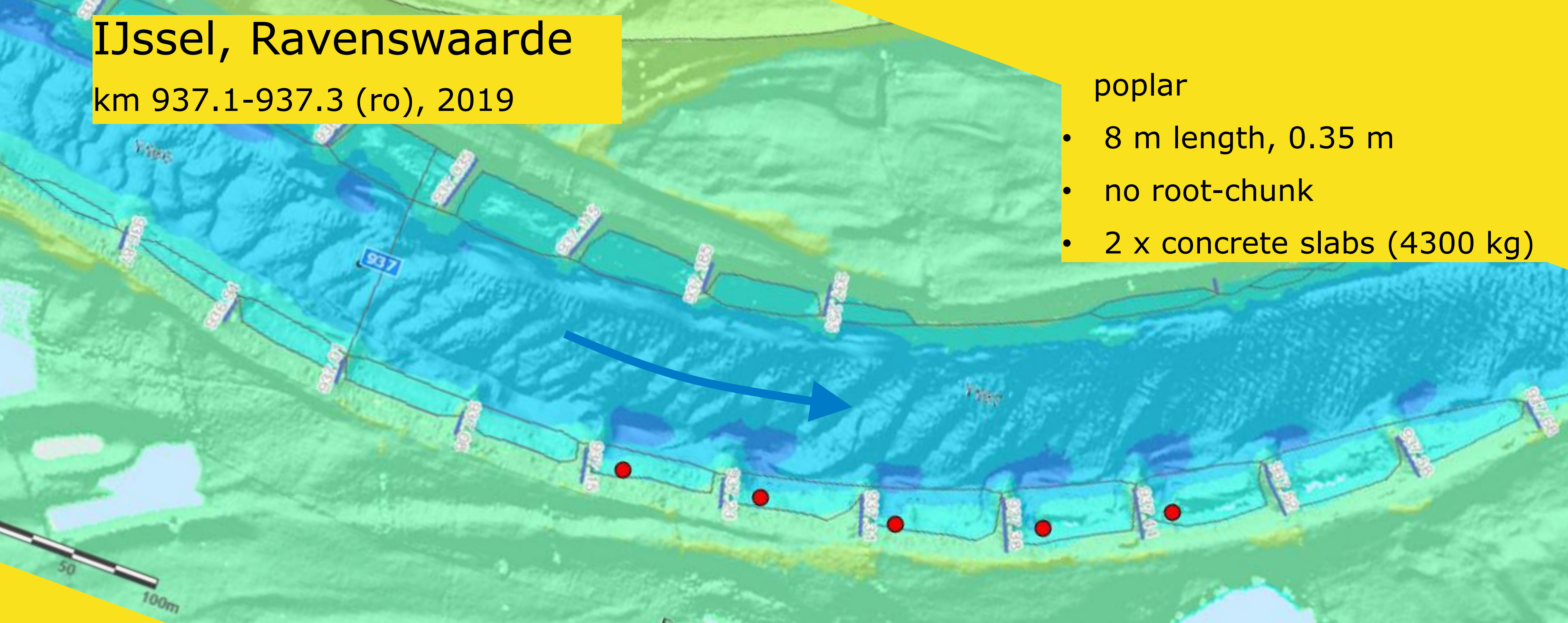
- *no drift, no rotation, no floating*
- *submergence (2 m at maximum)*
- *crown in flow direction*
- *2 HE beams, pressed 4 m into the bed at minimum*

IJssel, Ravenswaarde

km 937.1-937.3 (ro), 2019

poplar

- 8 m length, 0.35 m
- no root-chunk
- 2 x concrete slabs (4300 kg)

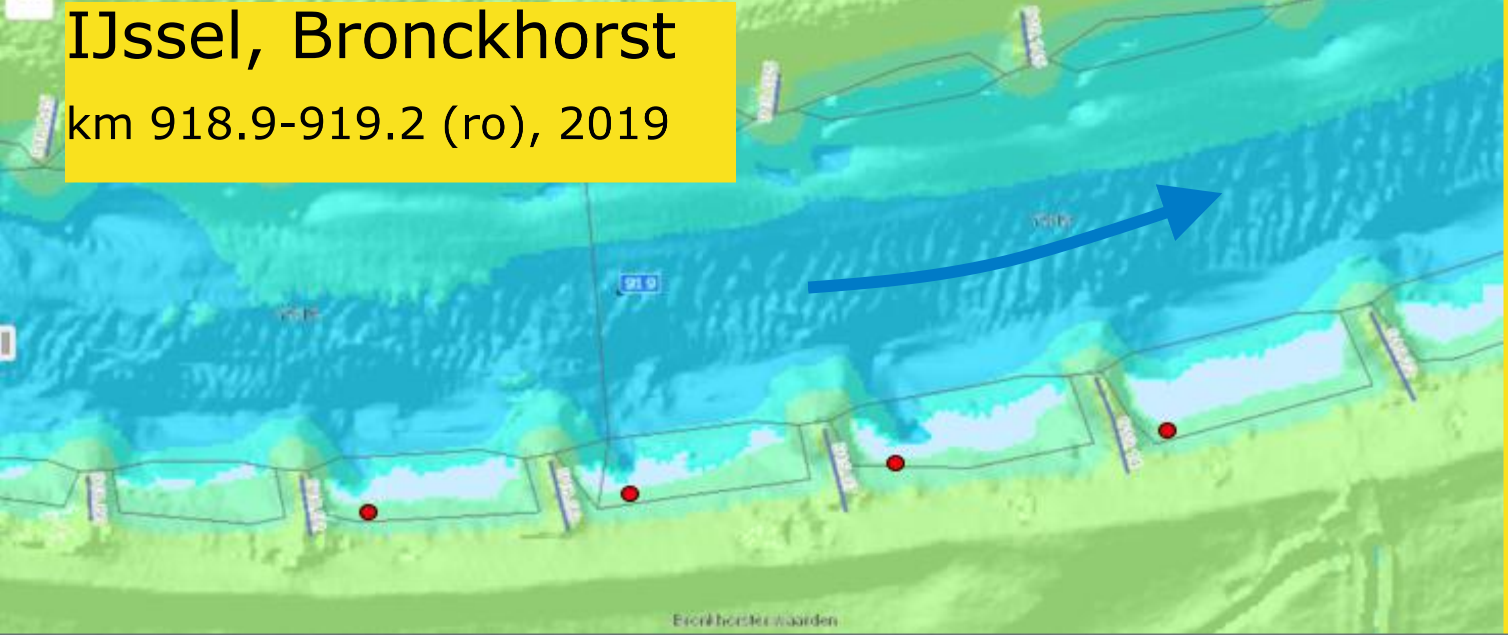


2020

2023

IJssel, Bronckhorst

km 918.9-919.2 (ro), 2019



domestic oak

- 8 m length, 0.35 m
- with root-chunk
- 4 x 6 m HE-a160 beam

content

brief review of development in Dutch part of Rhine and Meuse

backgrounds on the stabilisation of submerged wood

lessons and challenges


Lek (Everdingen)
2007
2008
inundated trees after flood plain excavation
2009
2011
2016
gradual deterioration
2010
2012
2021
20 m
20 m
20 m
20 m
20 m
20 m

2005

groyn field closure by wood rows

2008

tree on banks

2014

trees in side channels,

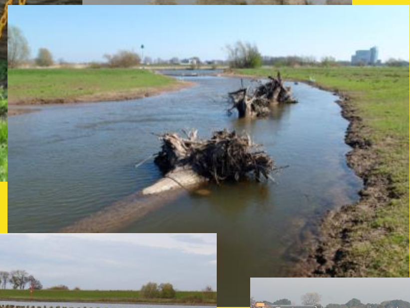
fish ladders,

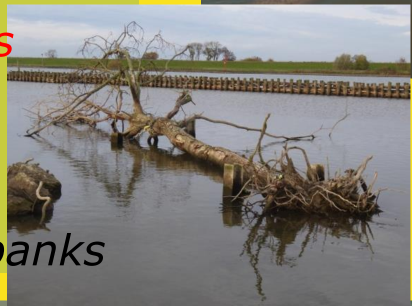
closed & open groyne fields

wood rows in inner bend

2019

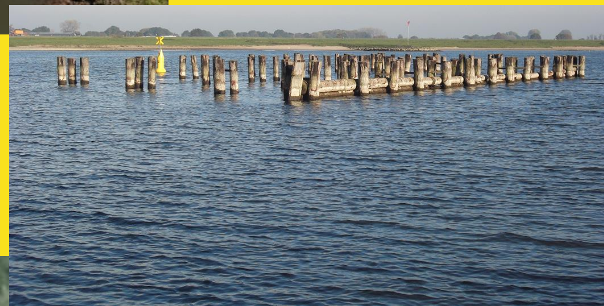
trees along main channel banks

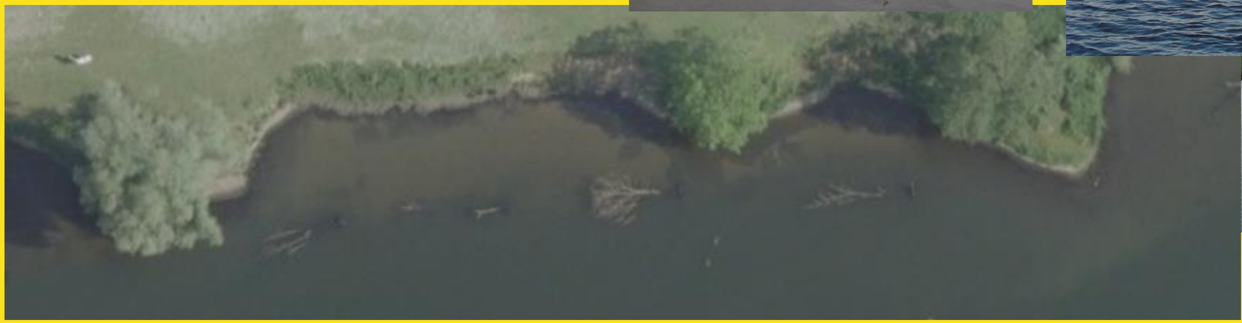




improving

- ecology (*substrate, shelter, morfodynamics*)
- flow regulation (*discharge side channel*)
- bank stability (*reduction wave attack*)
- bank line (*directing sediment transport*)
- bed stability (*scour holes*)





