Modelling Fluvial Geomorphic Responses to Human Perturbations

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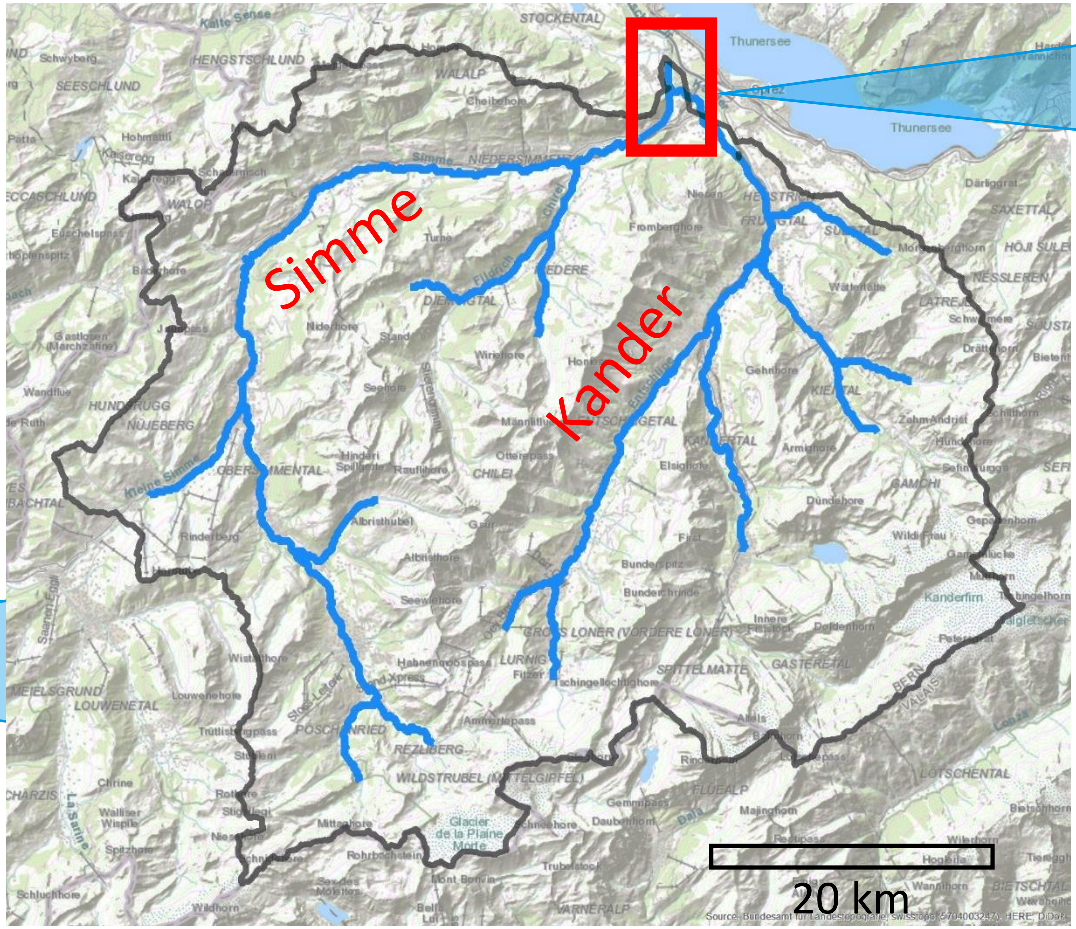
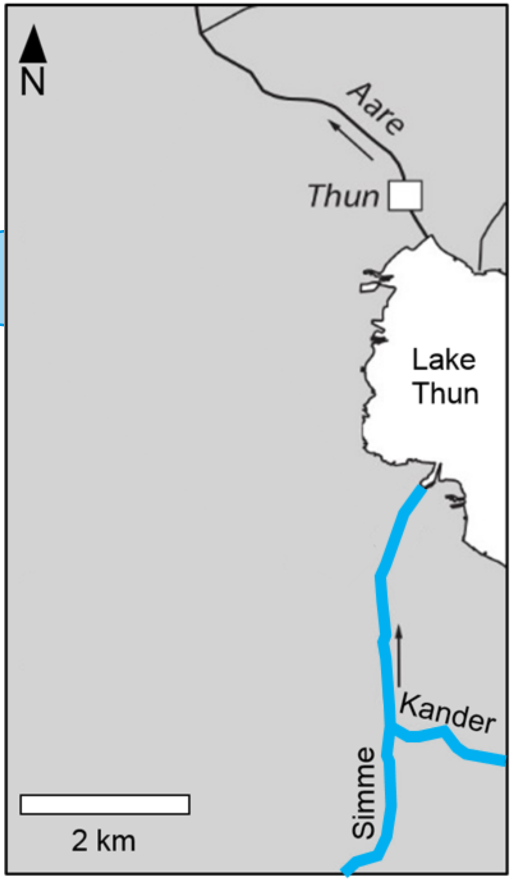
Background

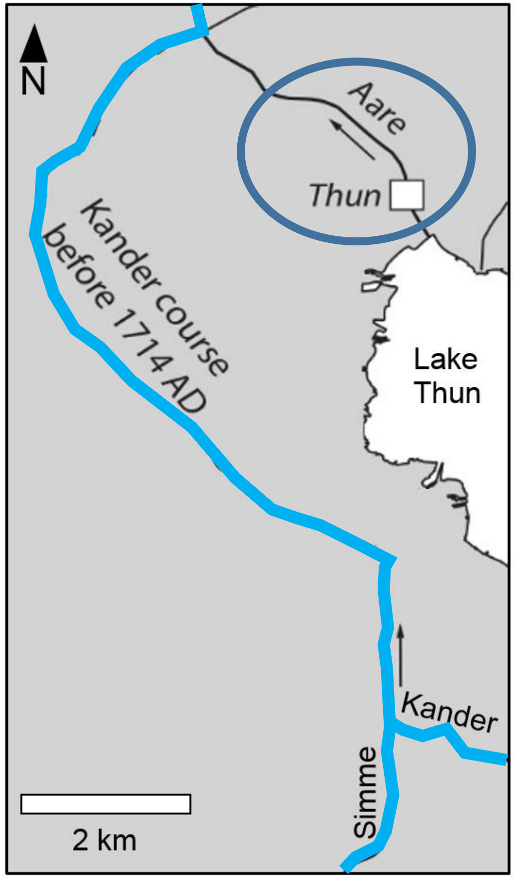
- Kander and Simme rivers are located in the Swiss preAlps
- Catchment area of 1000 km^2
- Today the Simme flows into the Kander, and downstream into Lake Thun





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



Source: Google maps, Wirth et al. (2011)

Background

- But, in 1714 Kander river flowed into the Aare river:
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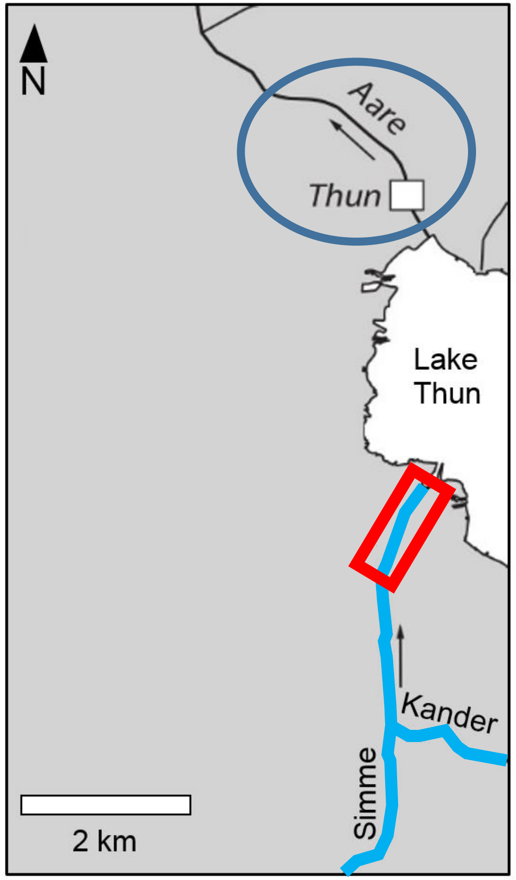
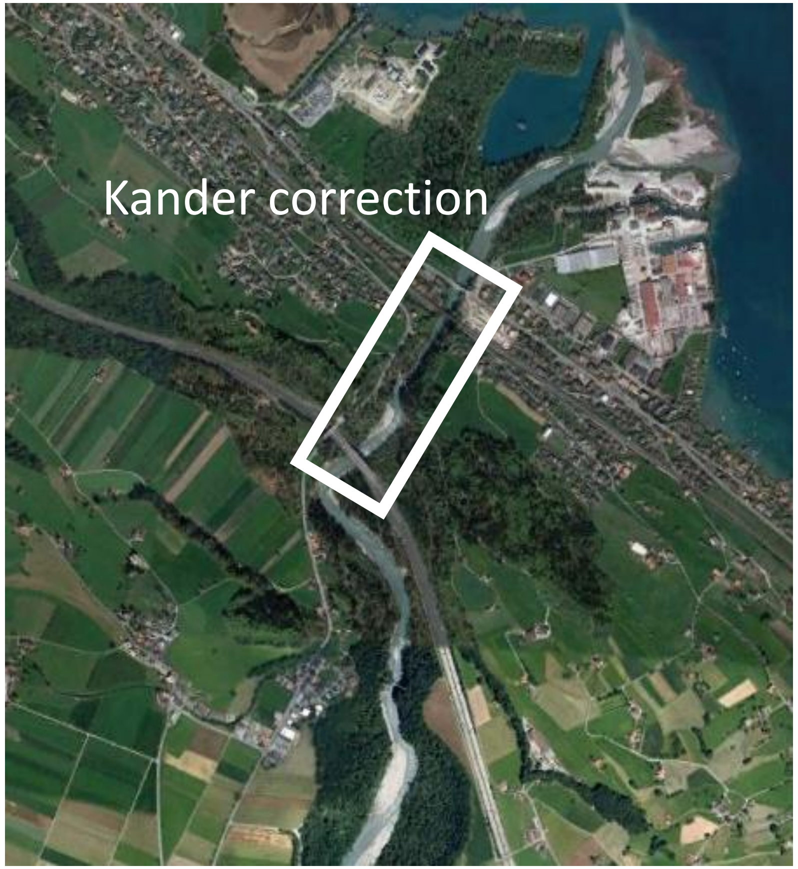
  - Kander river was deviated to lake Thun by engineering works from 1712-1714

