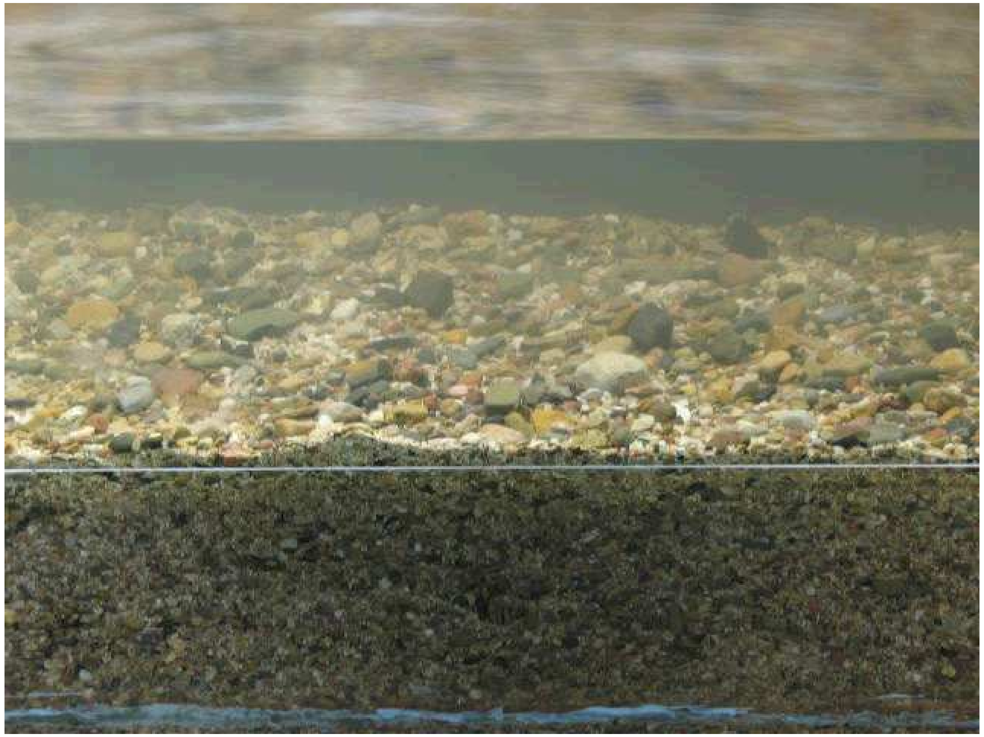
Technische Universität Braunschweig

Sampling Techniques of Sediment Transport



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XXX International School of Hydraulics

Wiejce, Poland, 14-17 September 2010

Outlook

- Characteristics of Sediment Transport
  - Classification of Sediment Load
  - Effect of the Hydrograph
  - Influence of the River Geometry
- Demands on Sampling Techniques
- Sampling Techniques
  - Suspended Load
  - Bed Load
- Summary

Classification of Sediment Load

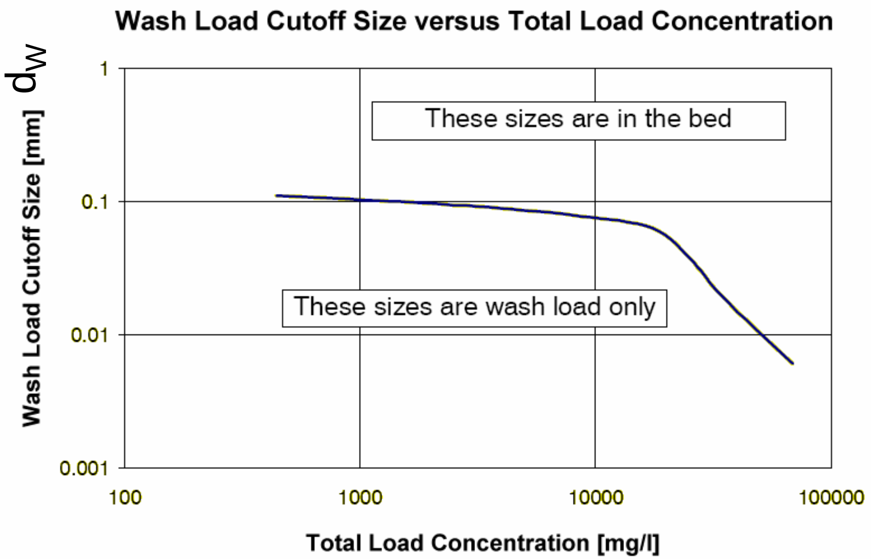
Total Sediment Load	By Origin	By Transport Mechanism	By Grain-Size
	Wash load	Suspended load	Wash load $Z < 0.06$
	Bed-material load		Suspended load $0.1 < Z < 5$
		Bed load	Bed load $Z > 5$
	Bed material		

$$\text{Rouse} - \text{Number} \qquad Z = \frac{w_s}{\kappa \cdot u_*}$$

Classification of Sediment Load

Wash load

- Sediment transported in the water column without contact to the river bed
- Controlled by land surface erosion
- Silt and clay with d < 0.062 mm (not part of the bed material)
- Rouse-Number Z < 0.06
- Concentration in mass/volume [g/l]
- Einstein & Chien (1953):
  not determined by hydraulics
- Paola & Parker (2000):
  d_W is a function of flow conditions and sediment loading



Classification of Sediment Load

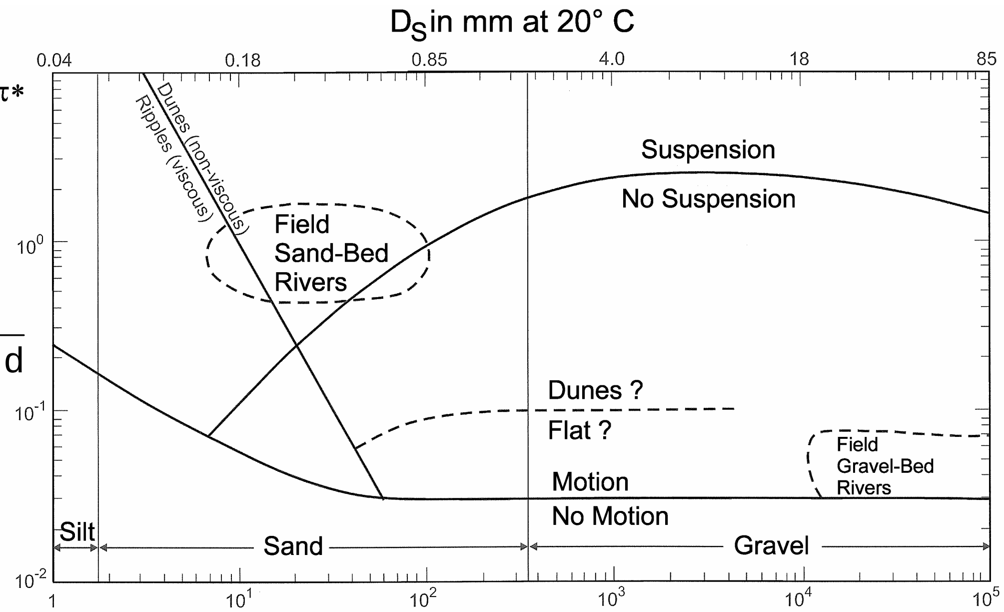
Bed material load

- Sediment transported with periodic or permanent contact to the river bed (suspended and bed load)

- Grain-sizes which can be found in the bed material (d > 0.062 mm)

- Transport mechanism depends on grain-size and flow strength

$$\tau^* = \frac{\tau_0}{(\rho_S - \rho)\cdot g \cdot d}$$



$$Re^* = \frac{u^* \cdot d}{\nu}$$

Re*

(García 1999)

Classification of Sediment Load

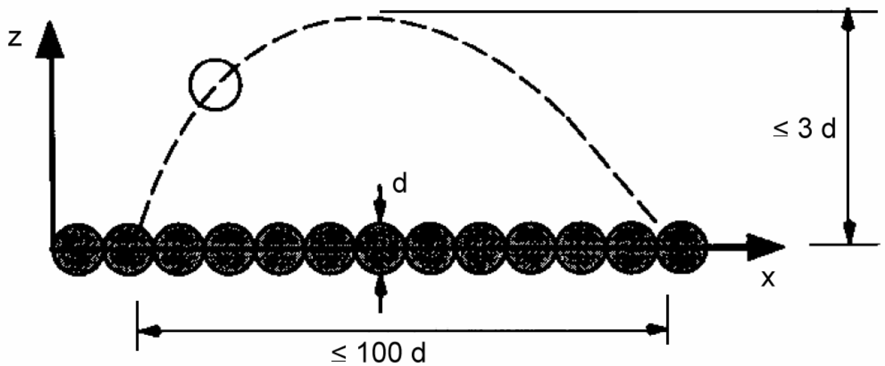
Suspended load

- Sediment transported in the water column
- Typically mud and sand d < 2 mm
- Classification by grain-size: Rouse-Number 0.1 < Z < 5
- Concentration in mass/volume [g/l]
- Threshold for entrainment depends on flow turbulence and fall velocity (see e.g. Niño et al. 2003)

Classification of Sediment Load

Bed load

- Sediment transported at the river bed
- Classification by grain-size: Rouse-Number Z > 5
- Grain-size d > 0.062 mm (> 2 mm)
- Transport rate in mass/(width time) [kg/(m s)]
- Movement occurs sliding, rolling or saltating



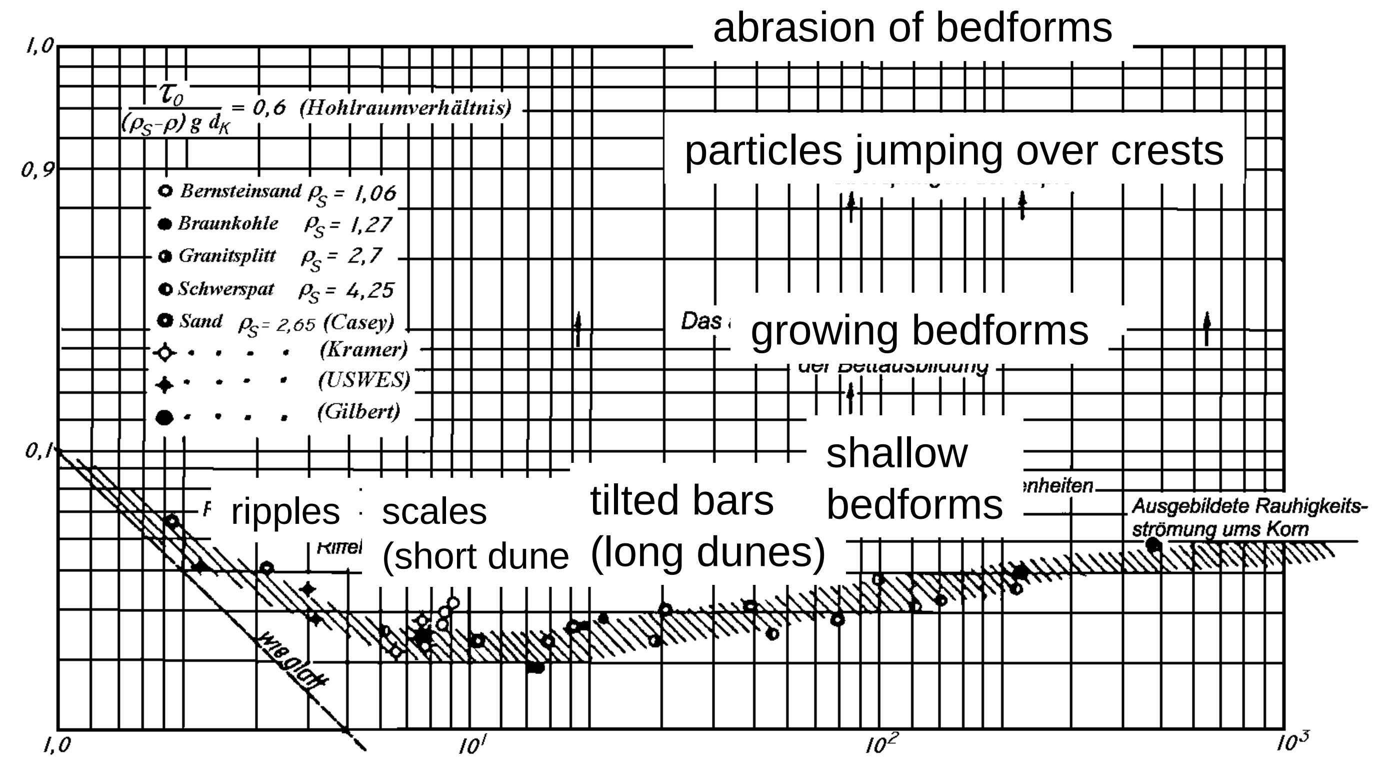
(Niño & García 1998)

