WAGENINGEN UNIVERSITY
ENVIRONMENTAL SCIENCES

Rijkswaterstaat
Ministerie van Infrastructuur en Milieu

Deltares
Enabling Delta Life

River scale model of a training dam using lightweight granulates

M.P. Boersema[1], A.J.F. Hoitink[1,2,*], A. Sieben[3], C.J. Sloff[4,5] and M. van der Wal[4]

BACKGROUND AND AIM

To manage the expected extremity in high and low river discharge, the state authority for infrastructure in the Netherlands, Rijkswaterstaat, is searching for an alternative river design. The aims of the new design are:

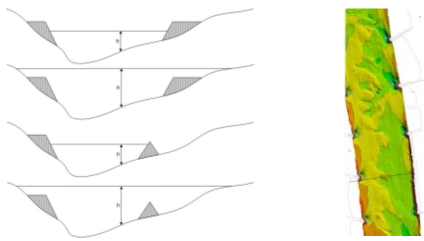
- Increase the water depth in the fairway during low discharges
- Decrease the water level during high discharges

This can be realized by replacing the groynes at the inner bend of the river by a training dam. Between the training dam and the bank a new channel is created. The flow into this side channel is regulated by a fixed weir (see picture below).

Location of training dam (red), intake weir (blue) and removed groynes (purple).

The results of the new design are to:

- narrow the channel at the shallow inner bend (width of fairway will not change) during low discharges
- increase the cross-sectional area, reducing the total roughness of the river during high discharges



Left: Cross-sections of the river, current design (upper) and training dam design (lower). Right: bed levels in the River Rhine (data source: Rijkswaterstaat).

The aim of this research is to investigate the morphological effects of the training dam on in the navigation channel, during low and high discharge, by means of a physical scale model.

SCALING ANALYSE

To scale the water movement properly, the Froude number (*Fr*), and hydraulic roughness (*C'*) must be in the same range. Dynamic similarity in bed load transport (*S*) is based on the following relations:

$$S = f(\theta, \theta_{cr}) \qquad \theta_{cr} = f(D_*) \qquad D_* = D_{50}\sqrt[3]{\frac{\Delta g}{\nu^2}}$$

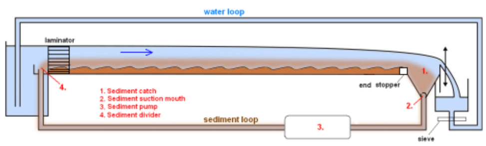
Scaling requirements, where n is the scale ratio ($n_x = X_{prototype}/X_{model}$):

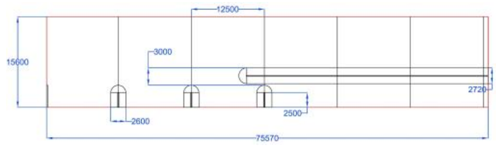
$$\theta_p = \theta_m \rightarrow n_\theta = \frac{{n_u}^2}{{n_C}^2 n_\Delta n_{D_{50}}} = 1 \rightarrow n_u = n_C\sqrt{n_\Delta n_{D_{50}}}$$

$$D_{*p} \approx D_{*m}$$

MODEL DESIGN AND FACILITIES

The geometrical scale factor (n_L) of the model is 60 and the physical model is built in a 2.60 x 12.60 m flume featuring sediment recirculation. The model has a mobile bed composed of light weighted polystyrene (BAW[6]) to simulate bed load sediment transport. The thickness of the initial sediment layer is 0.2 m and after each experiment, the bed levels are measured with a laser scanner. Half of the river including the training dam and side channel is modelled in the flume.





Position of scale model in the flume with prototype values in cm.

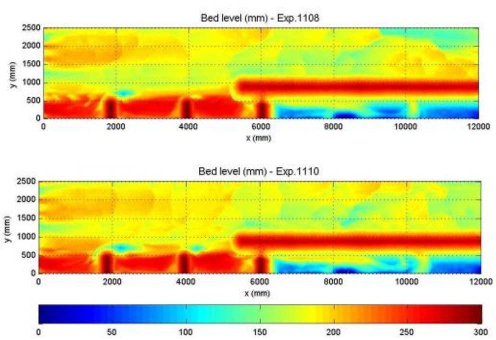
RESULTS AND CONCLUSIONS

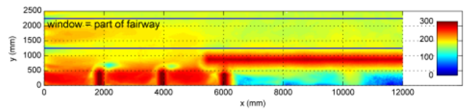
Results show a dynamic pattern of erosion and deposition, including dunes and scours. Displayed bed levels represent a near-equilibrium stage.