flood safety (discharge of water, sediment and ice)

preferably area's of lower velocity,

orientation with minimal flow obstruction

below average water level

consider hydraulic roughness

safe navigation

outside of fairway profile

no impact on navigability (flow, depth)

no drift

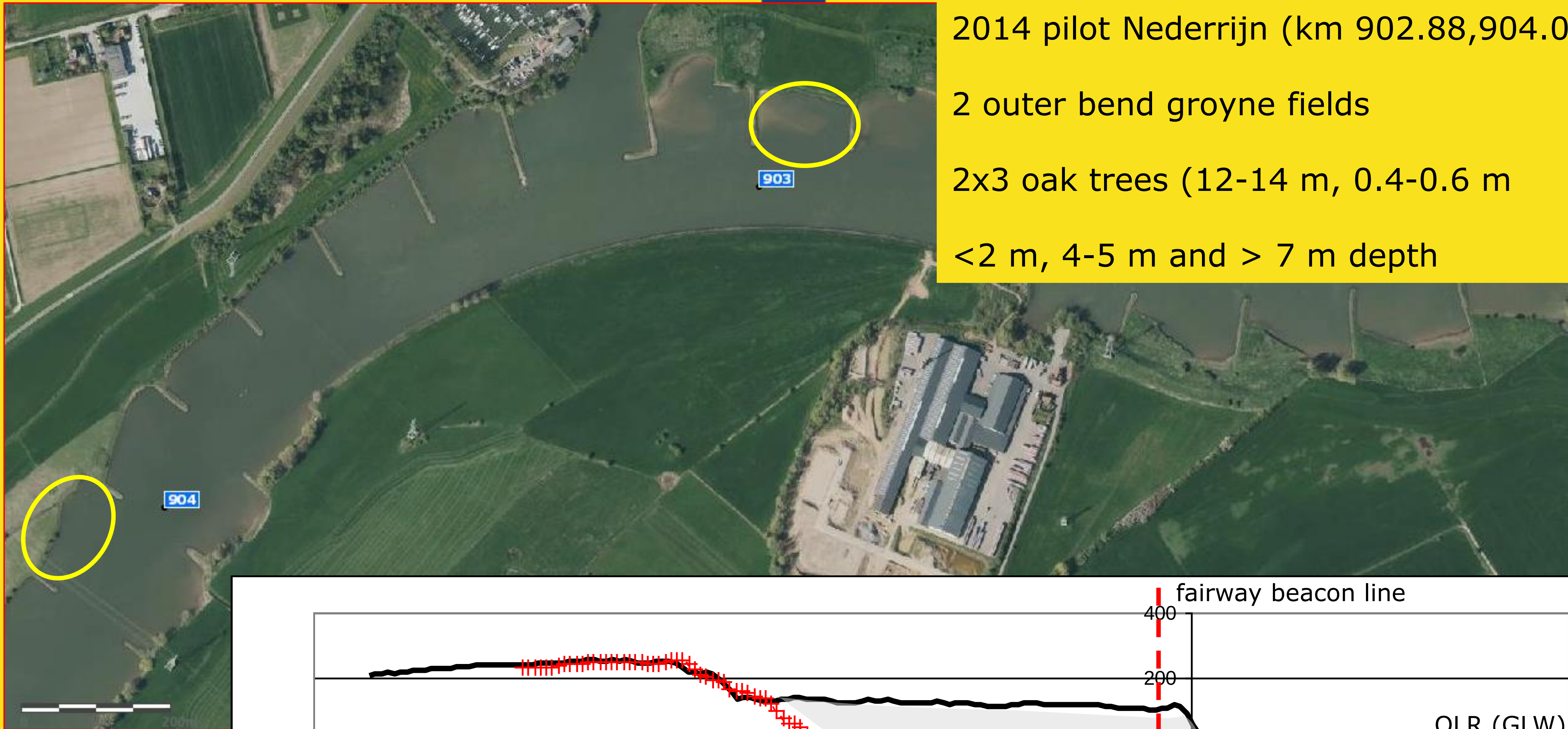
visability of objects

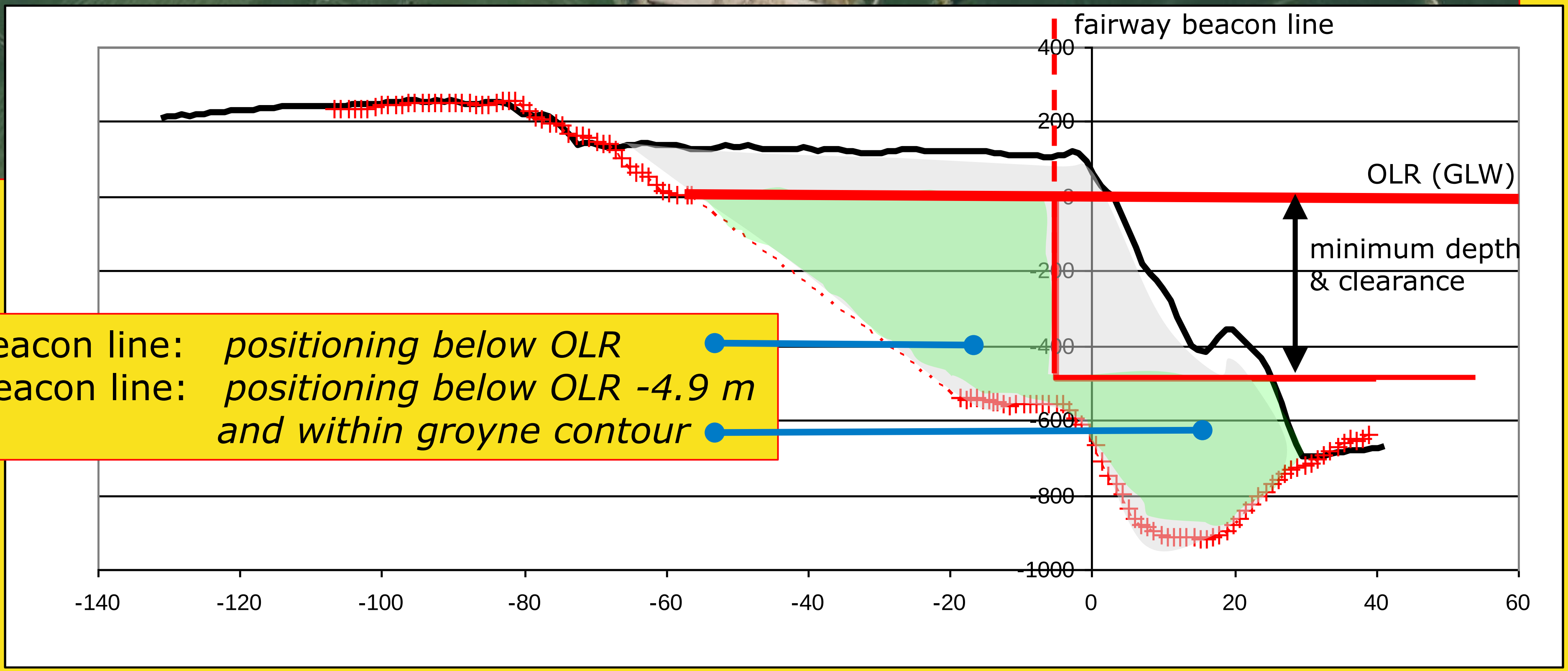
2014 pilot Nederrijn (km 902.88,904.04)

