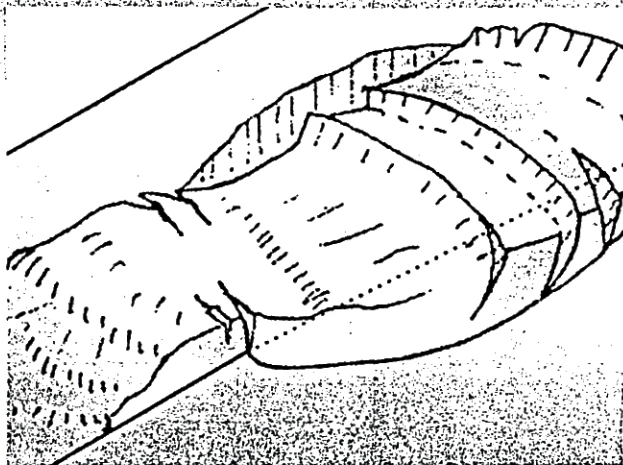


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# Floods and Landslides



Integrated Risk Assessment



Springer

# Longitudinal Evaluation of the Bed Load Size and of its Mobilisation in a Gravel Bed River

C. Deroanne · F. Petit

## 22.1

### Introduction

As water levels rise, the bed load of a gravel bed river is partly mobilised by drag forces. When the stream can no longer entrain these sediments, the pebbles are deposited on the bed and create locally depositional forms. These bars then perturb the flow and play an important role during subsequent floods.

That is why we set ourselves a dual goal target with regard to the bed load. First, to determine the sedimentological characteristics of the riverbed and more precisely the size of the material. Second, to analyse the processes of mobilization of these particles. But in both cases, we have focused on the longitudinal nature of the results, that is from the channel head to its mouth.

This paper is an abstract of a study (Deroanne 1995) carried out in the Department of Physical Geography at the University of Liège. Completed within the framework of a final year project, it was supervised by Professor Dr. F. Petit.

## 22.2

### Presentation of the Drainage Basin of the River Hoëgne

The gravel bed river that was chosen to support this study is the river Hoëgne situated in the Belgian Ardennes. Table 22.1 summarizes its main drainage basin characteristics.

## 22.3

### Longitudinal Grain-Size Distribution

Downstream fining of riverbed material has been an unanimously accepted principle for many years (Knighton 1980; Hoey and Ferguson 1994; Kodama 1994). But the explanation of this reduction caused by processes such as abrasion and selective transport is not quite clear.

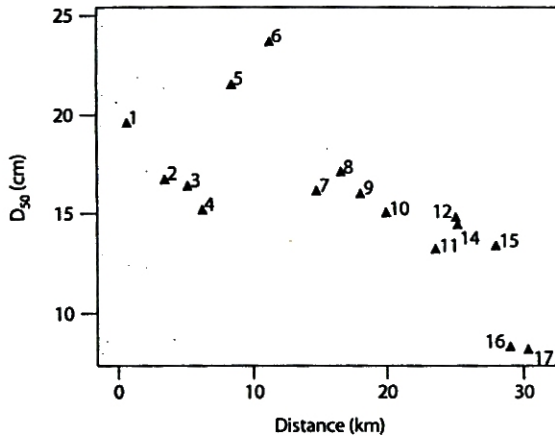
### 22.3.1

#### Methodology

To modelize this reduction tendency, 17 study-sites have been selected along the river from its head to its mouth. For each of these study-sites we took the appropriate measurements to determine the mean grain-size of a representative sample which was estimated by the  $D_{50}$  which is the median diameter.

**Table 22.1.** Main drainage basin characteristics of the Hoëgne River

Drainage area (km <sup>2</sup> )	190
Length (km)	31
Difference in height (m)	520
General slope gradient (mm <sup>-1</sup> )	0.017
Discharges near its mouth (1979–1987) (m <sup>3</sup> s <sup>-1</sup> )	
Mean discharge	3.5
Minimum discharge	0.05
Maximum discharge	70 (recurrence of 16 years)
Full bank discharge	35 (recurrence of 0.7 year)

**Fig. 22.1.** Longitudinal variation of the  $D_{50}$  along the 17 study-sites

Two measurement techniques were adopted. A *weighting technique* was used at those sites where the pebble-size and weight could be measured by hand and a *linear technique* where boulders could not be held (Grant et al. 1990). The data supplied by these two techniques are plotted on a grading curve for each study-site to measure the  $D_{50}$ .