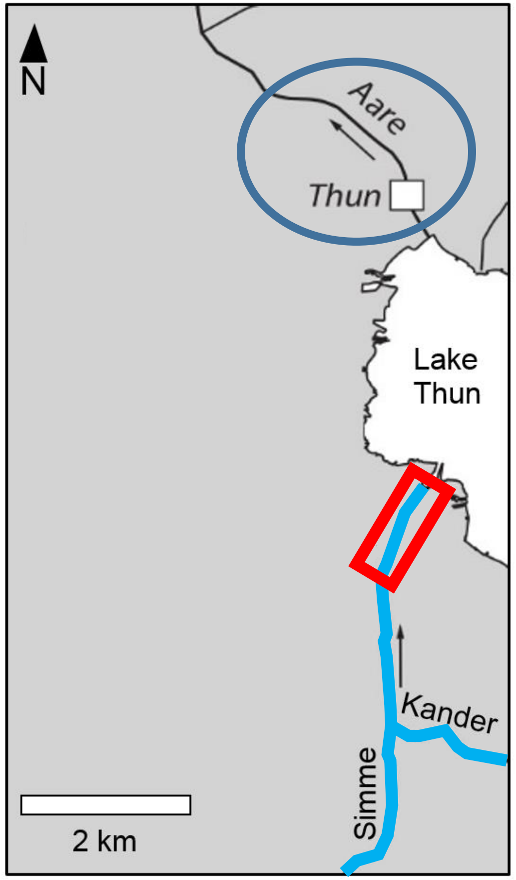


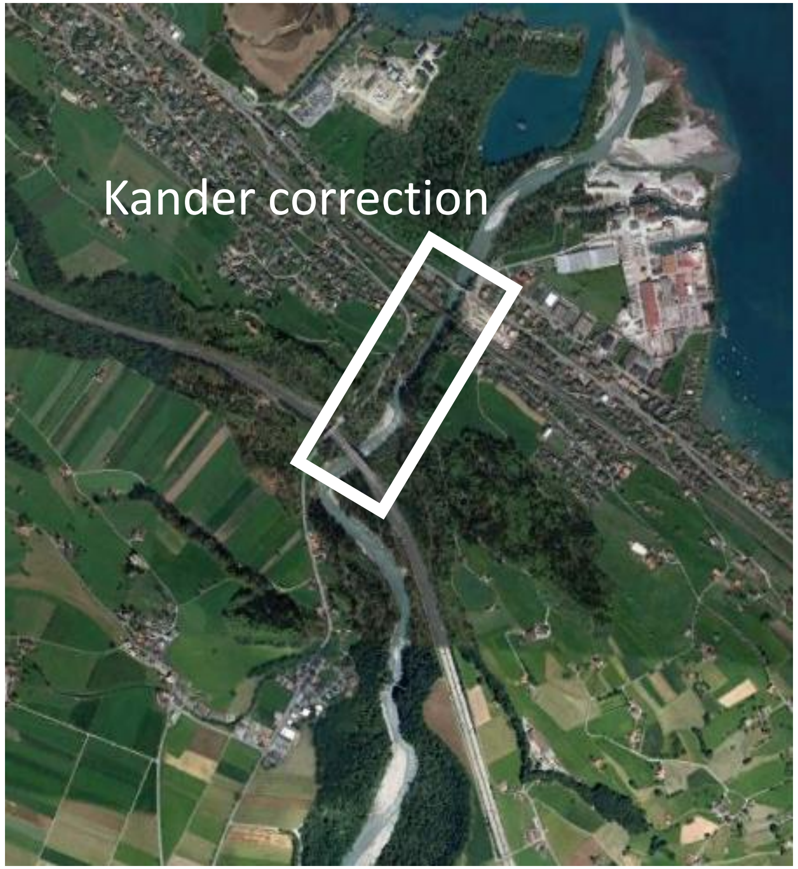


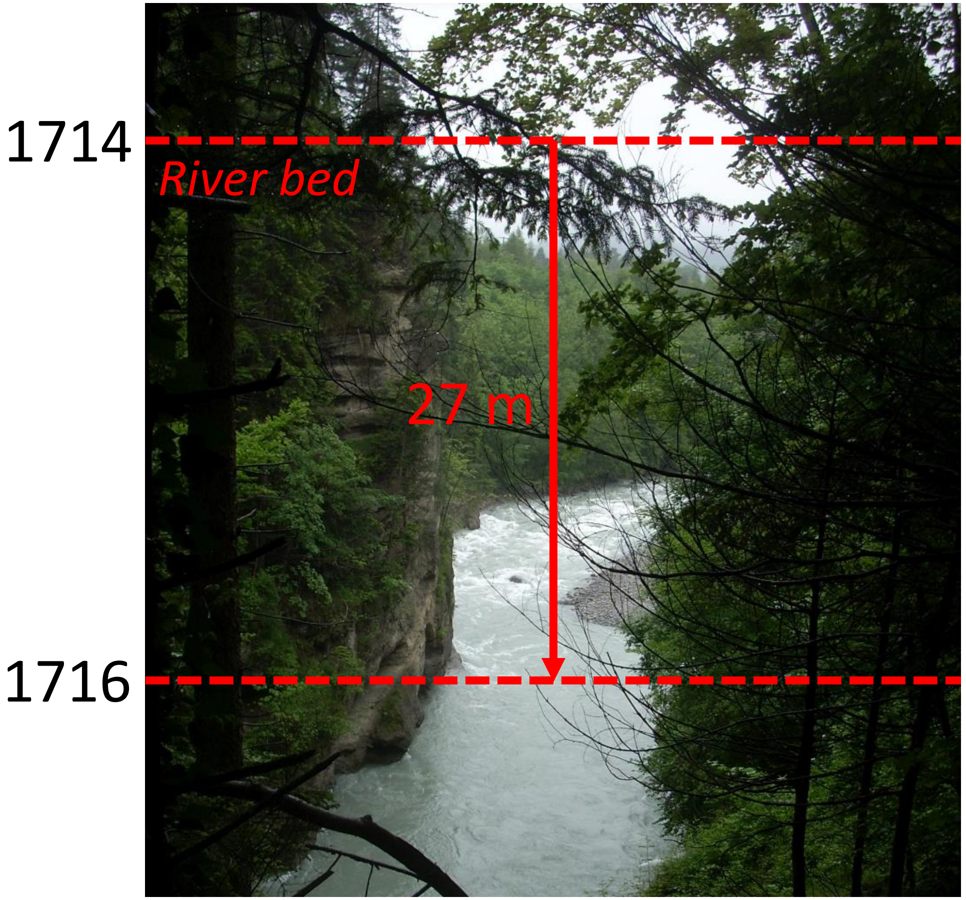
Source: Google maps, Wirth et al. (2011)

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)

Aims

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- 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

Restoration

Engineering

Steep channels

Source: https://mostlyaboutmayflies.wordpress.com, http://www.theadvocateproject.eu, www.gettyimages.ch, panoramio.com

CAESAR-Lisflood

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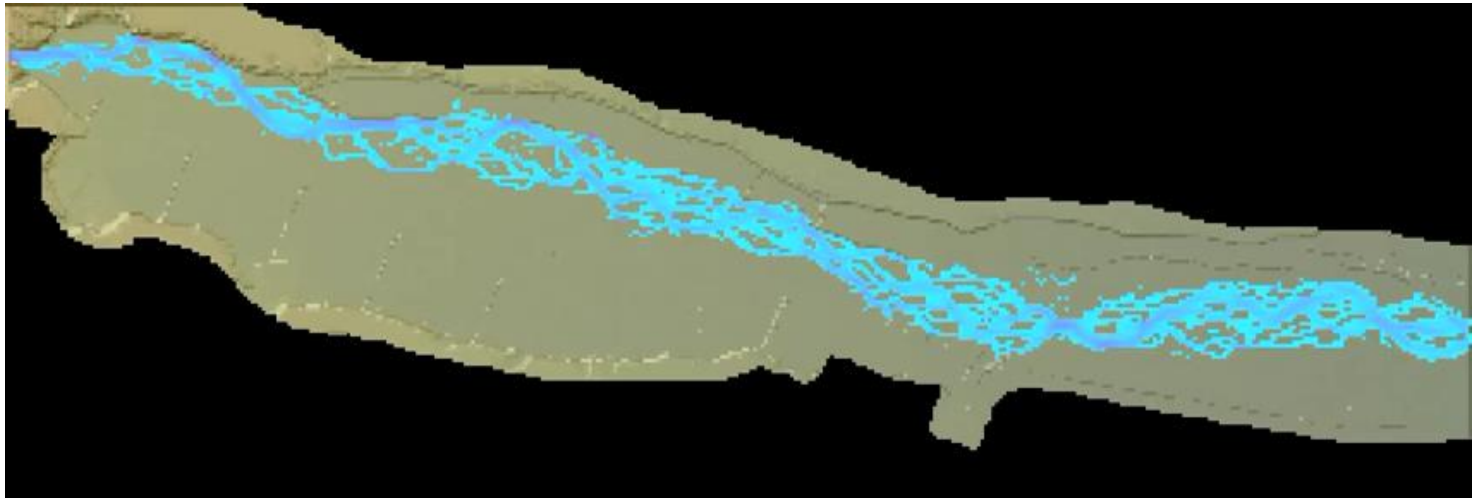
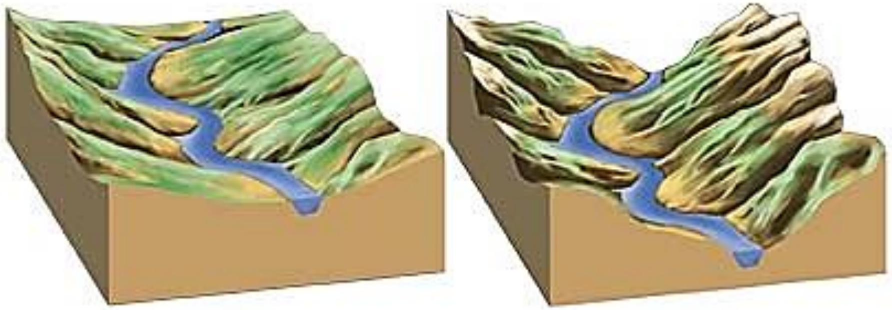
- Landscape evolution model simulating erosion and deposition within river reaches (CAESAR)
- A hydrodynamic 2D flow model (Lisflood FP model) that conserves mass and partial momentum



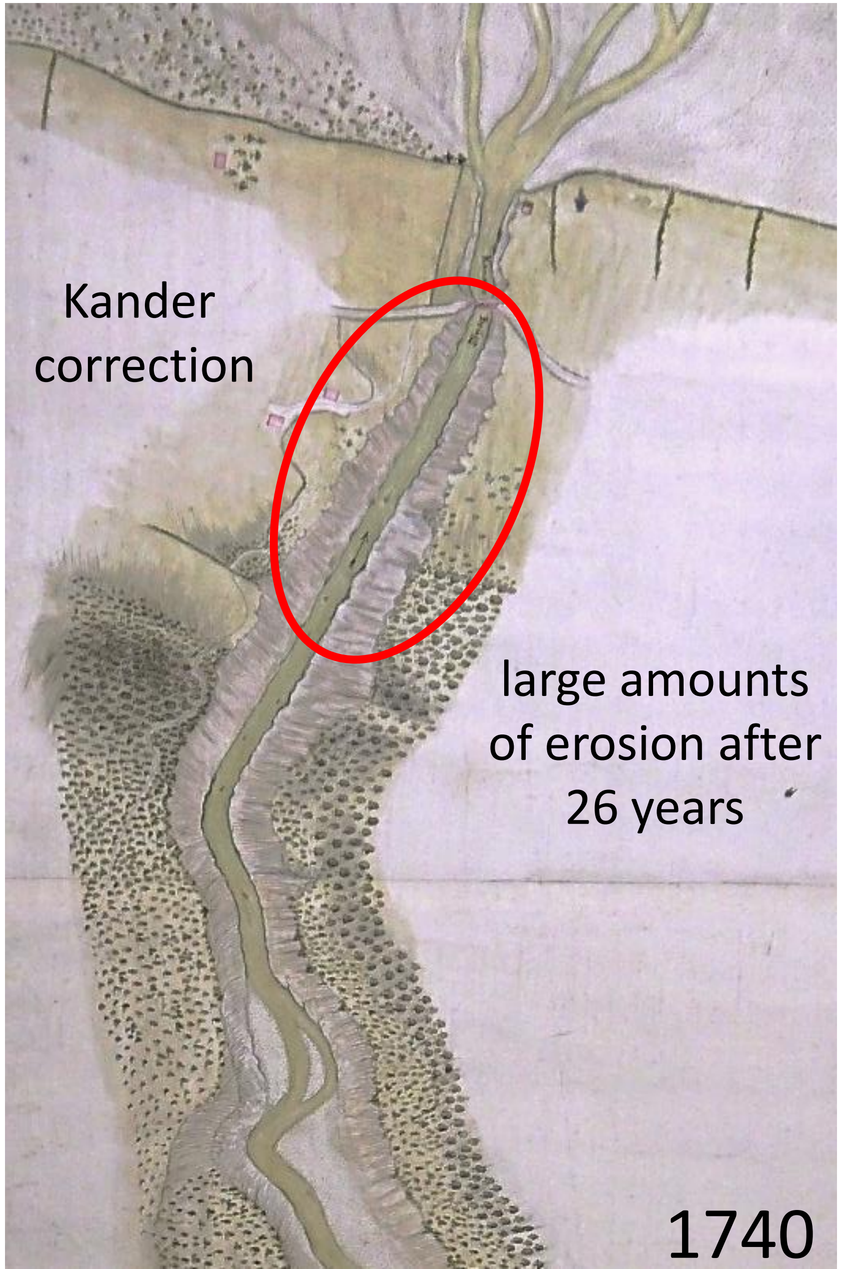
Source: https://sourceforge.net/projects/caesar-lisflood/

Model test

Erosion

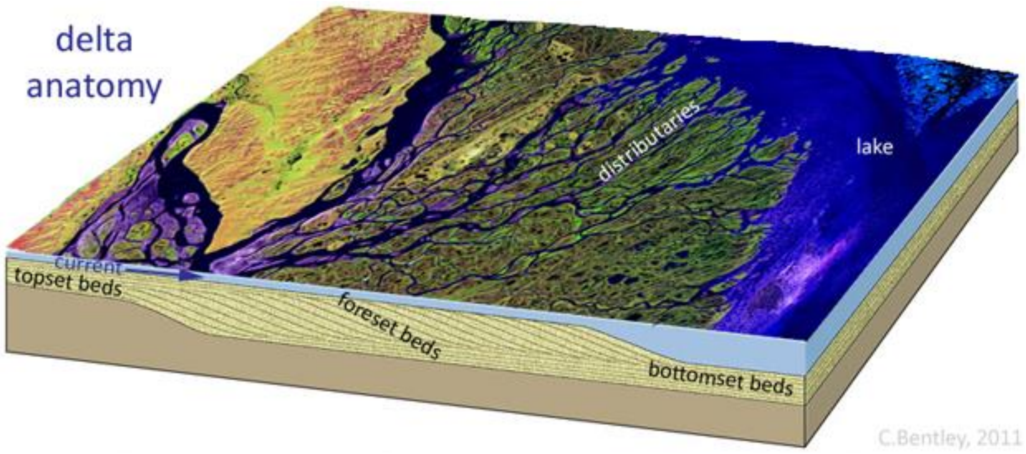


- Can the model replicate erosion in the:
  - Kander correction
  - Propagation of erosion upstream

