State of the art of sediment transport measurement techniques in rivers and reservoirs
1. INTRODUCTION

• Current situation
  • Rivival of hydro power due the CO$_2$ free energy production
  • BUT in Central Europe no new power plants possible
  • New and large power plants only possible in South America, Eastern Europe and Asia
  • BUT, here we are faced with a young tectonic leading to huge amount of sediment transport

• Why are sediments so bed?
  • Reduced lifetime due to sedimentation
  • High maintenance costs
  • Turbine destructions
  • Lower efficiency
1. INTRODUCTION

• **What is the solution?**
  • Mitigation measures after sedimentation has occurred
  • Mitigation integrated in the design process of the HPP with physical and numerical modeling.

• **BUT!**
  Both of this solution require a highly accurate knowledge of the amount of the sediments coming into the system.

• Prediction of sediment transport is up to date unreliable due to a high variability of sediment transport
• Measurement of sediment transport is difficult due to technical constraints
2. MOTIVATION & OBJECTIVES

WHAT?
To design sediment transport measurement techniques for a sustainable hydropower development

HOW?
To bring together the experts in this field to apply the recent techniques for measuring sediment transport to the hydro power industry.
3. CURRENT KNOWLEDGE OF BED LOAD MEASUREMENT TECHNIQUES

• Pressure difference type sampling
  The pressure-difference samplers are the most widely used devices for obtaining estimates of bedload transport in natural stream systems. The Helley-Smith bed-load sampler is commonly used in the United States. These devices consist of an open metal body with a front intake through which water and sediment pass and a flare that begins mid-body and expands to the back of the sampler. The overall sampling efficiency of a specific sampler is not constant, but varies with size distributions, stream velocities near the bed, turbulence, rate of bed-load transport, and the degree of filling of the sampler.
3. CURRENT KNOWLEDGE OF BED LOAD MEASUREMENT TECHNIQUES

• Pressure difference type sampling

Toutle River Sampler- US-TR2

Helley Smith sampler
3. CURRENT KNOWLEDGE OF BED LOAD MEASUREMENT TECHNIQUES

- Portable bed load traps
  The prominent characteristics of the bedload sampling device are a large opening and a long sampling time-attributes more typical of a “trap” than a “sampler.” Dimensions were selected to accommodate particles up to small cobble sizes (approximately 128 mm). In the field, the frame is placed onto a ground plate to ensure good contact with the stream bottom. The front edge of the ground plate is inclined down in the upstream direction to provide a smooth transition between the streambed and the trap entrance.
3. CURRENT KNOWLEDGE OF BED LOAD MEASUREMENT TECHNIQUES

• Permanent traps
  A trap is build preferably across the entire width of the stream. Openings of the trap should be larger than the maximum hop length of saltation particles. The material accumulates in an inner container that periodically requires emptying. Various systems were developed; the conveyor belt slot system, the Vortex tube system, the weighing slot (pit) sampler system, and the Birkbeck-type automatic monitoring slot sampler. The systems are semi-automatic or automatics.
3. CURRENT KNOWLEDGE OF BED LOAD MEASUREMENT TECHNIQUES

• Tracer techniques
  The pebbles are individually labelled with passive or active tracers. The total number of pebbles is normally restricted to about 1000 per site due to this time consuming procedure. The tracer method is an integrating method. Quantitative measurement of transport of bed load sediment by tracers can be founded mainly on procedures that are conceptually Lagrangian.
4. CURRENT KNOWLEDGE OF SUSPENDED LOAD MEASUREMENT TECHNIQUES

• Direct sampling – pumping
When pump sampling, the sample is collected by applying a vacuum to a line and drawing a sample into a bottle. Pump samplers allow the automatic collection of multiple samples. This technique does not give an isokinetic sample. Coarse particles (sand) may be under represented if flow velocity in the sample tube is not high enough to prevent particles from settling. The sample will need to be analyzed in the laboratory to determine its suspended sediment concentration. The automatic pumping-type samplers are very useful for collecting suspended-sediment samples during period of rapid changes caused by storm-runoff events.
4. CURRENT KNOWLEDGE OF SUSPENDED LOAD MEASUREMENT TECHNIQUES

- Direct sampling – isokinetic
  The sampler is usually made of a plastic bottle with a water inlet nozzle and an air outlet. The diameter of the water inlet can be selected (or changed) so that the sampler will fill more or less quickly, depending on the depth of the river. Isokinetic sampling occurs when water velocity through the inlet nozzle is equal to the water velocity at the depth of the sampler.

Point measurement

Depth integrated measurement
4. CURRENT KNOWLEDGE OF SUSPENDED LOAD MEASUREMENT TECHNIQUES

- Optical (backscattering)
  Infrared or visible light is directed into the sample volume where a portion of the light will be backscattered if particles are in suspension. A series of photodiodes positioned around the emitter detect the backscattered light. An empirical calibration is used to convert backscatter to concentration. The measurement volume varies according to turbidity but is on the order of several cubic centimeters. OBS devices are readily available and relatively inexpensive. The particle size range for best operation is 200-400 μm, and concentrations may range up to 100 g/L.

- Optical (transmission)
  Light is directed into the sample volume where sediment will absorb and/or scatter a portion of the light. A sensor located opposite the light source measures the attenuation of the light beam. The sediment concentration is determined using empirical calibration information. The size of the measurement volume will vary according to the geometry of the device.
4. CURRENT KNOWLEDGE OF SUSPENDED LOAD MEASUREMENT TECHNIQUES

- **Nuclear**
  This technique relies on the attenuation or backscatter of radiation, usually X or gamma rays, by sediment particles. An empirical calibration is used to convert backscatter to concentration. The concentration range is approximately 0.5-12 g/L.

