Modelling geomorphic responses to human impacts and extreme floods: Application to the Kander river, Switzerland

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GeomorphRisk

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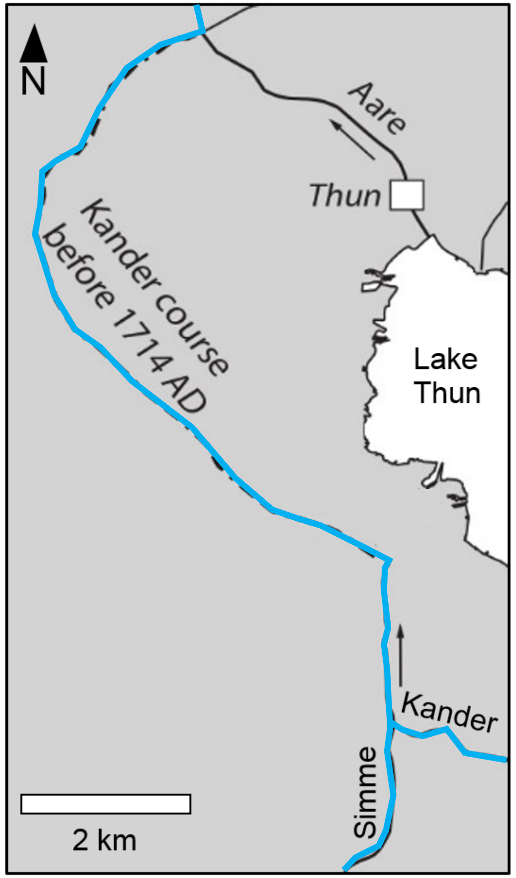
Source: https://en.wikipedia.org

Historical background

- In 1714 Kander river flowed into the Aare river:
  - Causing massive flooding in the region of Thun



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

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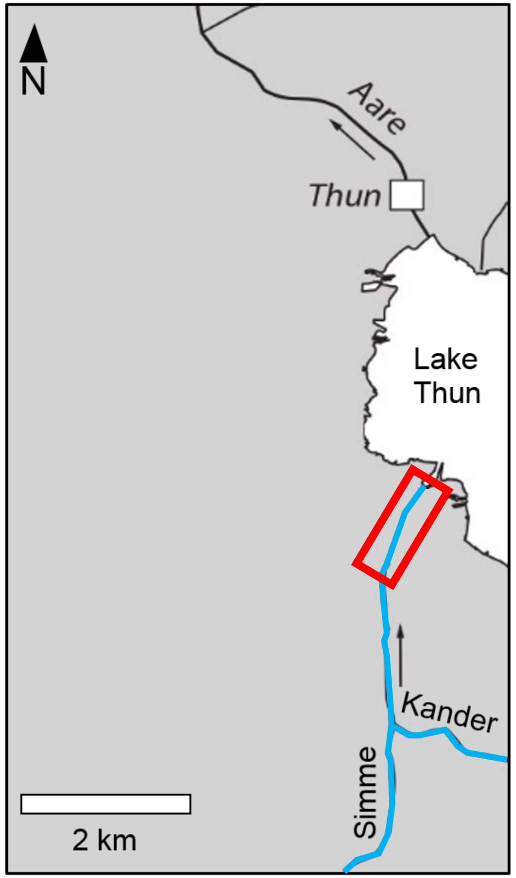
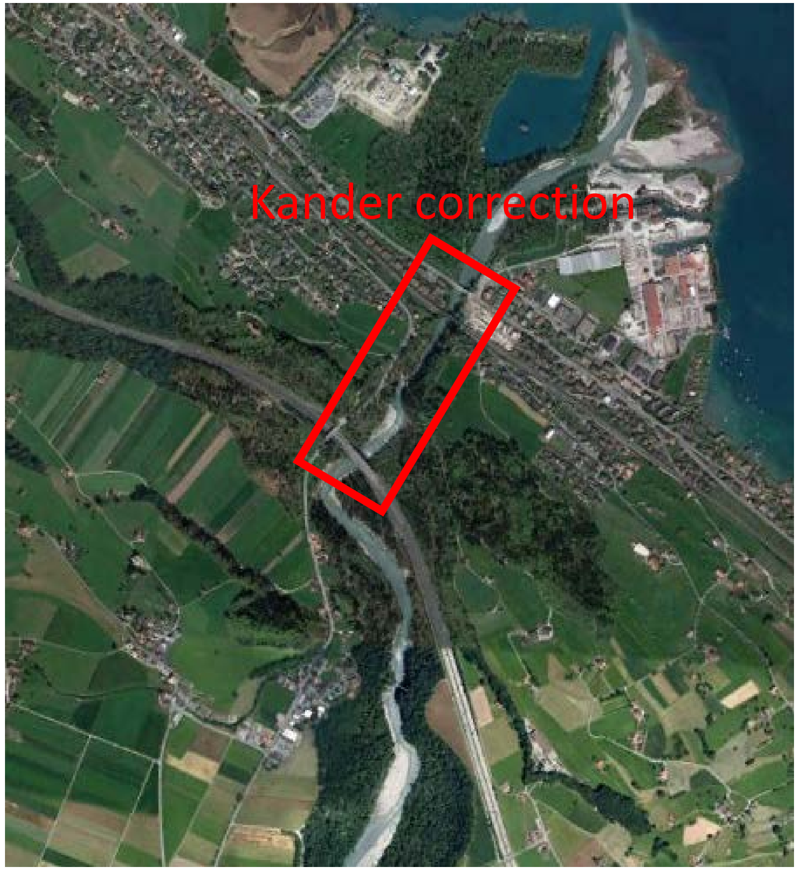
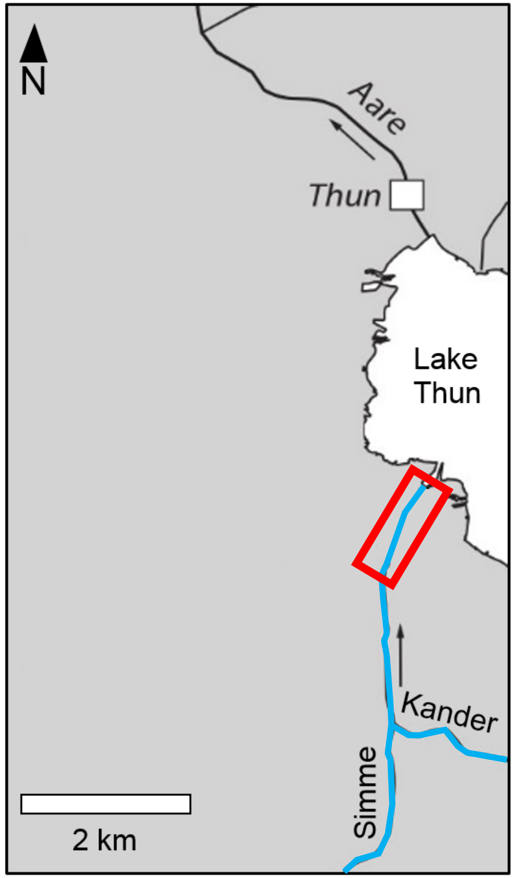


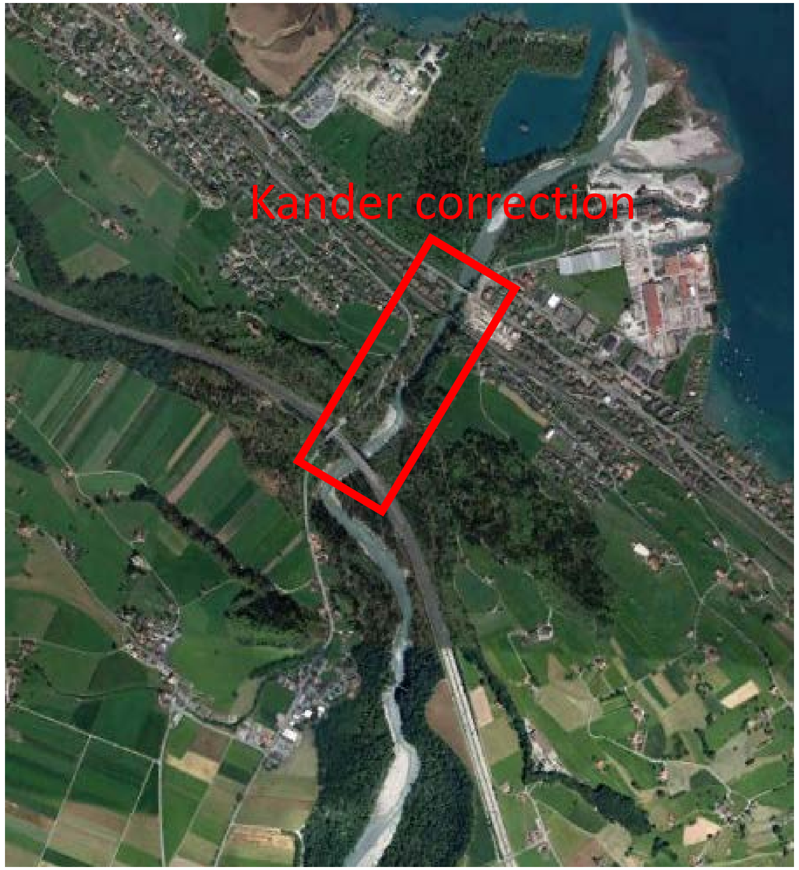


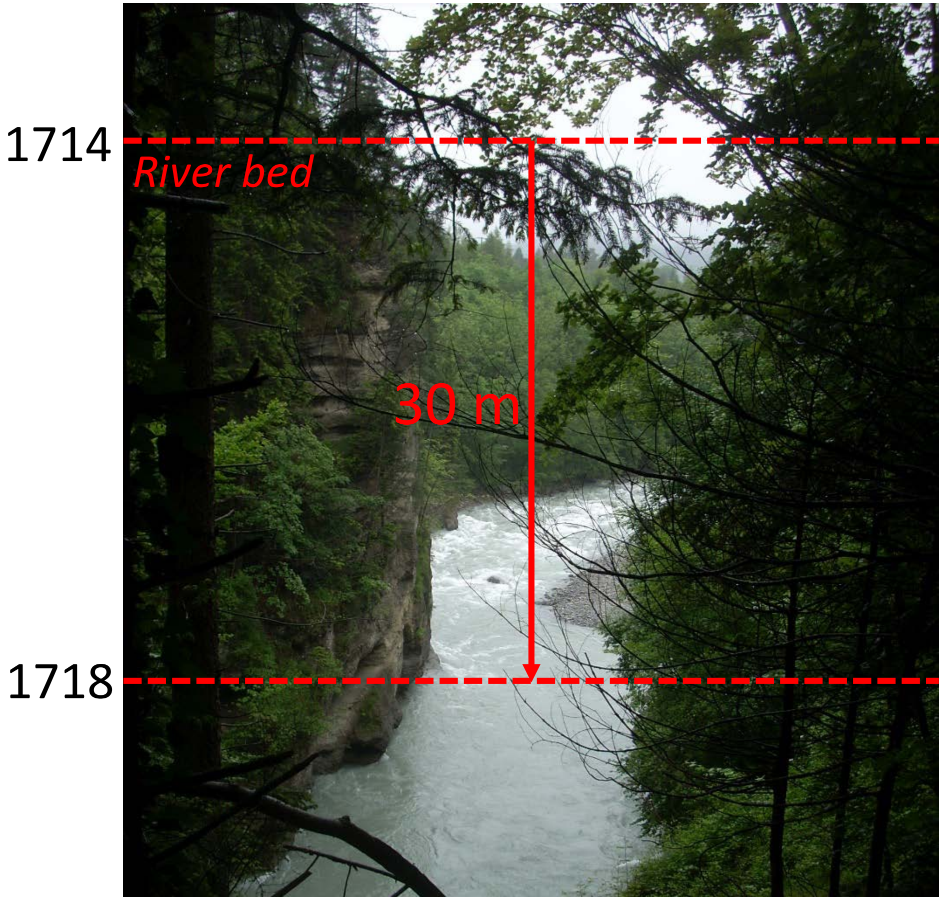
Source: Google maps, Wirth et al. (2011)

Historical background

- In 1714 Kander river flowed into the Aare river:
  - Causing massive flooding in the region of Thun
  - Kander river was deviated to lake Thun by engineering works
  - Four years after Kander correction eroded ~30 m