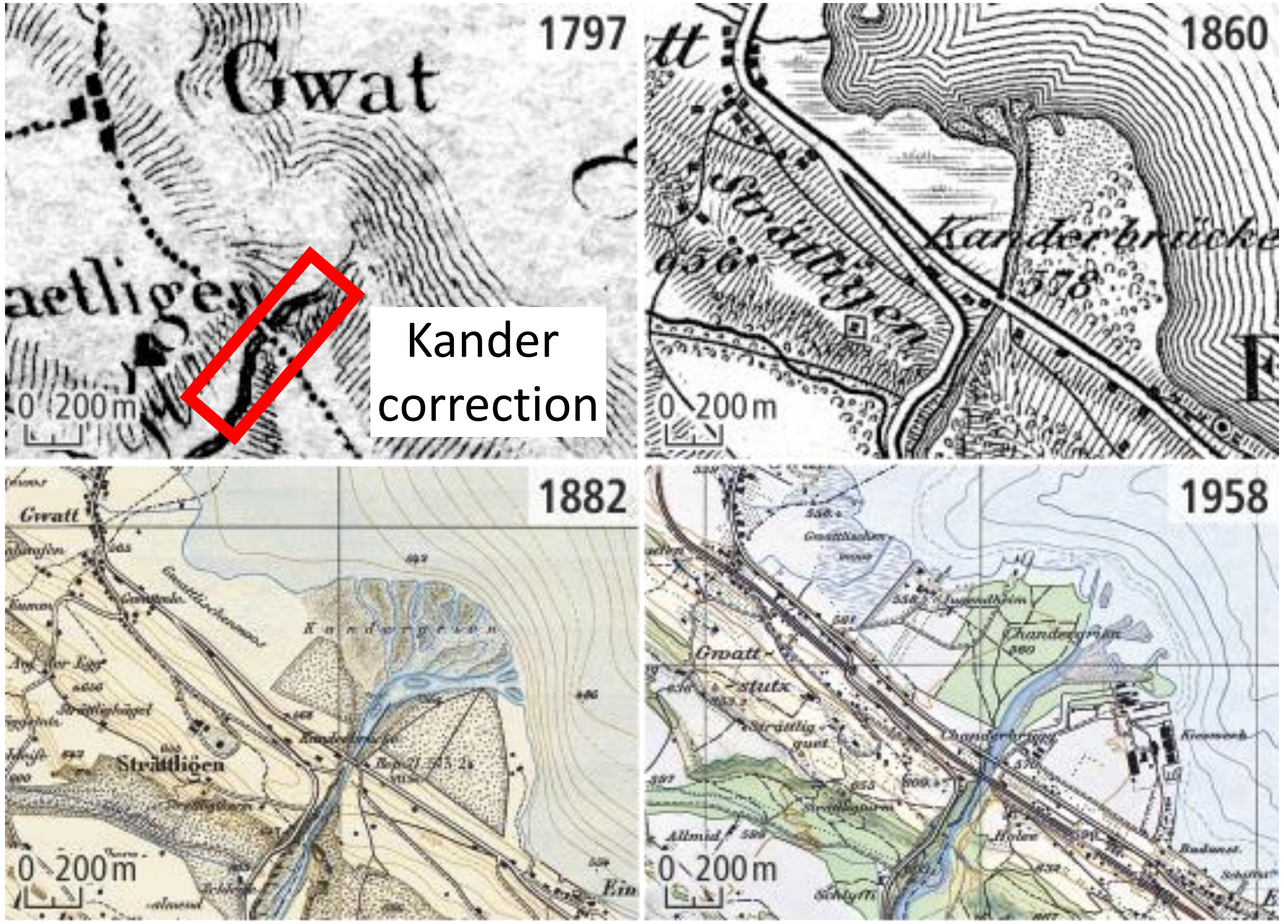


Model test

- **Deposition**

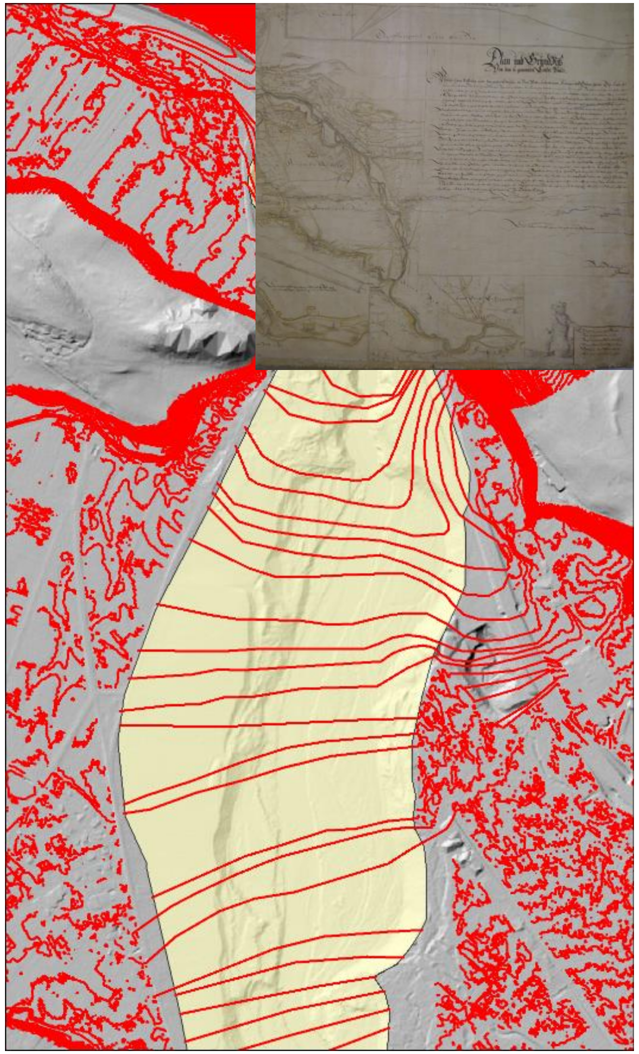


Historical maps of Delta

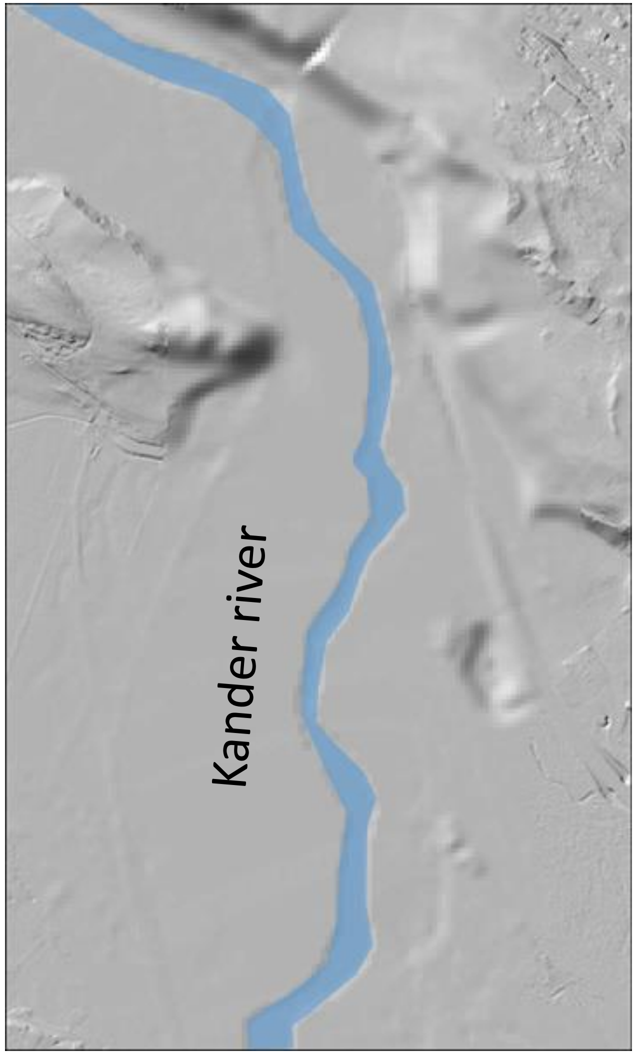


- Can the model replicate deposition in the:
    - Kander delta
    - Lake Thun

Historical topography



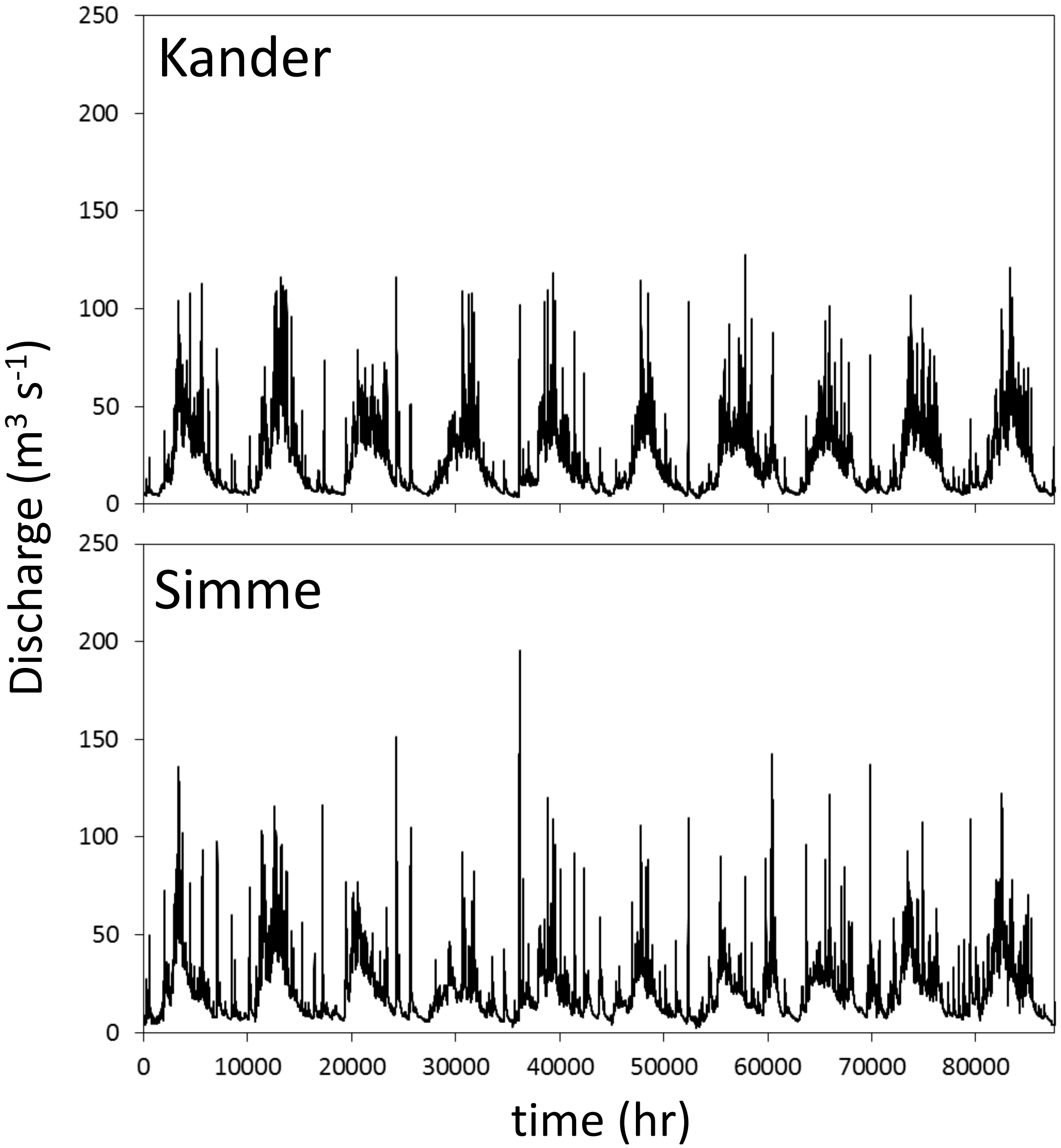
Reconstruction of paleo-DEM with historic maps