Bed load

- Threshold depends on shear stress and weight under buoyancy

Shields-Parameter

$$\tau^* = \frac{\tau_0}{(\rho_S - \rho)\cdot g \cdot d}$$



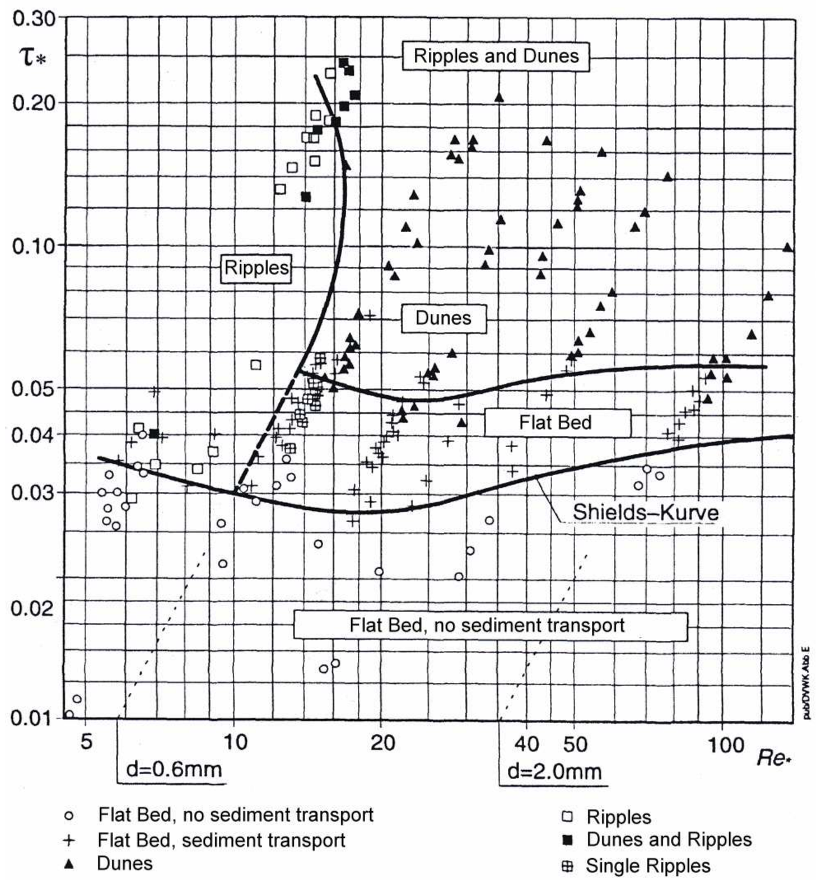
Grain-Reynolds-Number $Re^* = \frac{u^* \cdot d}{\nu}$

(Shields 1936)

Classification of Sediment Load

Bed load

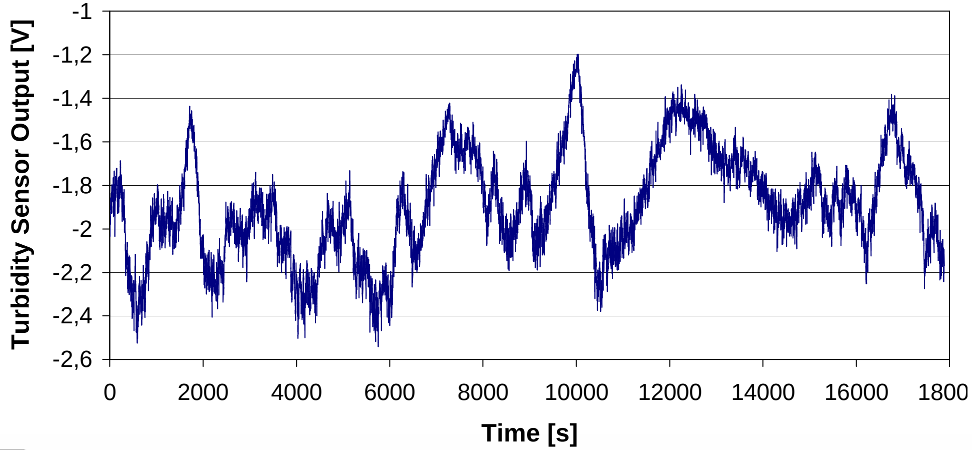
- Generation of bed forms depends on grain-size and shear stress



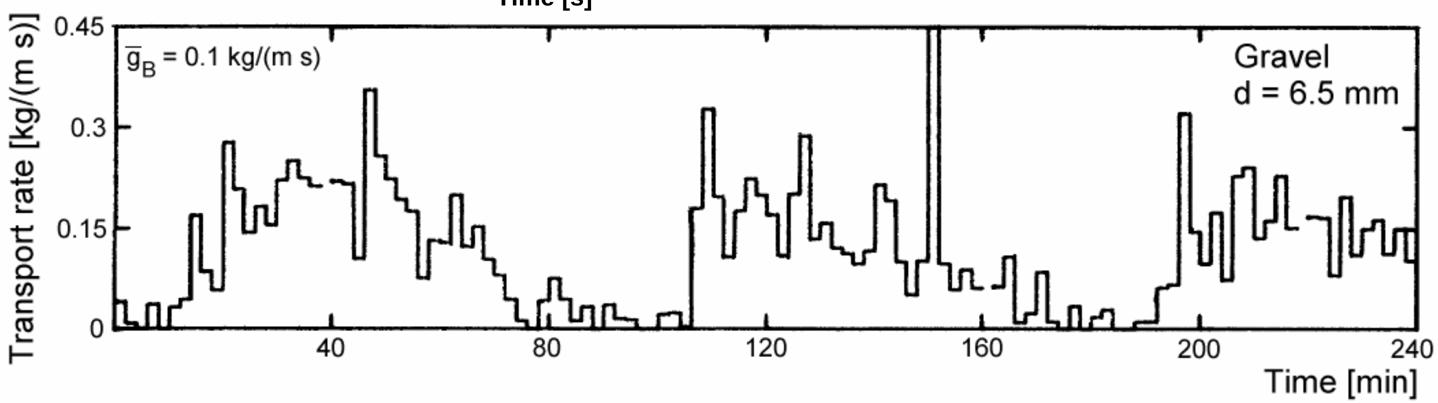
(Chabert & Chauvin 1963)

Bed load

- Long-term fluctuations due to bed forms



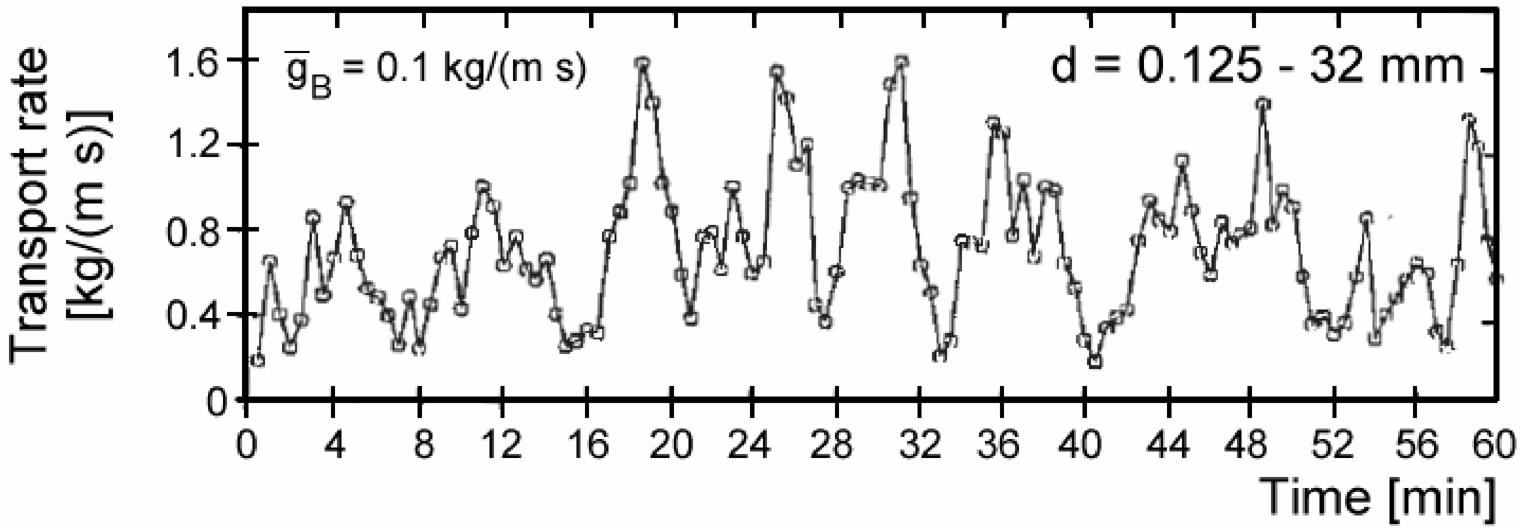
Sand
d = 0.7 mm



(Hubbell et al. 1987)

Bed load

- Short term fluctuations of transported sand and gravel under steady flow conditions



(Kuhnle & Southard 1988)

Demands on Sampling Techniques (1)

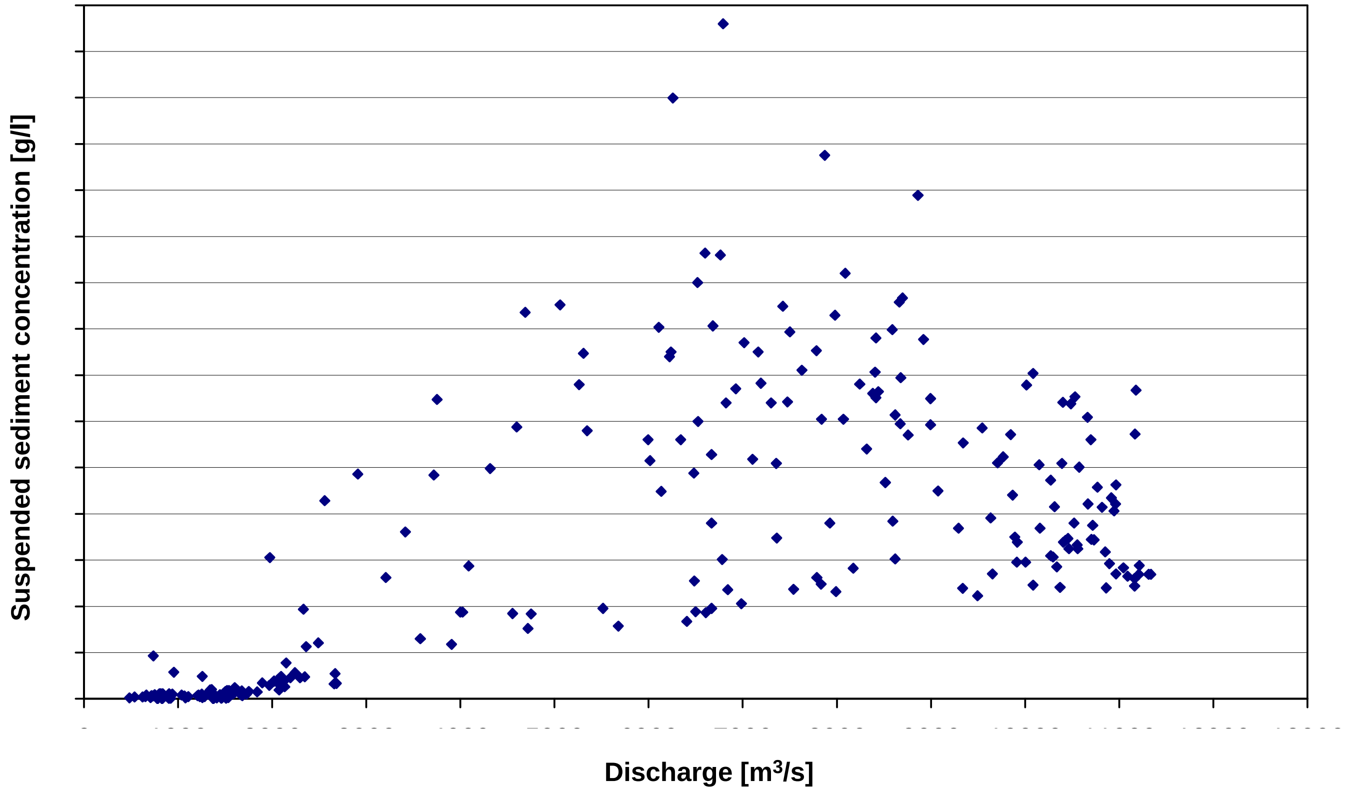
due to the classification of sediment load

