A STUDY OF SEDIMENTATION IN RIVERS USING SEDIMENT TRAPS

Sergey R. Chalov
Ekaterina Belozerova
Nikolay Alexeevsky
Suspended sediment origin

- watershed-sourced sediment
  (slope wash, gully erosion, volcanic eruptions)
  \[ d_w < d^* \]

- channel-sourced sediment
  \[ d_{ch} \geq d^* \]

\[ d^* = 0.05 \text{ mm} \]
Comparison between bed load (вл) and suspended load (взв)

**Interaction between bed deposits (W) and suspended load (R)**

\[ W_2 - W_1 = \Delta W \]

- \( W_1 \) – sediment input (m³), \( W_2 \) – sediment output from the channel reach (m³), \( \Delta W \) – sediment budget (m³),
Suspended sediment concentration

\[ \frac{\partial s}{\partial t} = \frac{A}{\rho} \left( \frac{\partial^2 s}{\partial x^2} + \frac{\partial^2 s}{\partial y^2} + \frac{\partial^2 s}{\partial z^2} \right) - \left( v \frac{\partial s}{\partial x} + u \frac{\partial s}{\partial y} + \frac{\partial s}{\partial z} \right) - \omega \frac{\partial s}{\partial y} \]

- Turbulent advection – longitudinal changes of water body parameters
- Dispersion – transverse changing of parameters
- Convection – vertical changing of parameters

Gravity
Methods

1. Sediment installation on the river bottom

Small trap:
2 sm diameter and 20 sm height.

Large trap:
height 30–50 sm, diameter 4,4 sm

2. Comparison with published data
## Parameters of sediment traps for rivers

<table>
<thead>
<tr>
<th>Type</th>
<th>Height, m</th>
<th>Diameter, m</th>
<th>Bottom area F, m²</th>
<th>Volume, m³</th>
<th>Total trap weight, kg</th>
<th>Location, m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large</td>
<td>0.4</td>
<td>0.075</td>
<td>0.004</td>
<td>0.001</td>
<td>5</td>
<td>1 - on the bed level</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2 - above bottom</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3 – above bottom</td>
</tr>
<tr>
<td>Small</td>
<td>0.25</td>
<td>0.04</td>
<td>0.002</td>
<td>0.001</td>
<td>2</td>
<td>1 - on the bed level</td>
</tr>
</tbody>
</table>
Field-based sediment trapping
1. \( TR = \frac{m}{F \Delta t} \) - «trapping rate»’ TR (gm\(^{-2}\) s\(^{-1}\) or gm\(^{-2}\)d\(^{-1}\))

2. Sedimentation rate for stream reach with bottom area \( F_1 = F \times n \): 
   \[ SED = TR \times F_1 \]

3. Dimensionless relative settling coefficient : 
   \[ C = \frac{TR}{vs} \]

“Input” data: S – suspended sediment concentration, V – stream velocity, h – depth
Obtained data

25 field experiments in the different rivers

- Protva river
- Koryak plateau river
- Oka river
- Selenga river
Variation of trapping rate’s for different rivers recorded by the sediment trap at different times (data bank fragment)

<table>
<thead>
<tr>
<th>River</th>
<th>Distance from the bank, m</th>
<th>Depth from the bank, $h$, m</th>
<th>Heigh above channel bed, $l$, m</th>
<th>Relative depth $h/l$</th>
<th>Stream velocity $v$, m/s</th>
<th>Re·10$^{-3}$</th>
<th>SSC, g/m$^3$</th>
<th>Weight of material in each trap, $m$, g</th>
<th>Average trapping rate $C_{cp}$, g·sm$^{-2}$·s$^{-1}$</th>
<th>Relative trapping rate $10^7C_{cp}/(vs)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protva</td>
<td>1,5</td>
<td>0,8</td>
<td>0,55</td>
<td>0,69</td>
<td>0,1</td>
<td>79</td>
<td>7,1</td>
<td>3,1</td>
<td>2,91</td>
<td>0,2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0,4</td>
<td></td>
<td>1</td>
<td>0,75</td>
<td>0,75</td>
<td>346</td>
<td>5,3</td>
<td>1,32</td>
<td>2,92</td>
<td>0,016</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1,5</td>
<td></td>
<td>0,5</td>
<td>0,25</td>
<td>0,50</td>
<td>74</td>
<td>4,4</td>
<td>4,06</td>
<td>2,61</td>
<td>0,022</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2,5</td>
<td></td>
<td>0,8</td>
<td>0,55</td>
<td>0,69</td>
<td>285</td>
<td>4,5</td>
<td>1,66</td>
<td>2,64</td>
<td>0,016</td>
</tr>
<tr>
<td>Koryak plateau rivers</td>
<td>1,5</td>
<td>0,35</td>
<td>0,10</td>
<td>0,29</td>
<td>0,15</td>
<td>52</td>
<td>1,44</td>
<td>0,005</td>
<td>0,00004</td>
<td>0,000048</td>
</tr>
<tr>
<td></td>
<td>2,5</td>
<td>0,4</td>
<td>0,15</td>
<td>0,38</td>
<td>0,42</td>
<td>166</td>
<td>15</td>
<td>0,31</td>
<td>0,017</td>
<td>0,0017</td>
</tr>
<tr>
<td></td>
<td>2,5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2,0</td>
<td></td>
<td>0,3</td>
<td>0,05</td>
<td>0,17</td>
<td>145</td>
<td>4,3</td>
<td>0,17</td>
<td>0,018</td>
<td>0,0018</td>
</tr>
<tr>
<td></td>
<td>2,5</td>
<td></td>
<td>0,4</td>
<td>0,15</td>
<td>0,38</td>
<td>178</td>
<td>8,0</td>
<td>0,11</td>
<td>0,0018</td>
<td>0,0005</td>
</tr>
</tbody>
</table>
Discussion: driving forces