Kander river before correction

Discharge

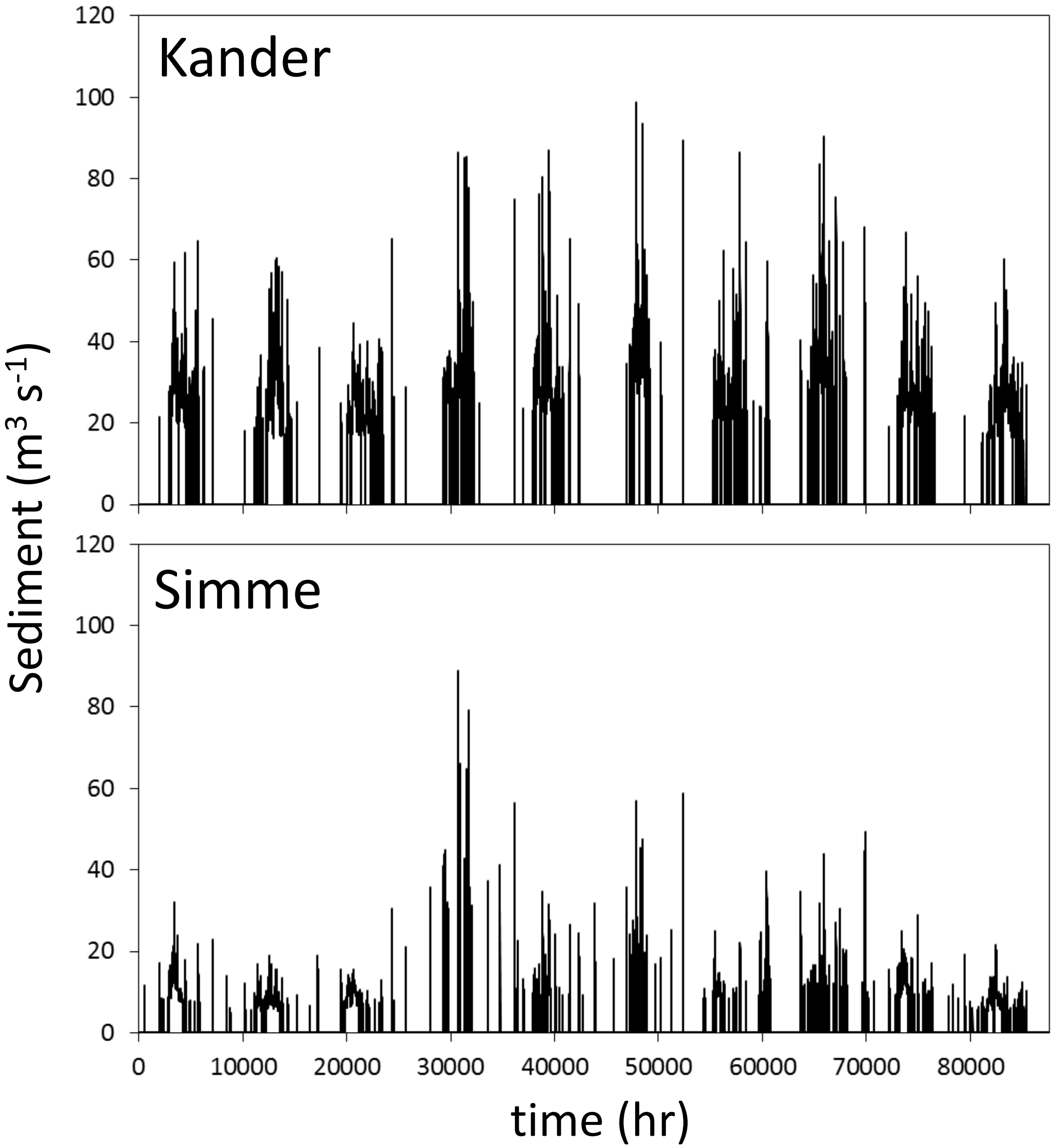
- 10 years of hourly discharge from 1986-1996
- No floods included in the simulation because none in historical records

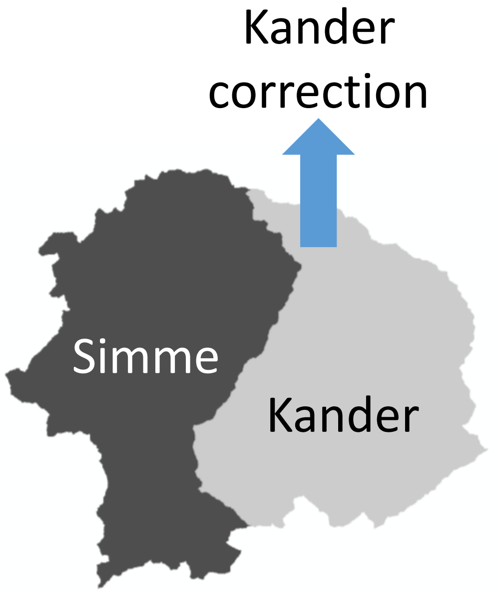


Kander correction

Sediment inputs

- Annual sediment inputs
  - Simme: **20,000 m^3 yr^{-1}**
  - Kander: **80,000 m^3 yr^{-1}**
- High flows were **≥ 30 m^3 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

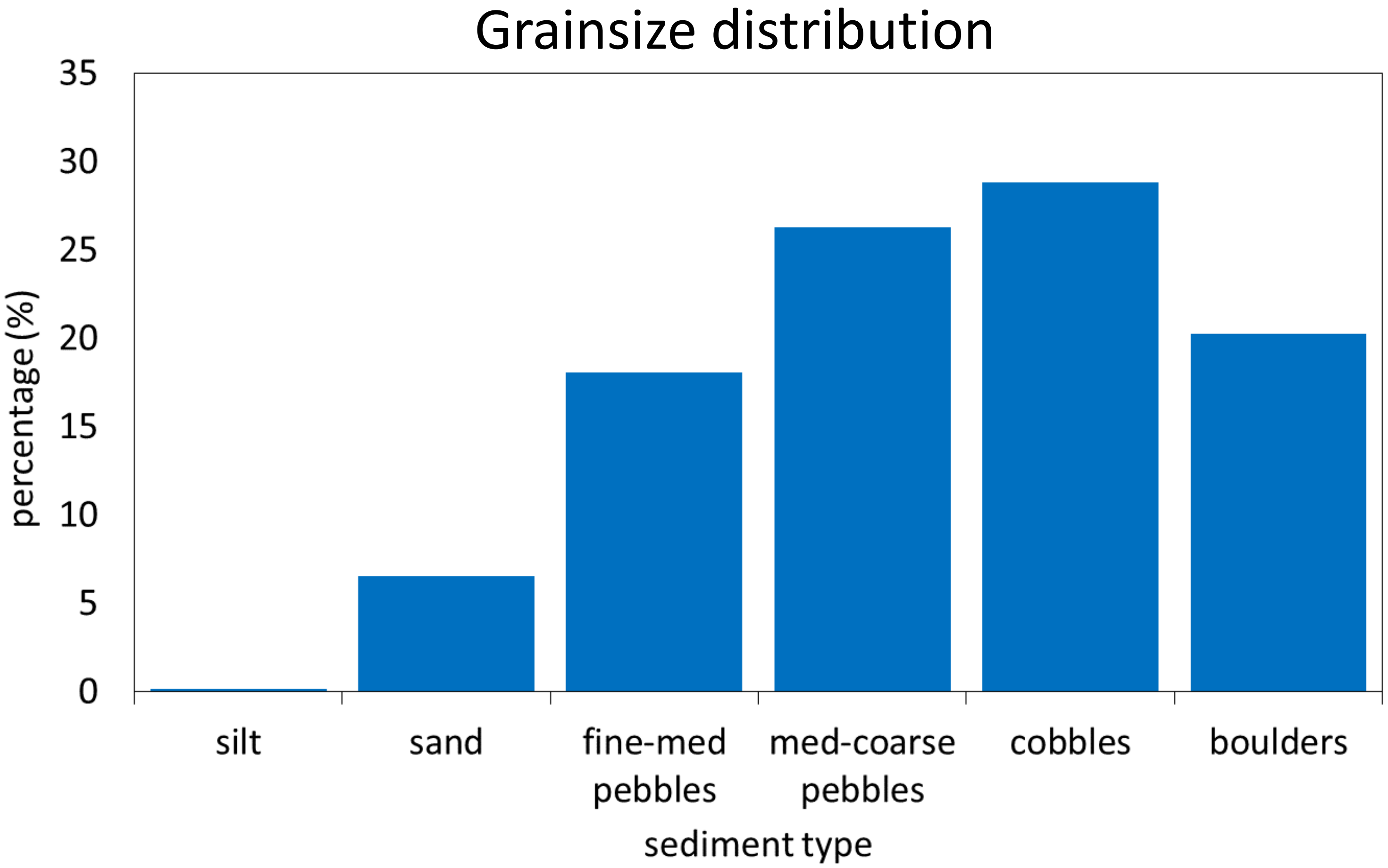




Source: Geschiebehaushalt Kander, 2014

Grain size

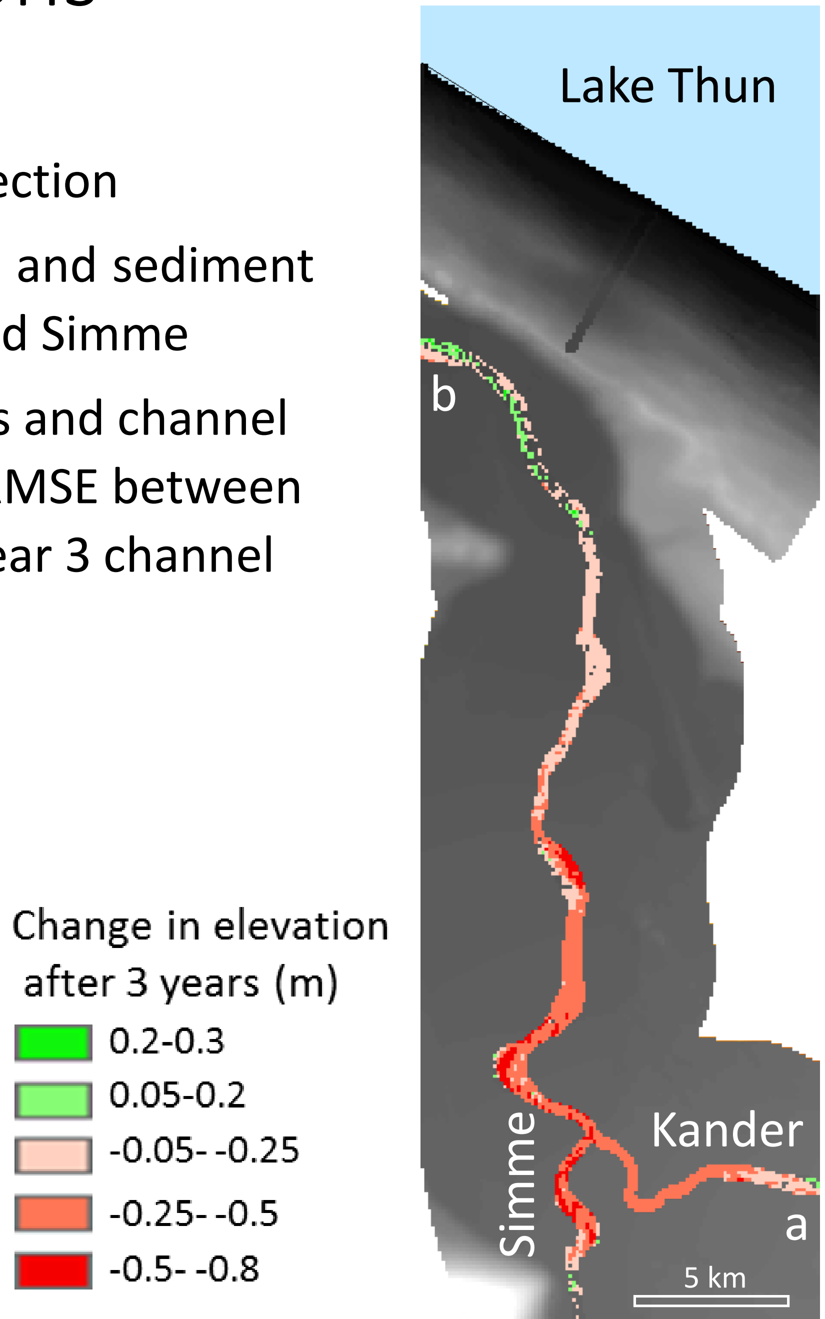
- 6 grain size classes (silt to boulder) were estimated from Kander and Simme
- Each grid cell in the model initially contains the same grainsize percentages