- Mesh size small enough to catch fine particles
- Nozzle size (entrance) large enough to catch coarse particles
- Streamlined sampler to be positioned in the water column
- Heavy sampler to stay on the river bed
- Sampling volume large enough to cover transport fluctuations

Effect of the Hydrograph

Suspended load

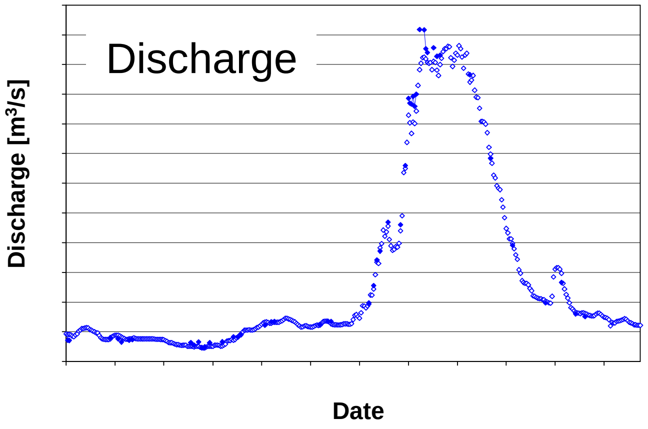
- Concentration as a function of discharge results in a scatter plot

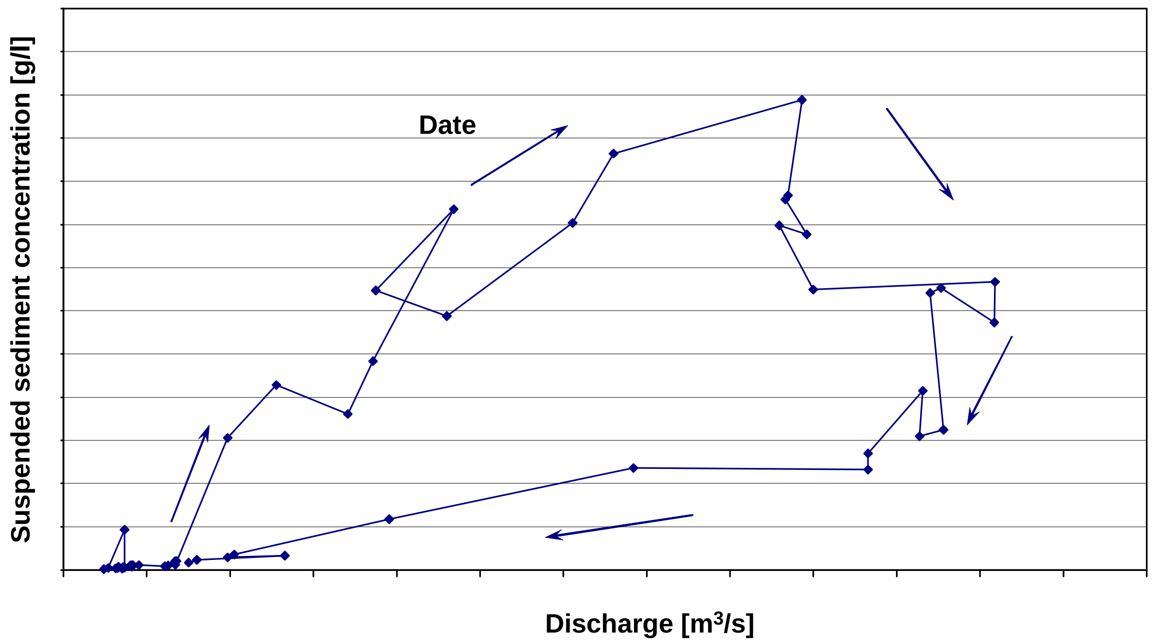


Effect of the Hydrograph

Suspended load

- Consideration of the time reveals hysteresis effects





Effect of the Hydrograph

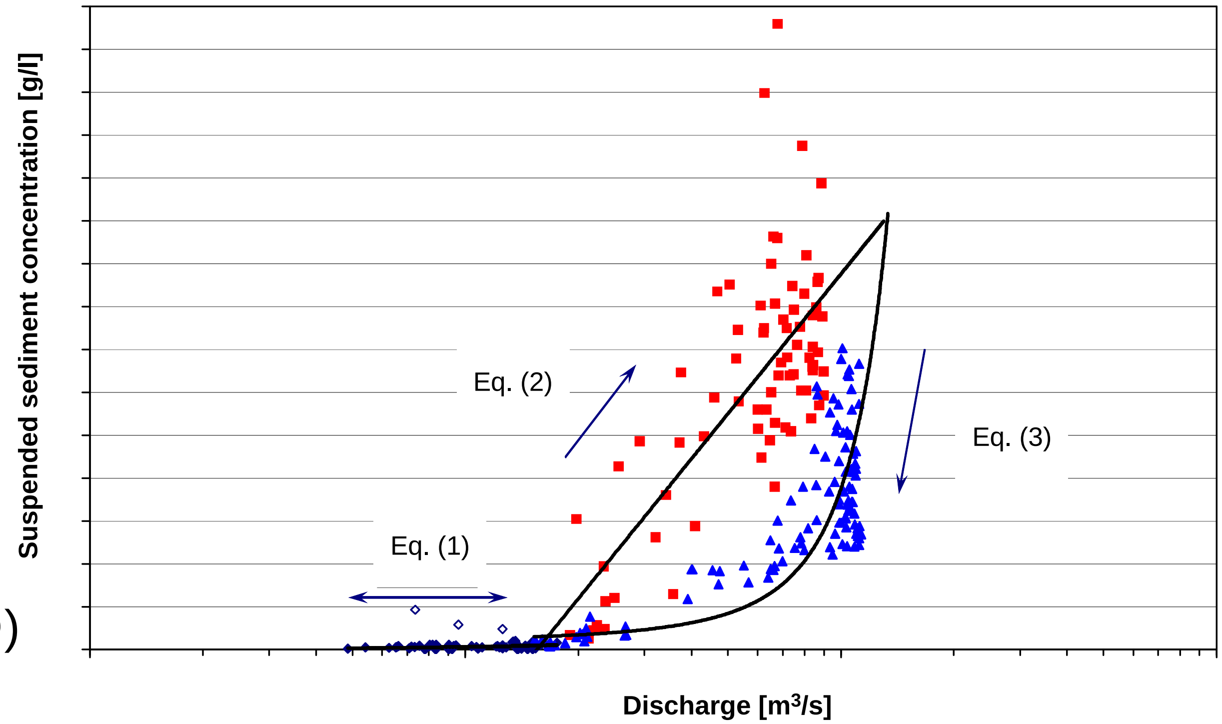
Suspended load

- Consideration of hysteresis effects enables development of functional relations between flow strength and transport rate

$$\text{Eq.}(1) \quad SSC = a_1 \cdot Q$$

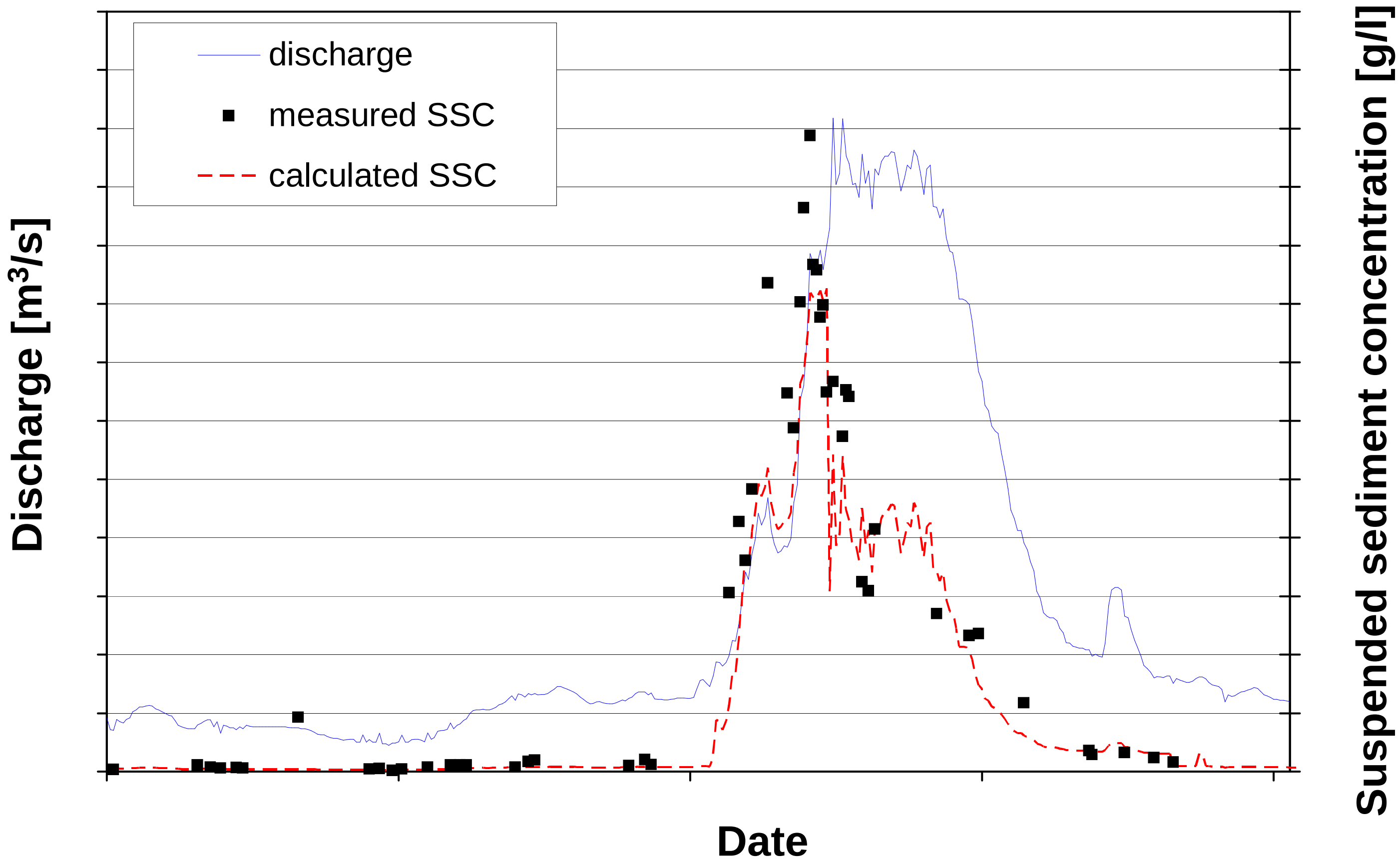
$$\text{Eq.}(2) \quad SSC = a_2 \cdot \ln Q + a_3$$