2 outer bend groyne fields

2x3 oak trees (12-14 m, 0.4-0.6 m

<2 m, 4-5 m and > 7 m depth

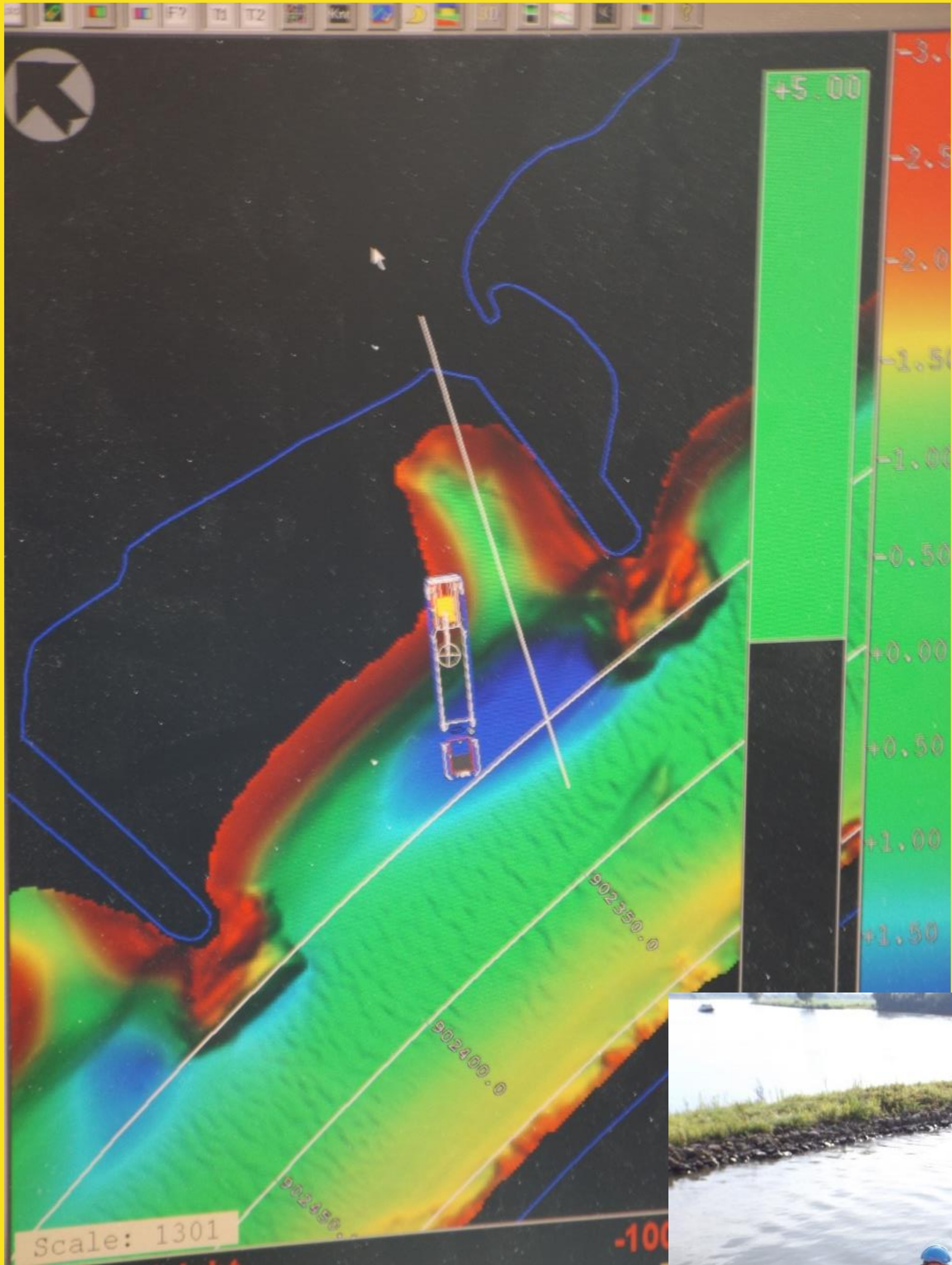




land-side of beacon line: *positioning below OLR*

river side of beacon line: *positioning below OLR -4.9 m and within groyne contour*

2014 pilot Nederrijn (km 902.88,904.04)



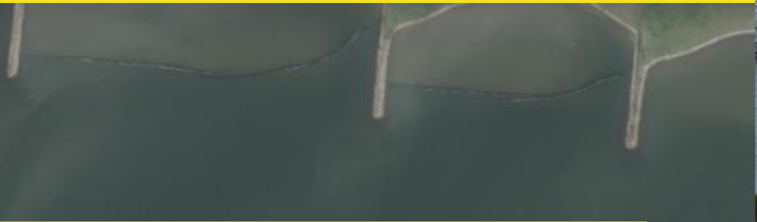
floating crane with lifting bar
positioning in deeper parts
decoupling by diver

2014 Nederrijn pilot

per tree

- two concrete slabs ($2x3x0.28\ m^3$, 4100 kg)
- 10 ton chains of steel
- double-ringed welded steel pin through the stem

2014 pilot Nederrijn closed groyne fields



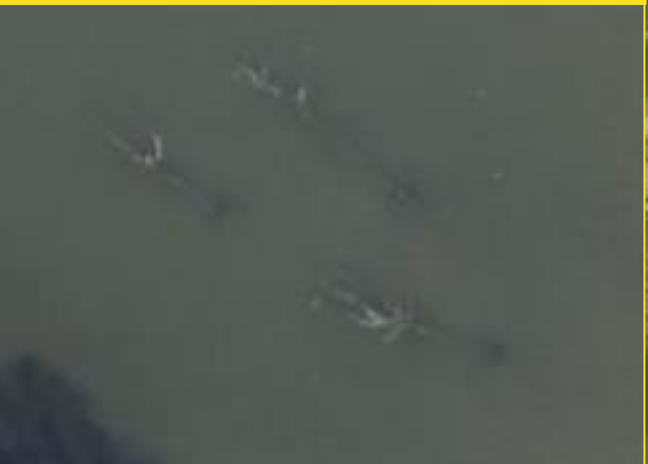
oak trees

> 12 m, 0.4 m, 2 ton

per tree

4 x 6 m HE 160A beam

2 x 10 ton chains.



2014 Nederrijn pilot
fishladder weir Maurik

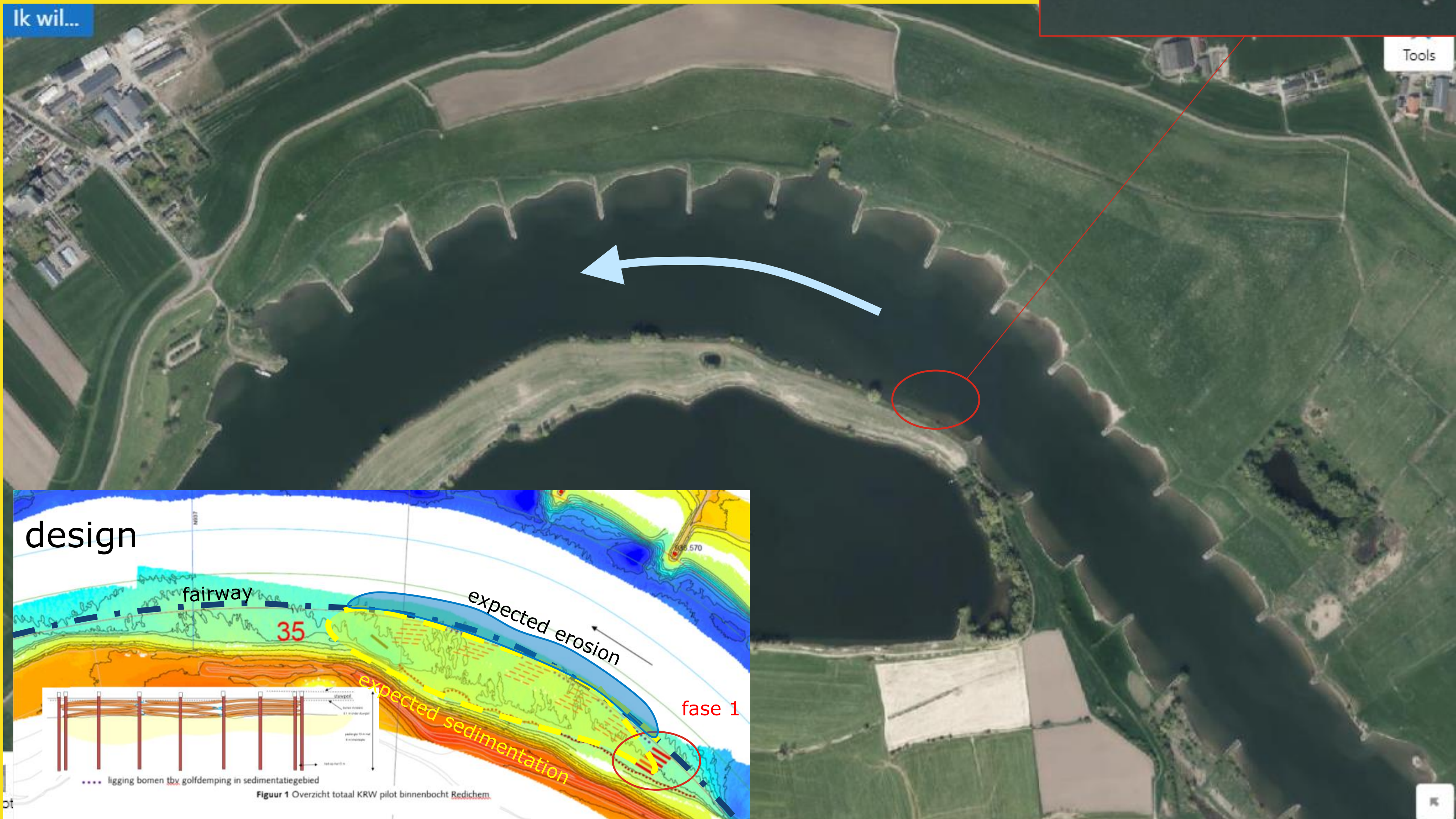
oak tree

- (> 10 m, 0.4 m. 2 ton)
- 2 x 6 m HE 160A beam
- 2 x 10 ton chain

anchored from the bank
to preserve bed protection

pilot Nederrijn km 937 2015

applying dead wood
- for improving fish&macro fauna habitat
- reduce innner bend shallow (improving alignement)