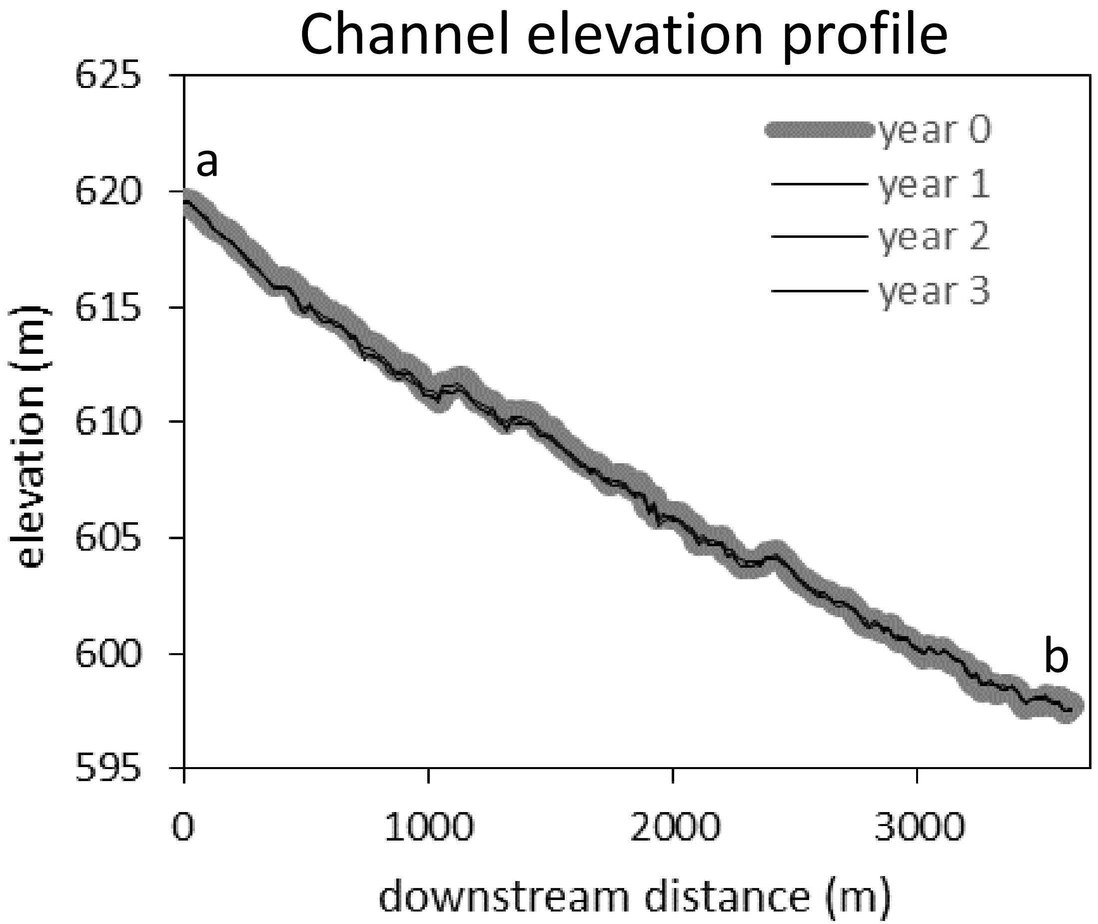


Source: Geschiebehaushalt Kander, 2014

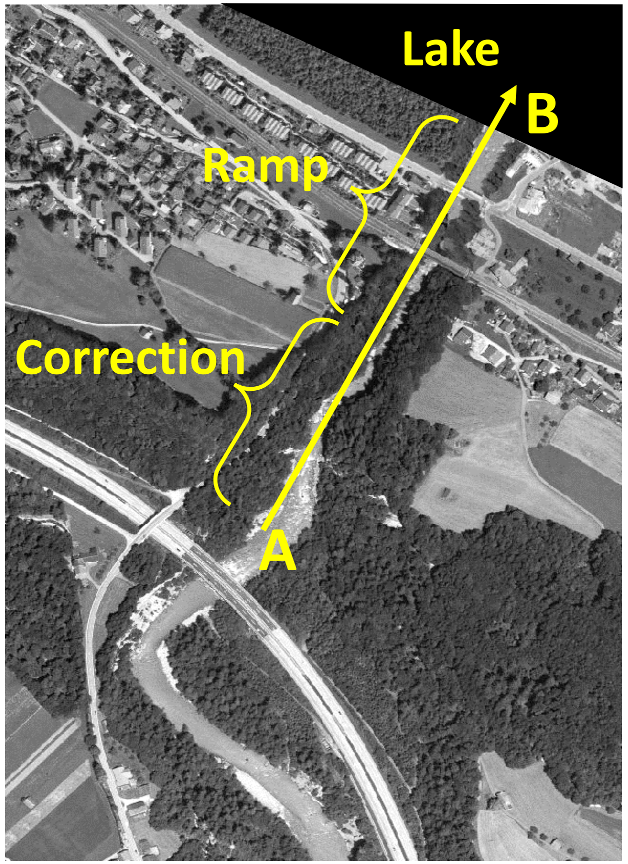
Initial conditions

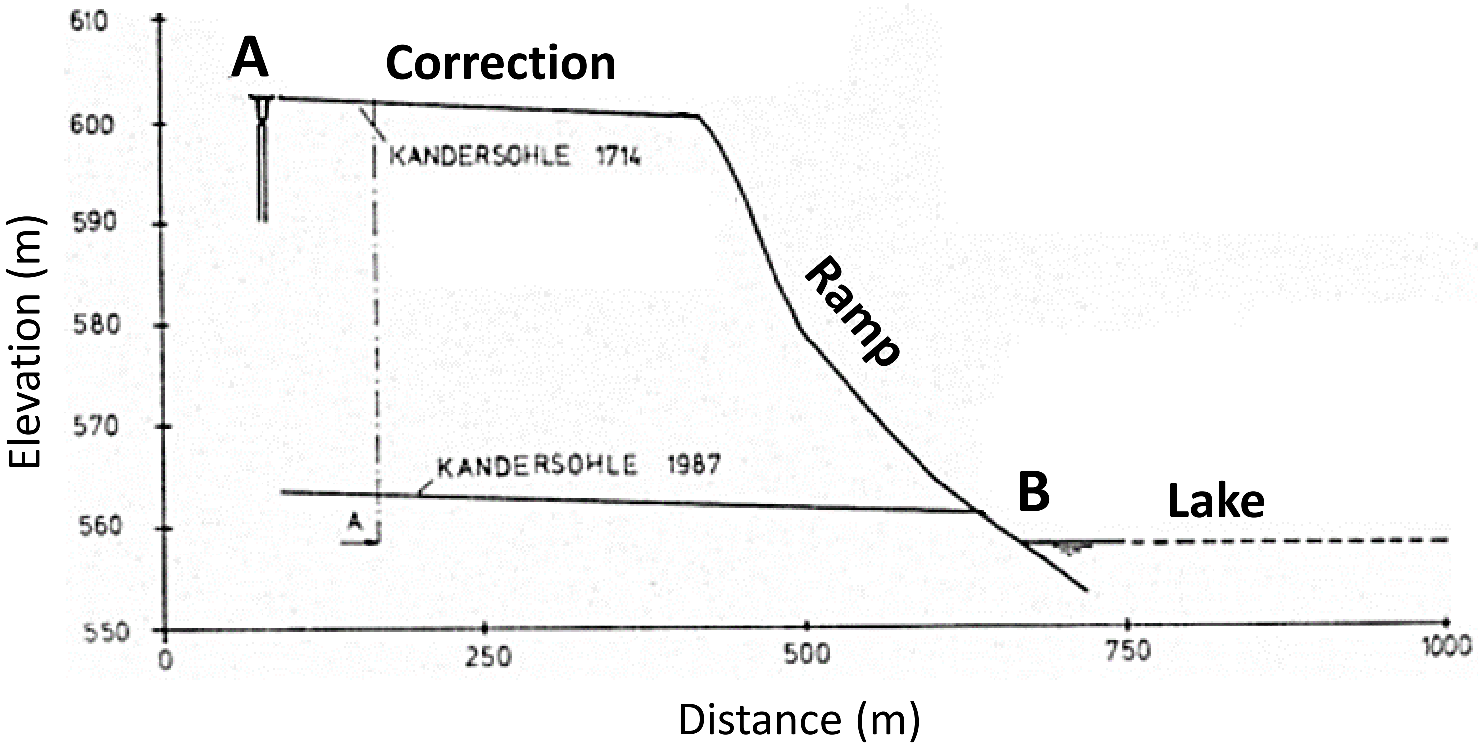
- Kander without correction
- 1986-1989 discharge and sediment inputs for Kander and Simme
- Model ran for 3 years and channel was in equilibrium (RMSE between initial channel and year 3 channel was 0.15 m)





Kander correction-1714



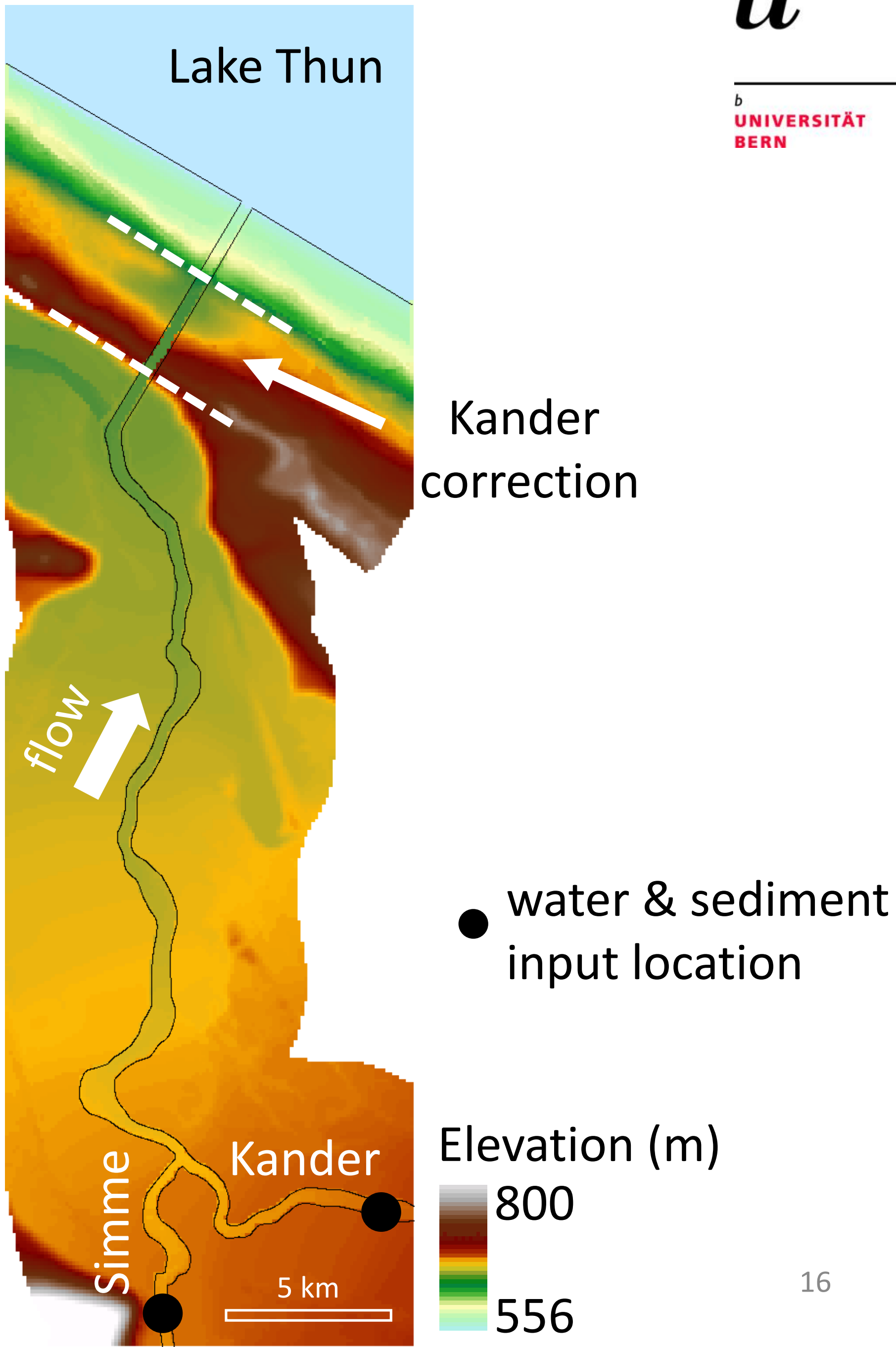


- The **<u>correction</u>** Length: 340 m, Width: 32 m, Slope: 0.8%.
- A **<u>ramp</u>** connected the correction to the lake, **steep slope 14%**
- **<u>Lake</u>** Thun was added to the DEM at the location of the shoreline.
  The lake was set as a non-erodible plane