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

Aims

- Can we model geomorphic effects of human intervention in fluvial systems?:
  - River restoration
  - River engineering
- Test landscape evolution model (LEM) on Kander correction
- Determine sensitivity of LEM to extreme flood events (climate change)

Restoration

Engineering

Extreme floods

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

CAESAR-Lisflood

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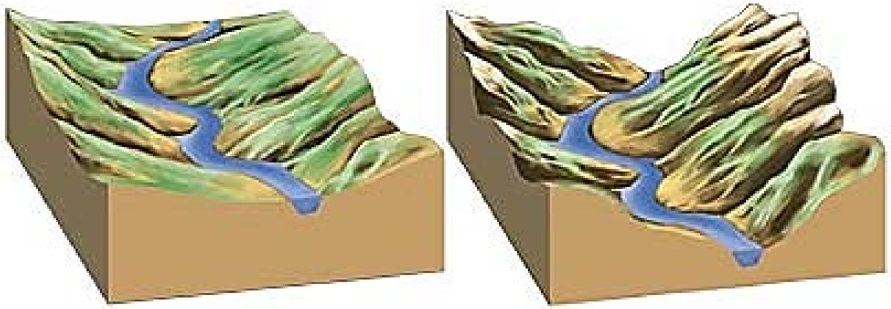
- Landscape evolution model simulating erosion and deposition within river reaches (CAESAR)
- A hydrodynamic 2D flow model (based Lisflood FP model) that conserves mass and partial momentum

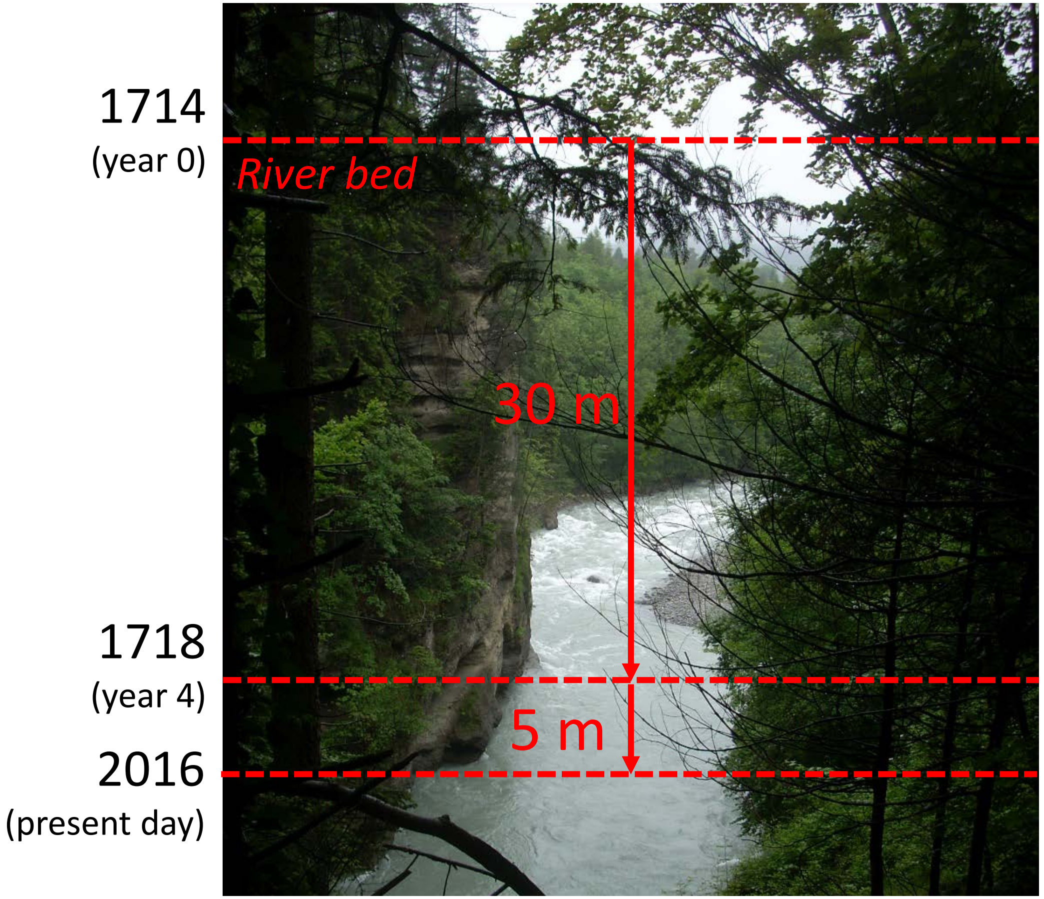
Source: https://sourceforge.net/projects/caesar-lisflood/

Model test using Kander Correction

- **Erosion:** incision of channel



- In ~4 years the Kander correction eroded ~30 m
- Afterwards the river eroded less and 'stabilized'
- Channel erosion propagated upstream



Source: http://media.web.britannica.com

Model test using Kander Correction

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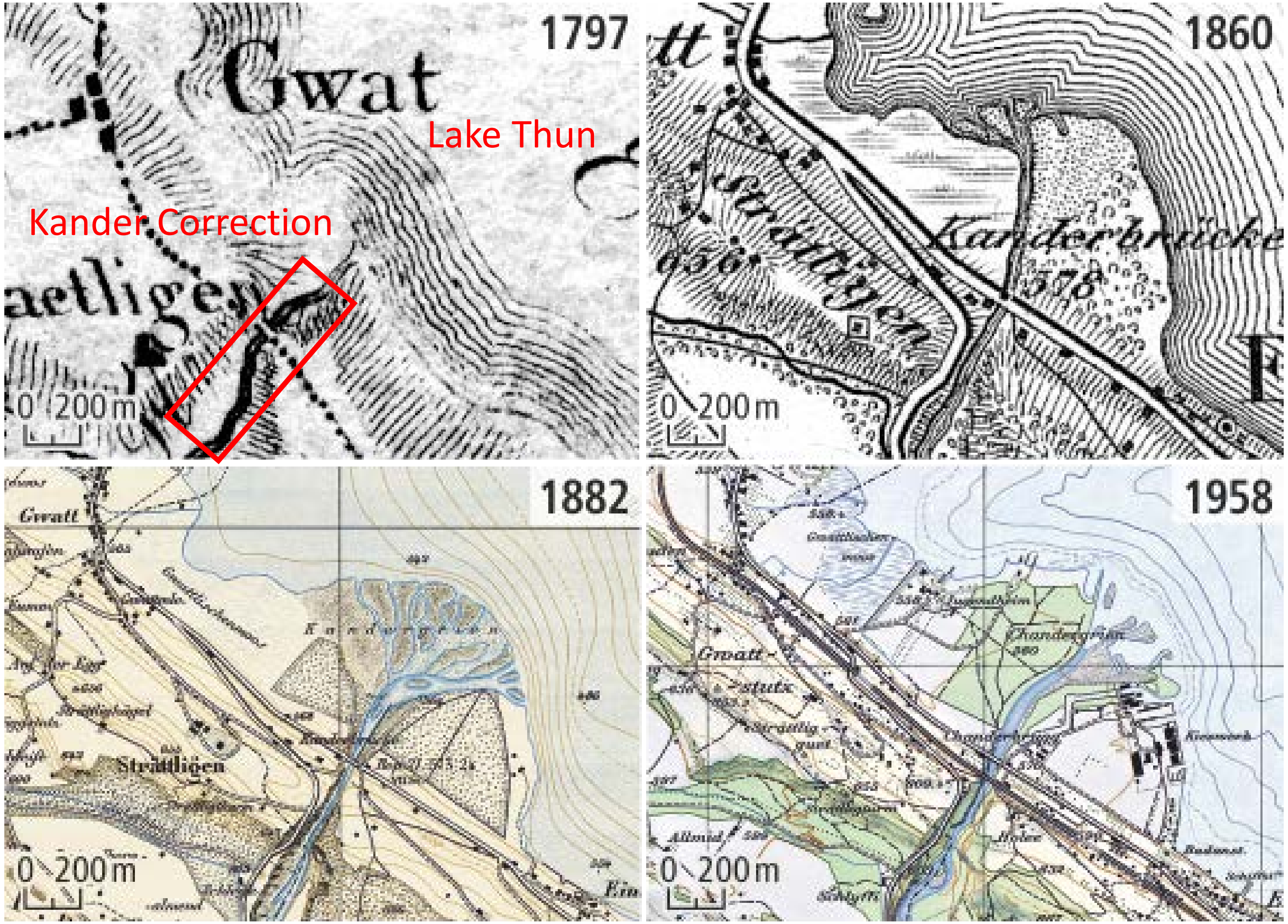
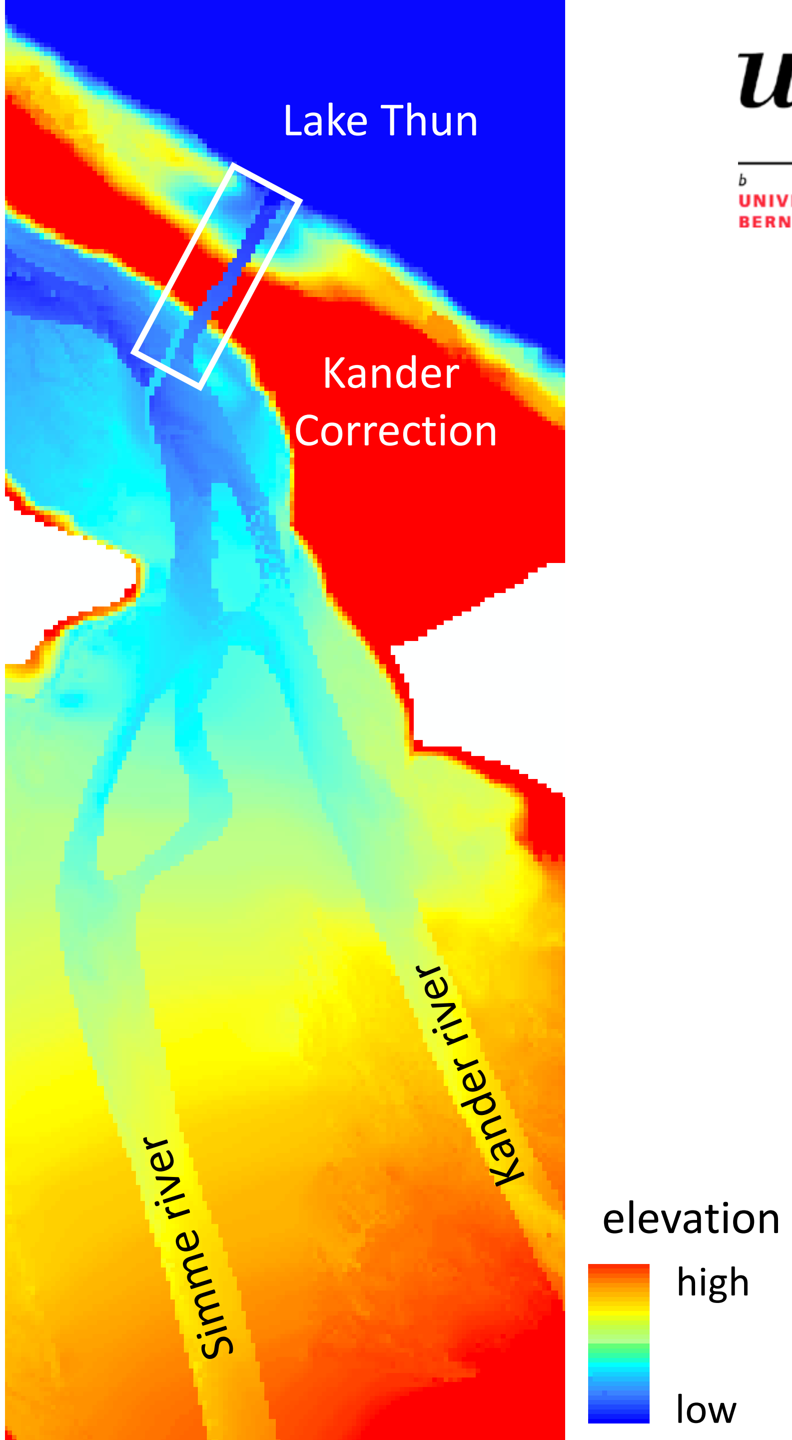
- **Deposition:** development of delta in lake Thun