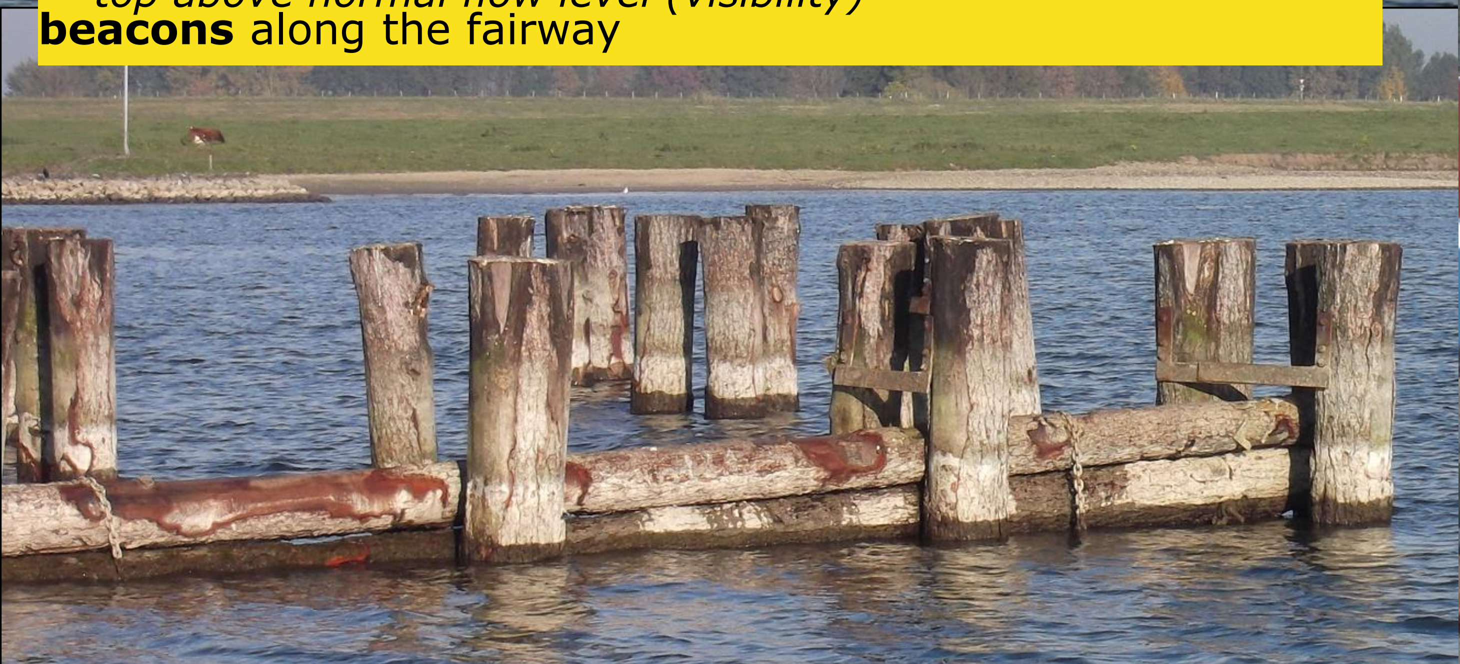
Pilot Nederrijn November 2015

planform
- *20 degrees relative to beacon line*
- *30 m length, 5 m distance*
- *1.5 m height (five stems piled)*

horizontal stems
- *douglas, 10 m length, 0.3 m ø, not saturated*
- *3 stems connected by chain to prevent drift after collision*
- *locked in by piles (incl. both ends)*
- *per 2.5 m anchored by two 0.3 m³ concrete slabs (700 kg)*
- *and a 20 ton chain*

vertical piles
- *douglas, 10 m length, 0.3 m ø, not saturated*
- *ca 7 m pressed in the bed (anticipating scour)*
- *top above normal flow level (visibility)*

beacons along the fairway



spring 2015

SSRS pilot IJssel Zalk 2019

RWS, Deltares, BAM/Van den Herik, Aquadrones

- improving alignement
- stop bank erosion
- reinforcing habitat

with *saturated* woods

watering of 110 stems (Corsican den)
(ca 1 year)

transport of
saturated stems

construction site

drilling of stems 2019

steel wire stabilisation

specifications Meuse (2016)

location
- outside of fairway
- nautically safe (visibility)
- sufficiently deep (sumergence)
- in flow direction

tree
- stem diameter > 0.35 m
- rough bark, roots, stem & crown
- domestic species
- no growth (no willows..)

anchoring
- no drift, no rotation, no floating
- submergence (2 m at maximum)
- tree crown in flow direction
- along banks: beams (> 4 m into the bed)
- in side channels: concrete (covered by 0.5 m sand)

backgrounds stabilisation submerged wood
(no drift, minimal shift and rotation)

approach piles/anchors in order of preference

a. xls guide line & pull test:

compute design load, determine pile-capacity by pulling per soil unit, derive number and length of piles

b. xls guide line & reference case:

verify design with reference to cases with comparable load, trees and soil

c. xls guide line (adequate input) & field survey:

compute design load, determine soil strength by field survey (Sondierung) and derive number and length of piles

d. xls guide line (conservative input)

compute design load, estimate soil strength conservatively, derive number and length of piles/anchors

approach ballast

xls guide line (conservative input) to compute slabs

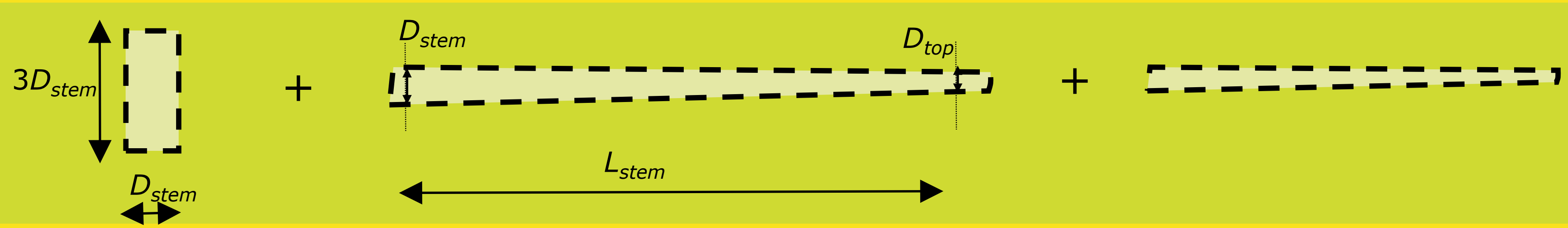
(2 elements at minimum)

piles or anchors (< 1.5 m) → *beds without dynamics*

ballast (> 1.5 m) → *flat beds*

characterization wood

root system | stem | branches



area [m²]

$$A_{roots} = \frac{\pi}{4}(3D_{stem})^2$$

$$A_{stem} = \left(\frac{D_{stem} + D_{top}}{2}\right) L_{stem}$$

$$A_{wood} = max[A_{roots}; A_{stem}]$$

volume [m³]

$$V_{roots} = f_r \frac{\pi}{4}(3D_{stem})^2 D_{stem}$$

f_r [-] root volume factor f.e. $f_r = 1$

$$V_{stem} = \frac{\pi}{3}\left(D_{stem}^2 + D_{top}^2 + D_{stem}D_{top}\right)L_{stem}$$

$$V_{branches} = f_{br}V_{stem}$$

f_{br} [-] branche fraction, e.g $(1 + f_{br})V_{stem} = \pi D_{stem}^2 L_{stem}$

$$V_{wood} = V_{roots} + (1 + f_{br})V_{stem}$$

specific weight [kg/m³]

f.e	light	ρ_{wood} ~540 kg/m³	(pine tree, spruce, alder,..)
	heavy	ρ_{wood}~ 700 kg/m³	(oak, beech, ash tree..)

A_{roots}	[m²]	area of root system
A_{stem}	[m²]	area of stem
A_{wood}	[m²]	flow area blocked by wood
D_{stem}	[m]	stem diameter near root system
D_{top}	[m]	stem diameter at the top
f_{br}	[-]	volume fraction branches
f_r	[-]	volume factor root
L_{stem}	[m]	stem length
V_{roots}	[m³]	volume of root system
V_{stem}	[m³]	volume of stem
V_{wood}	[m³]	volume of submerged wood
ρ_{wood}	[kg/m³]	specific weight of wood

design of stabilisation

vertical forces

buoyancy at submergence

$$F_{buoy} = (\rho_{water} - \rho_{wood}) g V_{wood}$$

lift by flow with velocity *U* [m/s]

$$F_{lift} \approx F_{drag}$$

horizontal force

drag by flow with velocity *U* [m/s]

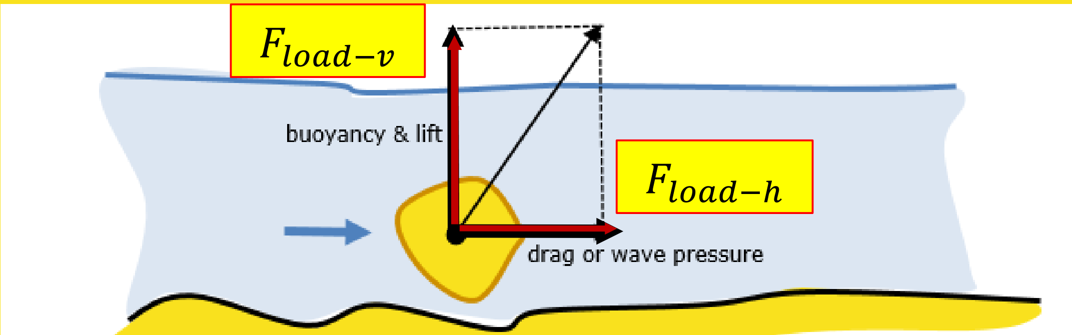
$$F_{drag} = \rho_{water} C_{drag-eff} A_{wood} U^2$$

