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Measuring suspended sediment characteristics using a LISST-ST in an embanked flood plain of the River Rhine

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Abstract

During two inundation periods in Spring 2002, we deployed a combined particle sizer and settling tube on an embanked flood plain along the River Waal (mean discharge = 2400 $m^3 s^{-1}$) in the eastern part of The Netherlands. This so-called LISST-ST device uses laser diffraction principles to measure *in situ* grain size distribution, settling velocities and concentrations of the suspended matter in the inundation water. To verify these measurements, we manually collected water samples and deployed an optical backscatter sensor to measure total sediment concentration and turbidity, respectively. The measurements revealed that the grain size distribution and suspended sediment concentration depend on the discharge, while the settling velocity does not vary with discharge, but depends on flocculation processes. In the near future, *in situ* measured sediment characteristics will be compared to those from sediment retained in sediment traps located in the same flood plain.

Key words flocculation; flood plain; grain size; laser diffraction; River Rhine; settling velocity; suspended sediment

INTRODUCTION

Recently, flood plains have been identified as major sinks for both sediments and pollutants (e.g. Walling, 1999). Attempts to quantify the amount of (sediment-associated) pollution of lowland flood plains often proceed through modelling. However, data on suspended matter characteristics in flood plain environments are scarce yet important for the calibration of flood plain sedimentation models and the assessment of the fate of sediment-associated pollutants in riverine environments.

This paper reports the results of field experiments conducted with a portable particle sizer and settling tube in an embanked flood plain environment. We present the results, compare them mutually, discuss the implications for modelling, and present ideas for future research.

STUDY AREA

We deployed the portable particle sizer and settling tube during two discharge peaks of the River Waal, which is the major distributary of the River Rhine in The Netherlands (mean discharge of 2400 $m^3 s^{-1}$ at the Dutch-German border). The study area is the flood plain of the Afferdensche and Deestsche Waarden in the eastern part of The

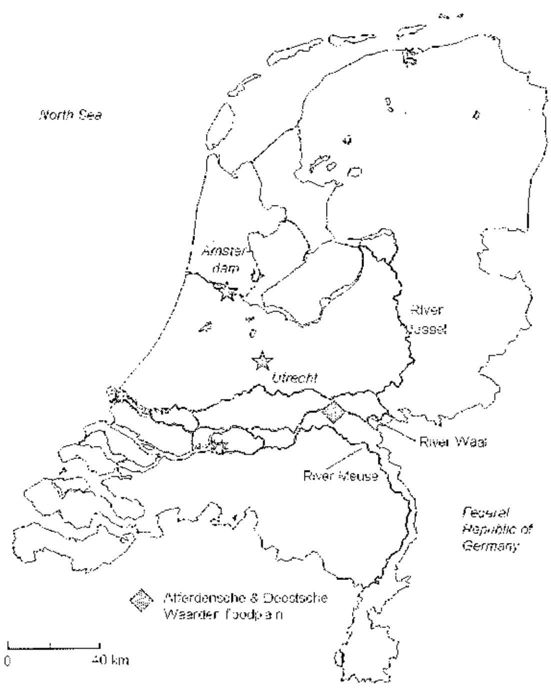

Fig. 1. Location of the fieldwork area.

Netherlands (Fig. 1). From 27 February to 21 March 2002 (rendering the "early March" data set), and from 24 March to 03 April 2002 (the "late March" data set), the instrument was deployed in a steel construction located in a meadow about 100 m from the minor embankment in the lee side of a non-flooded area.

MATERIALS AND METHODS

The portable particle sizer/settling tube we used is the LISST-ST Type C manufactured by Sequoia Scientific, Inc. (Bellevue, WA, USA) (Fig. 2). The Dutch National Institute

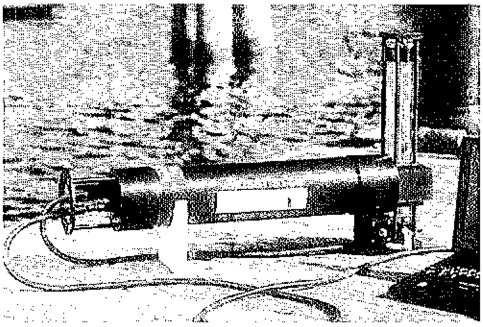

Fig. 2 The LISST-ST combined particle sizer and settling tube measures 86.36 × 48.90 cm. The horizontal tubing holds the laser. The settling tube (32.4 cm long) can be seen on the right. Photograph: Sequoia Scientific, Inc.

for Inland Water Management and Waste Water Treatment (RIZA) and the National Institute for Coastal and Marine Management (RIKZ) provided the device. We introduce the LISST-ST only briefly here, while the reader is referred to Agrawal & Pottsmith (2000) for a more comprehensive description.