$$\text{Eq.}(3) \quad SSC = a_4 \cdot \exp(a_5 \cdot Q)$$



Effect of the Hydrograph

Suspended load



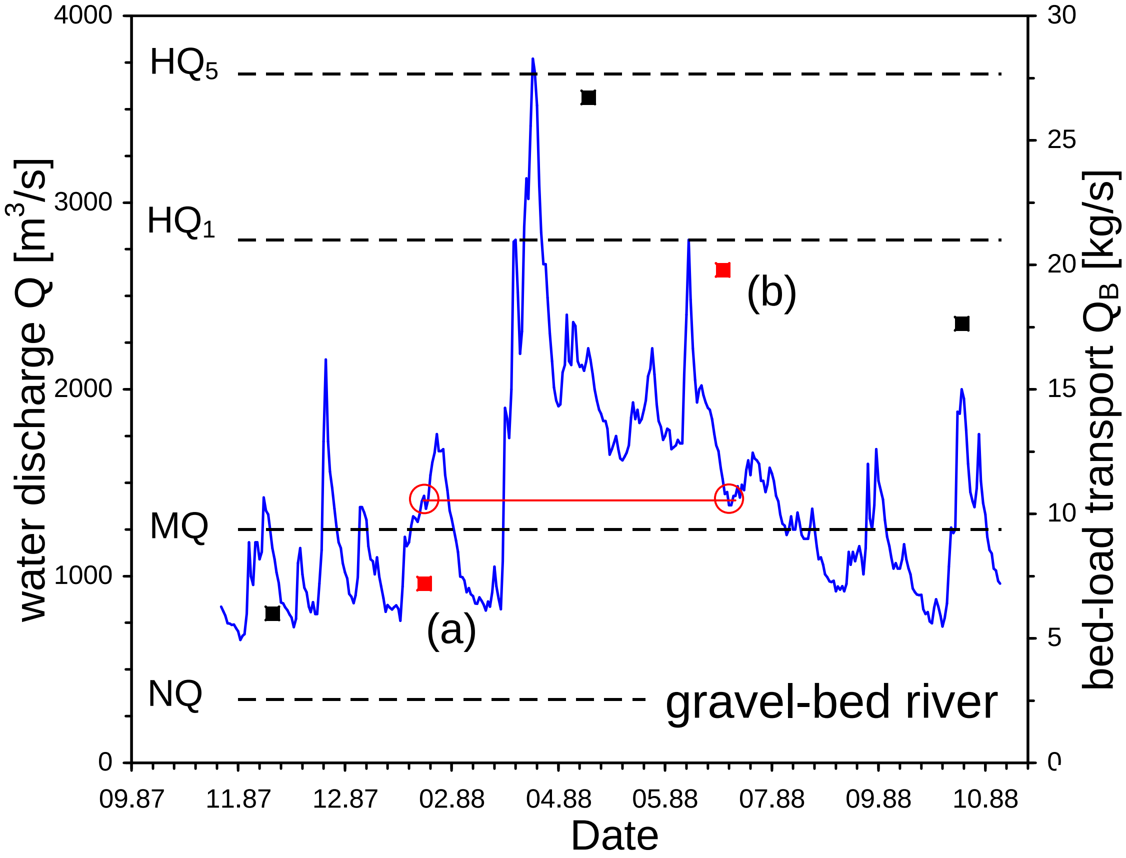
Effect of the Hydrograph

Bed load

- Hysteresis effects can be evident in transport rate and grain-size distribution of bed load

$Q_{(a)} \approx Q_{(b)}$

$Q_{B(a)} < Q_{B(b)}$



Effect of the Hydrograph

Bed load

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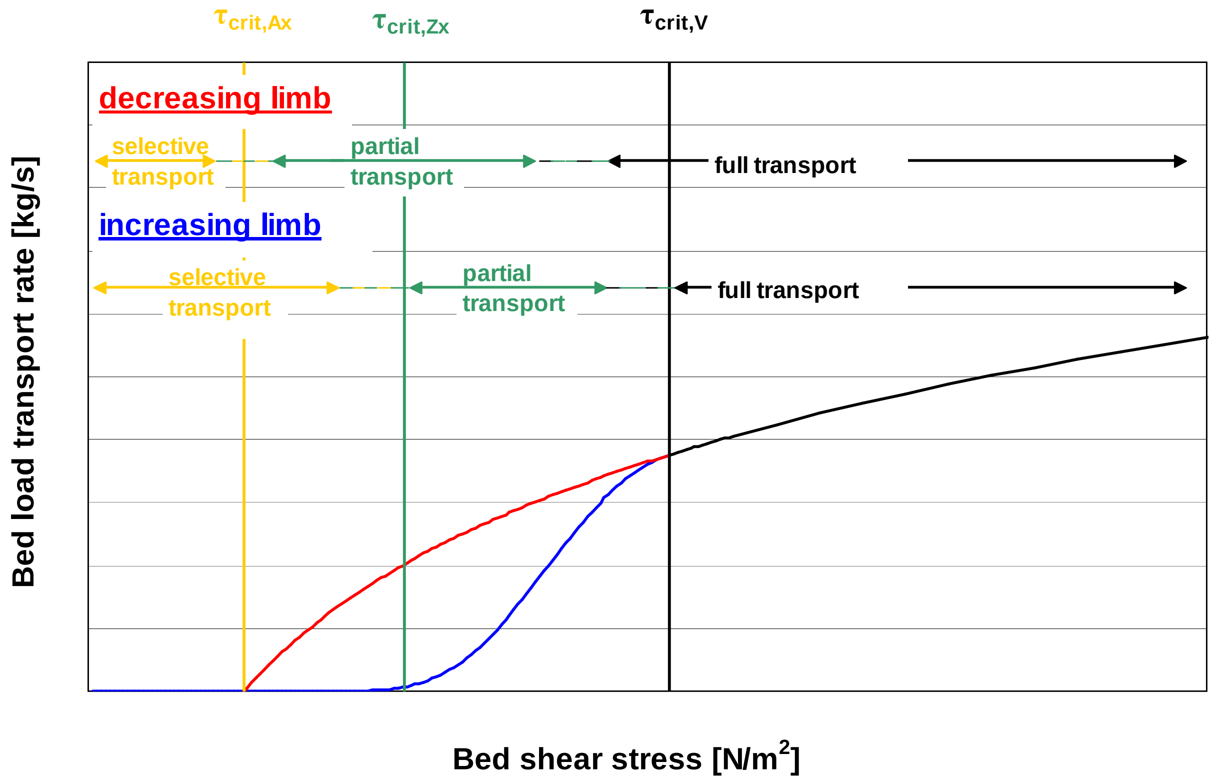


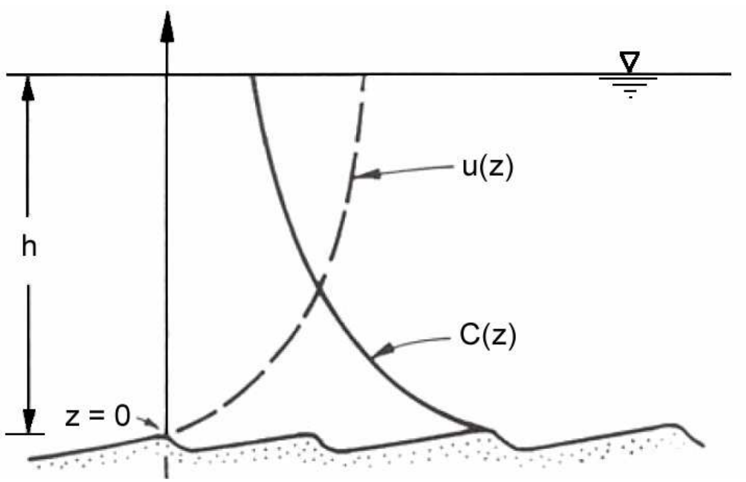
Demands on Sampling Techniques (2)

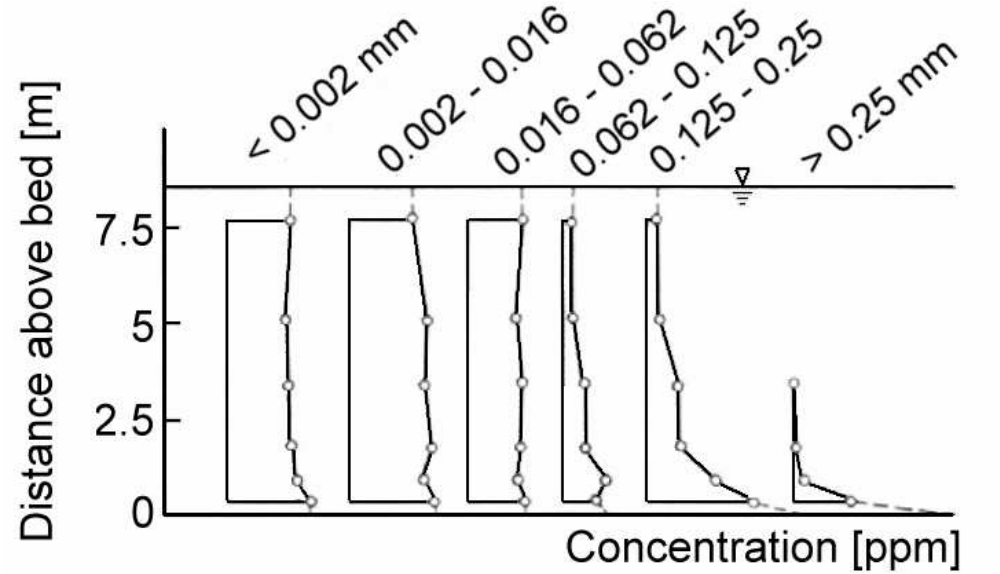
due to the hydrograph

- Ideal: continuous measurements with time dependent records
- Otherwise: easy to handle sampler for frequent samplings
- Small enough (streamlined) for sampling during low flow
- Strong enough for sampling during flood events

Suspended load

- Concentration increases towards the bed
- Grain-size distribution depends on depth

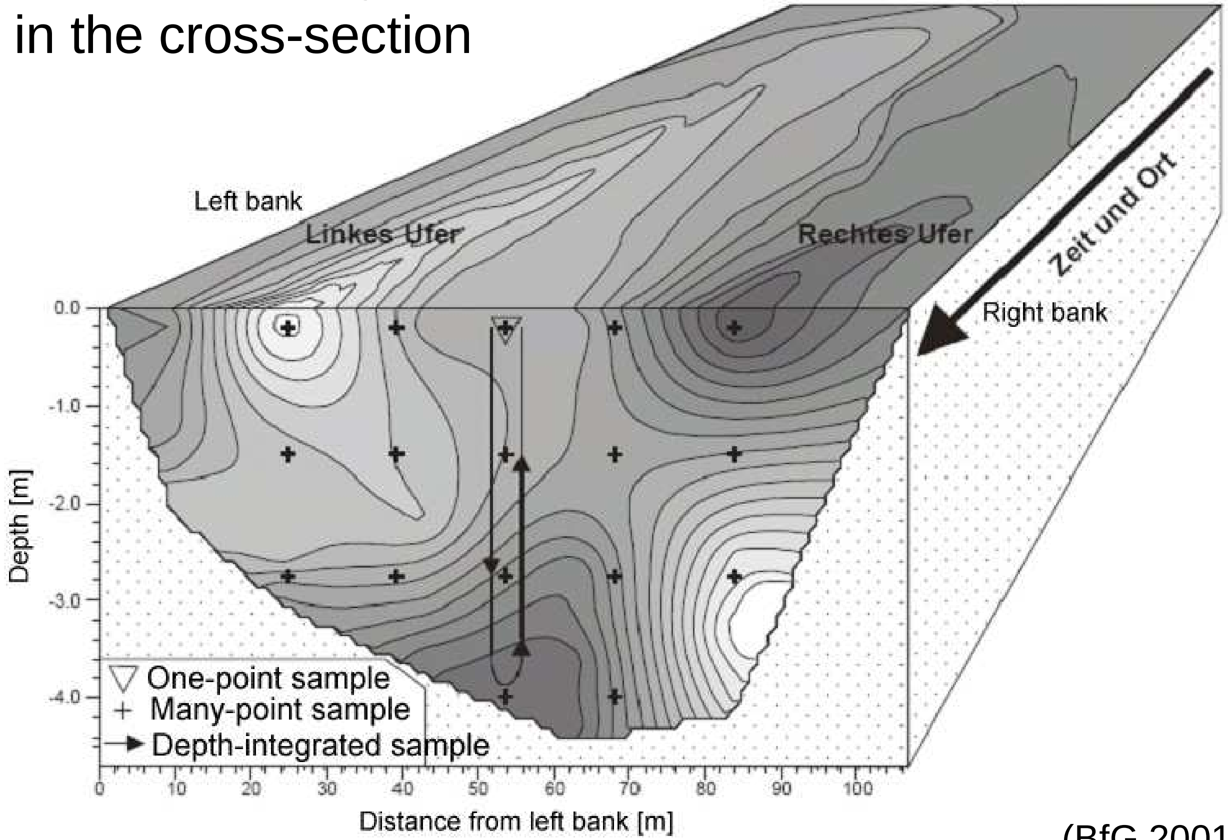




Influence of the River Geometry

Suspended load

- Concentration varies with flow velocity and thus with position in the cross-section and along the river