head difference *H* [m] by ship waves

$$F_{head} = \rho_{water} g A_{wood} H$$

$$F_{load-v} = \gamma_o \left(F_{buoy} + F_{lift} \right)$$

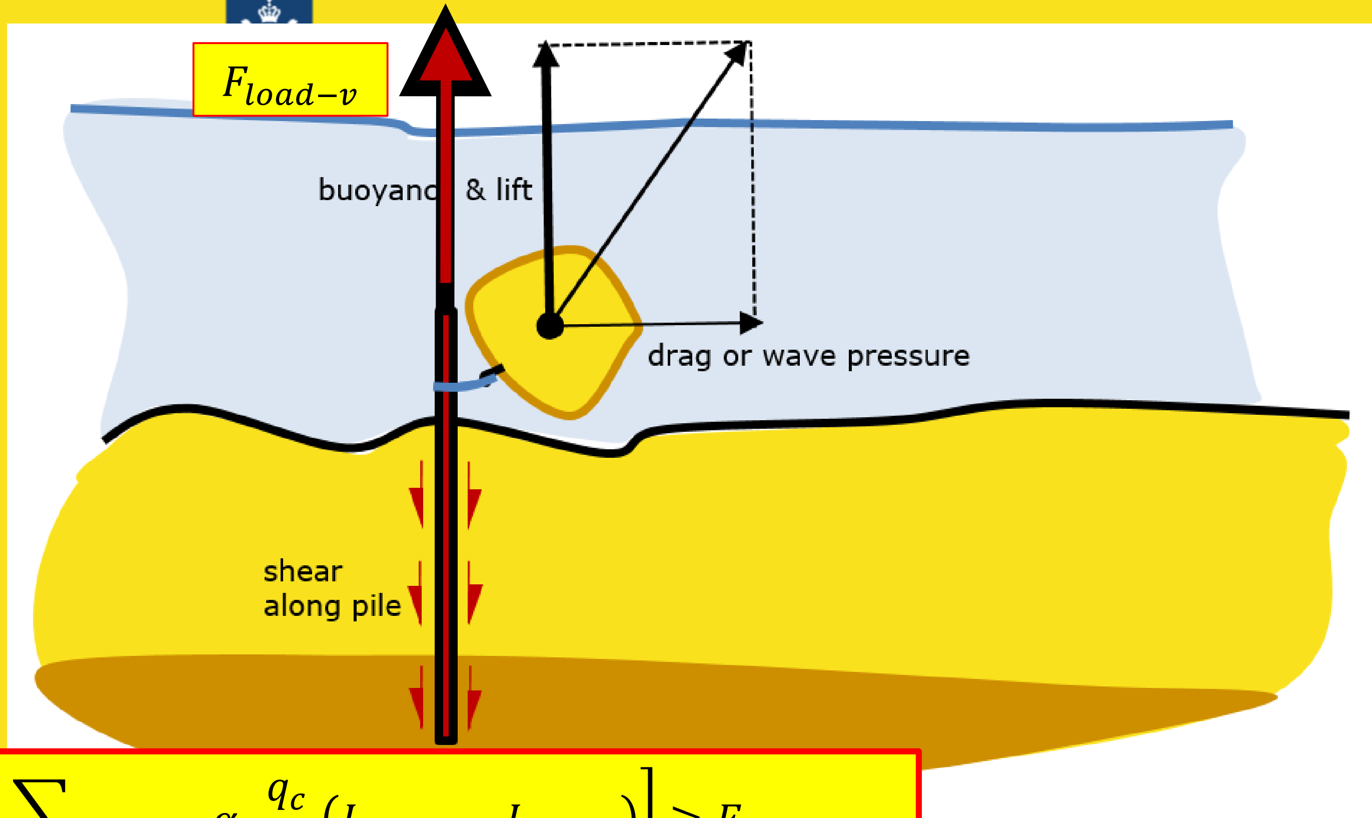
$$F_{load-h} = \gamma_o F_{drag}$$ or $$F_{load-h} = \gamma_o F_{head}$$



$F_{load\text{-}v}$	[kN]	total load in vertical direction
$F_{load\text{-}h}$	[kN]	total load in horizontal direction

A_{wood}	[m²]	flow area blocked by wood
$C_{drag\text{-}eff}$	[-]	drag coefficient of object in flow
F_{buoy}	[N]	buoyancy force on submerged wood
F_{drag}	[N]	drag force by flow
F_{head}	[N]	pressure force by head difference
F_{lift}	[N]	lift force by flow
H	[m]	head difference by ship wave
U	[m/s]	velocity of flow towards wood
V_{wood}	[m³]	volume of submerged wood
ρ_{water}	[kg/m³]	specific weight of water
ρ_{wood}	[kg/m³]	specific weight of wood
γ_o	[-]	safety factor (default γ_o=1.1)

design example stabilisation by piles



$$N_p\left[\left(\rho_{pile}-\rho_{water}\right)gV_{pile}+\frac{P_{pile}}{\gamma_d}\sum_{length\ of\ pile\ in\ soil}\alpha_t\frac{q_c}{\gamma_m}\left(L_{layer}-L_{scour}\right)\right]\geq F_{load-v}$$

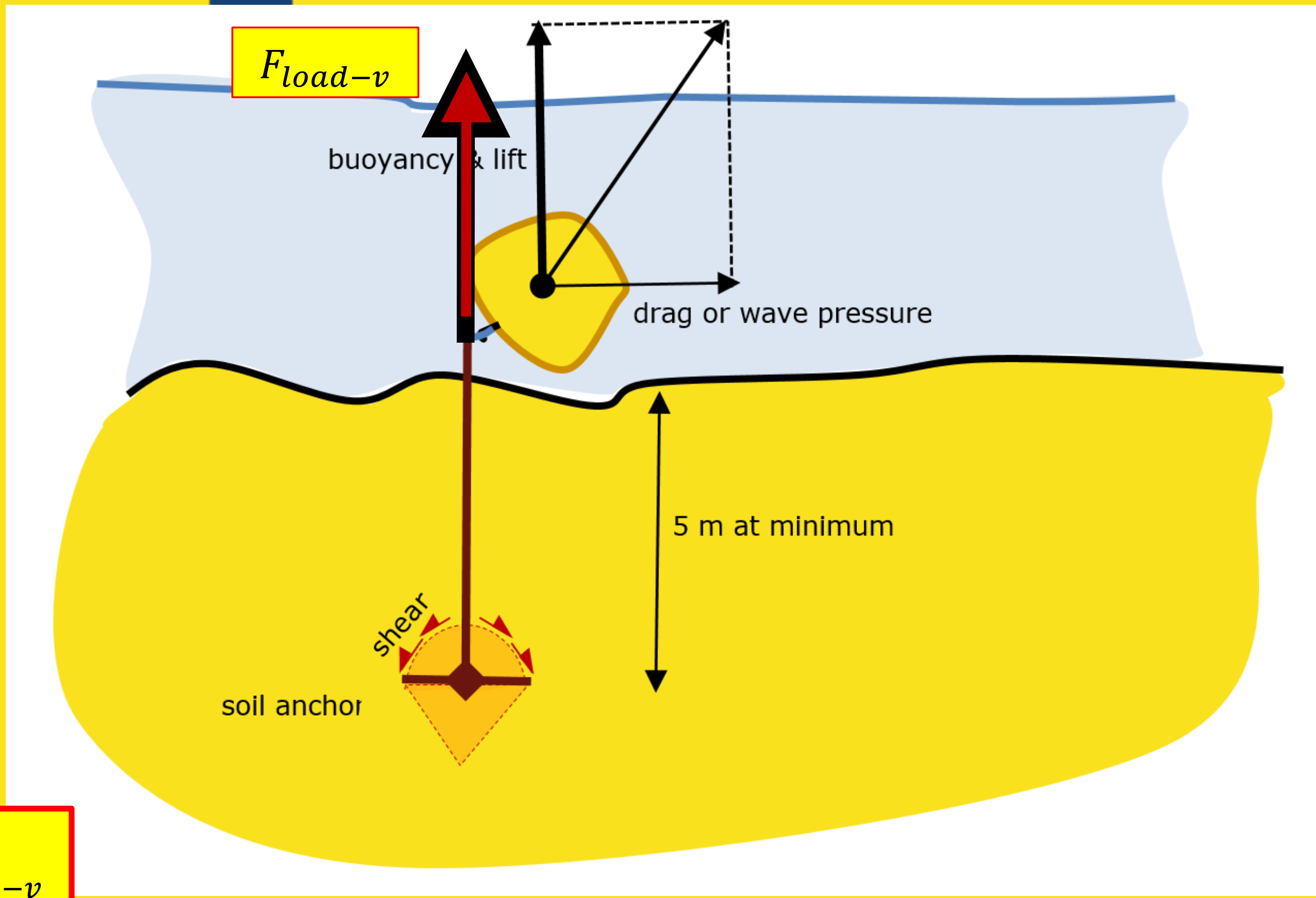
g	[m/s²]	gravitation constant
L_{layer}	[m]	length of pile-contact with layer
L_{scour}	[-]	reduction of L_{layer} by scour ($L_{scour}=2D_{stem}$ in sand, L_{scour}=0 m in clay)
N_p	[-]	number of piles
P_{pile}	[m]	pile perimeter
q_c	[kN/m²]	cone resistance (default $q_{c\text{-}sand}$=4000 kN/m², $q_{c\text{-}clay}$=1000 kN/m²)
V_{pile}	[m]	pile volume
α_t	[-]	shear coefficient (default α_{t-sand}=0.004, α_{t-clay}= 0.01)
γ_m	[-]	material reduction factor (default γ_m=1.0 in sand and γ_m=1.4 in clay)
γ_d	[-]	shear reduction due to dynamic load (default γ_d=1.25)
ρ_{pile}	[kg/m³]	specific weight of pile
ρ_{water}	[kg/m³]	specific weight of water

lower values for peat/weak clays..

design example stabilisation by anchors (vane/screw)

stable bed without dynamic fluctuations

(side channels)



$$N_a \, max\left[\frac{F_{max}}{\gamma_m}; c_{pull}\frac{q_c}{\gamma_m}A_{anchor}\right] \geq F_{load-v}$$