- **Acoustic sampling**
  High frequency sound, usually in the megahertz range, is propagated through the water/sediment mixture from an acoustic transducer that can be used to transmit and receive signals. When the sound waves impact suspended particles, a portion of the sound is scattered back toward the transducer where it produces an electrical signal. The amplitude of this backscattered sound is recorded.
4. CURRENT KNOWLEDGE OF SUSPENDED LOAD MEASUREMENT TECHNIQUES

- Laser diffraction
  A laser beam is directed into the sample volume where particles in suspension will scatter, absorb, and reflect the beam. Scattered laser light is received by a detector or array of detectors that allow measurement of the scattering angle of the beam. Particle size can be calculated from knowledge of this angle.

Sequoia LISST-SL and LISST 100
4. CURRENT KNOWLEDGE OF SUSPENDED LOAD MEASUREMENT TECHNIQUES

• Laser diffraction
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- Laser diffraction
5. NEW METHODOLOGIES – BED LOAD

- Acoustic – Doppler effect

The aDcp transects collected 24 and 25 June 2006 (yellow) and 12–13 June 2007 (cyan) in a 5.5 km long study reach.
5. NEW METHODOLOGIES – BED LOAD

- Acoustic – Doppler effect

Interpolated apparent bed velocity (m s\(^{-1}\))
5. NEW METHODOLOGIES – BED LOAD

• Passive acoustic
  Sound generated by particle impacts is employed for detecting bedload movement. The noninvasive acoustic system allows the measurement of spatially integrated bedload transport rates. The system consists of hydrophones and geophones deployed along a reach, with data recorded to disk after signal conversion. The phones are installed onto the bedrocks near the banks and onto large boulders in the centre of the stream. The sensor record acoustic energy of bedload impact on a plate fixed to the river bed.
5. NEW METHODOLOGIES – BED LOAD

- Sonar imaging
  
  The rate of sediment transport per unit width represented by a migrating bedform, called the bedform transport rate, is equal to the product of three terms: bedform height, bedform migration speed, and a dimensionless shape factor. These values can be incorporated into mean rates of the area over which bedform heights and migration rates are sampled. Rotating sidesonar is well suited for field observations of bedform migration.
5. NEW METHODOLOGIES – BED LOAD

- Weight sensors – scour plates
The Load-Cell Scour Sensor is ideal for shallow placement in spawning beds of fish for unattended monitoring of deposition, erosion and substrate temperature, monitoring transport of bedforms in experimental flumes, and monitoring scour at bridge piers or similar structures. The load-cell sensor weighs the sediment, water, and air above it, and an accompanying pore-pressure sensor weighs the water and air above it. The difference between the two weights is the weight of the sediment overlying the sensor pair.

![Load-Cell Scour Sensor](image-url)
6. NEW METHODOLOGIES – SUSPENDED LOAD

• Pressure differential
A differential pressure transducer may be used to determine differences in the specific weight of sediment bearing water versus water nearer the surface with lower concentrations. This difference in pressure can be used to determine the average suspended sediment concentration between the two inlets of the differential pressure transducer. The size of the measurement volume will depend on the separation of the pressure inlets of the differential transducer. The concentration range is dependent on the sensitivity of the transducer. The hardware for this device is readily available and relatively inexpensive. Changes in temperature gradient, turbulence, and dissolved solids concentration will affect measurements.

• Digital imaging
In digital imaging, charge coupled devices (the sensor of a digital camera) are used to collect images of the water sediment mixture that has either been pump sampled or directed isokinetically into some type of conduit. These images can be subjected to various numerical algorithms to count and size the imaged particles.
6. NEW METHODOLOGIES – SUSPENDED LOAD

- Dual frequency acoustic - The tower tank experiment
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6. NEW METHODOLOGIES – SUSPENDED LOAD

• Dual frequency acoustic - Parana River
  - 1000 kHz Sontek-ADCP calibrated in advance on vertical integrated water samples
  - 600 and 1200 kHz RDI-ADCP electro/acoustic calibration on mean features

<table>
<thead>
<tr>
<th>Mean discharge</th>
<th>15000 m³/s</th>
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<tbody>
<tr>
<td>Total load</td>
<td>130x10⁶ t/year</td>
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<tr>
<td>Wash load</td>
<td>100 µg/l</td>
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<tr>
<td>Suspended load</td>
<td>20 mg/l</td>
</tr>
<tr>
<td>Bed load</td>
<td>2 mg/l</td>
</tr>
</tbody>
</table>
6. NEW METHODOLOGIES – SUSPENDED LOAD

• Dual frequency acoustic - Parana River

- **Sontek**
- **1200 kHz RDI**

- **1200/600 kHz, 200 μm**
- **1200/600 kHz, 300 μm**
7. OUTLOOK

- Dual frequency acoustic for suspended load
  - Flume testing at NTNU
  - Field tests in Hydro power reservoirs
- Dual frequency acoustic for bed load
  - Field testing in Italy / South America
- 3D Numerical modeling
REFERENCES

• Rennie, CD, Millar, RG (2004), Measurement of the spatial distribution of fluvial bedload transport velocity in both sand and gravel, EARTH SURFACE PROCESSES AND LANDFORMS Volume: 29 Issue: 10 Pages: 1173-1193
• Rennie, CD., Church, M., (2010) Mapping spatial distributions and uncertainty of water and sediment flux in a large gravel bed river reach using an acoustic Doppler current profiler, JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 115,
• Fluvial sediment transport: Analytical techniques for measuring sediment load (2005)
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Thank you for your attention