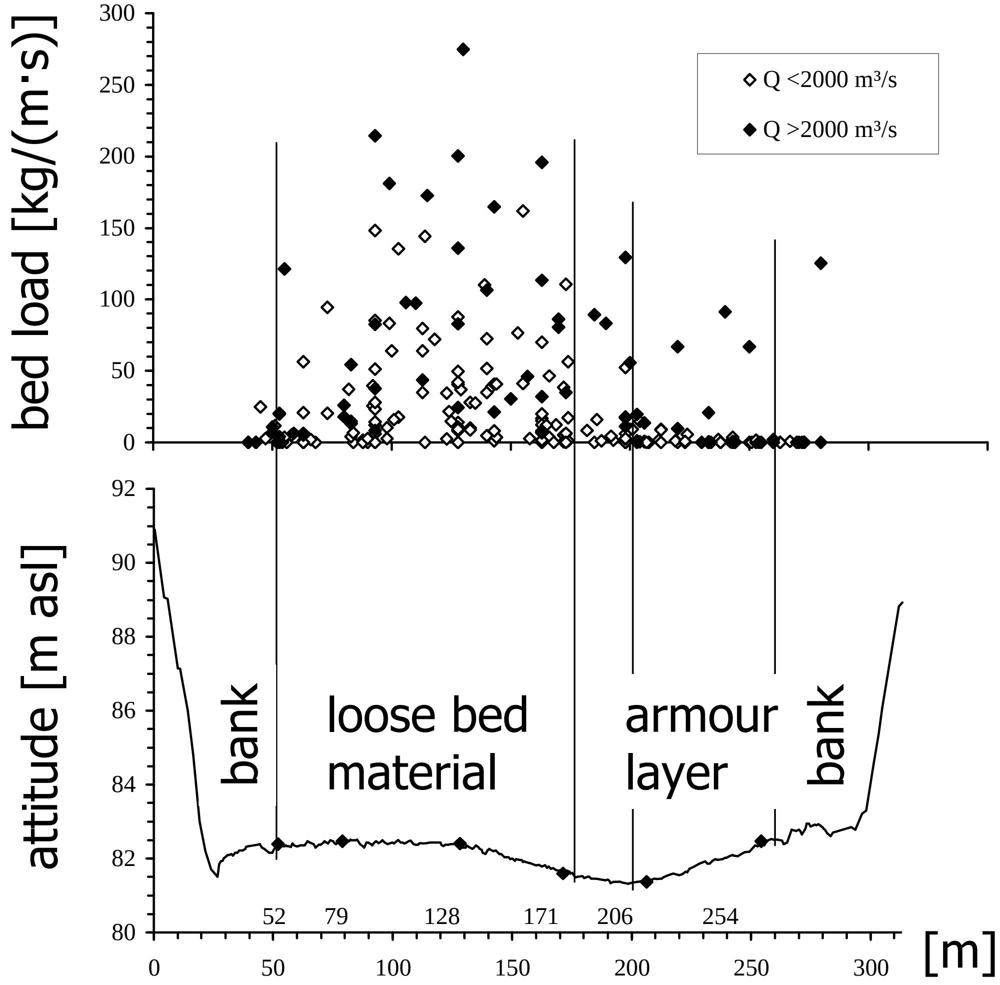


(BfG 2001)

Influence of the River Geometry

Bed load

- Transport rate depends on bed shear stress and bed stability
- Active part of the bed can vary with flow rate



Demands on Sampling Techniques (3)

due to river geometry

- Sampling over the whole cross-section
- Sampling over the whole bed width
- Ideal: simultaneous sampling at several positions
- Otherwise: short sampling intervals

Demands on Sampling Techniques

Summary

- Continuous measurements with time dependent records simultaneously sampled over the whole cross-section
- Easy to handle sampler for frequent samplings with short intervals but heavy enough for sampling during flood events
- Streamlined, small sampler with a sampling volume large enough to cover transport fluctuations
- Nozzle size large enough to catch coarse particles and mesh size small enough to catch fine particles

Sampling Techniques

Suspended load

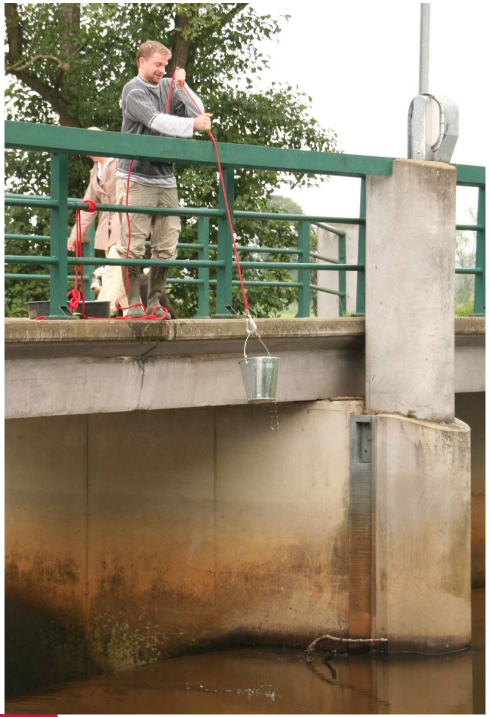
- Indirect methods: extraction of samples containing water and sediment
- Direct methods: optical and acoustic measurements

van Rijn, L.C. (1986):
Manual sediment transport measurements.
Delft, The Netherlands: Delft Hydraulics Laboratory

Suspended load - Indirect methods

- Depth-integrating sampling

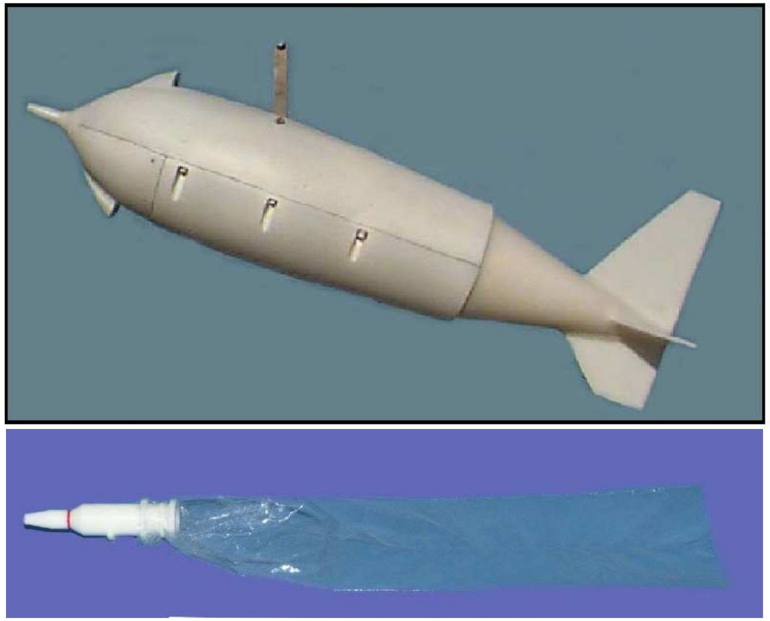
Buckets



Suspended load - Indirect methods

- Depth-integrating sampling

US D-96



- Static pressure determines inflow velocity
- Flow velocity:
  0.6 - 3.8 m/s
- Maximum transit rate:
  0.4 x flow velocity

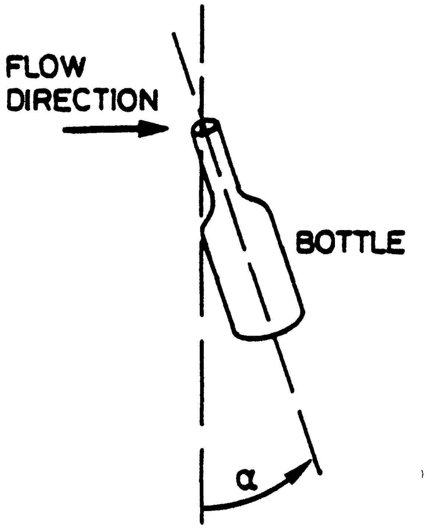
3l collapsible bag
weight ca 60 kg

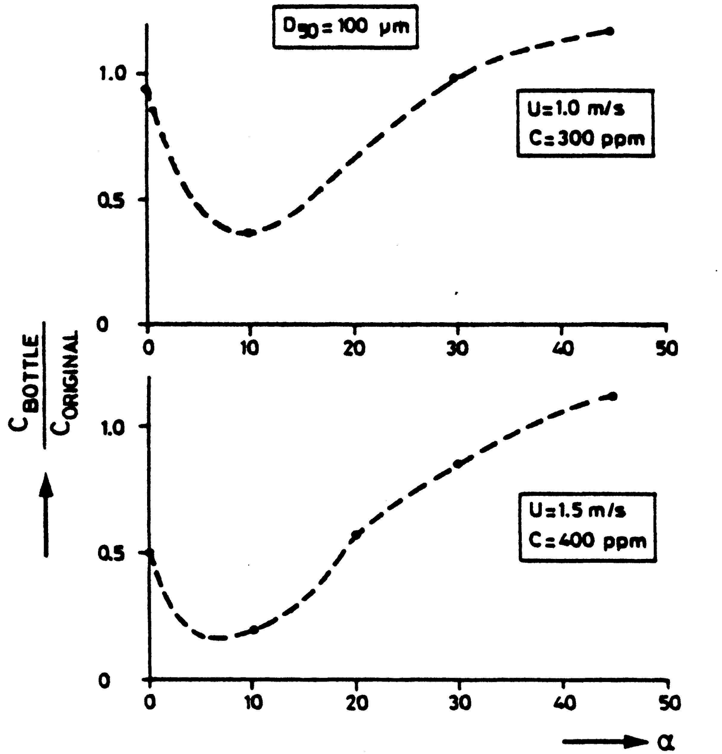
(FISP)

Suspended load - Indirect methods

- Point-integrating sampling

Bottles



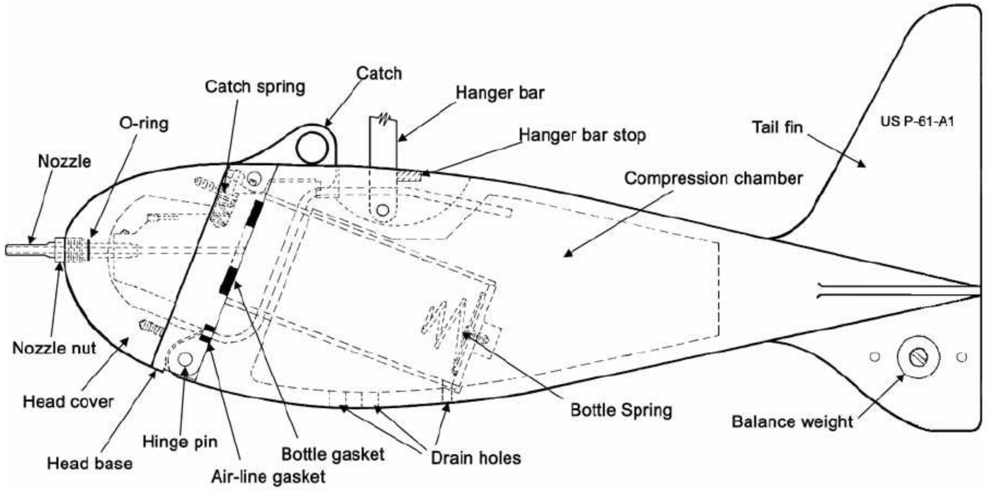


(van Rijn 1986)