The longitudinal variation in particle-size along the 17 study-sites is then analysed on a graph representing the  $D_{50}$  as a function of the distance of each sites from the river head (Fig. 22.1). A variety of scales can be adopted to fit a specific model to the measurements.

### 22.3.2 Results

Figure 22.1 shows the longitudinal variations in particle-size (weighting technique only) along the 17 study-sites. In keeping with the theory, the size of the bed material is seen to decrease progressively downstream. But this size reduction is perturbed by a sudden increase after the 4th site.

This increase can be explained by the long profile of the river (Fig. 22.2) where the usually observed concave appearance is locally perturbed. The perturbing convex section pro-

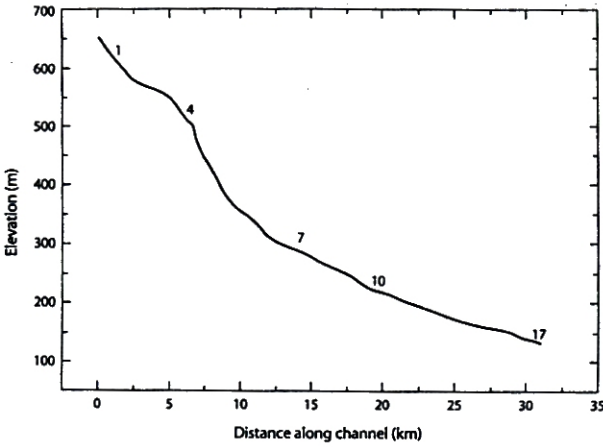
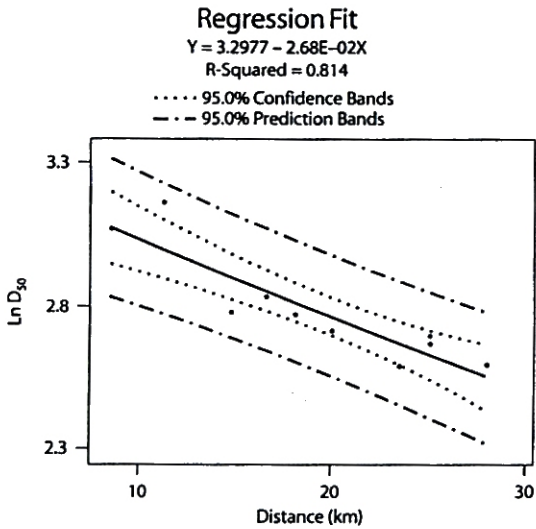


Fig. 22.2. Long profile of the Hoëgne River

Fig. 22.3. Regression of the  $D_{50}$  vs. the distance of the study-sites 5-15 (N° 13 excepted)



vides evidence of a new erosion point which either has not yet reached the plateau or is held back by stony accumulations at its extremity (Pissart 1953). In fact, this sector is a significant source of material which occasions an increase of the  $D_{50}$  in study-sites 5 and 6.

Then we tried to fit an exponential model (Werritty 1992) to the measurements situated downstream of this sector. We also decided not to take into account the sites numbered 16 and 17 where the size of the material is affected by geological and human influences. The data fit the model reasonably well (Fig. 22.3) with a coefficient of determination  $R^2$  above 80%.

## 22.4

### Mobilisation of the Bed Load

Having analysed the longitudinal distribution of the riverbed grain-size, we then tried to describe the processes that cause the downstream fining in a qualitative and quantitative way. Therefore, we estimated longitudinally the drag forces and also the critical parameters of mobilisation.

#### 22.4.1

##### Longitudinal Estimation of the Drag Forces

###### 22.4.1.1

###### Methodology

Our longitudinal estimation of drag forces was predominantly based on the measurement of the most frequently used criterion namely *shear stress*. This represents the drag force operating parallel to the bed which act on a particle to entrain it. It has been defined by the Eq. 22.1 of Du Boys (1879). The shear stress  $\tau$  can be divided (Petit 1989a) (Eq. 22.2) into:

- the *grain shear stress*  $\tau'$  due to the resistance of particles,
- the *bed form shear stress*  $\tau''$  due to the additional resistance from bed forms and stream banks.

$$\tau = \rho g Rh S_e \quad (22.1)$$

with the water density  $\rho$ , the gravity  $g$ , the hydraulic radius  $Rh$  estimated by the height of the water and the energy slope  $S_e$  estimated by the water surface slope.

$$\tau = \tau' + \tau'' \quad (22.2)$$

Consequently, on the 17 study-sites we measured the height of the water and the water surface slope to estimate respectively the hydraulic radius and the energy slope.

