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The Science Behind Room for the River 2.0's Bed Erosion Control Measures

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Introduction

The Room for the River 2.0 (RftR 2.0) program aims to stop large-scale bed erosion of the Rhine branches in the Netherlands. The authors have contributed to selecting and developing feasible solutions now under consideration for RftR 2.0. These solutions are grounded in a solid understanding of the flow and sediment transport processes driving the erosion. In this paper we show that not the total sediment transport, but the longitudinal gradient in transport is key to the large-scale erosion of the Waal River. We also discuss how this affects potential solutions and how uncertainties play a role.

Gradients

The RftR 2.0 prognosis is based on extrapolations of bed-level trends over the past 20 years. In the Waal, down to about km 930 (Zaltbommel), a clear erosion trend is present. Following Exner's law of mass conservation, this erosion translates to a positive gradient in sediment transport: more sediment leaves a river section than enters it. The cause of this gradient can be traced through the process of bed-material transport. We apply the Meyer-Peter and Müller (1948, MPM) shear-stress based transport formula for gravel and sand:

$$s_i \sim p_i D^{\frac{3}{2}} (\mu\theta - \xi\theta_{cr})^{\frac{3}{2}} =$$
$$= p_i D^{3/2} \left(\boldsymbol{u}^2 / \left(\sqrt{\boldsymbol{C}} \cdot C_{90}^{3/2} \Delta \boldsymbol{D} \right) - \xi\theta_{cr} \right)^{3/2}$$

Where D=grain size, C=Chézy roughness based on bed forms and grains, C_{90}=Chézy roughness based on grains, p_i=fraction, u=flow velocity, ξ=hiding and exposure function, θ=Shields value, θ_{cr}=critical Shields value.

Figure 1 shows a downstream fining gradient in measured grain size, while Figure 2 shows that flow velocity remains practically constant along the eroding reach for all discharges. Roughness does not contribute to the gradients either.

Using MPM in the 2D morphological model for the Rhine branches, we find that discharges between 1400 and 4500 m³/s at Lobith contribute most to annual transport rates and transport gradients (Figure 3).

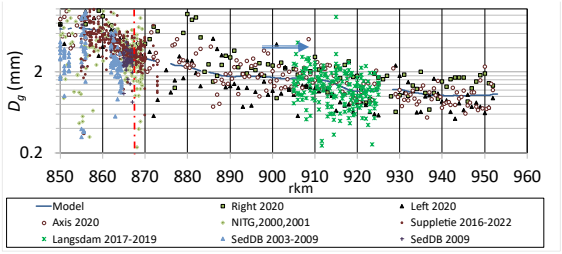


Figure 1. Geometric mean grain size along Boven Rijn and Waal measured and average model input. Dashed Red line is location of Pannerdense Kop

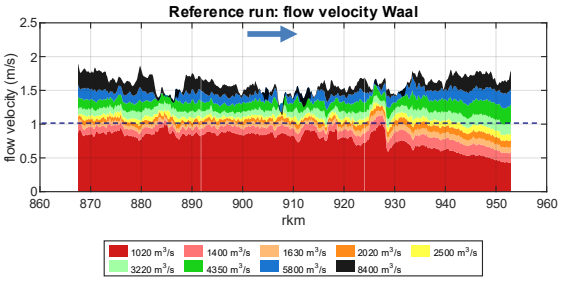


Figure 2. Flow velocities along the Waal for different discharges

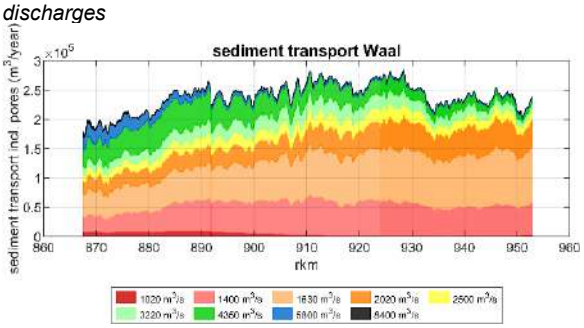


Figure 3. Computed annual sediment transport (DVR model) subdivided per discharge step

Similarly, Figure 4 shows that grain-size fractions 0.25–0.5 mm and 0.5–1.0 mm (sand) drive most of the transport gradient, due to the relative downstream increase in sand content.