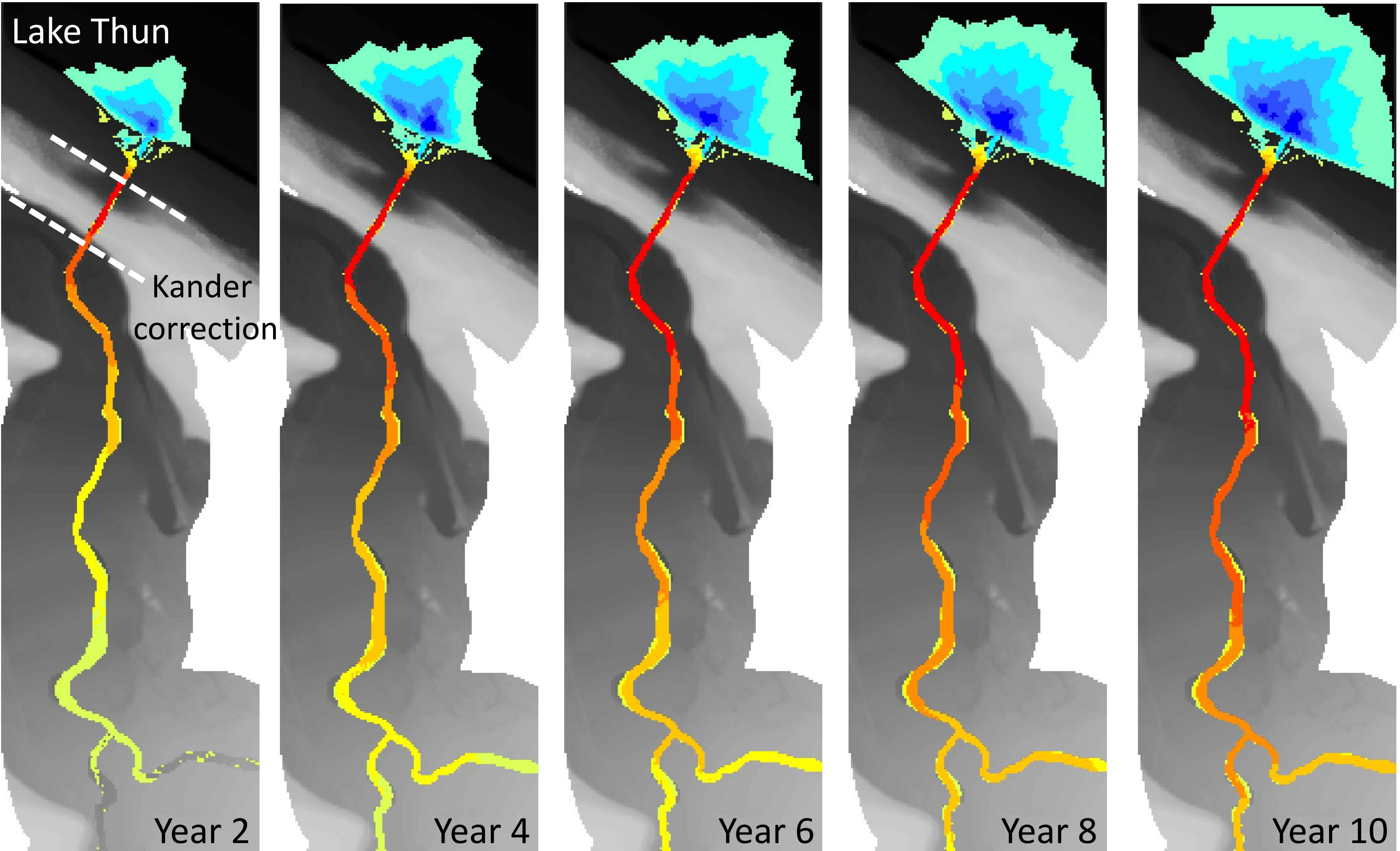
Source: Geschiebehaushalt Kander, 2004

Kander correction model

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



Results



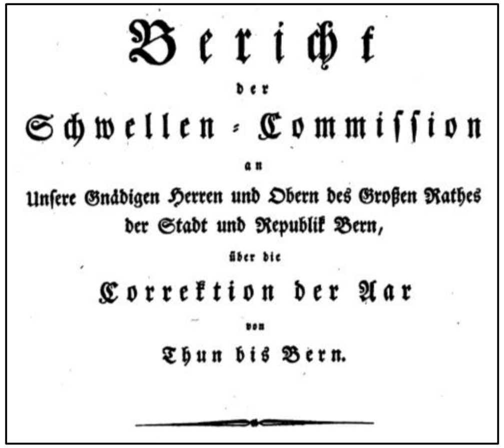
- Delta formation
- Significant erosion within Kander correction
- Rapid rates of upstream incision

$year_0 - year_X$

Erosion (m)	Deposition (m)
0.2-2	2-4
2-5	4-6
5-10	6-8
10-15	8-9
15-20	9-10
20-28	11-12

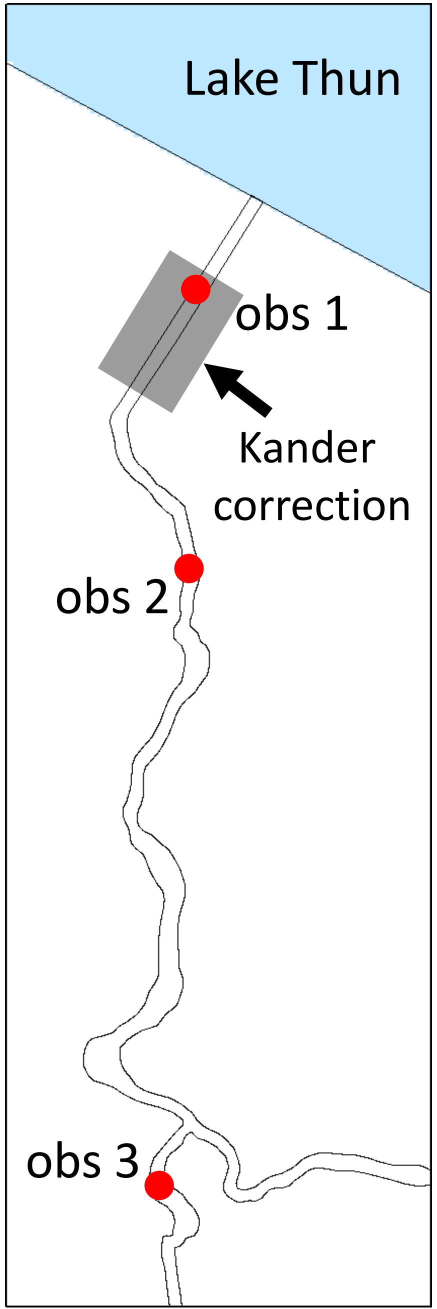
Channel incision

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



Bericht
der
Schwellen-Commission
an
Unsere Gnädigen Herren und Obern des Großen Rathes
der Stadt und Republik Bern,
über die
Correktion der Aar
von
Thun bis Bern.

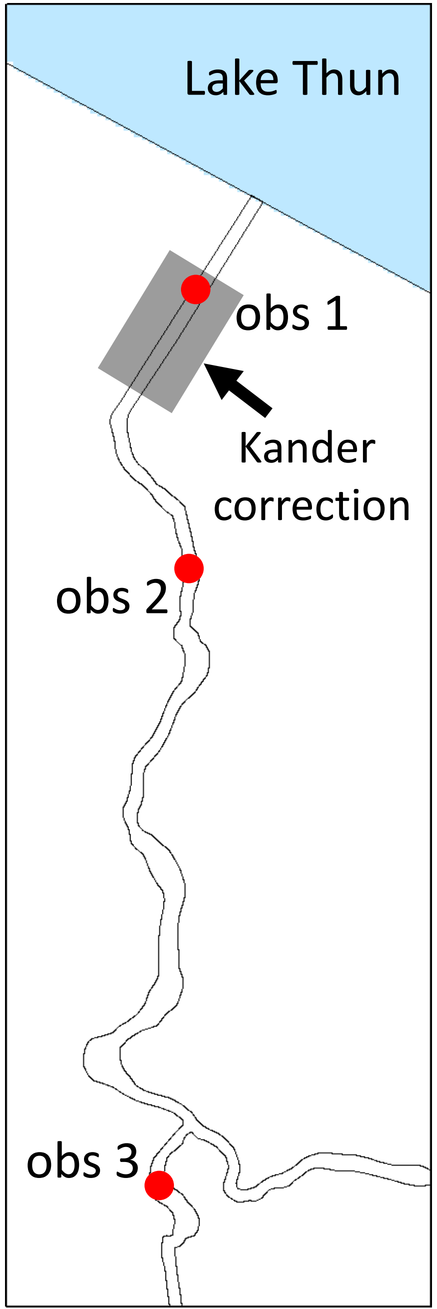
Historical observations

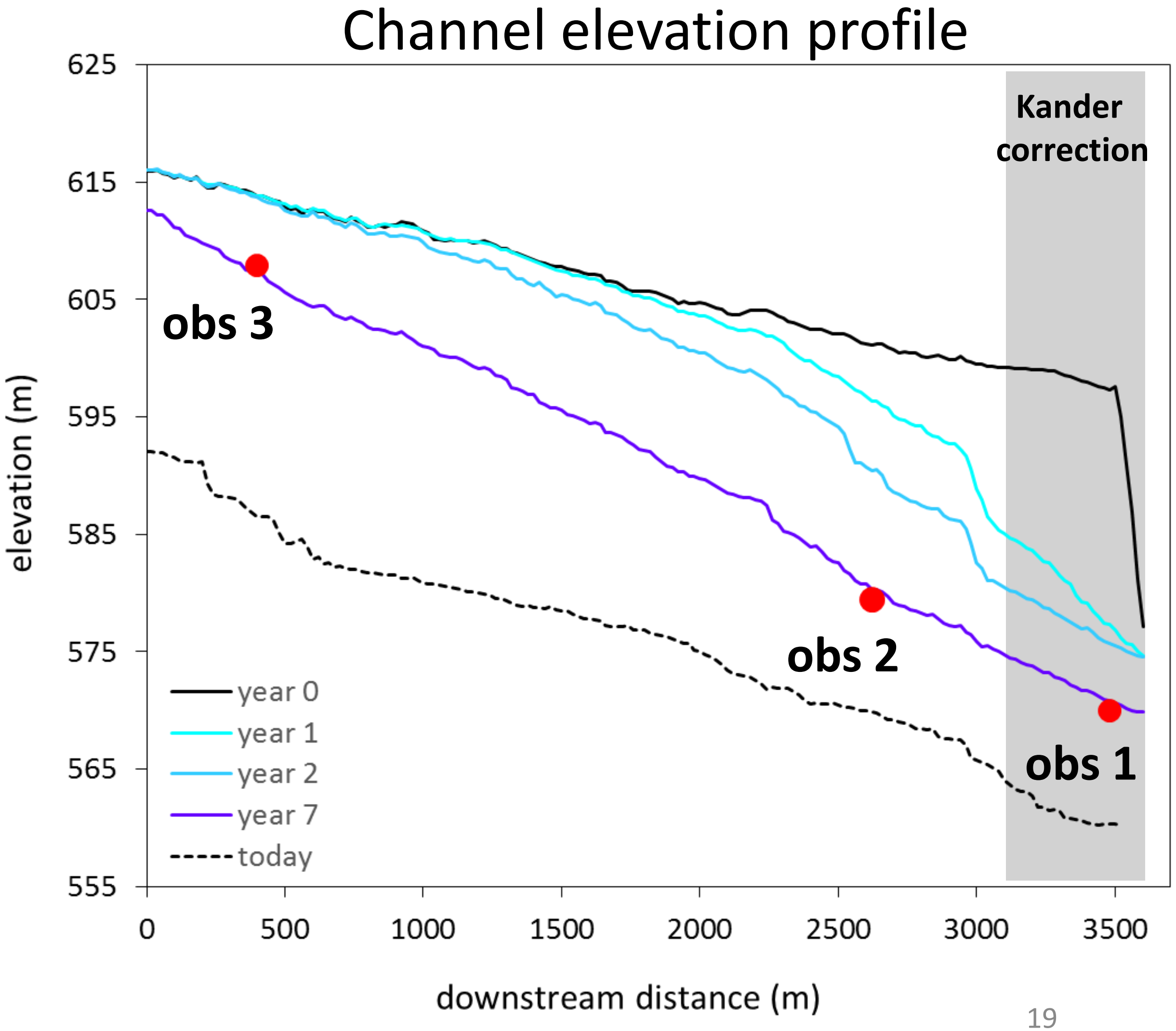


Source: Koch (1826)

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





Source: Koch (1826)