Topography

- Present day topography was used to represent the river banks
- Historical data was used to develop river channel and Kander correction



Discharge

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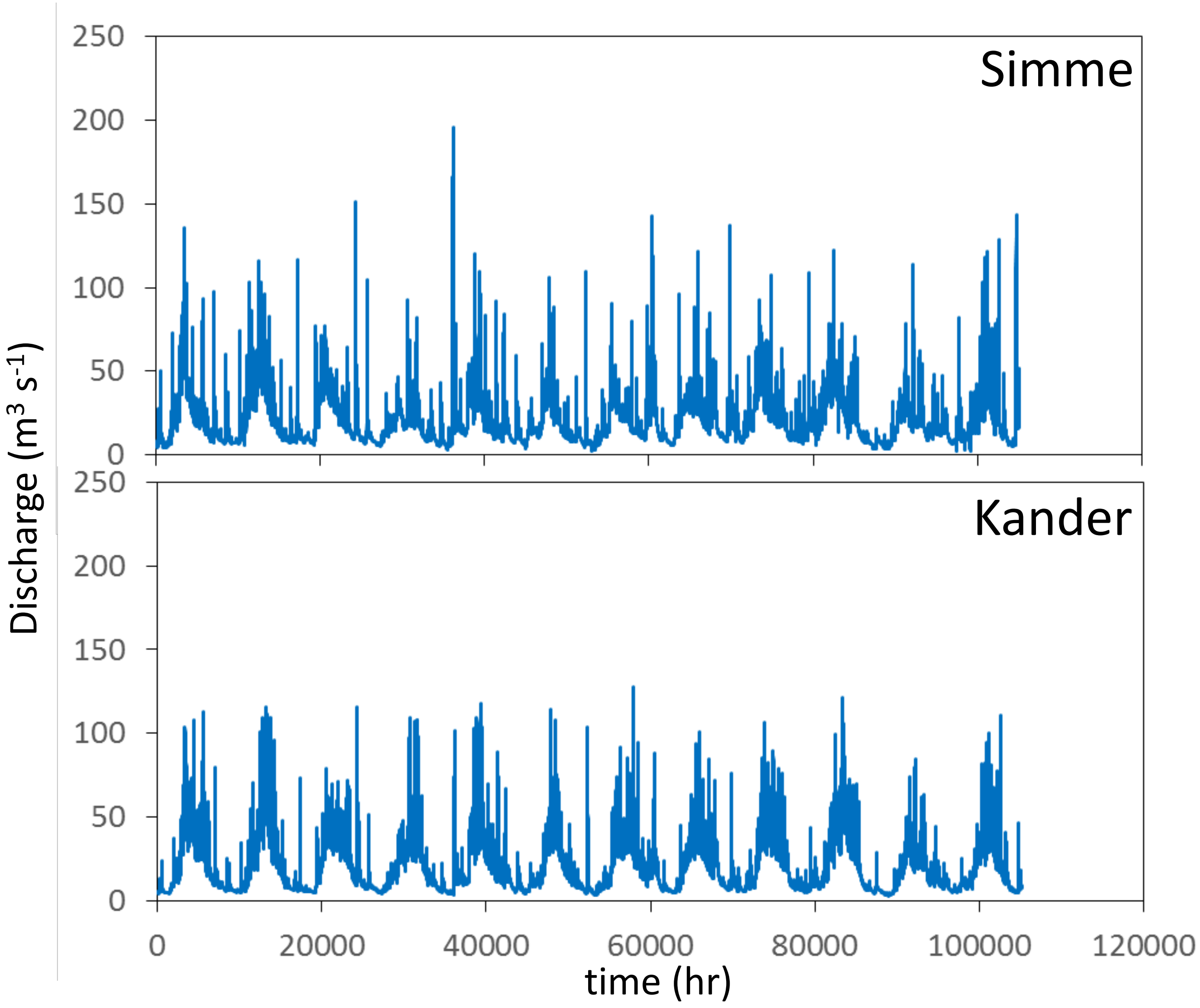
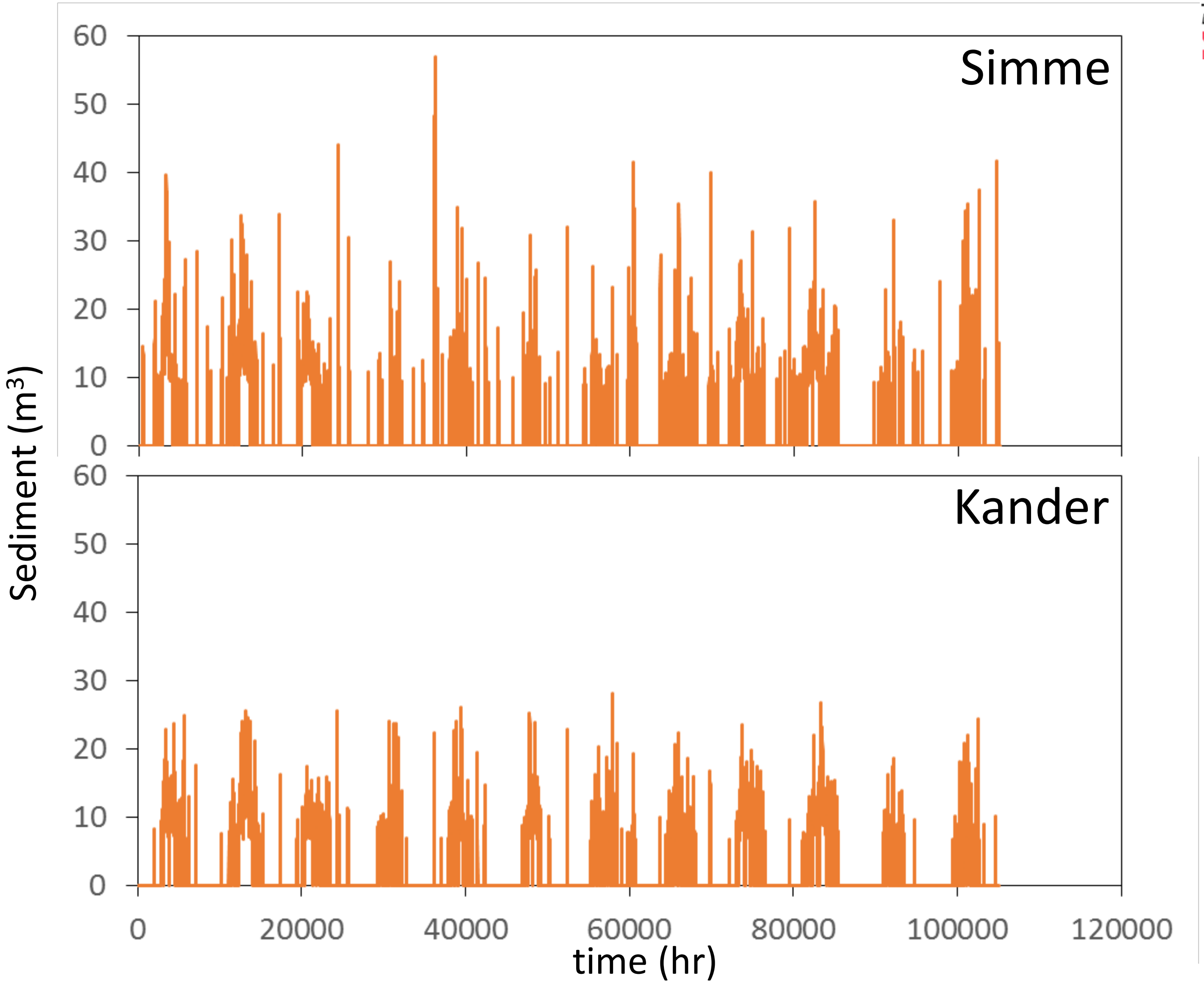
12 year simulation

Hourly Discharge 1986-1998



Sediment inputs

- 20,000 m^3 yr^{-1} were added to both the Simme and Kander
- High flows were ≥ 30 m^3 s^{-1} and we 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

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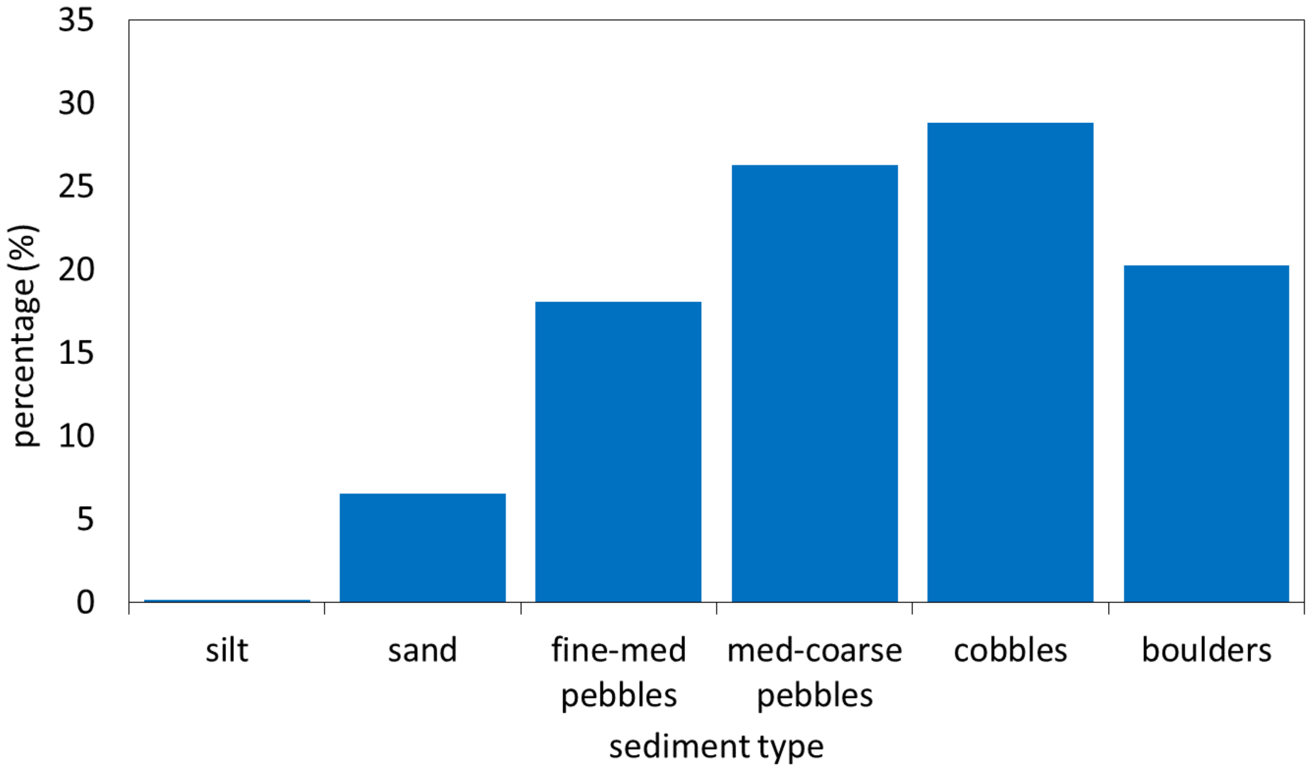
Grainsize distribution