The instrument has been used in several marine, coastal and estuarine studies, but has not often been deployed in a riverine environment. The LISST-ST measures particle sizes and settling velocities of particles ranging from 2.5 to 500 μm using laser diffraction principles following the "exact Mie theory". In addition, a photo-diode measures the transmissivity (clearness, τ) of the water. At the beginning of each experiment, in our case at 12:00 h, the settling tube is opened for 4 s and water with suspended matter is taken in. Next, the suspended matter settles within the settling tube and the grain size distribution is measured 71 times during 12 hours at logarithmically spaced time intervals.

We calculated the settling velocities (w_s) from the decrease of the volume concentration (VC) of the different particle fractions in time using software provided by Sequoia Scientific, Inc. Next, Stokes' law was used to derive the relative density ($\Delta\rho$, $\rho_{grain}-\rho_{water}$) from w_s and class mean diameter (d) for the eight classes. The mass concentration per class is calculated with:

$$\mathrm{SSC} = \mathrm{VC} \cdot \Delta\rho \qquad (1)$$

with SSC = mass concentration per class [mg l^{-1}]. To derive the mean parameters for each measurement, this was followed by:

$$d_m = \sum_{i=1}^{8} \mathrm{SSC} \cdot d \Big/ \mathrm{TSSC} \quad \text{and} \quad w_{sm} = \sum_{i=1}^{8} \mathrm{SSC} \cdot w_s \Big/ \mathrm{TSSC} \qquad (2, 3)$$

with d_m = mass-averaged diameter [μm], w_{sm} = mass-averaged settling velocity [mg l^{-1}] and TSSC = mass concentrations of all eight classes summed up [mg l^{-1}].

For the verification of the SSC measurements of the LISST-ST, we collected three 20-l water samples close to the location of the LISST-ST during the peak discharge on 2 March. On this occasion, and also on 27 February and 7 March, we collected half-litre water samples at 16 locations within the flood plain and one location on the river channel. We filtered 100 ml of these water samples in duplicate through 0.45 μm membranes (50 mm Ø, manufacturer: Schleicher & Schoell) using a vacuum pump. The membranes were subsequently dried for 4 h at 70°C and weighed. During the late March deployment, the measurement frame also included a Sea-Point Optical Backscatter Sensor (OBS), which recorded the turbidity of the water nearly continuously.

RESULTS

First, we checked τ for all the measurements done by the LISST-ST. If τ dropped during an experiment, the measurement was discarded, as was done with the last experiment of early March and the first and last experiment of late March. During the single settling experiments, τ increased on average 22.6% (early March) and 17.4% (late March). At the end of the data series, the transmissivity was the largest and its increase the smallest. It never reached 100% owing to the short time per experiment we adopted: not all sediment settled down within 12 h. Therefore, all results obtained by the LISST-ST refer to particles that settle in a 32.4 cm column within 12 h, i.e. have a theoretical settling velocity of more than 7.5×10^{-4} cm s^{-1}.

Suspended sediment concentrations

In Fig. 3, the SSC data for early March are depicted. The peak in SSC coincides with the peak stage at 2 March and the increase and decrease in SSC relate to the rising and falling stage, respectively. The LISST-ST SSC at peak stage (60 mg l^{-1}) is nearly the same as in the bulk water samples, which varied from 55.5 to 63.6 mg l^{-1}. This indicates that the error made in the exclusion of the finest particles by the LISST-ST owing to the short settling period is small. Note that the LISST-ST data are probably not representative for the whole flood plain, as the average concentrations are lower than the LISST-ST SSC. It appears that the concentrations at the location of the LISST-ST more closely resemble the concentrations in the river channel than those in the rest of the flood plain. This can be explained by the location of the measurements, which is relatively close to the river channel. Areas further away from the river channel receive less sediment. The reason for the high SSC recorded on 9 March is not clear. It can neither be explained by a sudden input of new sediment from the main channel, nor by input of other sediment sources.

Figure 4 contains the late March data series. There is no relation between water level and SSC for late March. During the second flood the water level in the river channel overtopped the minor embankment only just enough to inundate the flood plain. The water level in the river channel subsequently dropped below the top of the minor embankment and the flood plain no longer received water with suspended sediment. Nearly all of the sediment could therefore settle in the confined water body