A_{anchor}	[m^2]	area of anchor vane
c_{pull}	[-]	soil constant 10 (sand) or 0.4 (clay)
F_{max}	[kN]	upper limit pull force (default 230 kN)
N_a	[-]	number of anchors
q_c	[kN/m^2]	cone resistance in sand (default q_c=4000 kN/m^2) or undrained shear strength in clay (default q_c=18 kN/m^2)
γ_m	[-]	material reduction factor (default 1.2)

design example
grounding by ballast

vertical stability (perpendicular to bed level)

force equilibrium perpendicular to the bed level

$$F_{\perp-bed} + \cos\theta\, F_{load-v} + \sin\theta\, F_{load-h} - \cos\theta\, F_{g-ballast} = 0$$

design criterium vertical stability

$$F_{g-ballast} = \gamma_m [F_{load-v} + \tan\theta\, F_{load-h}]$$

ballast required

$$N_b V_{ballast} = \frac{F_{g-ballast}}{(\rho_{ballast} - \rho_{water})g}$$

horizontal stability (parallel to bed level)

resulting contact force bed-ballast

$$F_{\perp-bed} = (\gamma_m - 1)[\cos\theta\, F_{load-v} + \sin\theta\, F_{load-h}]$$

force equilibrium parallel to the bed level

$$F_{//-bed} + \sin\theta\, F_{load-v} - \cos\theta\, F_{load-h} - \sin\theta\, F_{g-ballast} = 0$$

required shear for horizontal stability

$$F_{//-bed} \geq \sin\theta\,(\gamma_m - 1) F_{load-v} + \cos\theta\,(1 + \gamma_m \tan^2\theta) F_{load-h}$$

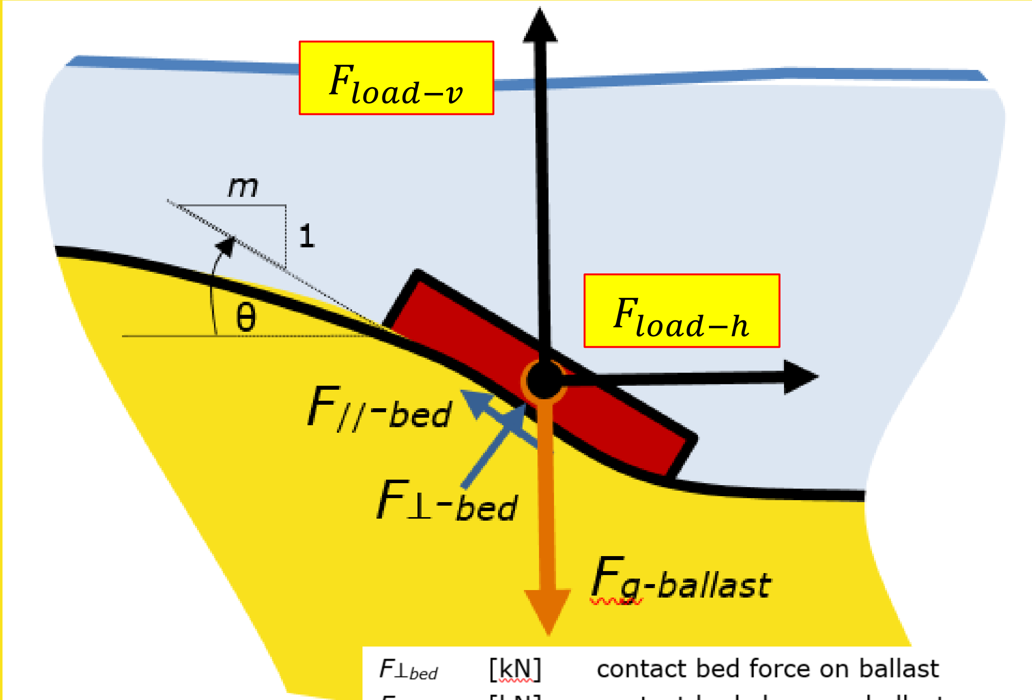
kinematic relation ballast-bed shear

$$F_{//-bed} = \mu\, F_{\perp-bed}$$

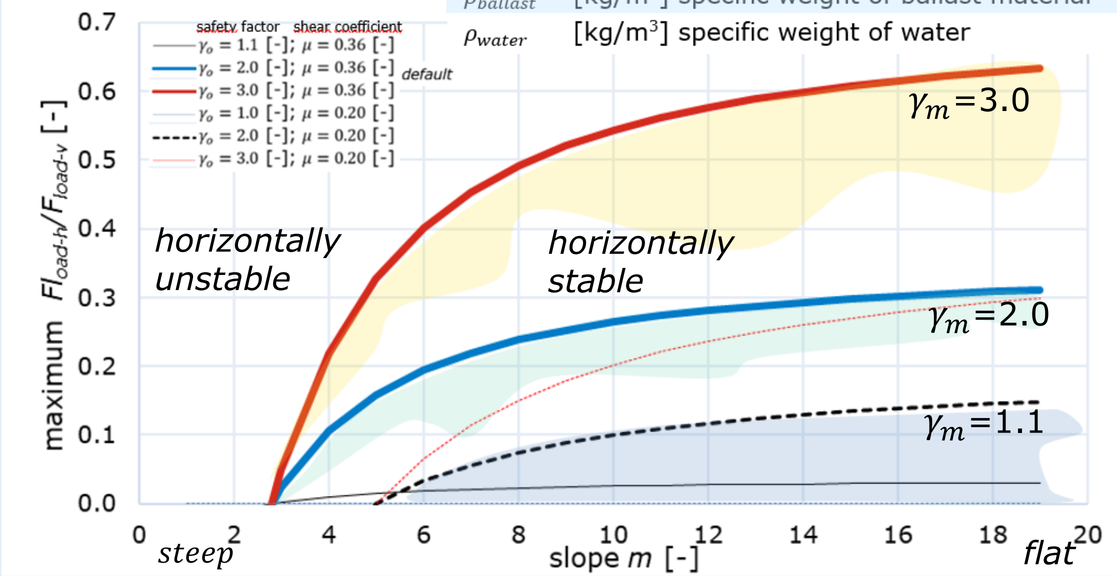
resulting criterium horizontal stability

$$\frac{F_{load-h}}{F_{load-v}} \leq m\,(\gamma_m - 1)\frac{\mu\, m - 1}{m^2 + \gamma_m - \mu\, m(\gamma_m - 1)}$$

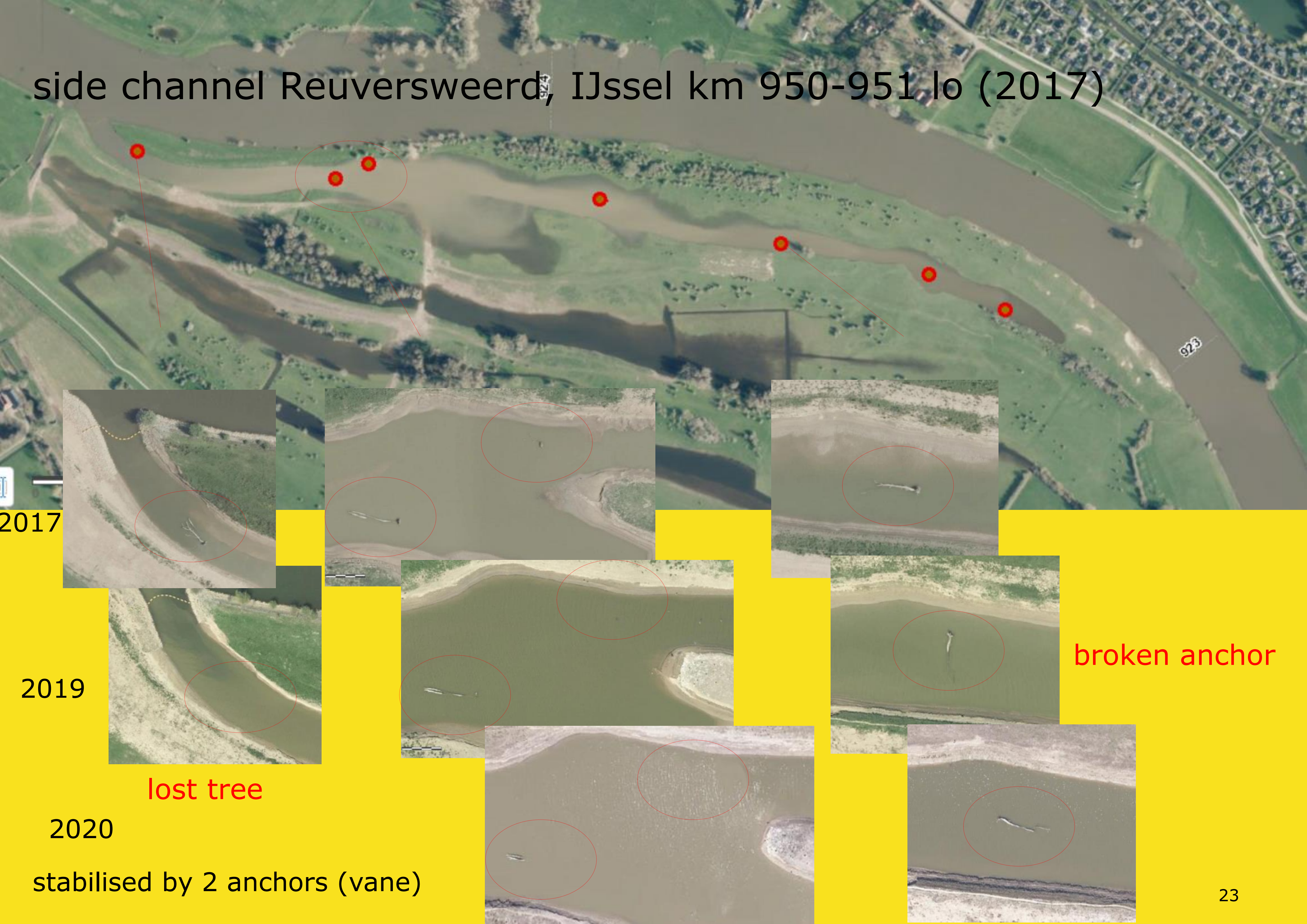
increased safety factor ($\gamma_m = 3$)



$F_{\perp bed}$	[kN]	contact bed force on ballast
$F_{//\text{-}bed}$	[kN]	contact bed shear on ballast
$F_{g\text{-}ballast}$	[kN]	submerged weight of ballast
θ	[rad]	bed slope 1:*m*
μ	[-]	shear coefficient (default μ=0.36)
g	[m/s²]	gravitation constant
N_b	[-]	number of ballast elements
$V_{ballast}$	[m³]	volume of ballast element
$\rho_{ballast}$	[kg/m³]	specific weight of ballast material
ρ_{water}	[kg/m³]	specific weight of water



side channel Reuversweerd, IJssel km 950-951 lo (2017)