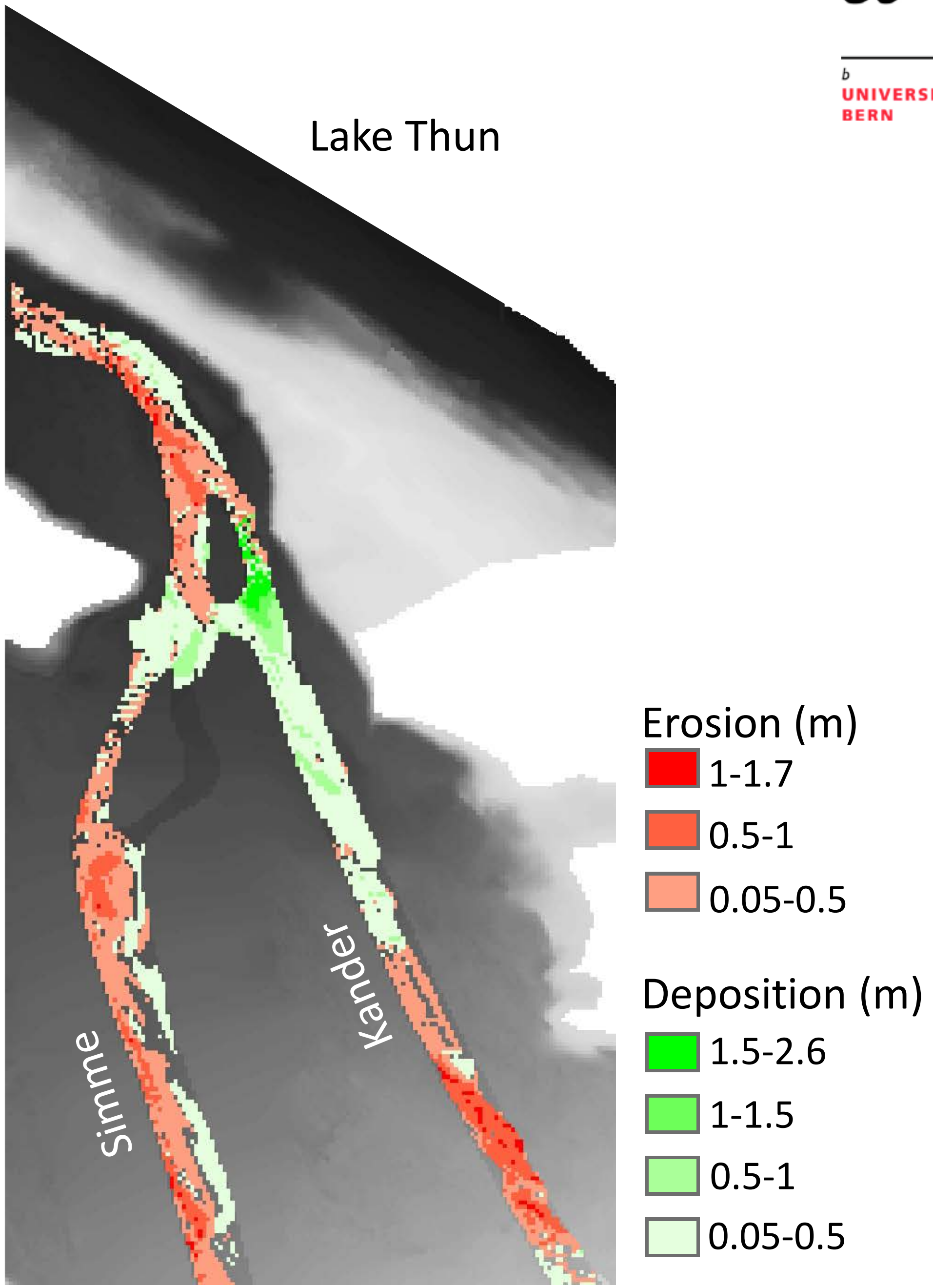
- 6 grain size classes (silt to boulder) were estimated from Kander and Simme
- Each gird cell in the model initially contains the same grainsize percentages



Source: Geschiebehaushalt Kander, 2014

Initial Conditions

- Kander without correction
- 1986 discharge and sediment inputs for Kander and Simme were repeated
- Grainsize mixing occurred, channel erosion and deposition
- Model ran for a total of **<u>8 years</u>** until the reach was in equilibrium: **<u>3%</u>** difference between sediment coming in and out of the reach



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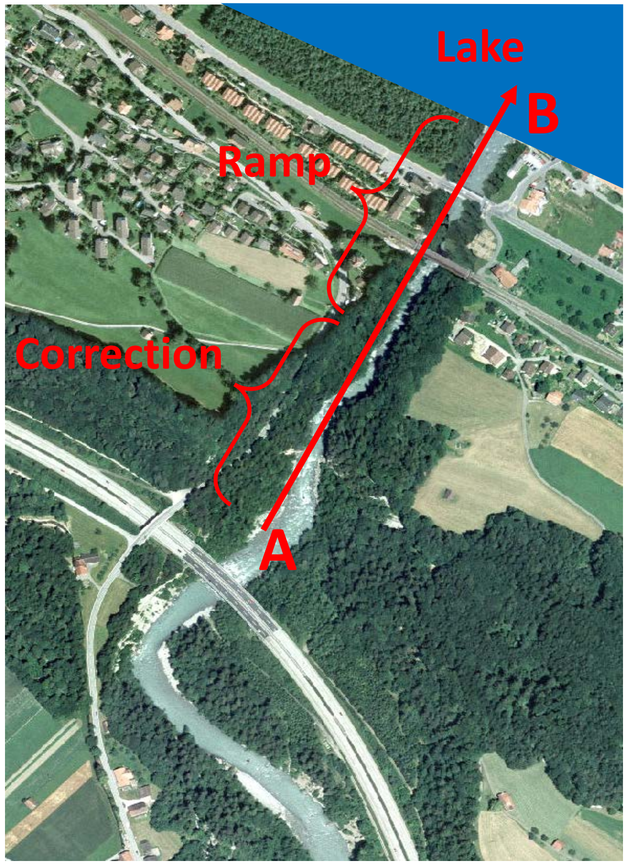
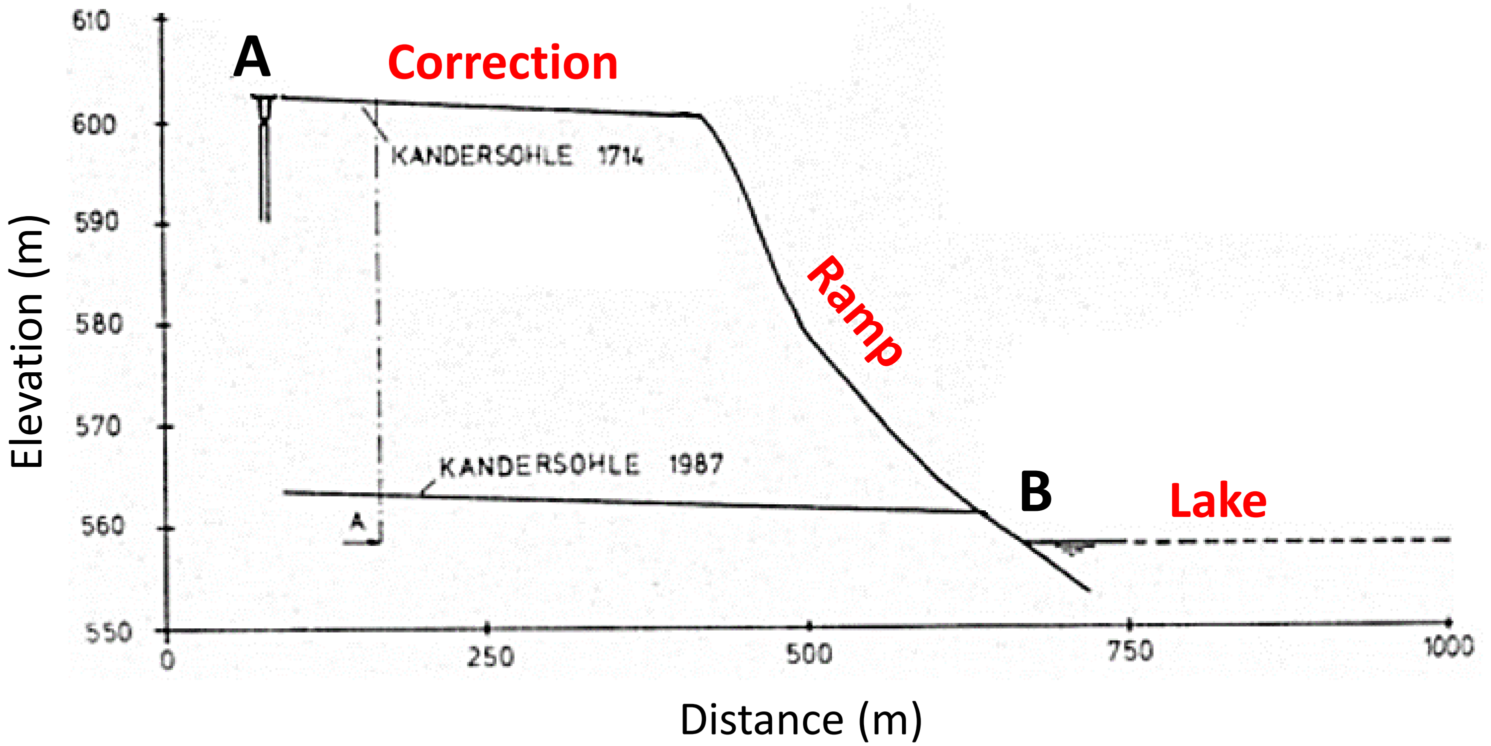
Kander correction: 1714





- The **correction** Length: 340 m, Width: 32 m, Slope: 0.8%.
- A **ramp** connected the correction to the lake
- **Lake** 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: 1714

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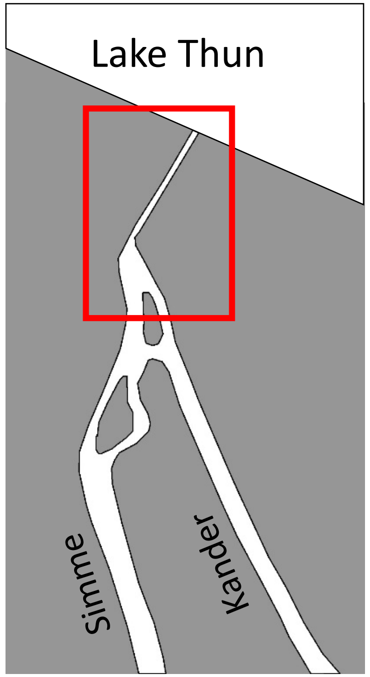
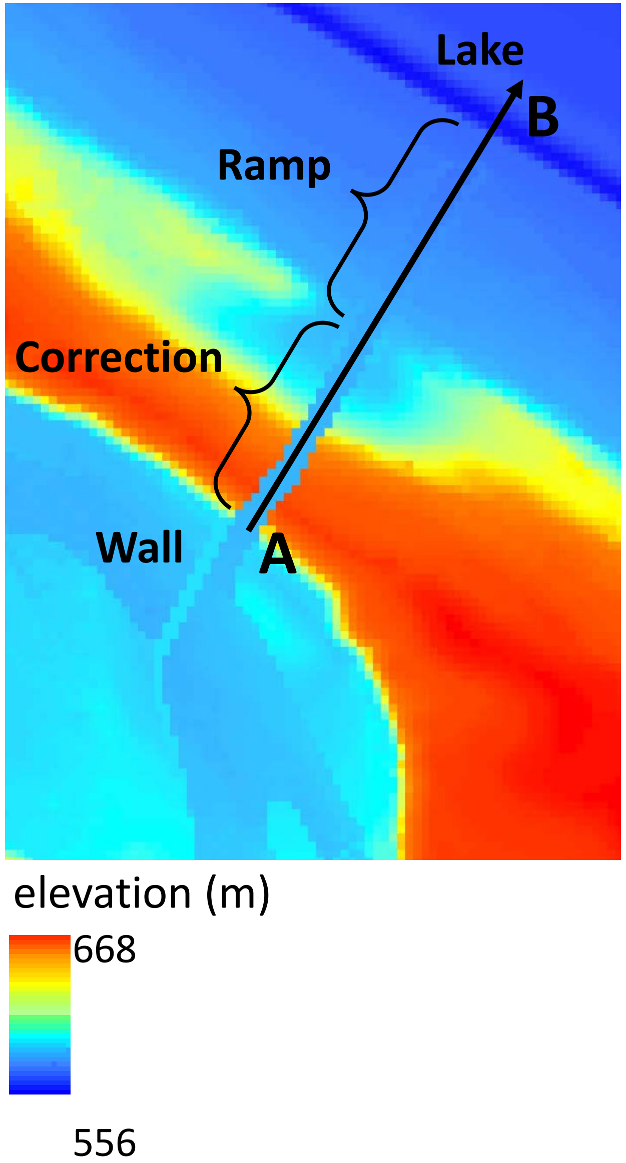
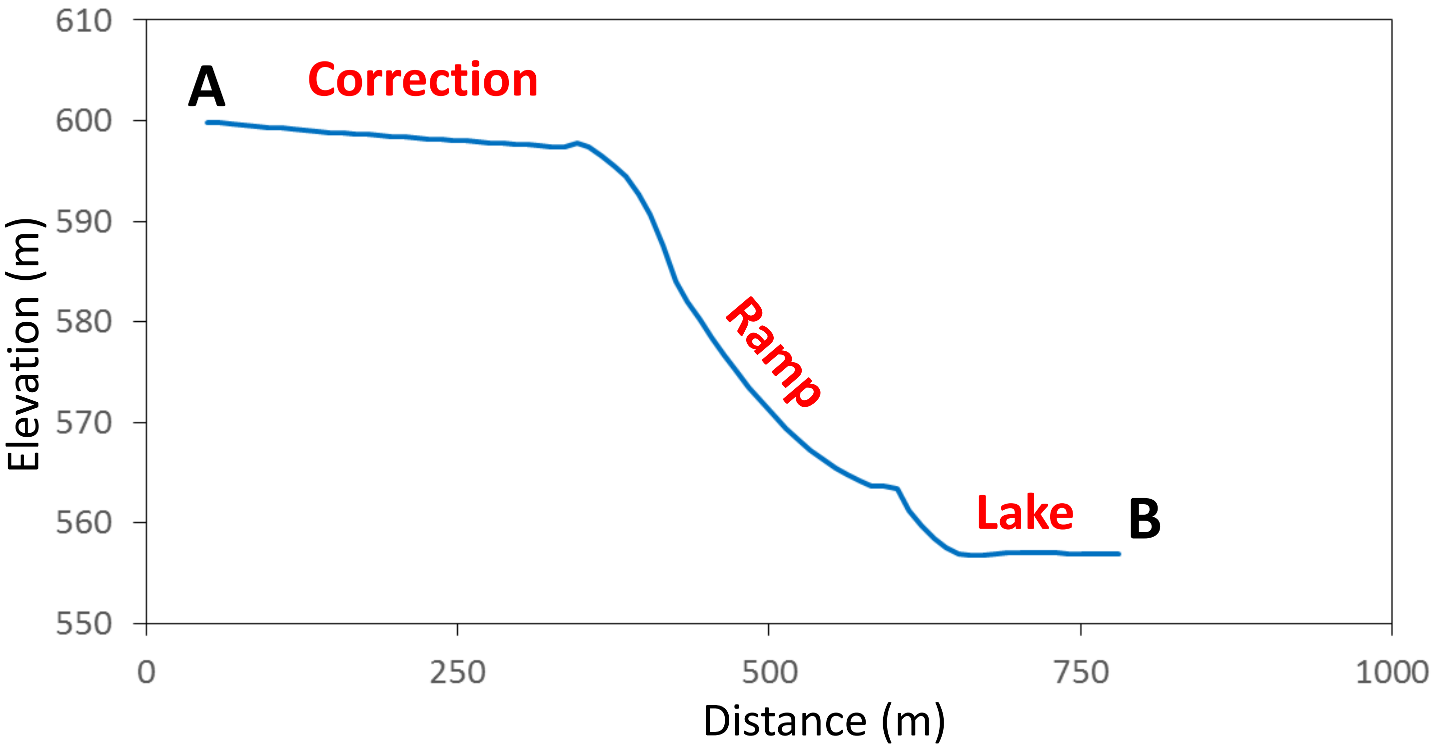