- gravitational vertical sediment fluxes
- downstream movement of sediment particles
- development of turbulent vortexes

**Quantitative parameters**

- $V$  
- $h_k/h$  
- SSC  
- Re
Sedimentation at different flow velocities (river Protva)

- high cylinder
- middle cylinder
- low cylinder

TR, kg/m²sec

Low water           High water

Protva
Correlation between flow velocity $v$ and «trapping rate» TR (by Kozerski (2006))

- Trap A:
  $TR = 31.1 + 3.3V$

- Trap B:
  $TR = 30.8 - 3.8V$
Relationship between Reynolds number and relative settling coefficient from trap installations on various rivers (marked by various symbols)

Dotted line – upper curve (corresponded to the highest sedimentation under Re = const)
Correlation between relative sediment trapping $C^*$ and relative depth $h_k/h$ (different size rivers)

$$1000 \frac{TR}{vs} = -23.2(h_k/h) + 20.5$$
Correlation between relative sediment trapping $C^*$ and relative depth $h_K/h$ (different size rivers)

$$1000 \frac{TR}{(vs)} = -23.2(h_K/h) + 20.5$$
Correlation between relative sediment trapping and relative depth $h_k/h$ (one river, different time)

$10^3 C^* = 20.4 y^* - 9.84$
## Spatial variability (Selenga basin)

<table>
<thead>
<tr>
<th>Site</th>
<th>Description</th>
<th>SSC, g/m³</th>
<th>Settling rate $C$, g/(m²·hour)</th>
<th>Suspended sediment load $R$, kg/s</th>
<th>Vertical sediment flux $R_z$, kg/s</th>
<th>$R_z/R$, %</th>
<th>Human impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>Tuul river 20 km upstream from Ulaanbaatar</td>
<td>1.68</td>
<td>6.38</td>
<td>0.050</td>
<td>0.00003</td>
<td>0.06</td>
<td>low</td>
</tr>
<tr>
<td>T2</td>
<td>Tuul river 1 km upstream from Ulaanbaatar</td>
<td>8.36</td>
<td>87.5</td>
<td>0.22</td>
<td>0.00028</td>
<td>0.13</td>
<td>average</td>
</tr>
<tr>
<td>T5</td>
<td>Tuul river upstream from Zaamar</td>
<td>107</td>
<td>2048</td>
<td>3.56</td>
<td>0.027</td>
<td>0.75</td>
<td>average</td>
</tr>
<tr>
<td>T6</td>
<td>Tuul river downstream from Zaamar</td>
<td>289</td>
<td>1364</td>
<td>8.22</td>
<td>0.017</td>
<td>0.21</td>
<td>high</td>
</tr>
<tr>
<td>O2</td>
<td>Orkhon river upstream from the confluence with Tamir river</td>
<td>1699</td>
<td>2675</td>
<td>204</td>
<td>0.102</td>
<td>0.05</td>
<td>average</td>
</tr>
<tr>
<td>S1</td>
<td>Selenga river near Hutyk village</td>
<td>114</td>
<td>465</td>
<td>20.0</td>
<td>0.026</td>
<td>0.13</td>
<td>low</td>
</tr>
</tbody>
</table>
Comparison of sedimentation values obtained by trapping and direct measurements

- Direct measuring thickness of fine sediments layer at stream bottom
  - Obtained values of fine sediments layer thickness at the bottom:
    - 3-5 mm
    - 6 mm

- Using point trap measurements \( TR \) (according to the average density of fine material, duration after high water period)

Placer-mined rivers in the Kamchatka peninsula
## Contribution to sediment fluxes

<table>
<thead>
<tr>
<th>River</th>
<th>Relative settling rates, kg/m²</th>
<th>Settled particles layer, m</th>
<th>Volume of settled particles, m³</th>
<th>MAss, t</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low water period duration, days</td>
<td>30</td>
<td>75</td>
<td>30</td>
</tr>
<tr>
<td>1</td>
<td>1,98</td>
<td>4,94</td>
<td>0,0025</td>
<td>0,0062</td>
</tr>
<tr>
<td>2</td>
<td>1,16</td>
<td>2,91</td>
<td>0,0015</td>
<td>0,0036</td>
</tr>
</tbody>
</table>
Conclusion

- Any attempt to provide a definitive assessment of the sedimentation processes in rivers causes faces a number of important constraints. Firstly it is instrumental error of trapping techniques which leads to the few apparent inconsistencies of the results obtained. Nevertheless absence of the analogue methods determines perspectives of the sediment trapping. It is regarded to be the only way in in-situ direct measurements of sedimentation.

- Future experiments will lead to the expanding of the data. Further multistatistical analyses will lead to describe exact laws and factors of sedimentation. Further investigations to introduce a method for the estimation of the average areal sedimentation flux for a section of a river based upon a series of point trap measurements should be done.
Thank you for your attention!

The study reported in this paper was undertaken with financial support from the Russian Fund of Basic Research.