Channel incision

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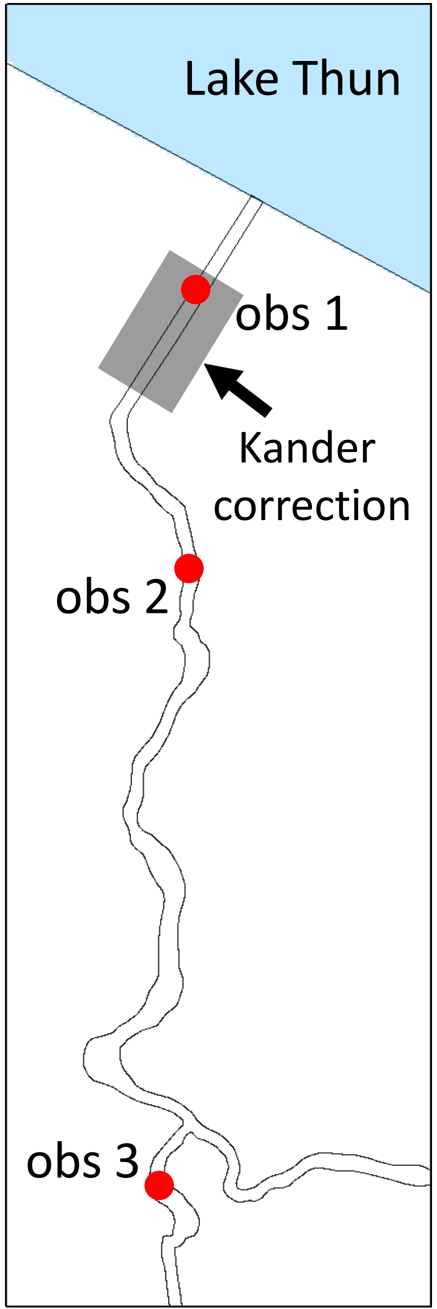
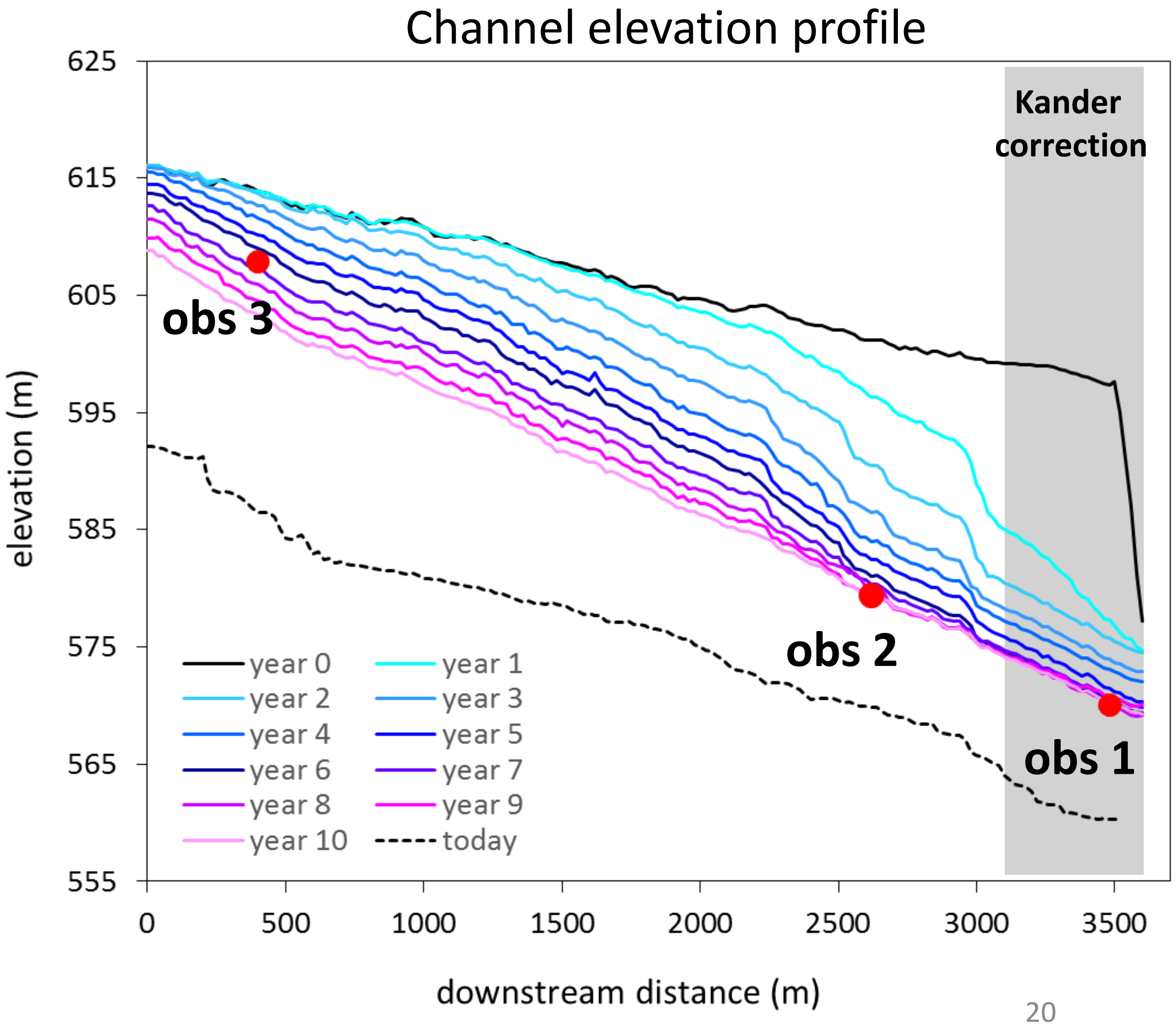
- Aggressive erosion rate of **2 m yr^{-1}** in first **10 years**
- **57%** total erosion to present day occurred during this time
- Erosion rate decreasing to **1 m yr^{-1}**
- Estimate **13 more years** to reach present day channel elevation

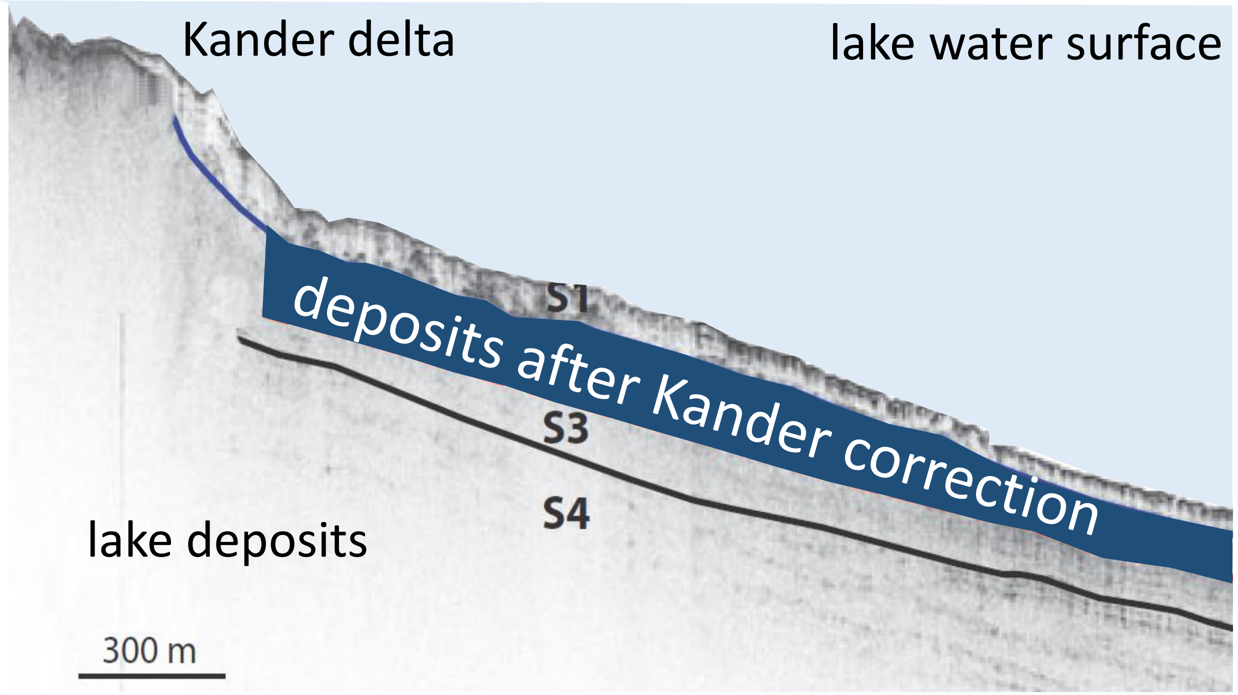


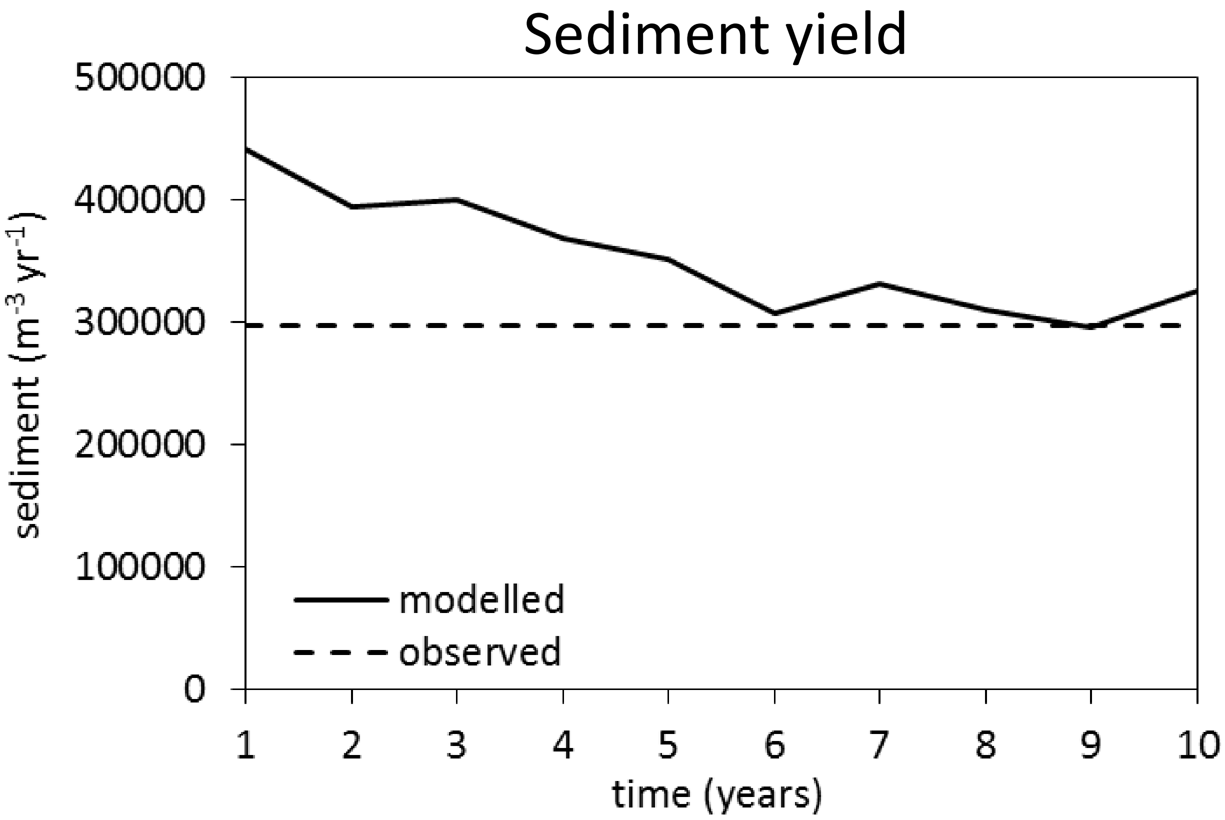


Source: Koch (1826)

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

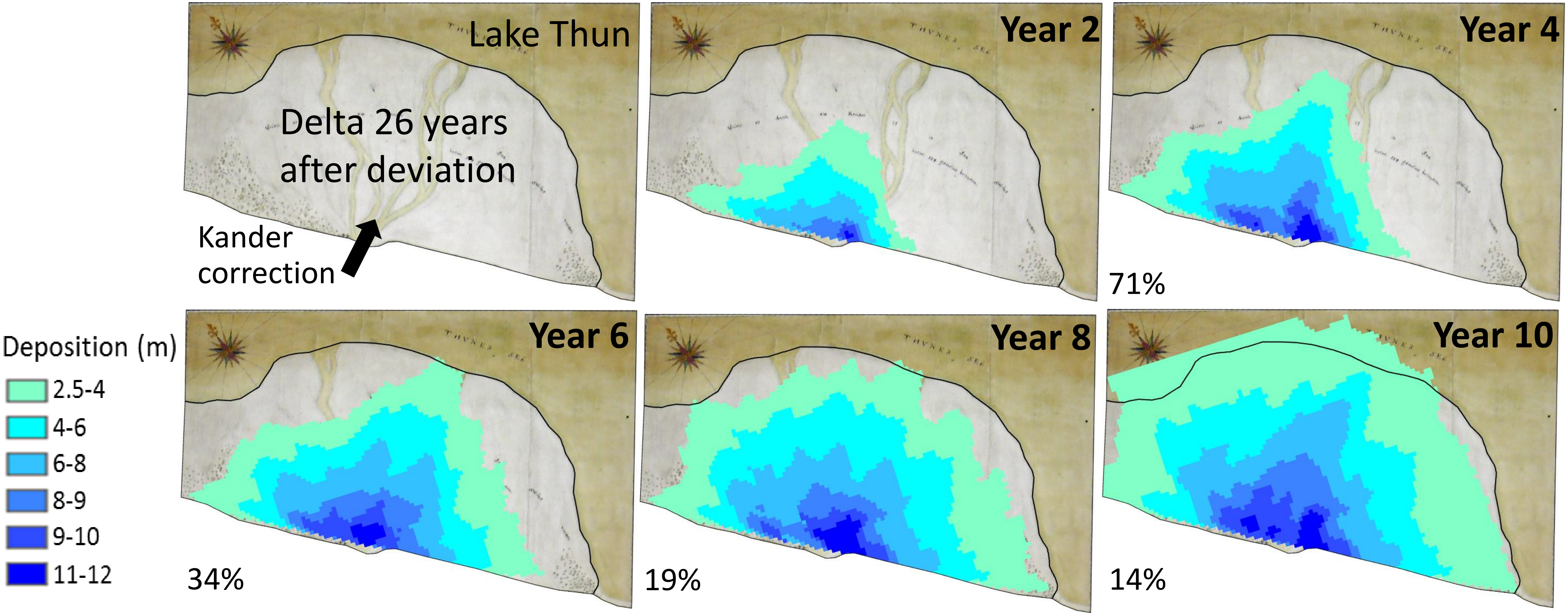




Source: Wirth et al. (2011)