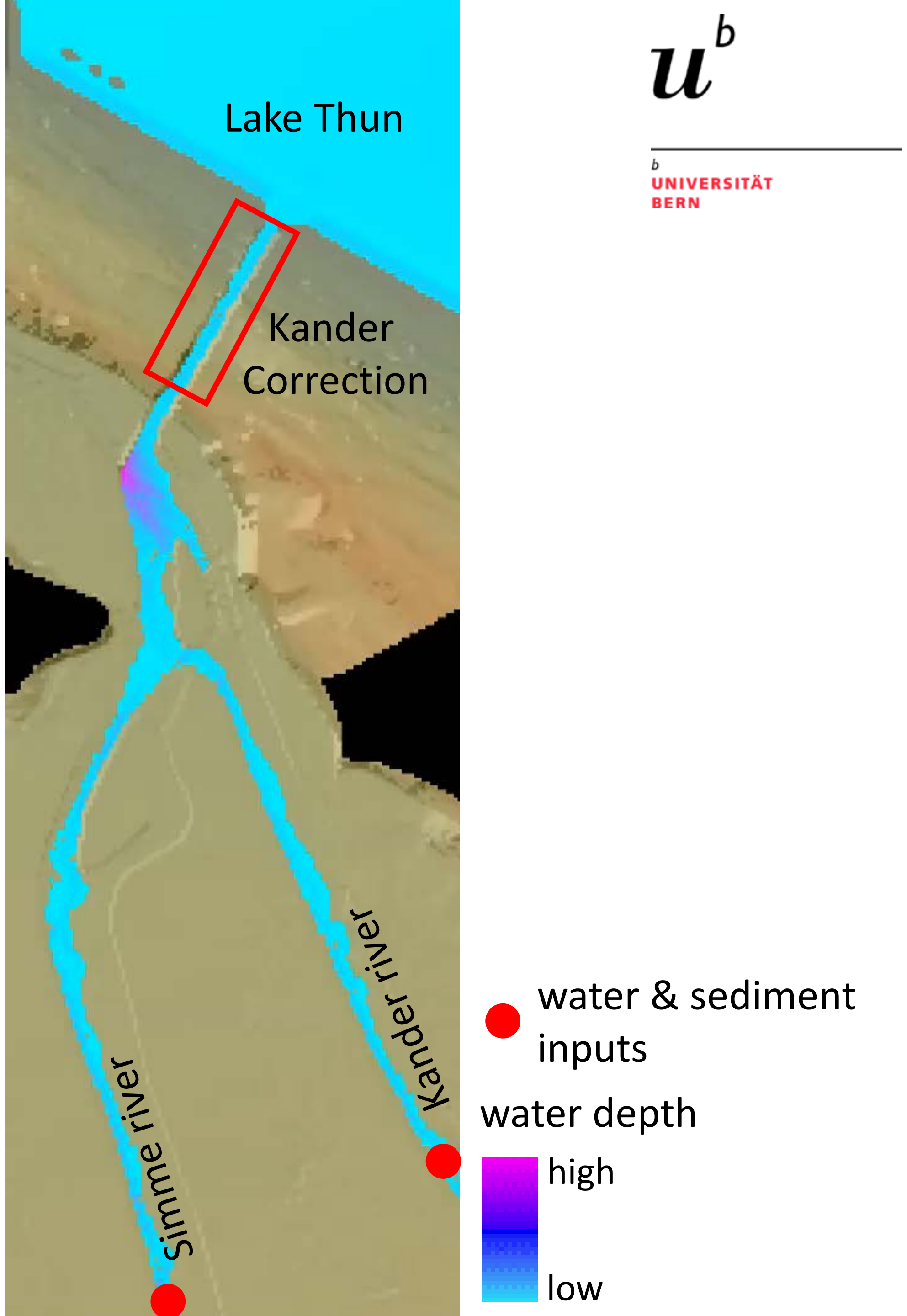




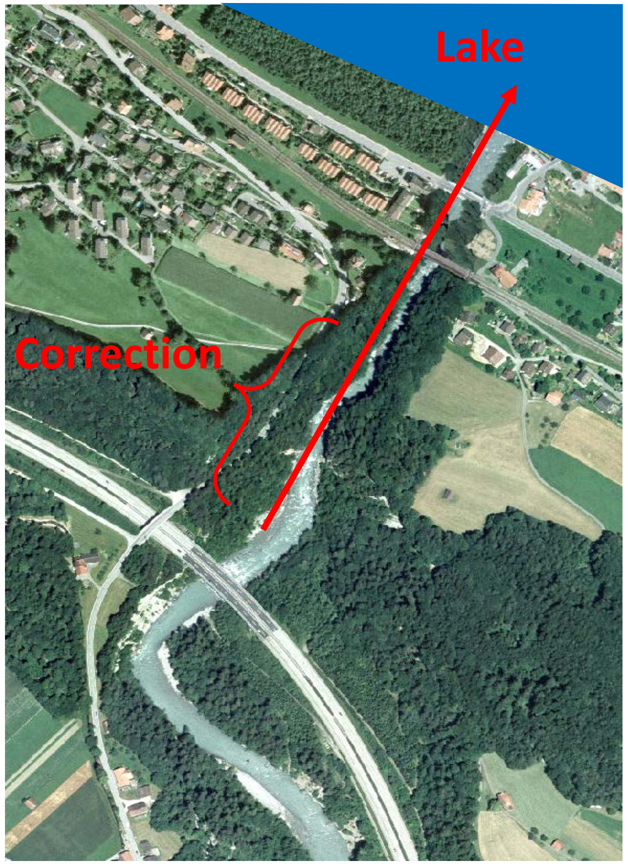
Source: Geschiebehaushalt Kander, 2004

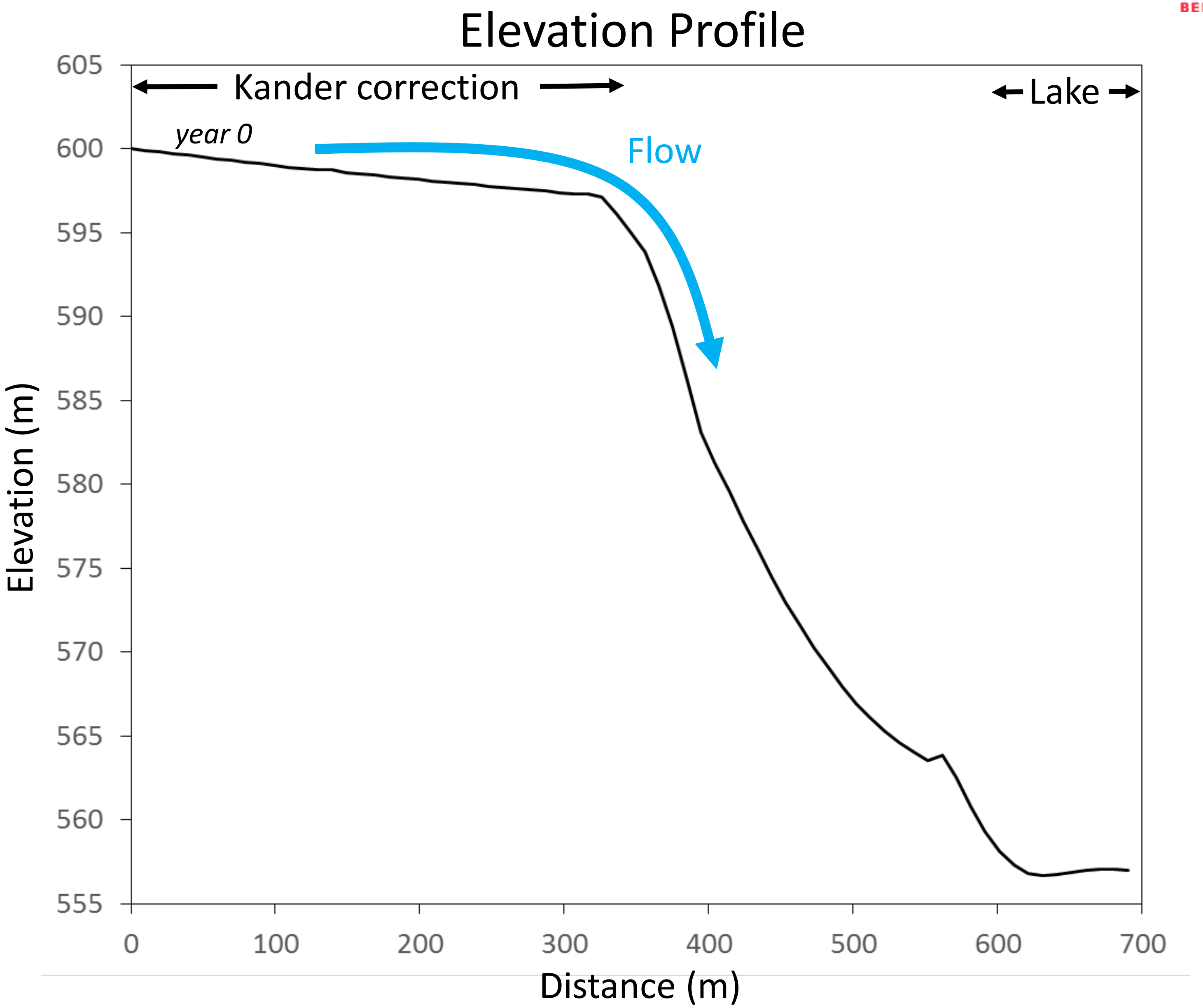
Kander correction model

- Simulated 12 years of movement of water and sediment
- Every year topography was recorded (1714-1726)