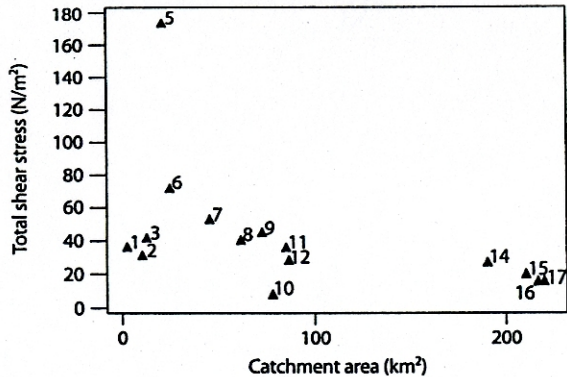
###### 22.4.1.2

###### Results

The results of shear stress for each study-site are plotted vs. their drainage area in Fig. 22.4. These measurements were, of course, taken in similar hydrological conditions ( $0.17 Q_b$ ).

This distribution recalls the one obtained for the  $D_{50}$ . The downstream decrease in shear stress is again disturbed in the sites where large boulders were found. So, as for the  $D_{50}$ , the shear stress is highly influenced by this channel unit. Further analyses of the measurements allow us to conclude that it is more precisely the bed-form shear stress component that is influenced by this section and therefore, is partly responsible for the entrainment of the bed load.

Fig. 22.4. Longitudinal estimation of the shear stress along the 17 study-sites



## 22.4.2

### Critical Parameters of Entrainment

#### 22.4.2.1

##### Methodology

To estimate the critical parameters of mobilisation, we observed the entrainment of tagged particles in seven study-sites for two rates of mobilising discharges.

After the floods, the size, weight and travel of each tagged particle were measured to ascertain the type of mobilisation which occurred. This objective was also achieved by calculation of the *critical shear stress* (Eq. 22.3) which requires measurement of the height of the water and of the water surface slope during the two mobilising discharges considered.

$$\tau_c = \rho g R h S_e \quad (22.3)$$

Finally, we calculated the *critical dimensionless shear stress*, known as the criterion of Shields (Eq. 22.4), which is the ratio of fluid forces keeping a particle in motion and gravity forces tending to keep the particle at rest.

$$\theta_{ci} = \frac{\tau_{ci}}{(\rho_s - \rho_f)gD_i} \quad (22.4)$$

where  $\theta_{ci}$  is the criterion of Shields,  $\tau_{ci}$  the critical shear stress responsible for the mobilisation of a particle of size  $D_i$ ,  $\rho_s$  the density of the material ( $\pm 2650$ ),  $\rho_f$  the water density ( $\pm 1000$ ) and  $g$  the gravity.

Interested in the variation of that criterion of Shields in relation to the sedimental structures along the river, we also measured the  $D_{50}$  of the tagged pebbles before the rise of the water and the  $D_{50}$  of the entrained pebbles and of those not entrained. These measurements were carried out on a photograph taken before the floods to avoid disturbing the overlapping of pebbles, and by means of a weighting technique after the floods respectively.

### 22.4.2.2

#### Results

The two discharges considered as responsible for the mobilisation of more than 50% of the tagged particles are lower than the full bank discharge. Also, the recurrence of the observed discharges in the upstream sites (0.32 years) is higher than that for the downstream sites (<0.3 years).

The two regressions shown in Fig. 22.5 express the relationships between the travel distance of tagged pebbles and either the size, or the weight, of particles for one study-site; type of mobilisation that occurred can thus be describe.

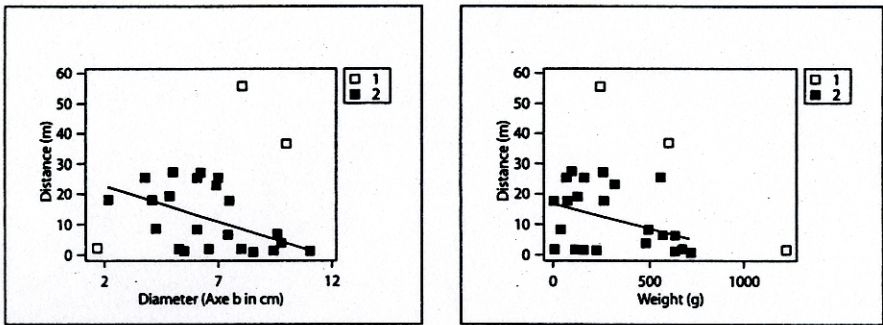


Fig. 22.5. Regression of travel distances vs. either the particle-size (left) or weight (right) at the Mousseux study-site for the mobilized pebbles (1 points representing aberrant values, 2 points from which regression was plotted)