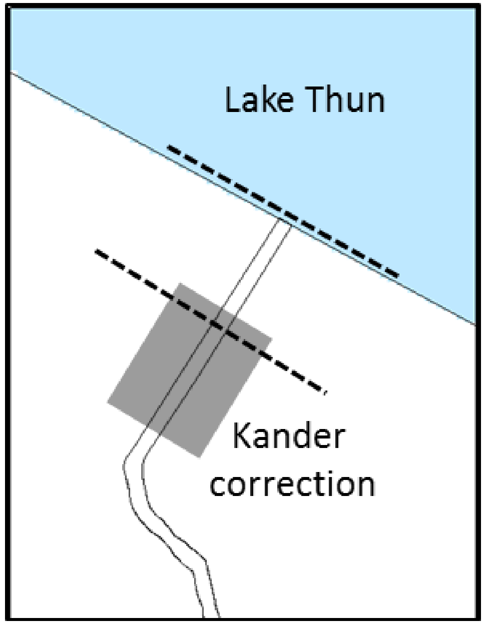
Delta formation

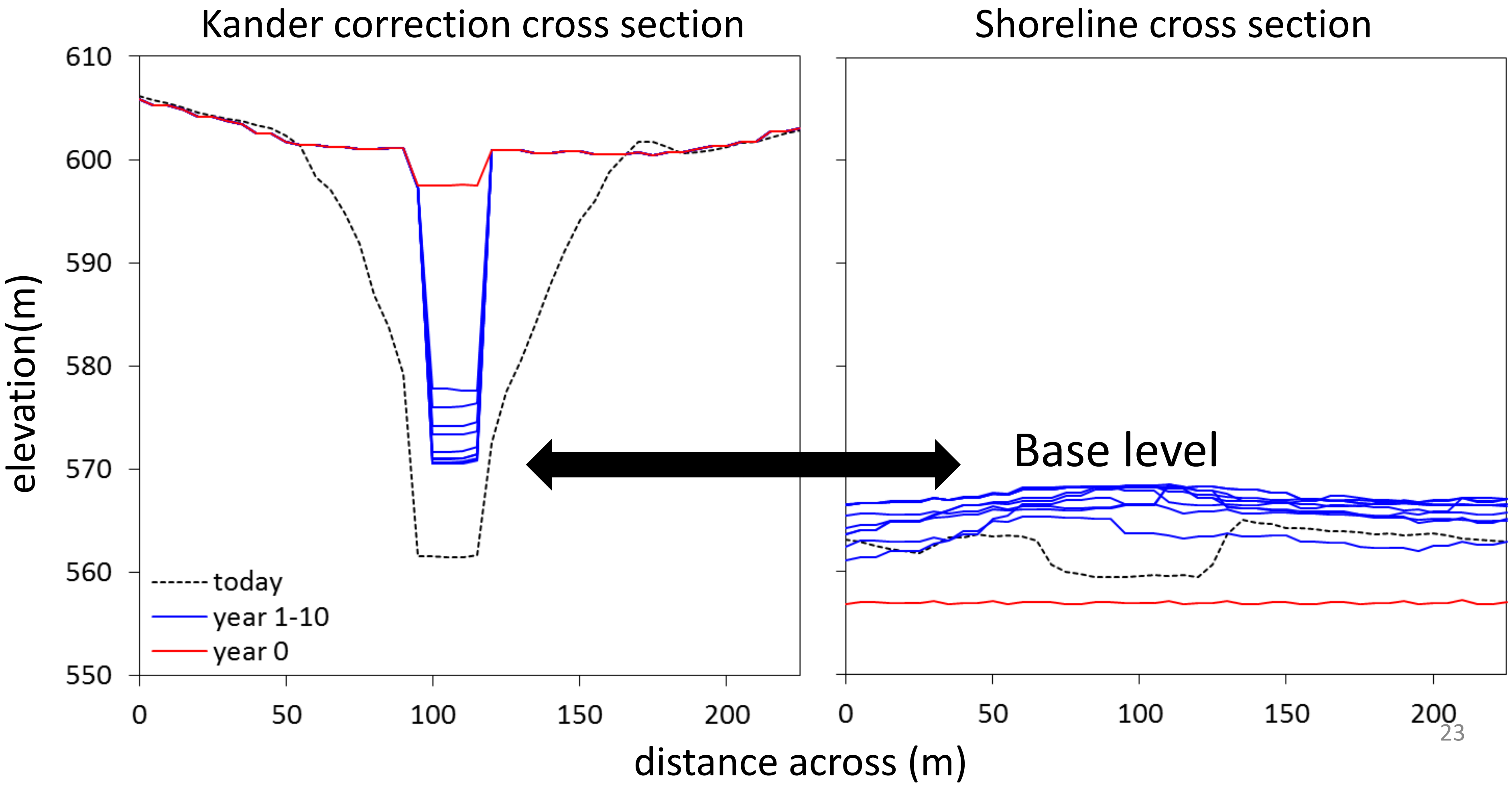
- Model produces delta with semicircular shape, and suggests delta formed quickly
- Percent change in total delta deposits indicates stabilization after **10 years**
- Modelled delta deposition is in range of present day deposits **(0.5-14 m)**



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?





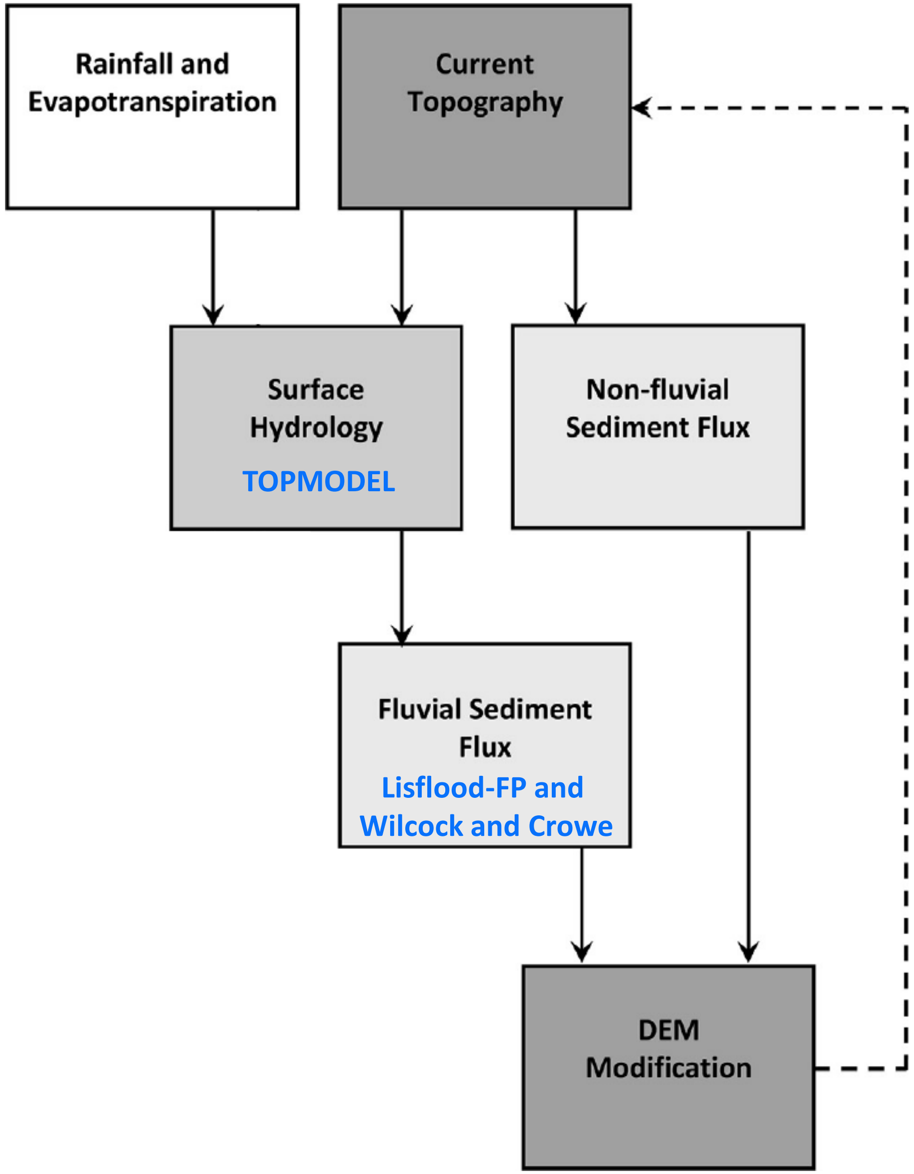
Conclusion

- 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

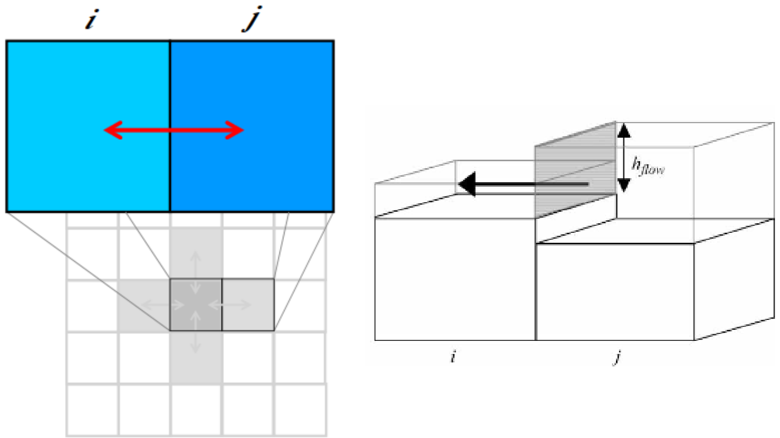


Lisflood-FP

calculate the flow (Q) between cells

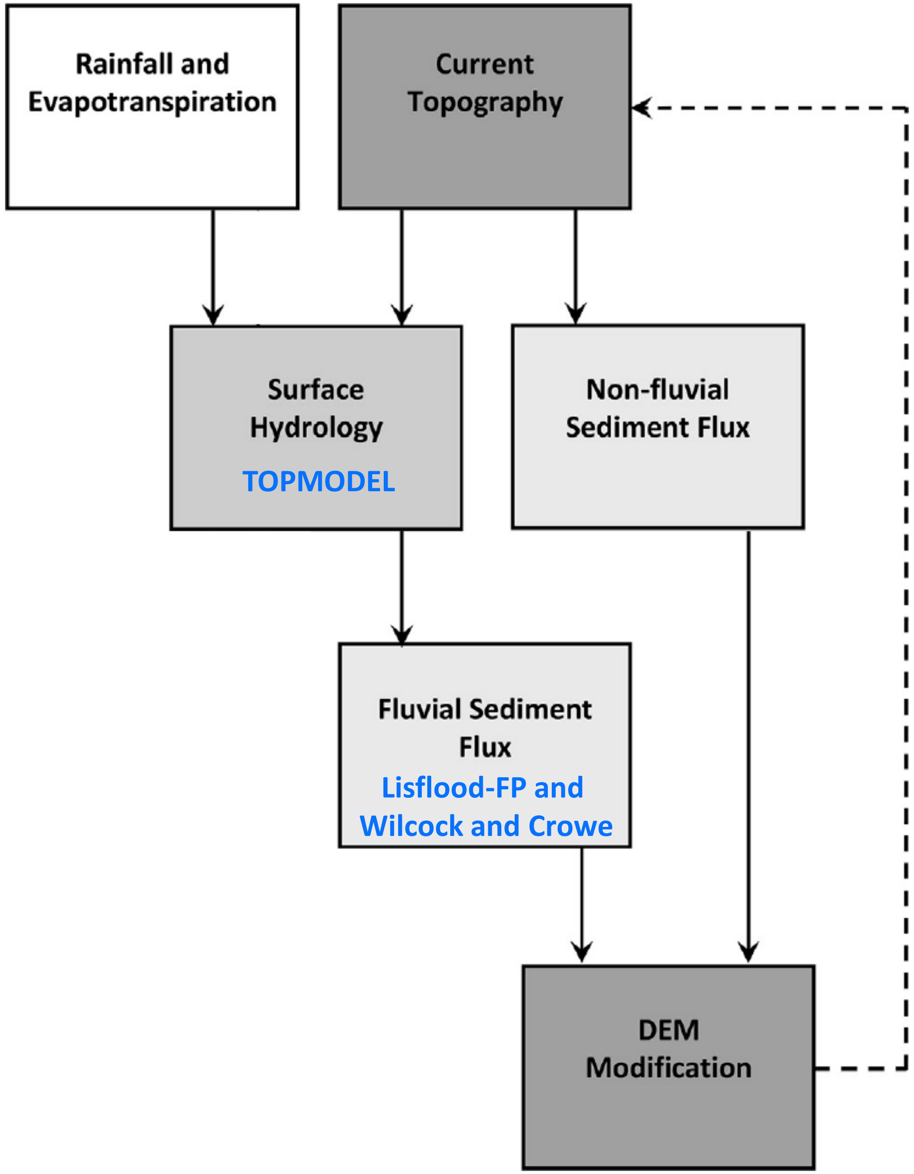
$$Q = \frac{q - g h_{flow} \Delta t \frac{\Delta(h+z)}{\Delta x}}{\left(1 + g h_{flow} \Delta t n^2 |q| / h_{flow}^{10/3}\right)} \Delta x$$

q is the flux between cells from the previous iteration ($m^2 s^{-1}$)
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)
hflow is the maximum depth of flow between cells
x is the grid cell width (m)
t is time (s)



Barkwith et al. (2015), Coulthard et al (2013)

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

Barkwith et al. (2015), Wilcock and Crowe (2013)