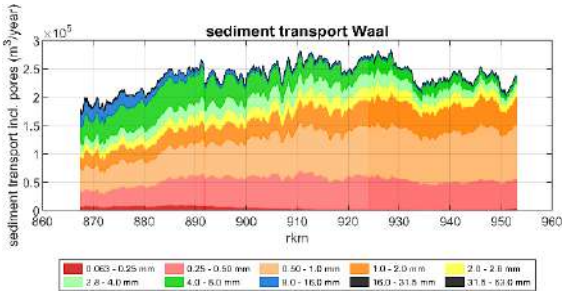


Figure 4. Computed annual sediment transport (DVR model) subdivided per size fraction

Due to ongoing erosion in both the Waal and the Pannerdensch Kanaal and Nederrijn, the discharge distribution gradually shifts toward the Waal. Because the Waal is much wider, equal erosion in both branches leads to a relatively larger increase in flow area in the Waal, making this a robust trend. Model simulations show that strong deepening of the Pannerdensch Kanaal cannot stop or reverse this shift. This confirms that mitigating erosion in the Waal is more effective and urgent than stopping erosion in the Pannerdensch Kanaal and Nederrijn.

Uncertainties

At shorter time scales (5–10 years), measured bed-level trends show much larger variation in both time and space. This is caused by, for example, the gradual implementation of RftR 1.0 measures such as groyne lowering and floodplain works, and by discharge fluctuations. Also, not all remaining sediment extractions in recent years have been fully accounted for in the translation of bed-level trends to transport gradients, meaning the defined gradient may be somewhat smaller than estimated.

The choice of transport formula also introduces uncertainty. When testing alternatives such as Ashida and Michiue (1972), Wilcock and Crowe (2003), and Engelund and Hansen (1967) in the 2D model, the overall contributions of discharge steps and sediment fractions remain comparable. However, most alternative formulas — except Engelund and Hansen — give a larger overall transport gradient than MPM. Increasing the effect of hiding and exposure also amplifies the computed erosion rates in the Waal.

Bed-erosion control measures

Which are the possible solutions for RftR 2.0 that are following from these analyses, and how can they be made effective or not?:

- Nourishments are the most flexible approach, as they can be adjusted if the effect differs from expectations or conditions change. However, they do not eliminate the gradient causing erosion and must therefore be continued indefinitely. A volume of approximately 150,000 m³/year is needed, largely from external sources, and must be distributed evenly over the eroding reach.
- Elimination of the downstream fining trend is considered too uncertain and too intrusive. This option has not been studied further.
- The multi-channel approach is most effective for creating a counteracting gradient in flow velocity by gradually widening the river downstream. For this to work, the multi-channels must reduce flow velocity in the main channel for middle-range discharges between 1400–5000 m³/s — the range shown to dominate the transport gradient. The channels must also increase in size downstream to allow a gradual decrease in flow velocity. As a result, the multi-channel solution must cover the full length of the Waal down to around Zaltbommel, where the transport capacity naturally drops to the level at the upstream start of the Waal. Sections that are not widened will continue to erode and will reduce the effectiveness of adjacent widened reaches. Disadvantages include limited adaptiveness and potential maintenance issues.

Further research and pilots with intensive monitoring are needed before a final decision can be made. For example, pre-nourishment with coarse material before regular finer sediment nourishments has proven effective in the Niederrhein, but it is not yet known whether this approach would work for the sand bed of the Waal.

Conclusions

The gradient in sediment transport — not total volume — drives Waal erosion, caused mainly by downstream fining at constant flow velocity.

Medium discharges and sand fractions dominate the gradient and must be the target of any solution. The discharge shift toward the Waal is irreversible — fixing the Pannerdensch Kanaal won't help. Nourishments are flexible but must continue forever. The multi-channel approach can structurally fix the gradient, but must cover the full Waal length to Zaltbommel — gaps will undermine the entire solution. Both the prognoses for future erosion, and the effects of proposed solutions still contain various uncertainties. More research is needed to guarantee no-regret solutions for the future.

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