Suspended load - Indirect methods

- Point-integrating sampling

US P-61



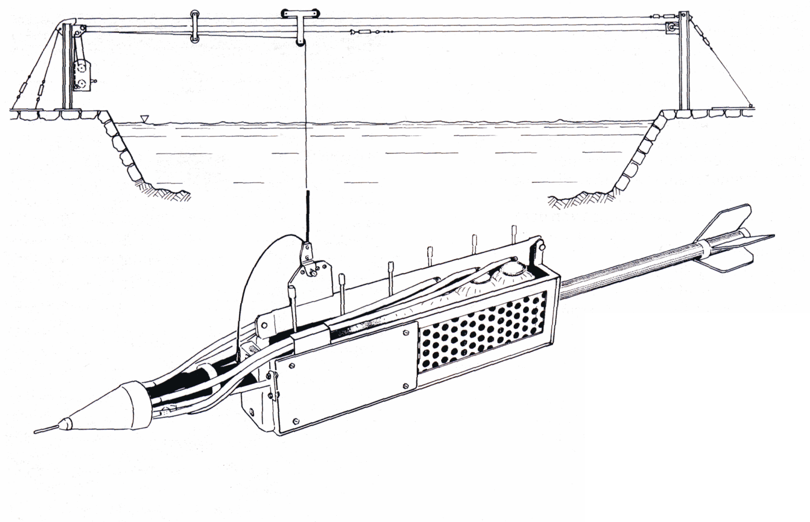
1 bottle with ca 0.5 l or 1 l
grain-size < 5 mm
electronic valve opening
weight ca 50 kg

(FISP)

Suspended load - Indirect methods

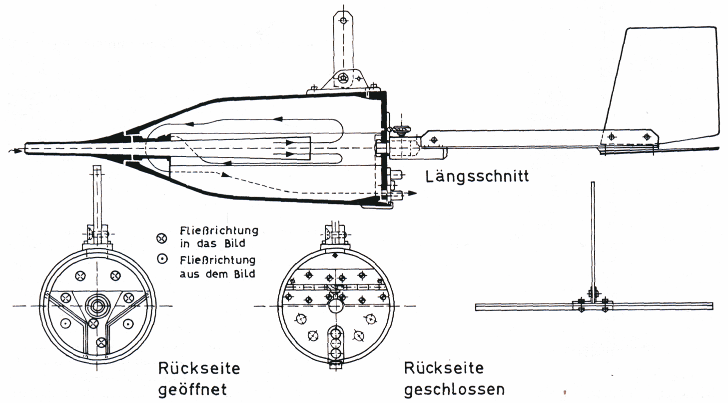
- Point-integrating sampling

Ott-Sampler



6 2l bottles
electronic valve opening
weight ca 80 kg

Delft Bottle



flow-through principle
collecting only sediment > 0.1 mm

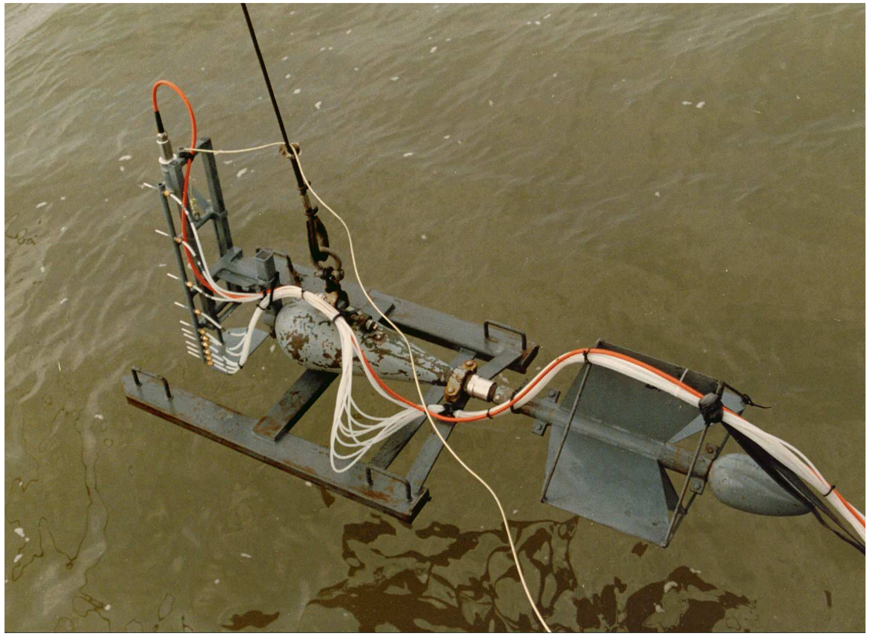
(DVWK 1986)

Sampling Techniques

Suspended load - Indirect methods

- Point-integrating sampling

Pump-Sampler



- Pump speed has to be adjusted to flow velocity
- Velocity in the hose > 1 m/s
- Hose length < 25 - 50 m

(van Rijn 1986)

Suspended load - Indirect methods

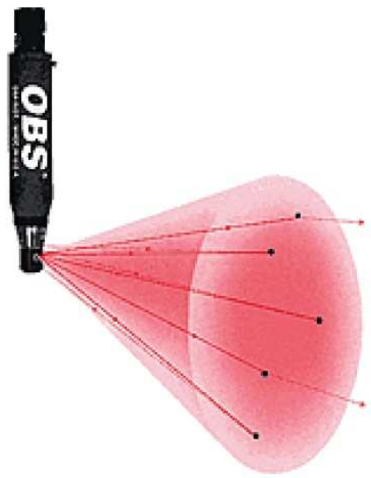
- Standard method used to calibrate other techniques
- Disadvantages:
  - Disturbance of the flow field
  - Assumption of iso-kinetic flow
  - Samples have to be analysed in the lab

Sampling Techniques

Suspended load - Direct methods

- Optical and acoustic measurements

Optical Backscatter (OBS)

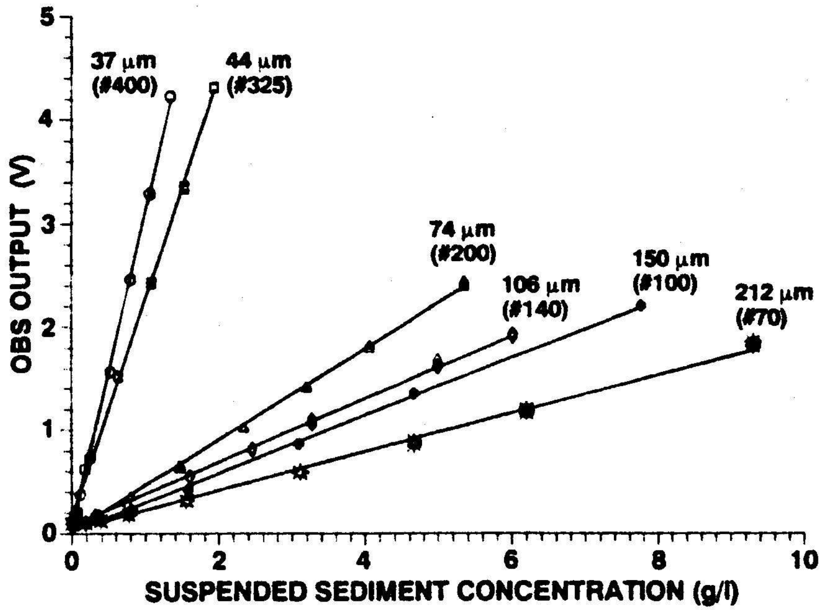


- Infra-red light is reflected by particles and detected by photo detectors
- The resulting photo current depends on illuminated area
particle size, shape, and reflectivity
- Site dependent calibration is necessary to get SSC [g/l]

Suspended load - Direct methods

- Optical and acoustic measurements

Optical Backscatter (OBS)



- Linear relation between OBS output and SSC
- Different relations for different particle sizes

(van Rijn 1986)

Suspended load - Direct methods

- Optical and acoustic measurements

Optical Laser Diffraction instruments (LISST)

Inlet

Settling tube

Laser

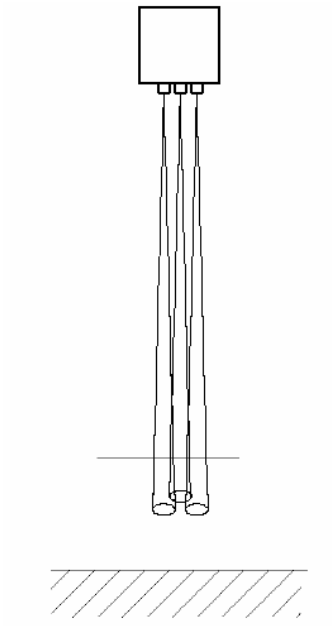
Outlet

- Simultaneous measurement of SSC and particle-size
- Determination of settling velocity (settling time 12 or 24 h)
- Assumption: no particle interaction
- SSC < 5 g/l
- Grain-size < 0.25 mm

Suspended load - Direct methods

- Optical and acoustic measurements

Acoustic Backscatter (ABS)



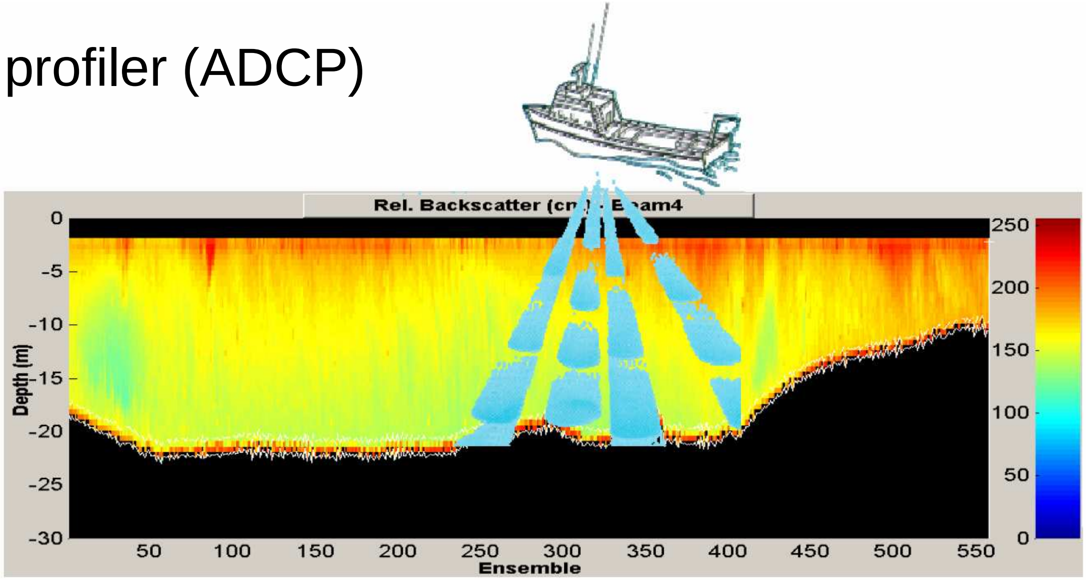
- Emission of short pulse acoustic energy (0.5 - 5 MHz)
- Backscattered signal is related to sediment concentration, particle size, and time delay
- Non-intrusive technique
- Grain-size 0.01 - 0.5 mm

(Smerdon, Rees & Vincent)

Suspended load - Direct methods

- Optical and acoustic measurements

Acoustic Doppler current profiler (ADCP)



- Echo intensity depends on sediment concentration and grain-size
- Site-specific relation between echo intensity and SSC
- Extensive calibration required