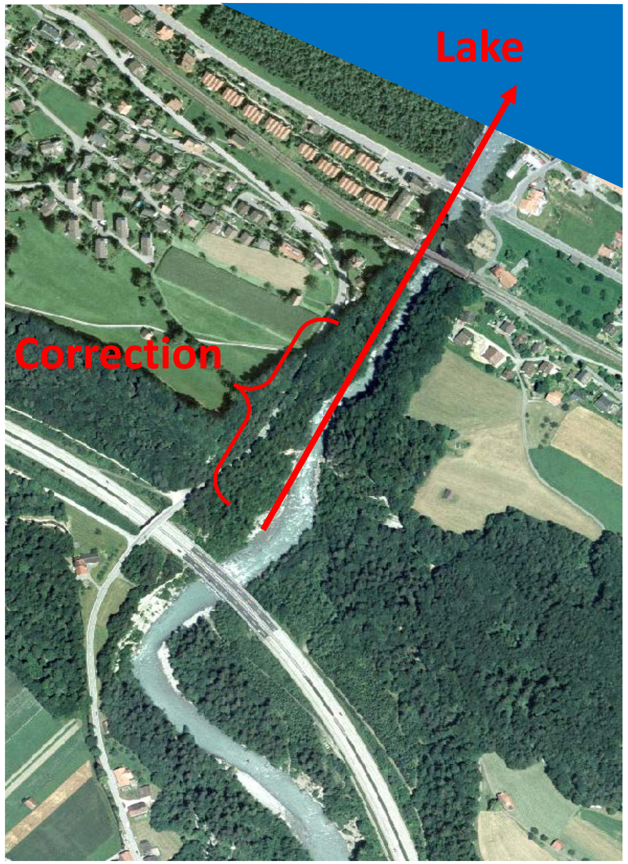
Model test: Kander erosion

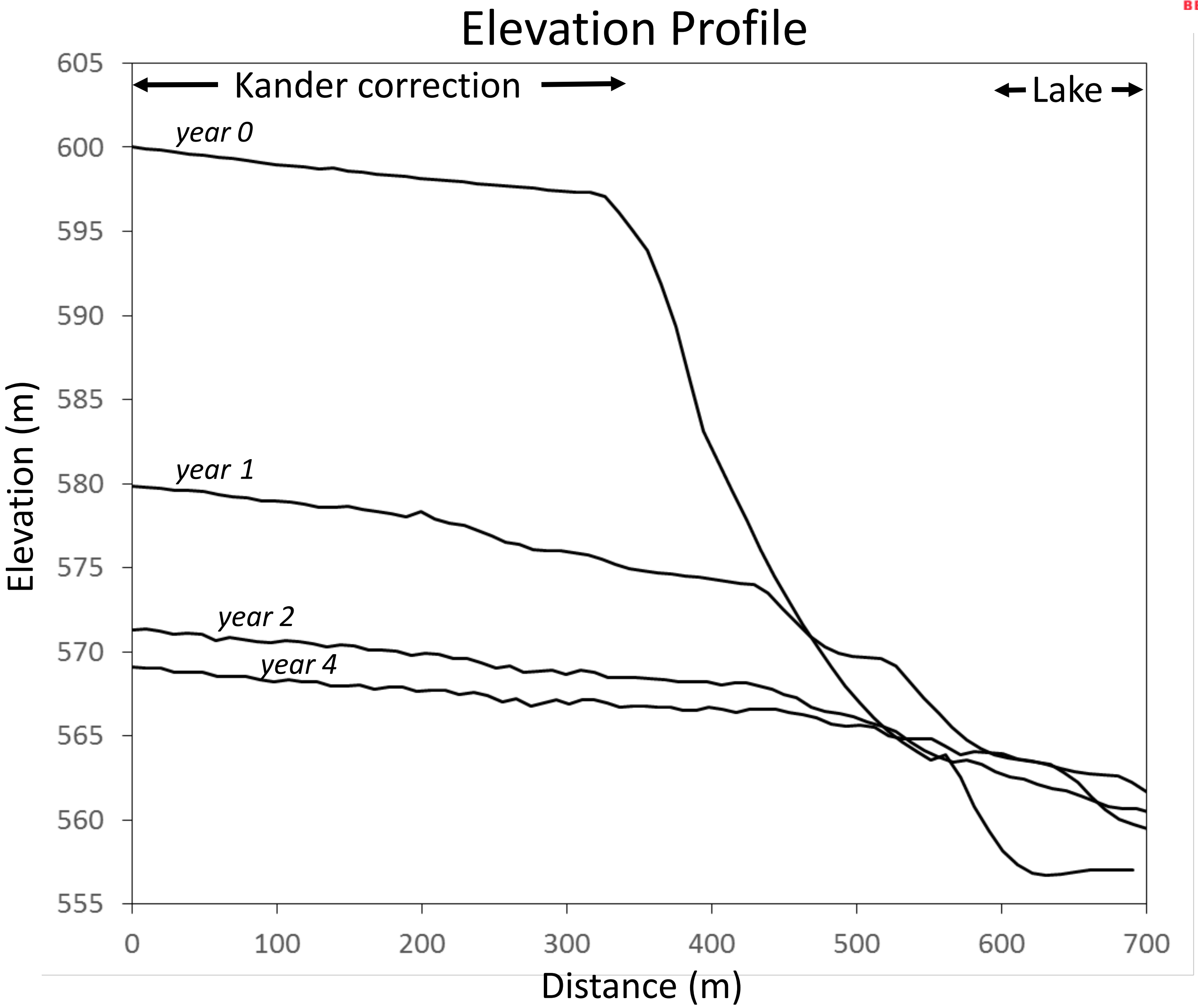




Model test: Kander erosion

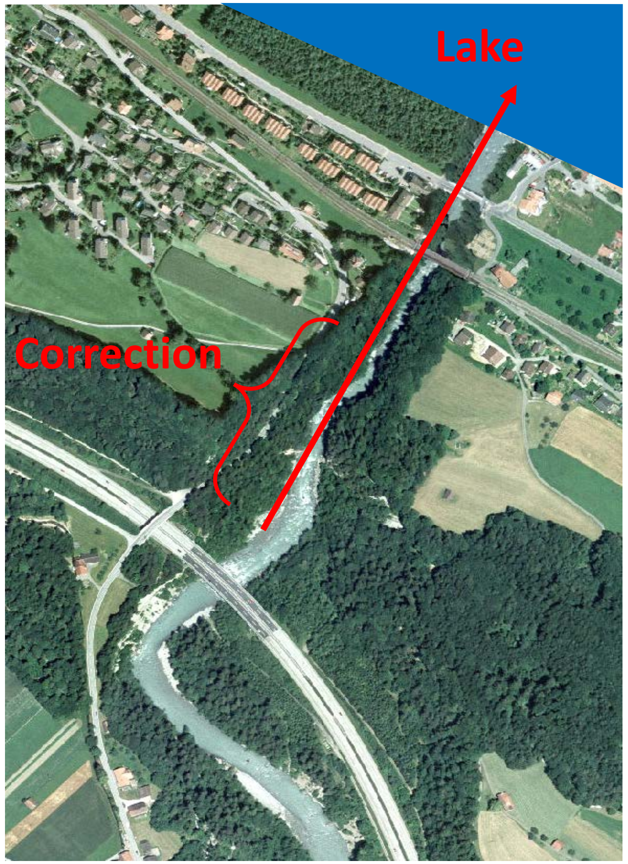
- 29 m of erosion within 4 years

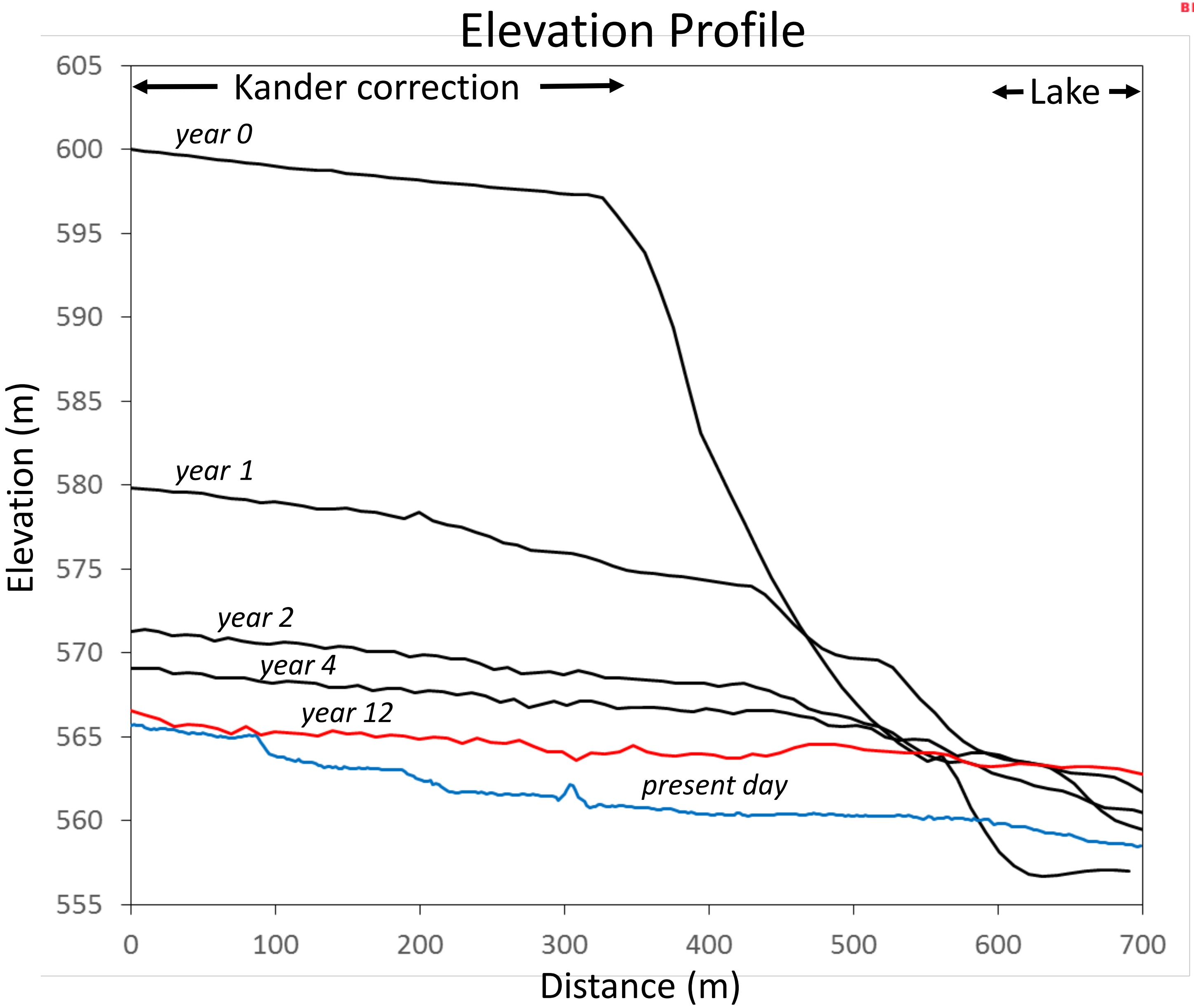




Model test: Kander erosion

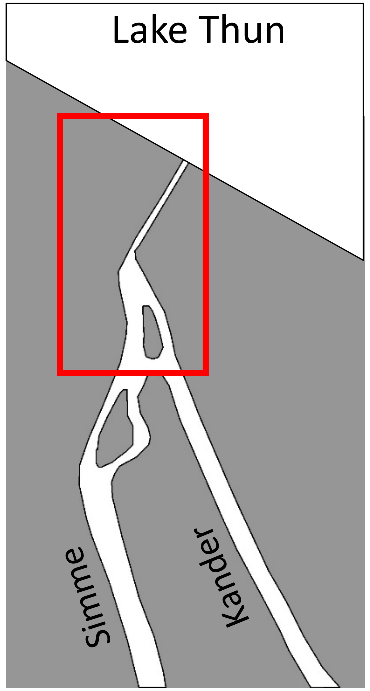
- 29 m of erosion within 4 years
- 2 m difference with todays river