2017

2019

lost tree

2020

broken anchor

stabilised by 2 anchors (vane)

side channel Dorperwaarden,
IJssel km 950-951 lo (2017)

Lessons learned

- *wood in flow can induce bed level dynamics*
- *bed level dynamics (scour) can reduce the stabilization by pile/anchor*

- *account for risks of increased load (floating debris)*

- *subsoil obstacles (bed/bank protection) can limit drill depth of pile/anchor*

- *ballasting increased safety factor γ_m to account for horizontal stability*
- *ballasting preferably at flat beds and/or within scour holes*

- *use certified chains and chain closures*
- *limit tree movements to prevent wear*

- *apply minimum diameters to prevent breaking of branches and stems*
- *at risk locations; remove vulnerable branches thicker than a fist*
- *exclude locations with dry fall (emerging) and sedimentation*
- *if not accounted for, no revival of tree branches (willow)*

Challenge; how to

- *combine ecology & river engineering (e.g. bed level management)*

- *anticipate reduced flow resistance when clustering*
- *anticipate reduced flow resistance after bed level adjustment*

- *anticipate loss of buoyancy by temporal/reusable stabilization*
- *develop application of saturated woods (planning, storage, transport..)*

- *develop application of saturated logs as bed protection*

- *Hydraulic load reduction as a function of depth in a filter layer consisting of logs*, R.M.Rubaij Bouman, MSc thesis TU Delft 2018
- *Stability of randomly placed logs*, Mario van den Berg, MSc thesis TU Delft 2019

wood-layers acting as a bed protection filter layer

Hydraulic load reduction as a function of depth in a filter layer consisting of logs, R.M.Rubaij Bouman, MSc thesis TU Delft 2018

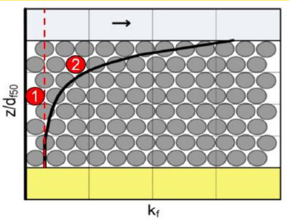
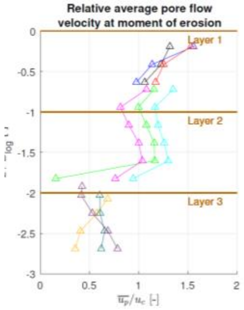
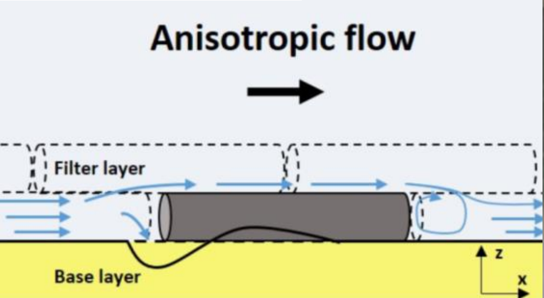


Figure 2.12: The turbulent kinetic energy depends on the influence of the energy slope (1) and the flow over the filter structure (2).





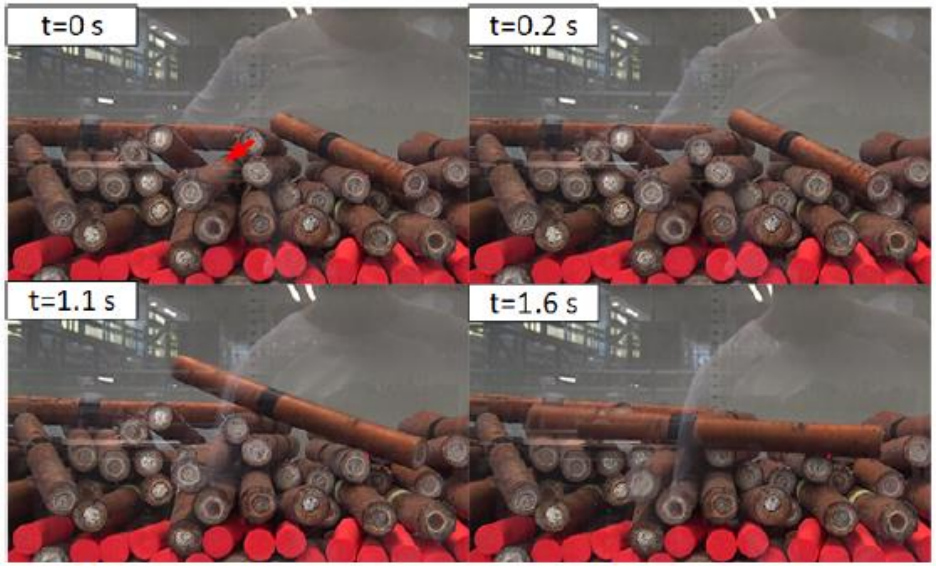
-minimum bed shear reduction at layers > 2 a 3 D

-account for anisotropic character (stems)

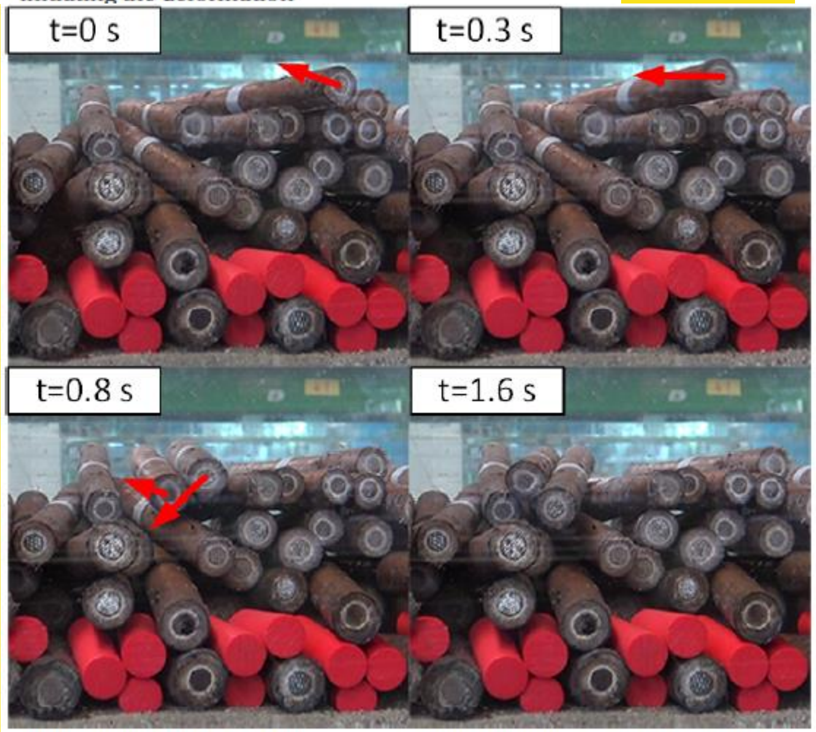
-sand (0.14 mm) stable up to 1 m/s (Shields: 1.0 mm stable up to 2.8 m/s)

stability of saturated wood logs in flow

Stability of randomly placed logs, Mario van den Berg, MSc thesis TU Delft 2019



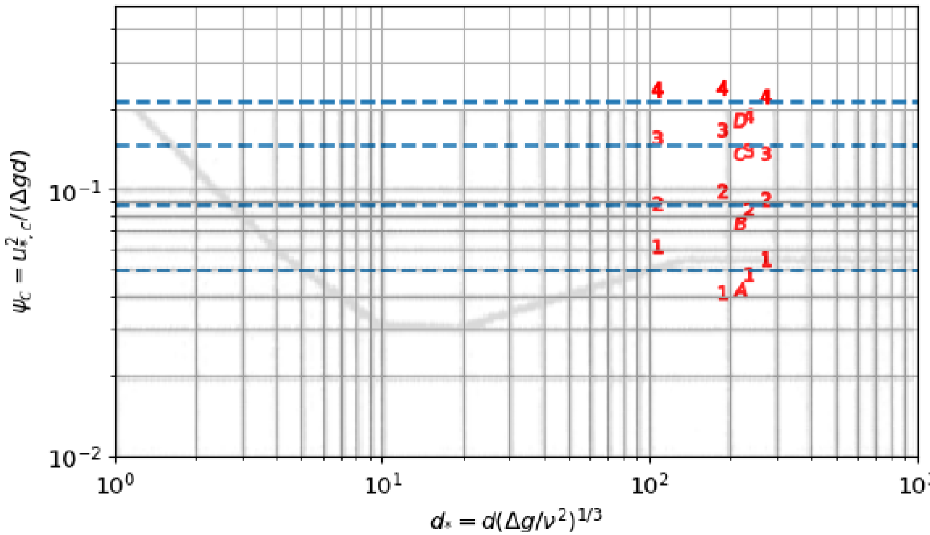
(a) Experiment SP18a: relocation by turning. One log shoots away (red arrow) initiating the deformation



(b) Experiment SP16a: relocation by sheltering. Movement of the logs indicated by

Experiment	Avg. critical Shields parameter ψ_c [m/s]			
	1. Initial motion	2. Deformation	3. Transport	4. Failure
SP18	0.055	0.093	0.137	0.224
SP16	0.049	0.085	0.141	0.190
SP14	0.041	0.099	0.169	0.240
SP17	0.061	0.089	0.156	0.237
CP15	0.042	0.075	0.137	0.182
Average	0.050	0.088	0.148	0.215