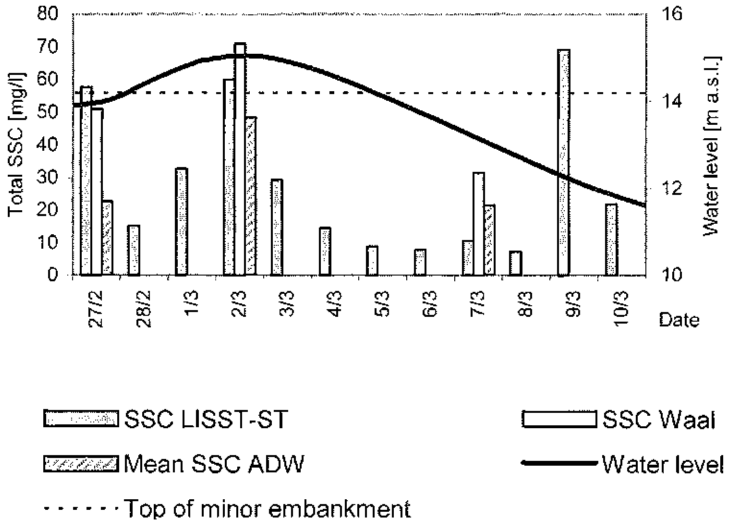

Fig. 3 The total suspended matter concentrations recorded by the LISST-ST and derived from the 0.5 l water samples taken on the River Waal (n = 1) and the Afferdensche & Deetsche Waarden (ADW) flood plain (n = 16).

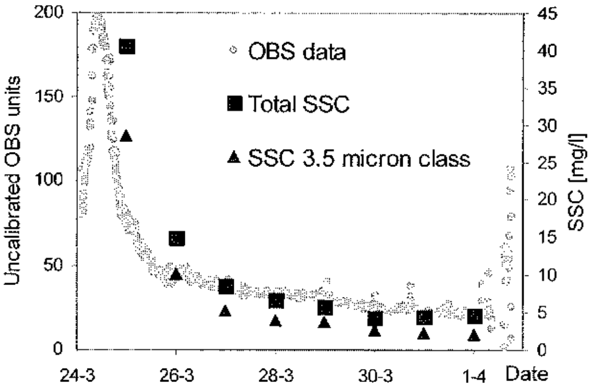

Fig. 4 The uncalibrated OBS output against the suspended sediment concentrations obtained by the LISST-ST for all size classes and the finest size class.

of the flood plain. Instead of water level, Fig. 4 contains the uncalibrated OBS signal. The OBS records the turbidity of the water every 10 min. The OBS data verify that gradual settling of suspended matter takes place, as is indicated by the decreasing SSC values. Note that the SSC are lower during late March than early March, showing the dependency of the SSC on (peak) discharge: the higher the discharge, the more sediment is conveyed to the flood plain resulting in higher SSC in the inundation water.

Grain size distributions (GSD)

The LISST-ST provides measurements within 32 grain-size classes, which are resampled by the software to 8 size classes, their midpoints being logarithmically spaced at 3.5, 6.8, 13.1, 25.4, 49.2, 95.5, 185 and 359 μm. In Fig. 5, only the six finest classes are displayed, since the concentrations within the 185 and 359 μm classes were generally very low. During the early March flood (Fig. 5(a)), the sediment is at its coarsest during the peak. After the passage of the peak, the GSD remains more or less the same, despite the diminishing SSC (Fig. 3): there is no evidence that larger particles settled first. The contrary is visible for the late March data series: Fig. 5(b) shows the fraction taken up by the finest class diminishes in favour of the next finest class during the period of diminishing SSC. This may be attributed to the formation of flocs in the quiescent water behind the minor river dike. Despite the somewhat different GSD, both mean grain sizes fluctuate around 10 μm and were not significantly different ($\alpha = 0.05$).

Settling velocities

The settling velocities for the different grain sizes are displayed in Fig. 6. The two data series are only significantly different for the 13.1 and 25.4 μm classes (two-tailed Wilcoxon signed ranks test, $\alpha = 0.05$). The other classes within the two data series