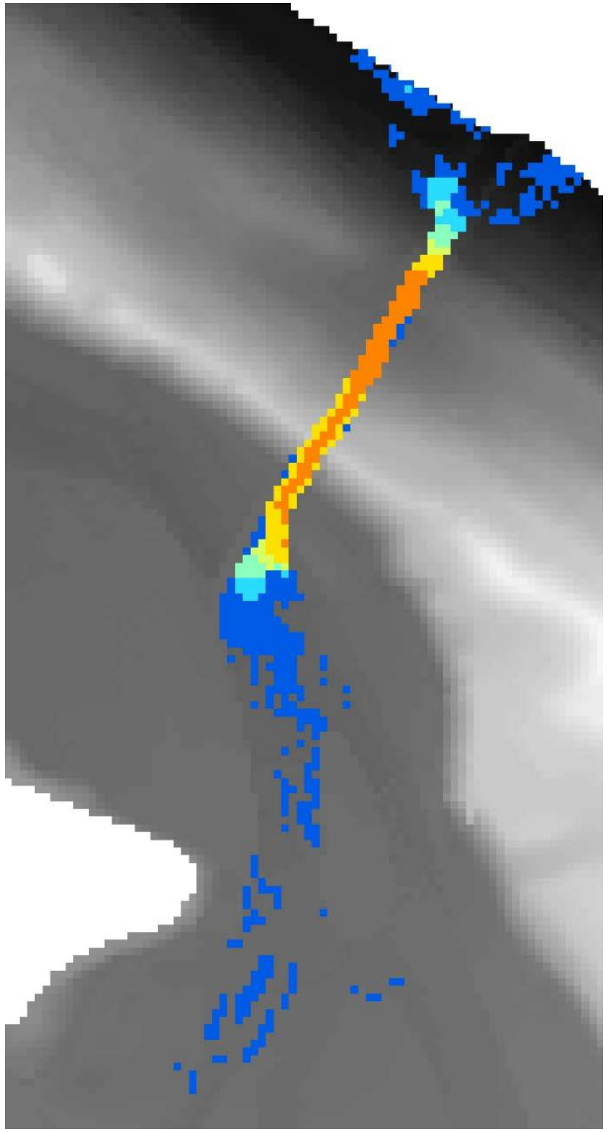




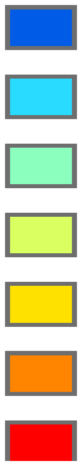
Model test: Kander erosion

900 m of upstream incision within 12 yrs





Year 1 (1715)



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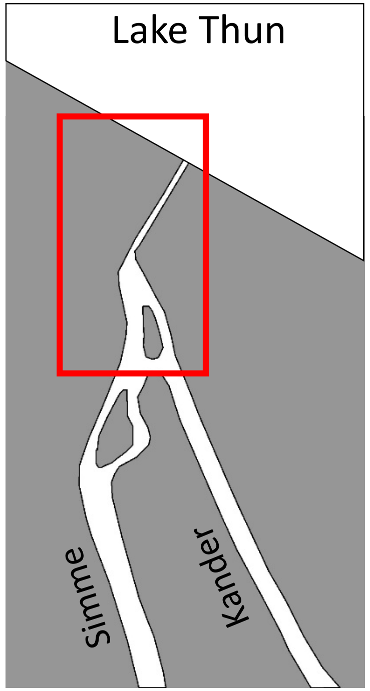
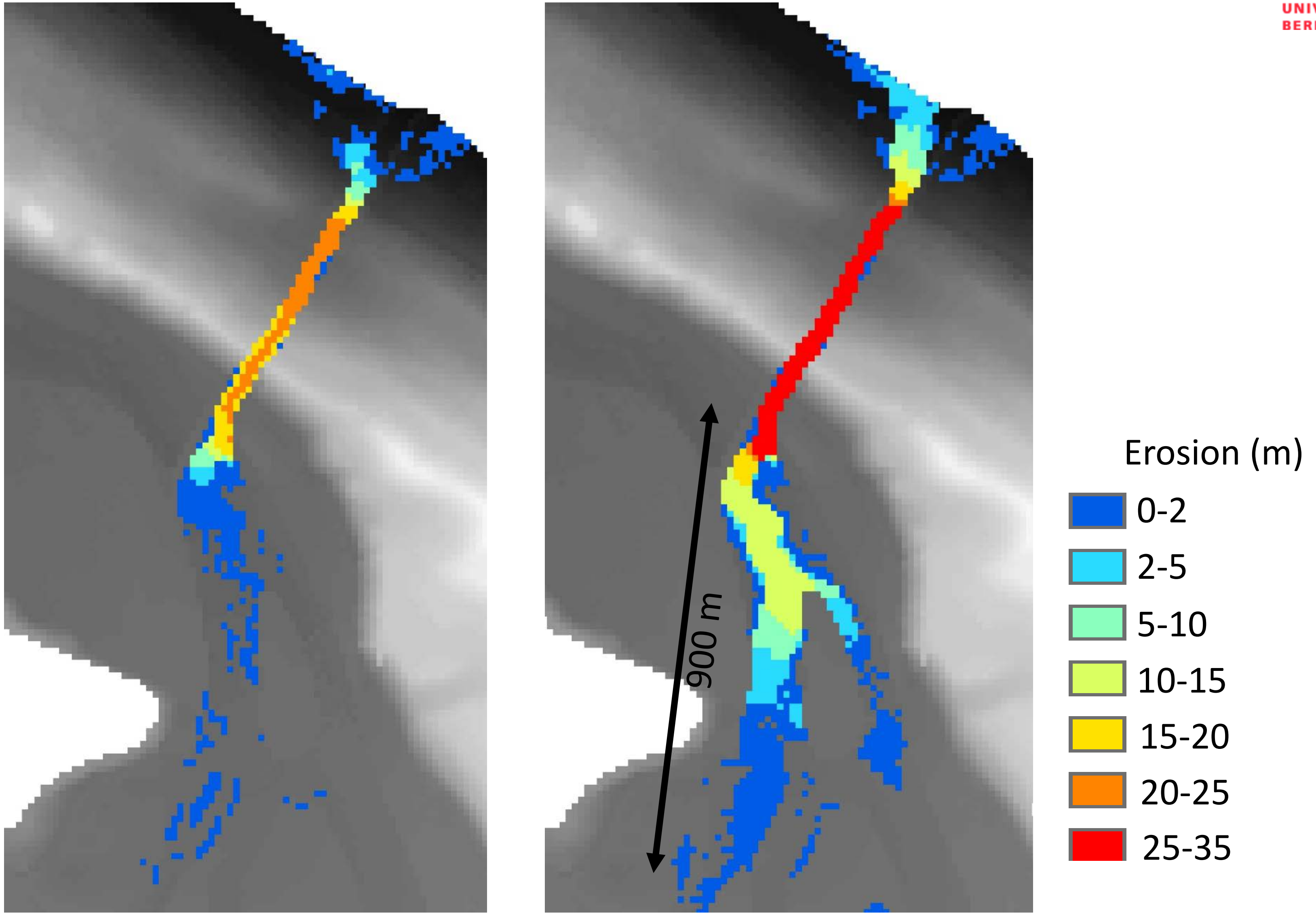
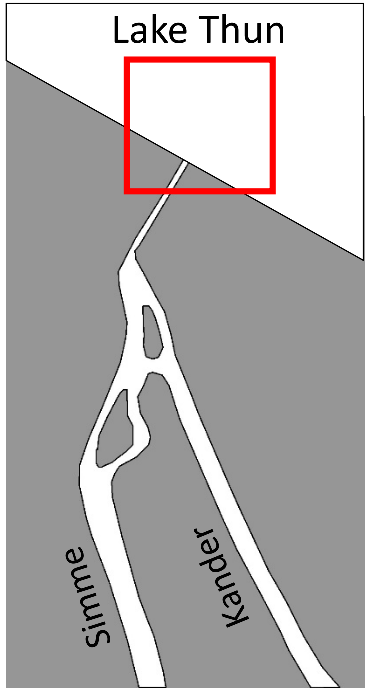




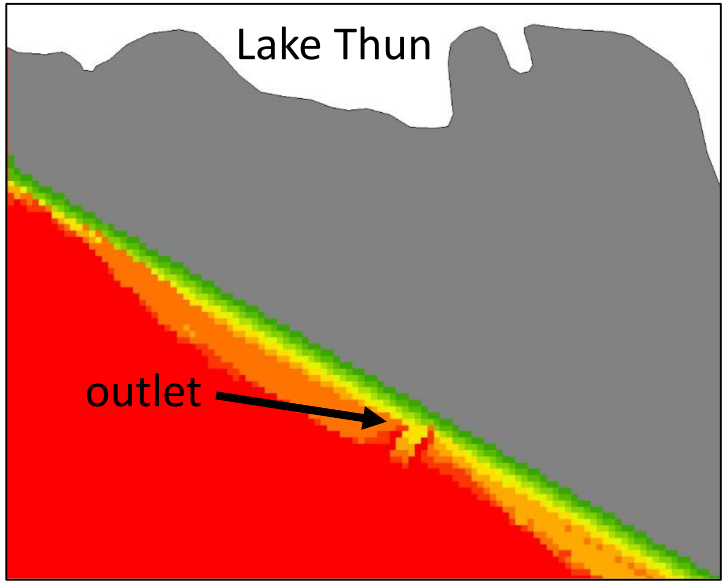
Year 1 (1715)

Year 12 (1726)

Model test: Delta formation



Year 0 (1714)



Elevation (m)

558-559
559-560
560-561
561-562
562-563
563-564
564-565
565-566
566-567
567-614
Delta 1860

Model test: Delta formation

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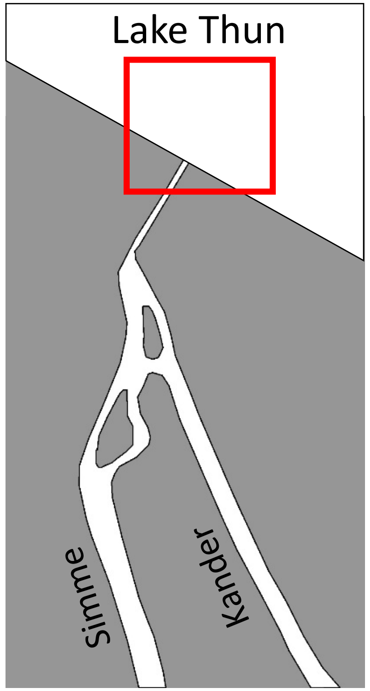
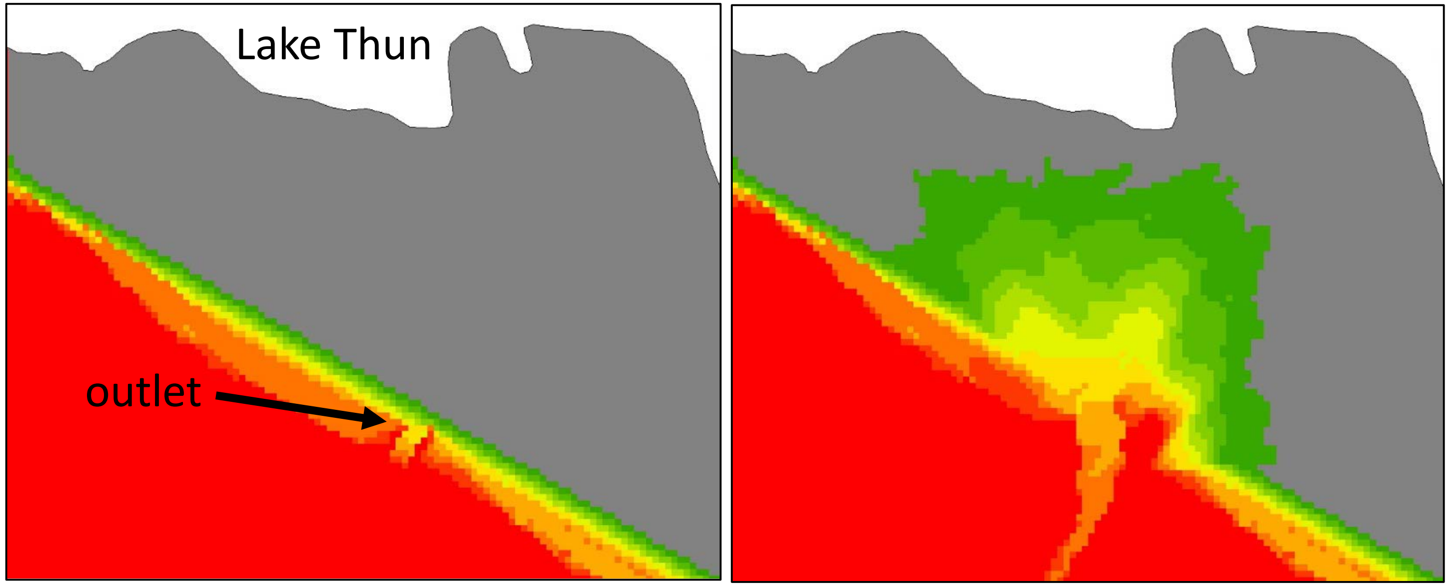