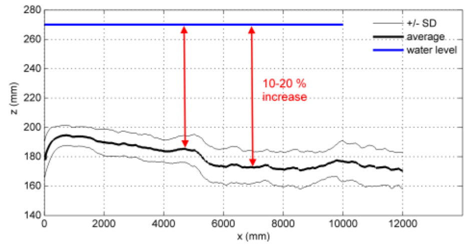
		PROTO TYPE	MODEL
sediment density	ρ_s (kg/m³)	2650	1055
50th percentile of particles	D_{50} (mm)	1.20	2.10
90th percentile of particles	D_{90} (mm)	2.00	2.90
relative sediment density	Δ (-)	1.65	0.055
kinematic viscosity	ν (m²/s)	1.33E-06	1.08E-06
critical Shields parameter	θ_{cr} (-)	0.033	0.030
particle parameter	D_* (-)	25.06	16.23

Low discharge		PROTO TYPE	MODEL	n
Discharge – channel/flume	Q (m³/s)	1250	0.021*	
flow velocity	u (m/s)	1.00	0.15	6.67
water depth	d (m)	5.00	0.083	60
Chézy	C ($\sqrt{m}$/s)	45	*30*	1.50
Froude number	Fr (-)	0.14	0.16	0.92
Reynolds number	Re (-)	3750000	13181	284
Shields parameter	θ (-)	0.25	0.22	1.15

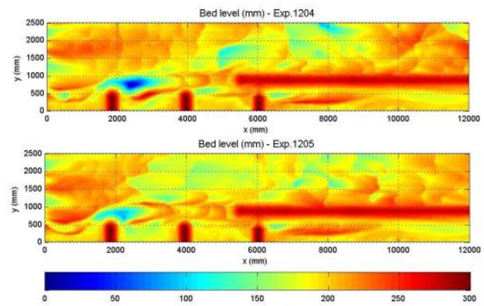
High discharge		PROTO TYPE	MODEL	n
Discharge – channel/flume	Q (m³/s)	4600	0.039*	
flow velocity	u (m/s)	1.00	0.15	6.67
water depth	d (m)	8.00	0.133	60
Chézy	C ($\sqrt{m}$/s)	45	*30*	1.50
Froude number	Fr (-)	0.11	0.13	0.86
Renolds number	Re (-)	6000000	18500	324
Shields parameter	θ (-)	0.25	0.22	1.15



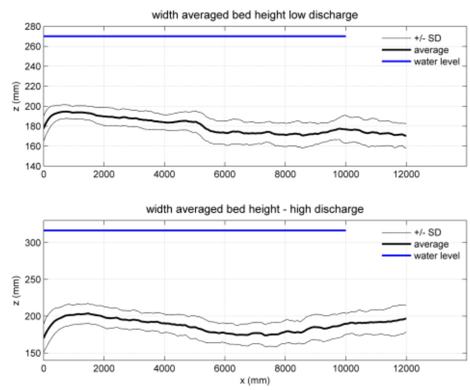




Average bed level (low discharge), based on 15 bed scans.



Near-equilibrium bed level during the high discharge experiment



Average bed level, low discharge and high discharge

- Morphodynamics is dominated by narrowing and widening of the cross-section
- During low discharge, the presence of the training dam results in a deeper navigation channel
- Polystyrene allows for dynamic similarity of bed load sediment transport
- Dunes in polystyrene scale with the water depth, and are dynamically similar to those in the prototype
- Scours near the tip of the river groynes are too deep with respect to the prototype, which may relate to slope effects
- Morphological impact of the intake section is limited

[1] Hydrology and Quantitative Water Management Group, Department of Environmental Sciences, Wageningen University, Wageningen, Netherlands
[2] Institute for Marine and Atmospheric Research Utrecht, Department of Physical Geography, Faculty of Geosciences, Utrecht University, TC Utrecht, Netherlands
[3] Rijkswaterstaat, Waterdienst, Lelystad, Netherlands
[4] Deltares (formerly WL Delft Hydraulics), Delft, Netherlands.
[5] Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, Netherlands.
[6] Bundesanstalt für Wasserbau (BAW) in Karlsruhe, Germany, made the polystyrene available for this research.
Laboratory: Kraijenhoff van de Leur Laboratory *for Water and Sediment Dynamics* (www.watersedimentlab.wur.nl)
* correspondence: Ton Hoitink (ton.hoitink@wur.nl)

WAGENINGEN UR