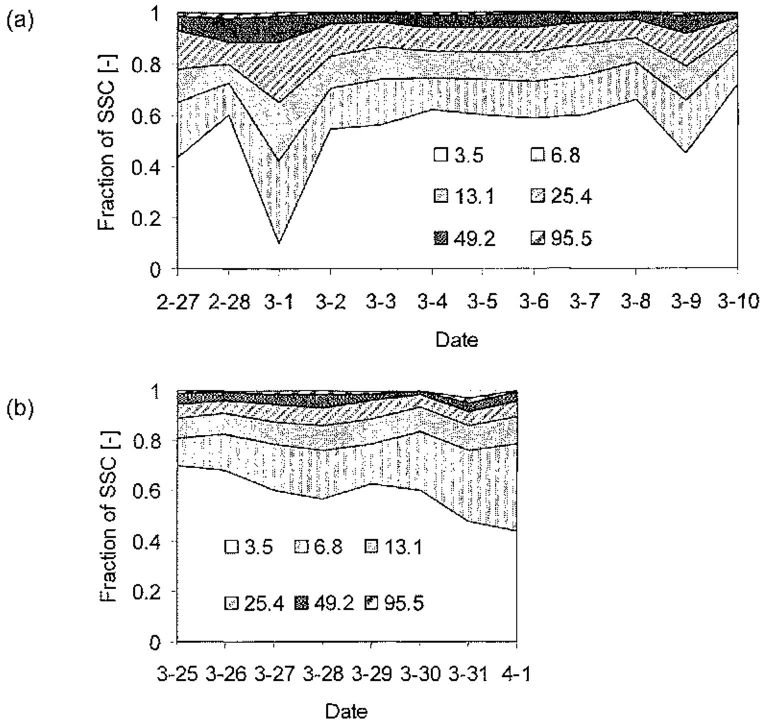

Fig. 5 The grain size distribution for the six most important size classes for (a) the early March data series and (b) the late March data series. Grain sizes are in μm.

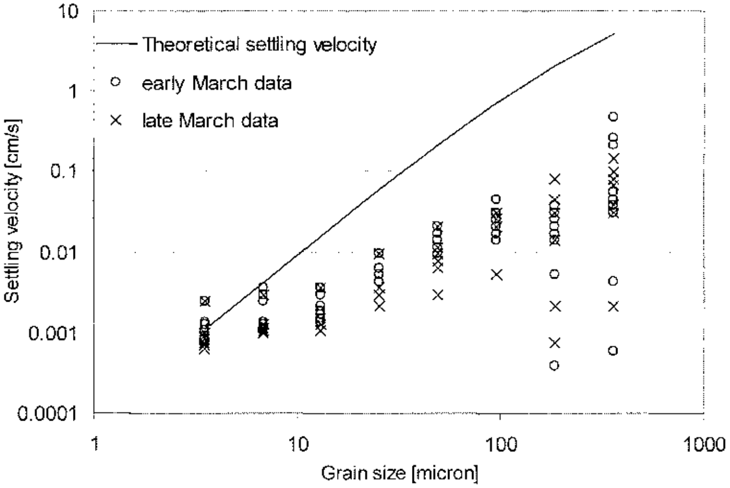

Fig. 6 Theoretical settling velocity (calculated from Stokes' law) *vs* settling velocities measured with the LISST-ST.

overlap. The data gathered during the field experiments severely underplot the theoretical particle size–settling velocity relationship (Stokes' law). Stokes' law over predicts the settling velocities by up to 70 times, with the degree of overprediction increasing with grain size. For the two largest grain size classes, Droppo *et al.* (1997, see Fig. 4) reports comparable data with values around 0.2 cm s^{-1} for the 185-μm class and around 0.3 cm s^{-1} for the 359-μm class.

DISCUSSION AND CONCLUSIONS

The early March data series exhibits a larger input of suspended matter with a coarser size distribution. This can be explained by the higher water level during the early March deployment: higher discharges are generally accompanied by higher SSC. This was verified by data from RIZA measured at the Dutch-German border: the river water carried 59.0 mg l^{-1} during the peak discharge on 2 March, while it carried only 14.5 mg l^{-1} during the peak on 24 March. Besides, at higher water levels lower parts of the water column can also reach the flood plain. These lower parts are more turbulent and therefore supposed to contain larger flocs. This combination of higher SSC and a coarser GSD at peak discharge lasts longer than the period in which the water level in the river channel overtops the minor dike. Also, during the rest of the inundation period, the early March SSC values are higher and the GSD is coarser than for late March. This indicates that the general relationship between discharge and suspended sediment characteristics for river channels also holds for embanked flood plains.

We found a significant difference between the two floods regarding settling velocities for only two size classes. Therefore, it can be concluded that discharge does not influence w_s. It probably depends on the sources and composition of the suspended matter, i.e. the evolution of the flocs in the flood water.

The data on settling velocity further show that the particle size-settling velocity relationship according to Stokes' law cannot readily be used in flood plain sedimentation modelling, since this would lead to severe over prediction of sedimentation amounts in the case of the presence of particles that are coarser than the fine silt fraction. In suspended matter, these particles are most probably flocs. These flocs do not meet the assumptions of Stokes' law, since they are heterogeneous and porous instead of spherical and impervious.

PERSPECTIVE

In the near future, the characteristics of sediment from sediment traps that were also placed in the flood plain and around the steel construction, will be compared with the LISST-ST data and the concentration data from the water samples. This will reveal the discrepancy between the 'effective' (suspended) and 'ultimate' (deposited) grain sizes within a flood plain environment. Next, it will reveal the relation between suspended sediment concentrations and sedimentation amounts throughout the flood plain.

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