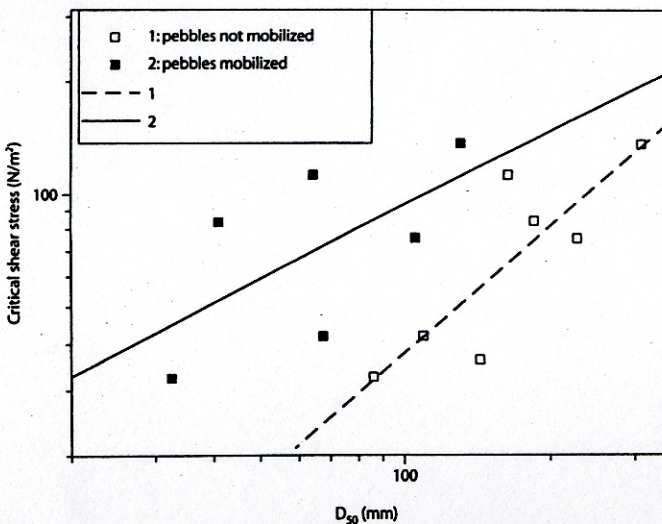


Fig. 22.6. Regression of the critical shear stress vs. the  $D_{50}$  of the pebbles (1 not mobilized, 2 mobilized) for each study-site

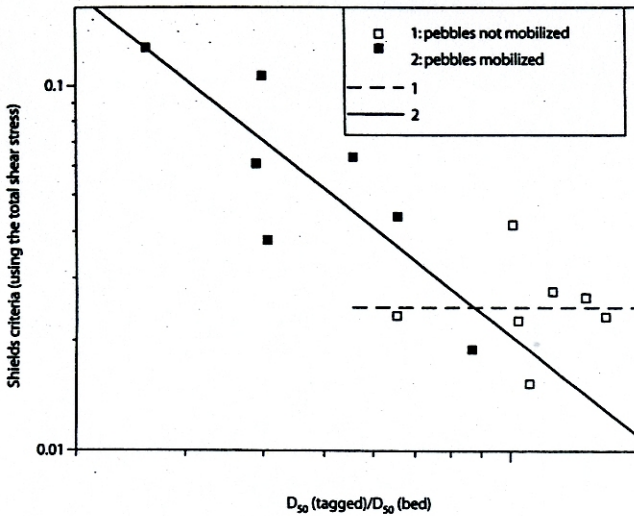


Fig. 22.7. Regression of the criterion of Shields vs. the ratio  $D_{50}$  of tagged pebbles (1 not mobilized, 2 mobilized) and  $D_{50}$  of bed load for each study-site

In fact, in most study-sites, the slope of these regressions indicate selective transport of the particles (Ashworth and Ferguson 1989). This conclusion is reinforced by the calculation of the critical shear stress plotted vs. the  $D_{50}$  of each study-site (Fig. 22.6). Again, the slope of the regression defines selective transport.

Although the ratio  $D_{50}$  of tagged pebbles and  $D_{50}$  of bed load represents the processes of hiding and protrusion of the riverbed material (Andrews 1983; Richards 1991; Petit 1994), the regression slope of the criterion of Shields vs. that ratio (Fig. 22.7) shows the importance of these sedimental structures.

## 22.5 Conclusions

The hydrological processes responsible for the entrainment of the material of a gravel bed river are extremely complex. If this study can confirm that there is downstream fining of particles, it also shows that this tendency can be perturbed locally by sources of material.

Similar to downstream fining, the longitudinal distribution of the shear stress is also perturbed by bed forms. We can therefore, conclude that grain shear stress is not the only factor responsible for the mobilisation of the material.

Although the discharges considered were inferior to full bank discharge, they were sufficient to set up partial entrainment of the bed load. It will also be noticed that these partial mobilisations of particles were generated by a discharge of lower recurrence in the downstream sites than in the upstream sites.

Finally, we observed that the influence of the sedimental structure of bed load on the critical parameters of entrainment is important for those discharges inferior to full bank discharge.



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