Suspended load - Direct methods

- Sampling of profiles and cross-sections is possible
- Continuous data acquisition is possible
- Main disadvantage:
  - Site-specific / repeated / extensive calibrations

Sampling Techniques

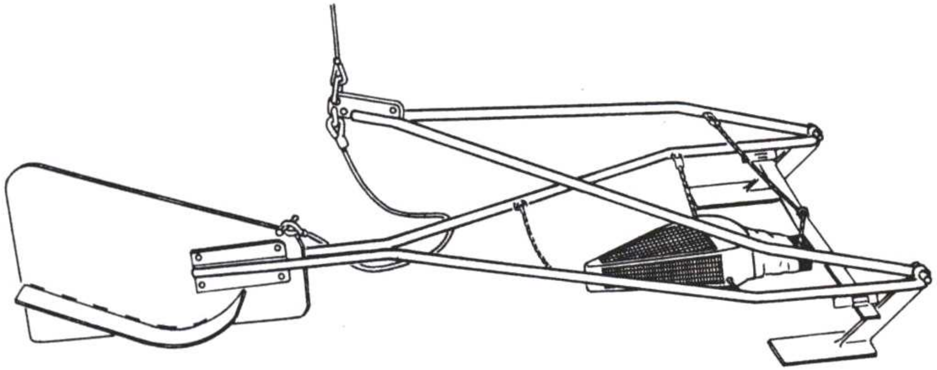
Bed load

- Samplers and Traps
- Tracer (natural /artificial magnetic; colour; radioactive)
- Acoustic techniques (hydrophones, ADCP)
- Bed form tracking (echo-sounders, ADCP)

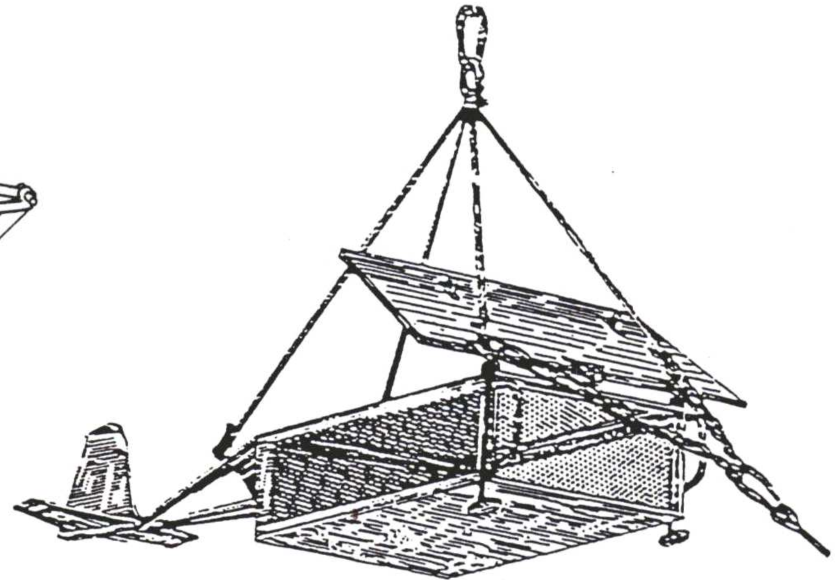
Bed load

- Portable sampler

Bed load Transport Meter Arnhem (BTMA) (1930)



Mühlhofer sampler (1933)

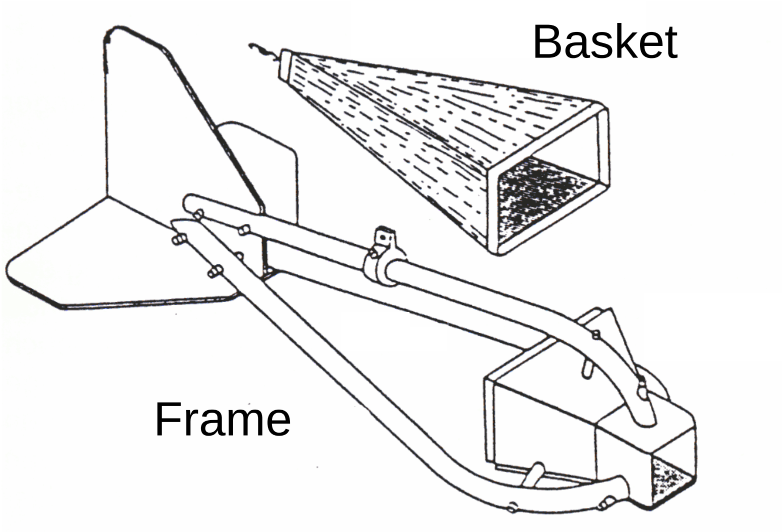


Sampling Techniques

Bed load

- Sampler

Helley-Smith (1971)
(HS-76, BL-84)



Expanding entrance

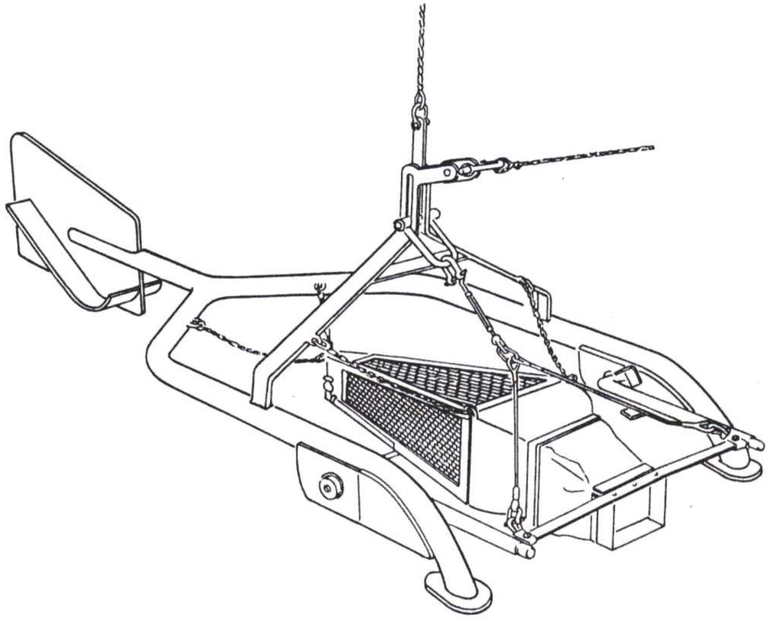
- Pressure-differential entrance to counterbalance blocking effects

Sampling Techniques

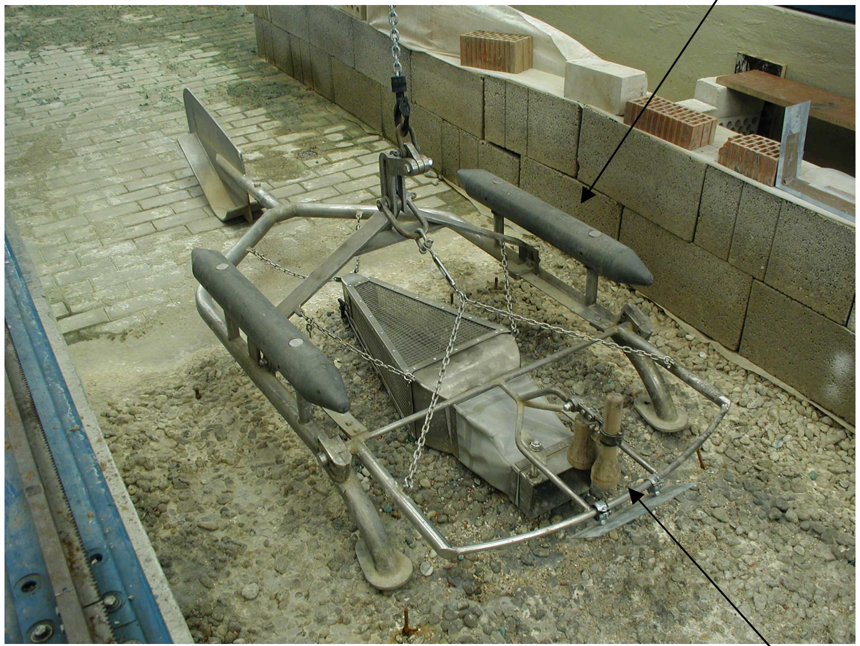
Bed load

- Sampler

BfG-Sampler



detachable weights



video camera, light

Sampling Techniques

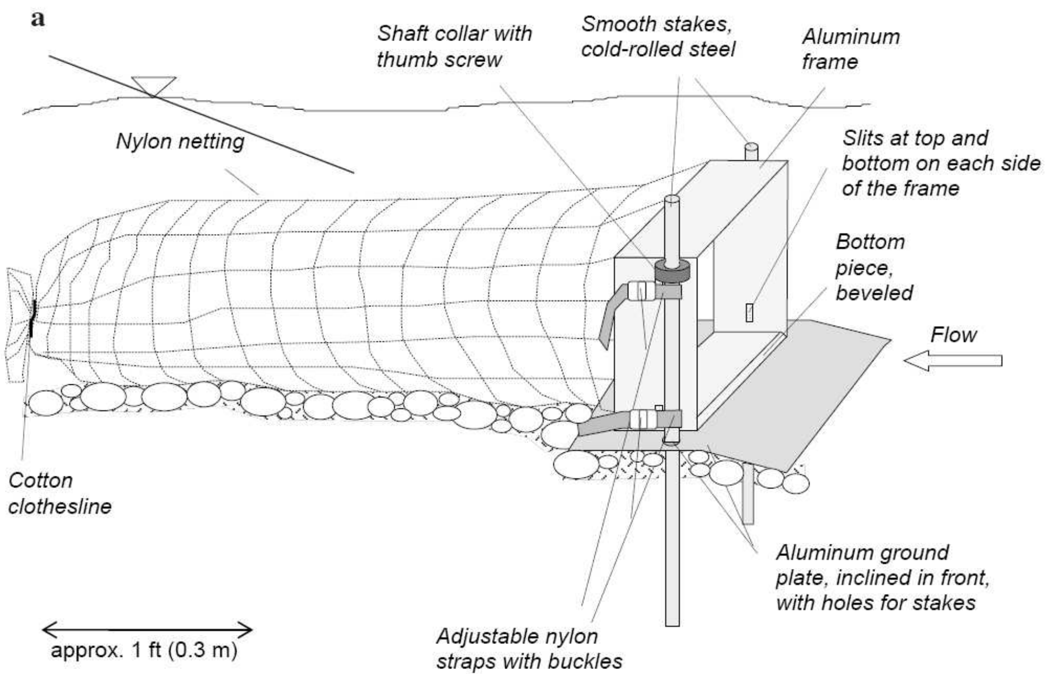
Bed load

- Typical problems of portable sampler:
  - Initial effect:
    stirring up of bed material when the instrument is placed on the bed (oversampling)
  - Gap effect:
    occurrence of a gap between the bed and the sampler mouth due to stones, migrating ripples or erosion processes (undersampling)
  - Blocking effect:
    blocking of the bag by fine sediment and organic materials (undersampling)
  - Scooping effect:
    downstream drifting during lowering to the bed and forward pulling (scooping) over the bed when raising it again (oversampling)

