Modelling Fluvial Geomorphic Responses to Human Perturbations

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Background

- Kander and Simme rivers are located in the Swiss preAlps
- Catchment area of 1000 km²
- Today the Simme flows into the Kander, and downstream into Lake Thun
Background

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  • Damming the Aare river with sediments and massive flooding in the region of Thun

Source: Google maps, Wirth et al. (2011)
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  • Damming the Aare river with sediments and massive flooding in the region of Thun
  • Kander river was deviated to lake Thun by engineering works from 1712-1714

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Background

• But, in 1714 Kander river flowed into the Aare river:
  • Damming the Aare river with sediments and massive flooding in the region of Thun
  • Kander river was deviated to lake Thun by engineering works from 1712-1714
  • Two years after the correction the new river eroded ~27 m of the bed

Source: Google maps, Wirth et al. (2011)
• Landscape evolution models (LEMs) can be used to simulate erosion and deposition in river reaches
• It remains uncertain if LEMs are stable in replicating:
  • geomorphic effects of human intervention in fluvial systems (e.g. river restoration and engineering)
  • extreme situations that include large movements of sediment
  • geomorphic change in steep channels found in mountainous landscapes
CAESAR-Lisflood

- Landscape evolution model simulating erosion and deposition within river reaches (CAESAR)
- A hydrodynamic 2D flow model (Lisflood FP model) that conserves mass and partial momentum

Source: https://sourceforge.net/projects/caesar-lisflood/
Model test

Erosion

- Can the model replicate erosion in the:
  - Kander correction
  - Propagation of erosion upstream

1740

large amounts of erosion after 26 years
Model test

• Deposition

  • Can the model replicate deposition in the:
    • Kander delta
    • Lake Thun

Historical maps of Delta
Historical topography

Reconstruction of paleo-DEM with historic maps

Kander river

Kander river before correction
Discharge

- 10 years of hourly discharge from 1986-1996
- No floods included in the simulation because none in historical records
Sediment inputs

- Annual sediment inputs
  - Simme: $20,000 \text{ m}^3 \text{ yr}^{-1}$
  - Kander: $80,000 \text{ m}^3 \text{ yr}^{-1}$

- High flows were $\geq 30 \text{ m}^3 \text{ s}^{-1}$ and assumed upstream sediment transport occurred above this threshold

- Amounts of sediment were proportionally added over time based on the discharge that was above the threshold

Source: Geschiebehaushalt Kander, 2014
Grain size

- 6 grain size classes (silt to boulder) were estimated from Kander and Simme
- Each grid cell in the model initially contains the same grainsize percentages

Grainsize distribution

Source: Geschiebehaushalt Kander, 2014
Initial conditions

- Kander without correction
- 1986-1989 discharge and sediment inputs for Kander and Simme
- Model ran for 3 years and channel was in equilibrium (RMSE between initial channel and year 3 channel was 0.15 m)

Channel elevation profile
• The **correction** Length: 340 m, Width: 32 m, Slope: 0.8%.
• A **ramp** connected the correction to the lake, **steep slope 14%**
• **Lake** Thun was added to the DEM at the location of the shoreline. The lake was set as a non-erodible plane
Kander correction model

- Simulated 10 years of movement of water and sediment
- Every year topography was recorded (1714-1724)
Results

- Delta formation
- Significant erosion within Kander correction
- Rapid rates of upstream incision
Channel incision

- Observed erosion in 2 years:
  - Obs 1: 27 m
  - Obs 2: 21 m
  - Obs 3: 5 m

Historical observations

Source: Koch (1826)
Channel incision

- Observed erosion in 2 years:
  - Obs 1: 27 m
  - Obs 2: 21 m
  - Obs 3: 5 m
- After 7 years modeled erosion matches observed

Channel elevation profile

Source: Koch (1826)
Aggressive erosion rate of \(2 \text{ m yr}^{-1}\) in first 10 years.

57% total erosion to present day occurred during this time.

Erosion rate decreasing to 1 m yr\(^{-1}\).

Estimate 13 more years to reach present day channel elevation.

Source: Koch (1826)
Sediment yield

• Data from lake deposits estimates the sediment yield of the Kander and Simme river from 1714-1852 was **300,000 m$^3$ yr$^{-1}$**

• Mean modelled sediment yield: **350,000 m$^3$ yr$^{-1}$**

• Modelled sediment yield stabilizing near observed sediment yield
Delta formation

- Model produces delta with semicircular shape, and suggests delta formed quickly
- Percent change in total delta deposits indicates stabilization after 10 years
- Modelled delta deposition is in range of present day deposits (0.5-14 m)
Unexpected channel stabilization

- Kander correction erosion is controlled by delta elevation (base level)
- Model has not developed a channel in delta and this has caused the correction to stabilize
- Will channel in delta form? Did dredging help create channel?
Conclusion

- For the Kander and Simme rivers CAESAR lisflood adequately replicated:
  - Channel incision
  - Sediment yield
  - Delta formation

- Results suggest that CAESAR lisflood can be used to model:
  - geomorphic effects of human intervention in fluvial systems (e.g. river restoration and engineering)
  - extreme situations that include large movements of sediment
  - geomorphic change in steep channels found in mountainous landscapes
Backup slides
CAESAR-Lisflood hydraulics

- Rainfall and Evapotranspiration
- Current Topography
- Surface Hydrology
- Non-fluvial Sediment Flux
- Fluvial Sediment Flux
- DEM Modification

Lisflood-FP

Calculate the flow ($Q$) between cells:

$$Q = \frac{q - gh_{flow}\Delta t \left(\frac{h+z}{\Delta x}\right)}{\left(1 + gh_{flow}\Delta t n^2 |q|/h_{flow}^{10/3}\right) \Delta x}$$

$q$ is the flux between cells from the previous iteration ($m^2s^{-1}$)
$g$ is acceleration due to gravity ($m s^{-1}$)
$n$ is Mannings roughness coefficient ($m^{1/3}s^{-1}$)
$h$ is depth (m)
$z$ is elevation (m)
$h_{flow}$ is the maximum depth of flow between cells
$x$ is the grid cell width (m)
$t$ is time (s)

CAESAR-Lisflood sediment transport

Wilcock and Crowe

Sediment transport is driven by a mixed-size formula, which calculates transport rates, $q_i$, for each sediment fraction $i$

$$q_i = \frac{F_i U^3 W_i^*}{(s - 1)g}$$

$F_i$ denotes the fractional volume of the $i$-th sediment in the active layer
$U^*$ is the shear velocity
$s$ is the ratio of sediment to water density
$g$ denotes gravity
$W_i^*$ is a complex function that relates the fractional transport rate to the total transport rate