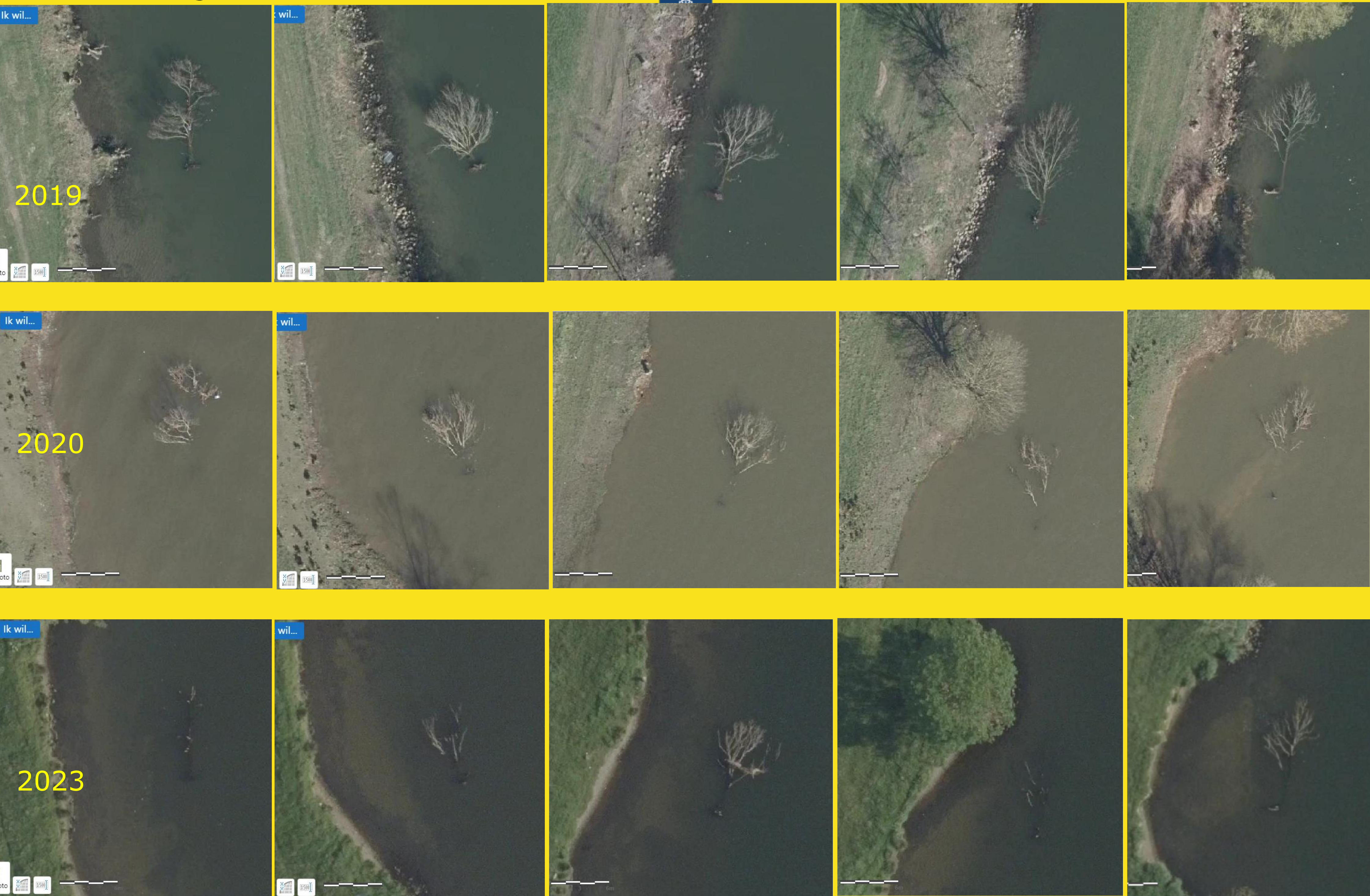
Table 7.3: Average Shields parameters (ψ_c) for experiments SP18, SP16, SP14, SP17 and CP15



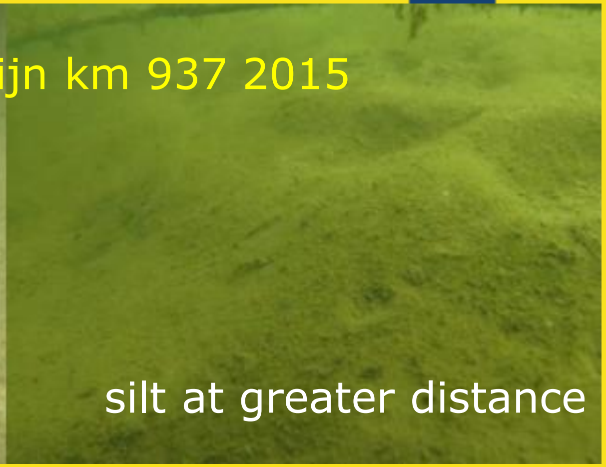
$$\frac{D_{wood}}{D_{stone}} \approx \frac{\rho_{stone} - \rho_{water}}{\rho_{saturated\ wood} - \rho_{water}}$$

Shields similarity

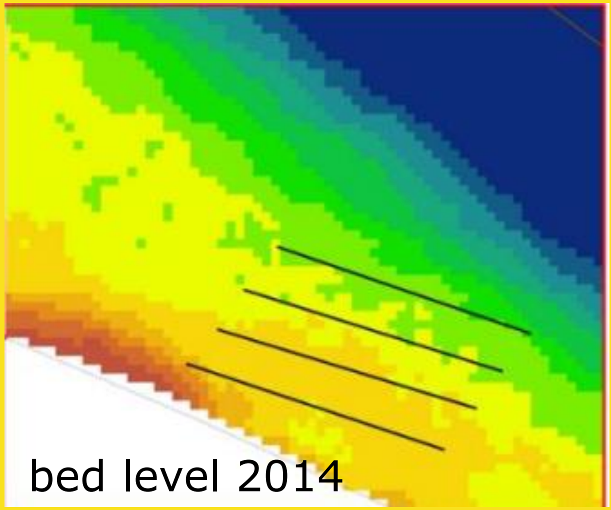
Meuse Vierlingsbeek km 137.7-139 lo

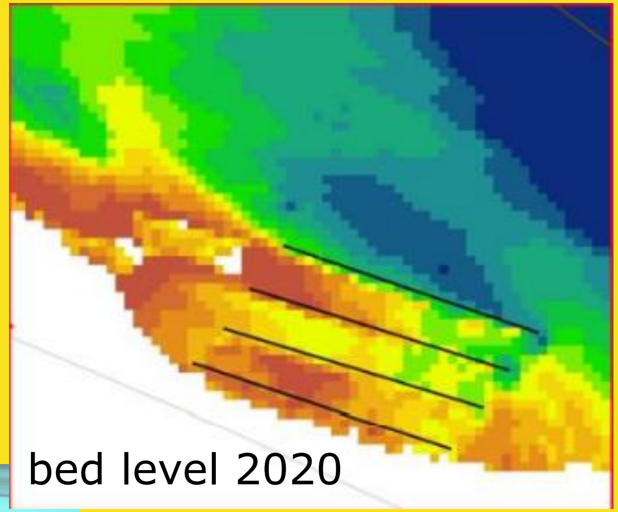


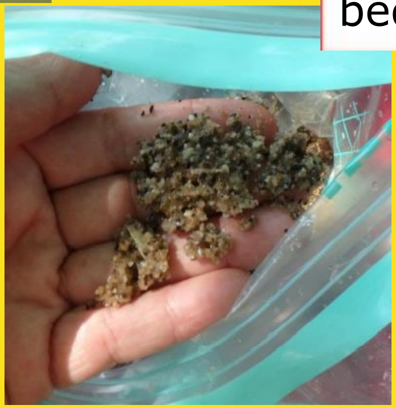
developing improvement of alignment



Evaluatie pilot rivierhout , effect op vis, macrofauna en bodem (2014-2016), Bureau Waardenburg & Hydrologisch Adviesbureau Klink (2017)





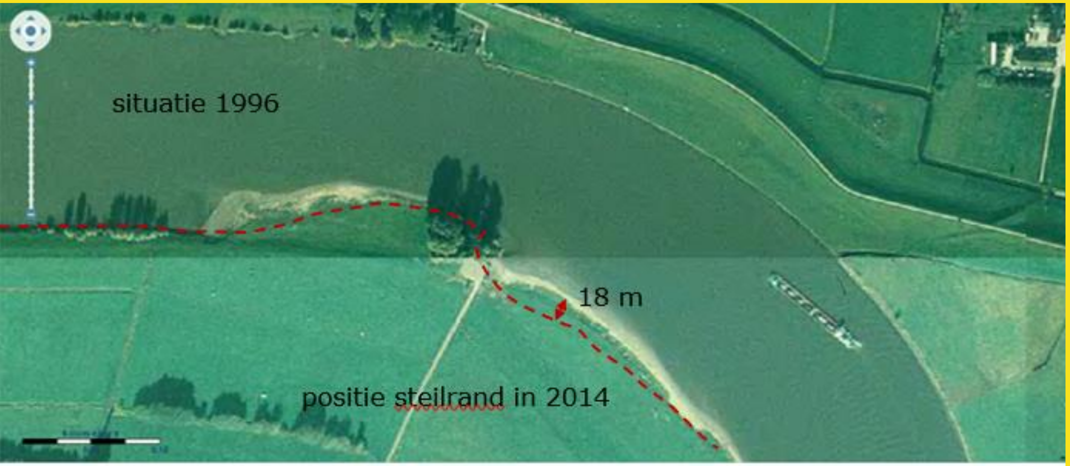


Rapid assessment of river-bend improvement at Redichem using wooden screens, Deltares 2021

SSRS pilot IJssel Zalk 2019

RWS, Deltares, BAM/Van den Herik, Aquadrones

rare relict of IJssel banks before large-scale normalisation



shallow inner bend

- sharp turn
- local widening
- sedimentation by bank erosion (1 m/yr)

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developing improvement of alignment

November 2020