Bed load

- Sampler

Bedload trap

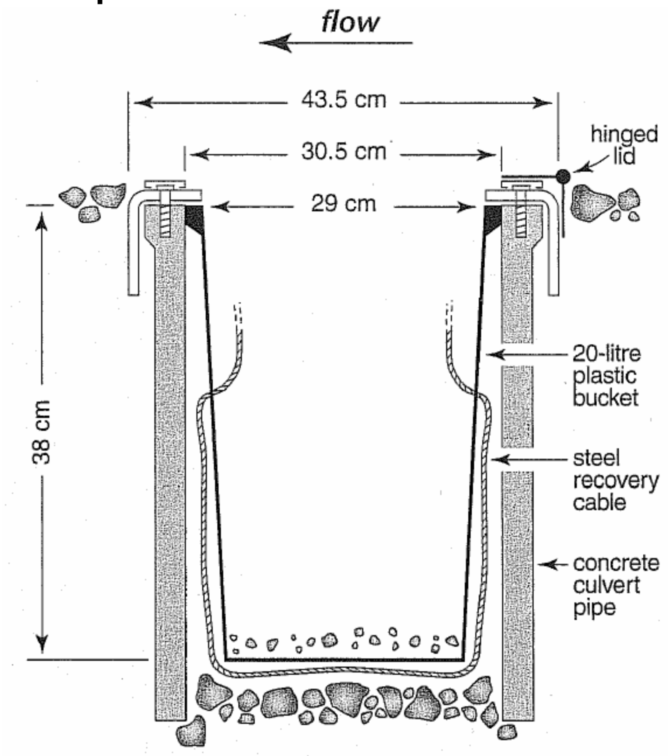


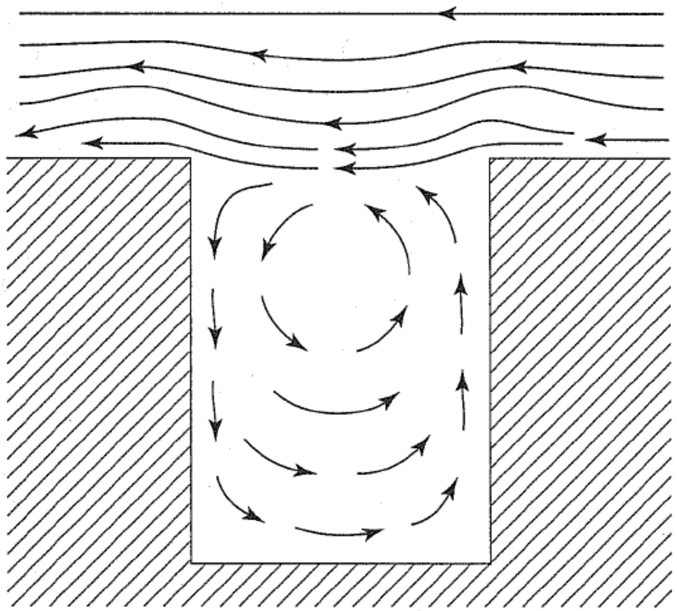
(Bunte et al. 2008)

Bed load

- Trap

Pit trap





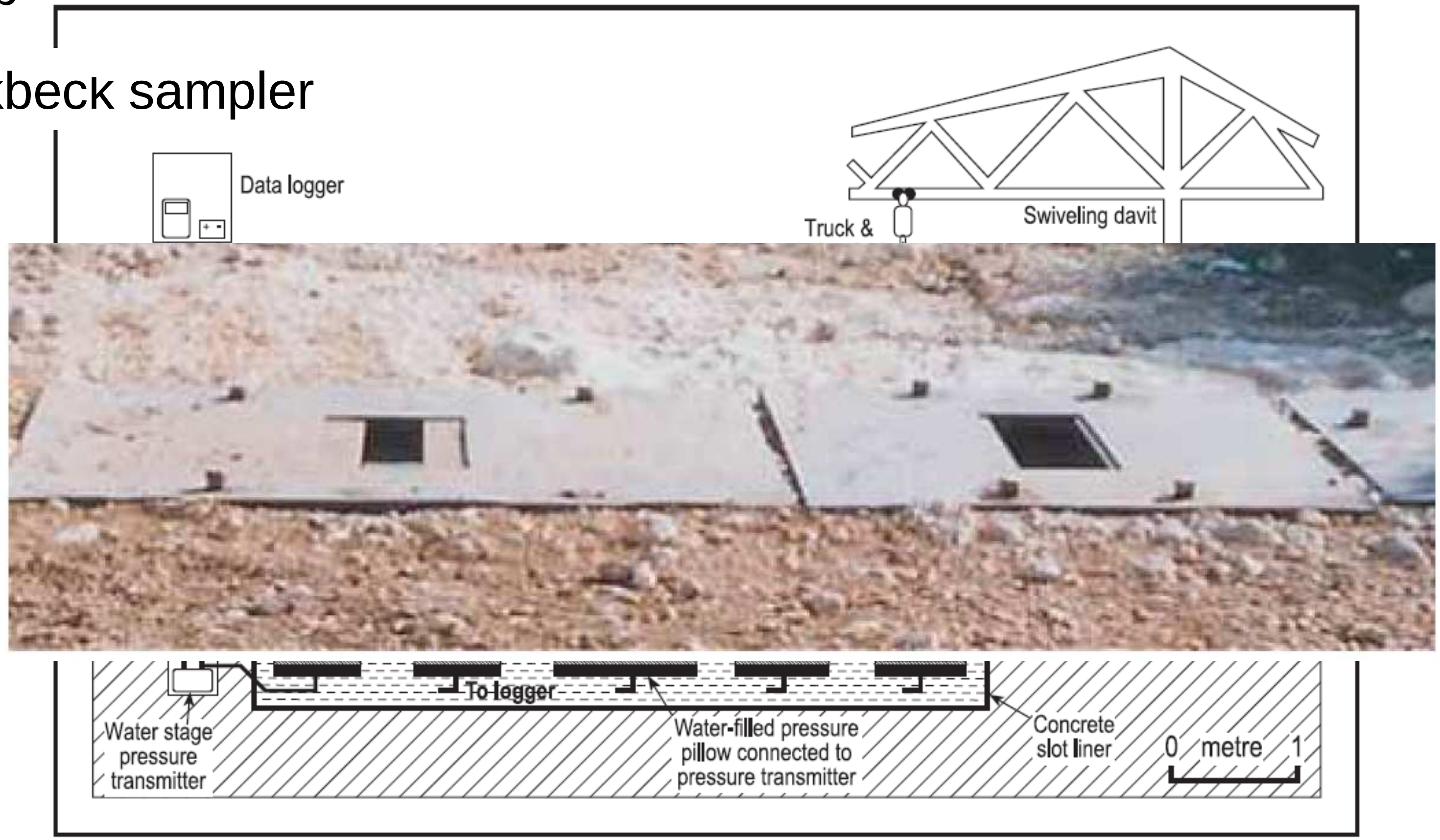
(Sterling & Church 2002)

Sampling Techniques

Bed load

- Trap

Birkbeck sampler

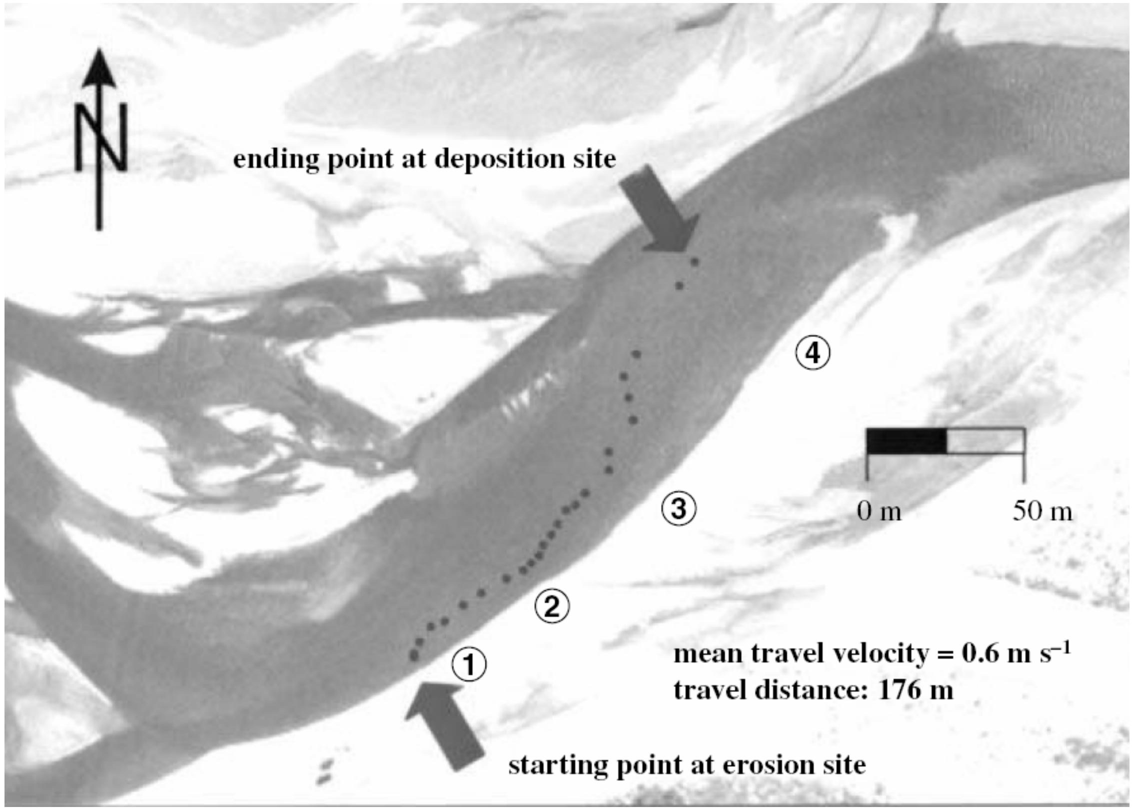


(Bergmann et al. 2007)

Bed load

- Tracer

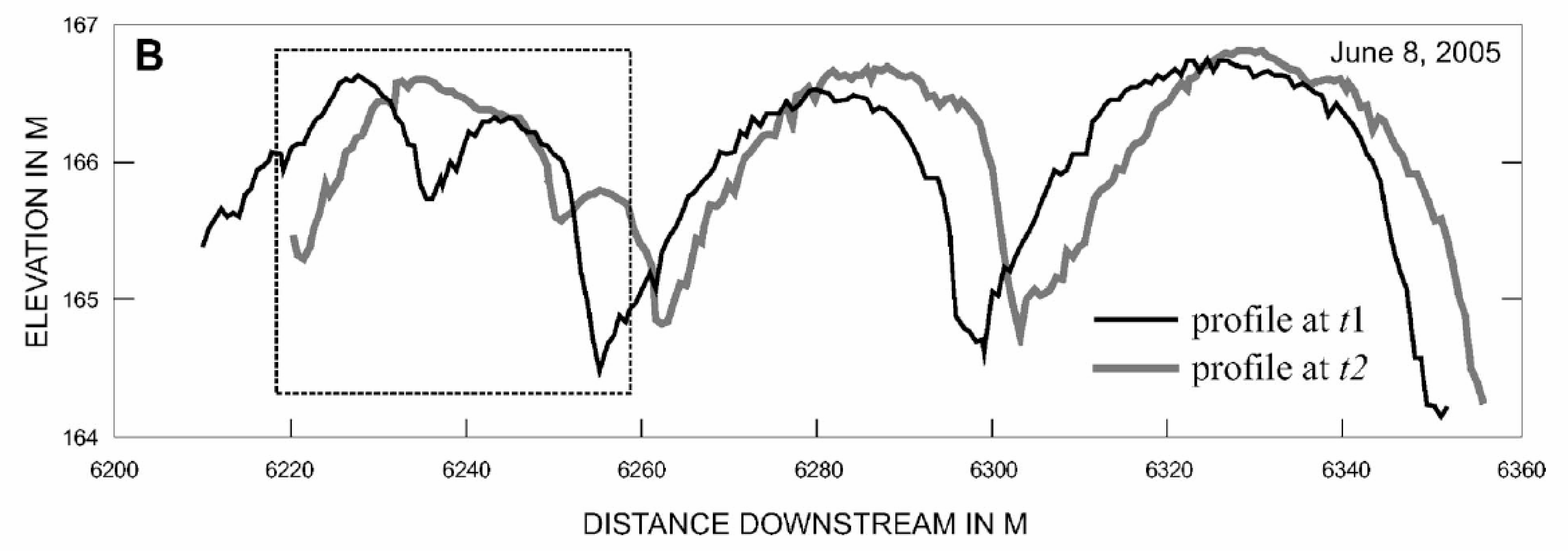
  Particle tracking



(Habersack 2001)

Bed load - Indirect methods

- Bed form tracking



Repeated scan of a longitudinal profile of the river bed

(Gaeuman & Jacobson 2007)

Summary

- Overview about characteristics of sediment transport
- Compilation of demands of sampling techniques
- Presentation of techniques to determine suspended and bed load