The importance of sediment supply data to modelling river morphodynamics

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Dutch reach of the Rhine River
Bovenrijn and Waal branches

Source: Rijkswaterstaat

-3.3 < \Delta \eta < -1.7 \text{ cm/a}
Content

1. Long-term bed degradation
2. Potential causes of bed degradation
3. The equilibrium river profile
   • The equilibrium river profile under steady flow
   • The effect of variable flow
   • The effect of tributaries
   • The effect of mixed sediment
4. Conclusions
Dutch reach of the Rhine River
Pannerden channel, Nederrijn, Lek

-3.2 < $\Delta \eta$ < -1.6 cm/a
Dutch reach of the Rhine River
IJssel branch

-2.6 < \Delta \eta < -1.3 \text{ cm/a}
Does the degradation rate decrease?

We may observe a decrease in the degradation rate over the past 10-20 years.

This may be due to a lack of peak flows over this period:
German reach of the Rhine River

Frings et al. (Catena, 2014)
Elbe River

Source: PG Erosionsstrecke Elbe (2009)
Problems related to bed degradation

and also:

• destabilization of structures;
• flood water level increases;
• flood risk downstream of bifurcations may increase.

Frings et al. (Geomorphology, 2014)
### Potential causes of long-term bed degradation

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*Frings et al. (2009)*
Coarse sediment nourishment

Source: MSc project
Bart Berkhout (ongoing)

This preceding degradational wave was first observed by Ribberink (1987).

Bed level measured E2

x coordinate (m)

Bed elevation

flow

time (hh:mm)

high

low

0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00

hh:mm

m
Source: MSc project Bart Berkhout (ongoing)
A certain river reach in equilibrium
Local constriction (due to levees or groynes)
Local constriction (due to levees or groynes)

M1 backwater

M2 backwater

INITIAL OR SHORT-TERM RESPONSE

\[ H_n \]
Local constriction (due to levees or groynes)

LONG-TERM RESPONSE OR EQUILIBRIUM RIVER PROFILE
Local constriction (due to levees or groynes)

Narrowing produced up to 10 m bed degradation

Source: Erik Mosselman
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The equilibrium river profile

1. **The undisturbed equilibrium river profile**
   The equilibrium longitudinal profile the river tends to approach before human intervention

2. **The engineered equilibrium river profile**
   The equilibrium longitudinal profile the river tends to approach after human intervention

3. **The restored equilibrium river profile**
   The equilibrium longitudinal profile the river tends to approach after river restoration measures

Viparelli et al. (2015)
Equilibrium river profile, for unisize sediment

Conservation of sediment mass (Exner)
\[ c_b B \frac{\partial \eta}{\partial t} = - \frac{\partial Q}{\partial x} \]
where \( Q = \frac{B K U^n}{D} \)
Engelund & Hansen (1967)

Conservation of water mass
\[ \frac{\partial BH}{\partial t} + \frac{\partial Q_w}{\partial x} = 0 \]

Conservation of streamwise momentum
\[ \frac{\partial UH}{\partial t} + \frac{\partial U^2 H}{\partial x} = -gH \frac{\partial H}{\partial x} - gH \frac{\partial \eta}{\partial x} - C_t U^2 \]

In a steady state \( \rightarrow \) all \( \frac{\partial}{\partial t} = 0 \)

Equilibrium river profile, for unisize sediment

Flow velocity

\[ U_e = \left( \frac{QD}{BK} \right)^{1/n} \]

Flow depth

\[ H_e = \frac{Q_w}{BU_e} = \frac{Q_w}{B^{1-1/n}} \left( \frac{K}{QD} \right)^{1/n} \]

Slope

\[ S_e = \frac{C_f B^{1-3/n}}{gQ_w} \left( \frac{QD}{K} \right)^{3/n} \]

\[ \eta + H = \eta_w \]

VAN BENDEGOM-DE VRIES EQUATIONS

Morphodynamic steady state, for unisize sediment

Fig. 2. Longitudinal velocity profile of the lower Rhine Embayment (SOBEK model computation, period 1993–2010).

Frings et al. (Catena, 2014)
Equilibrium river profile, for unisize sediment

Local constriction (due to levees or groynes)

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Temporal variation of the flow

Water discharge at Lobith

Water level at Lobith

Source: Rijkswaterstaat
How to deal with temporal variations

De Vries (1974),
Jansen (1979)
The effect of tributaries

As they generally add more water than sediment (De Vries, 1974, Parker, 2004), tributaries induce a stepwise reduction in slope.

\[ S_e = \frac{c_i B^{1-3/n} Q^{3/n}}{gQ_w/m} \]

Importance of the load!
Yet, we see no *stepwise* reduction in slope.

**Typical river long profile**

slope $S = -\frac{\partial \eta}{\partial x}$

typically $\frac{\partial S}{\partial x} < 0$

→ upward concave

Parker (2004, E-Book)
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Coarser unisize grains are harder to move
Coarser unisize grains are harder to move.

After Wilcock & Crowe, 2003

Egiazaroff (1965)
Particle abrasion

- Gravel
- Sand
- Silt
Abrasion acts as a trigger for profile concavity and so downstream fining.
Ongoing work: comparison between model results and field data

IJssel branch of the Dutch Rhine

$D = D_0 e^{-\alpha L}$

Sternberg (1875)

**NEEDED:**
- sand and gravel sediment supply data
- GSD bed surface

$D_{90}$ measured
$D_{50}$ measured

Flow direction
Workshop on Modelling Mixed-Sediment River Morphodynamics
27-28-29 May 2015
Delft – The Netherlands

www.sortingworkshop2015.nl