Year 0 (1714) | Year 6 (1720)



Elevation (m)

- 558-559
- 559-560
- 560-561
- 561-562
- 562-563
- 563-564
- 564-565
- 565-566
- 566-567
- 567-614
- Delta 1860

Model test: Delta formation

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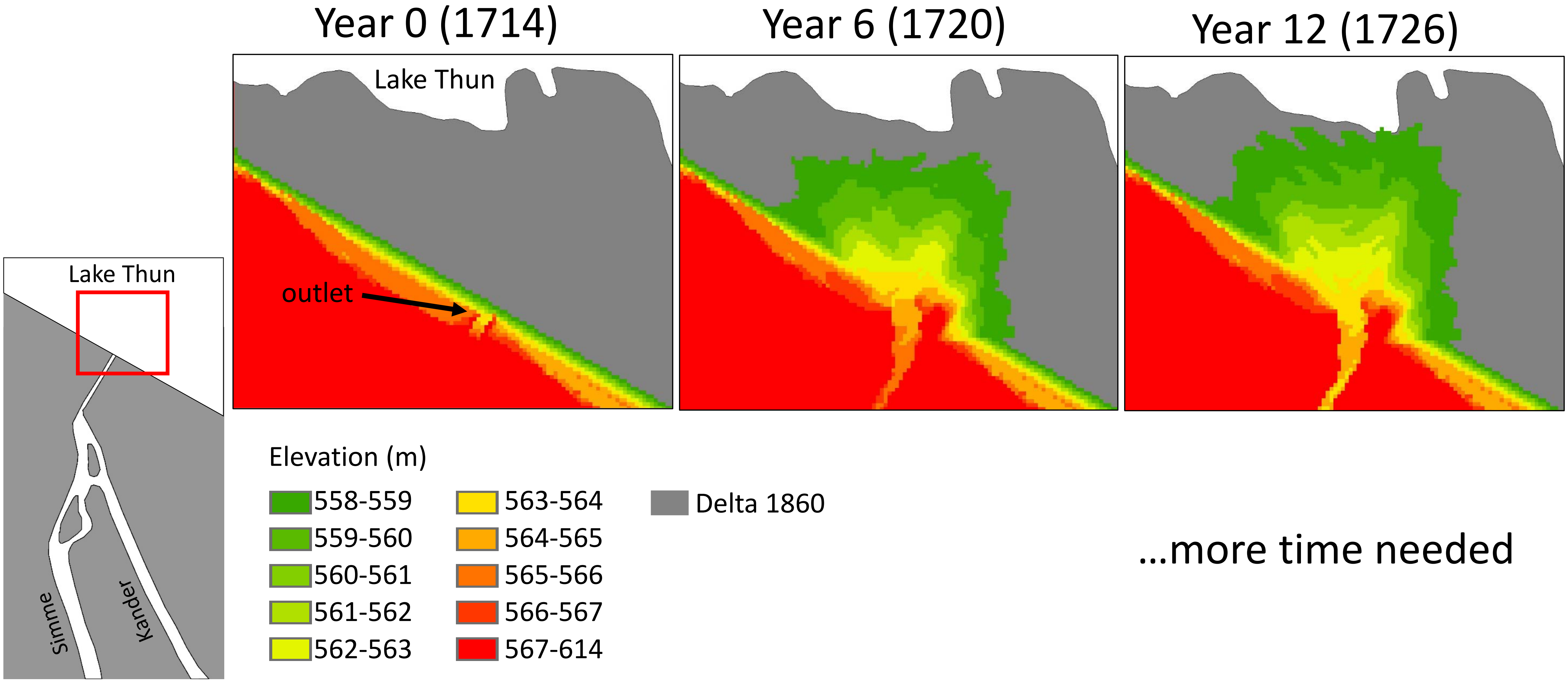

…more time needed

Response to extreme floods

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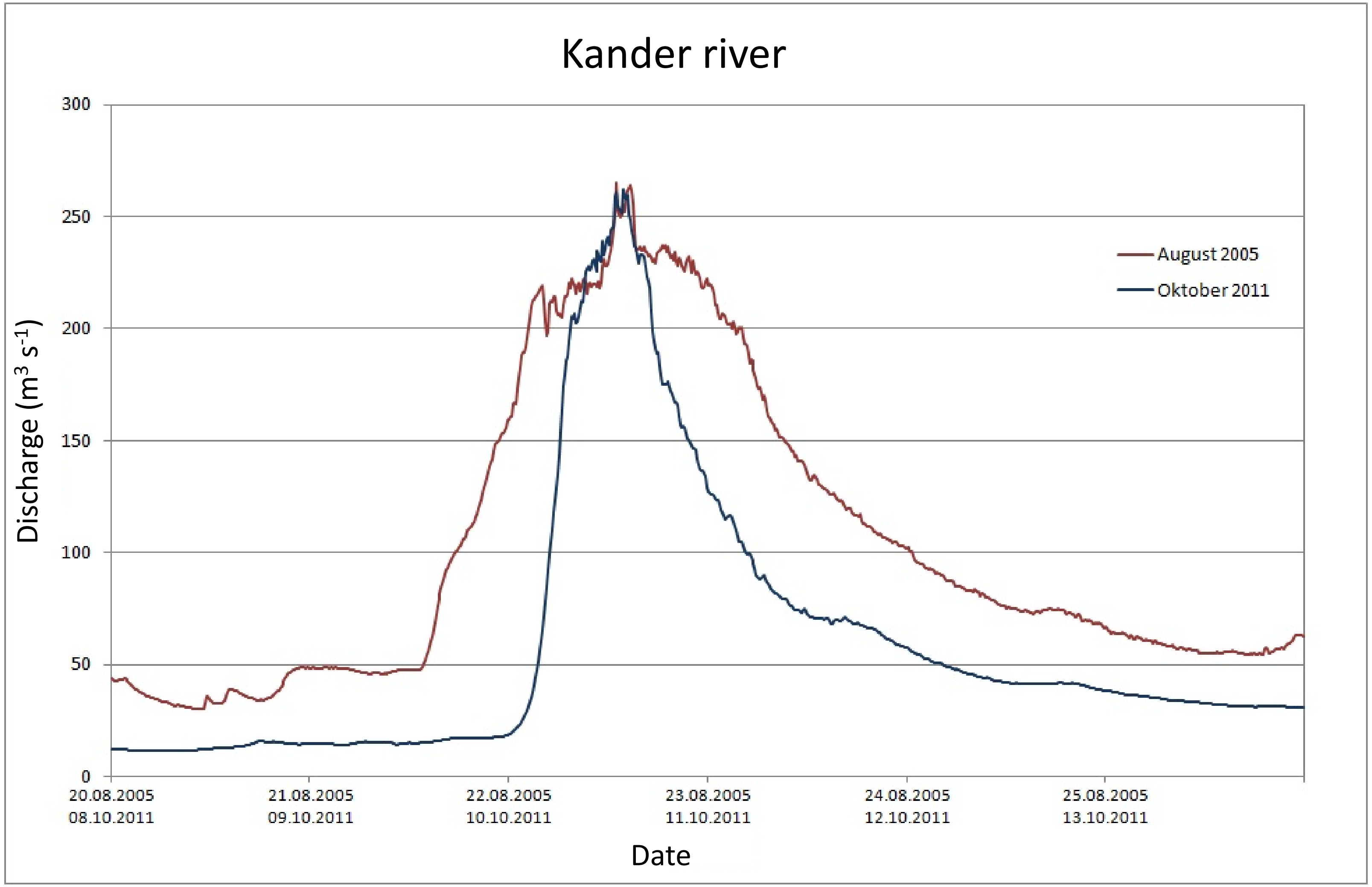
Determine sensitivity of LEM applied to steep rivers and extreme flood events



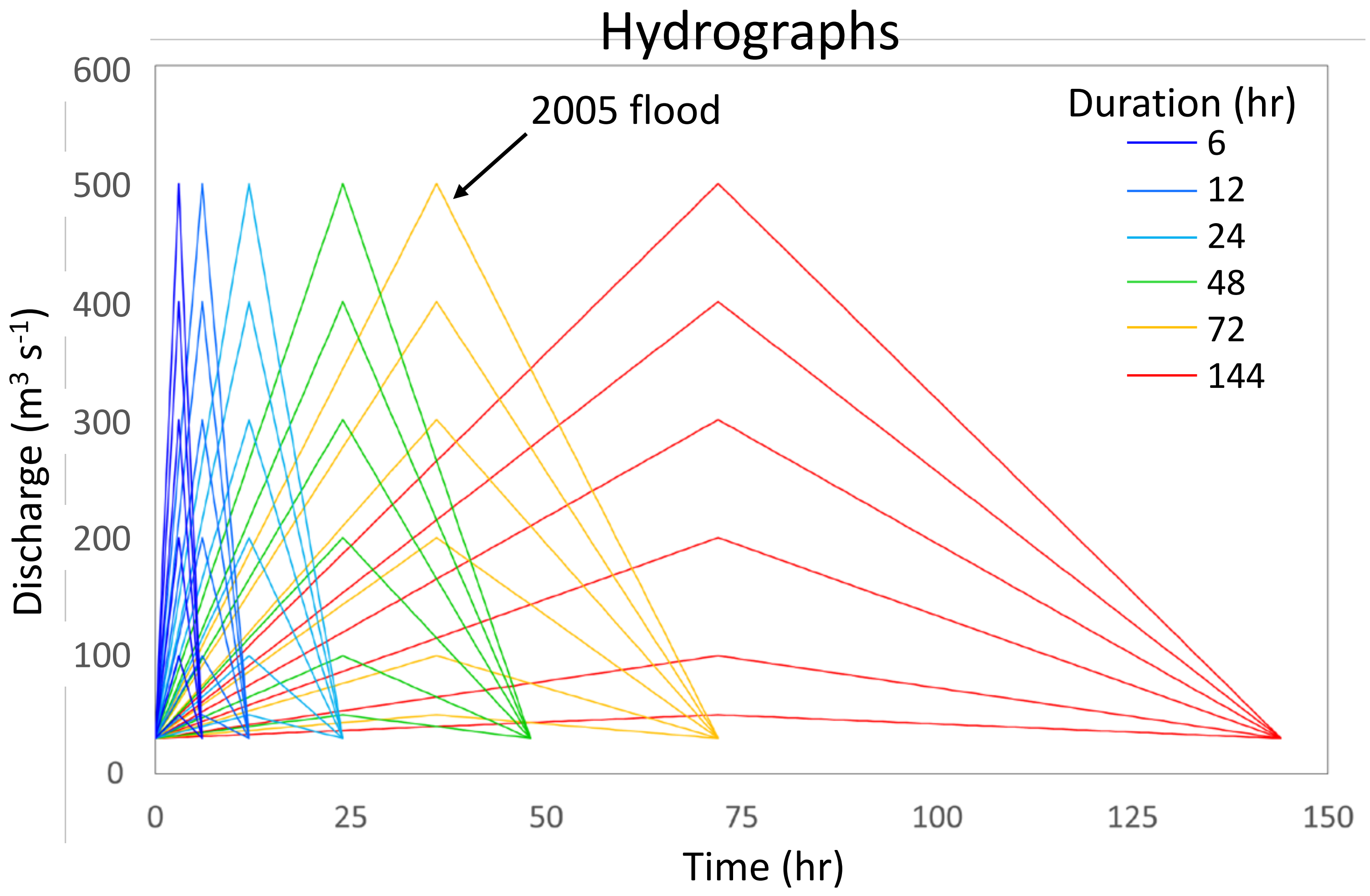
Source: http://www.bafu.admin.ch

Extreme hydrographs

36 scenarios

Sediment added proportional to discharge

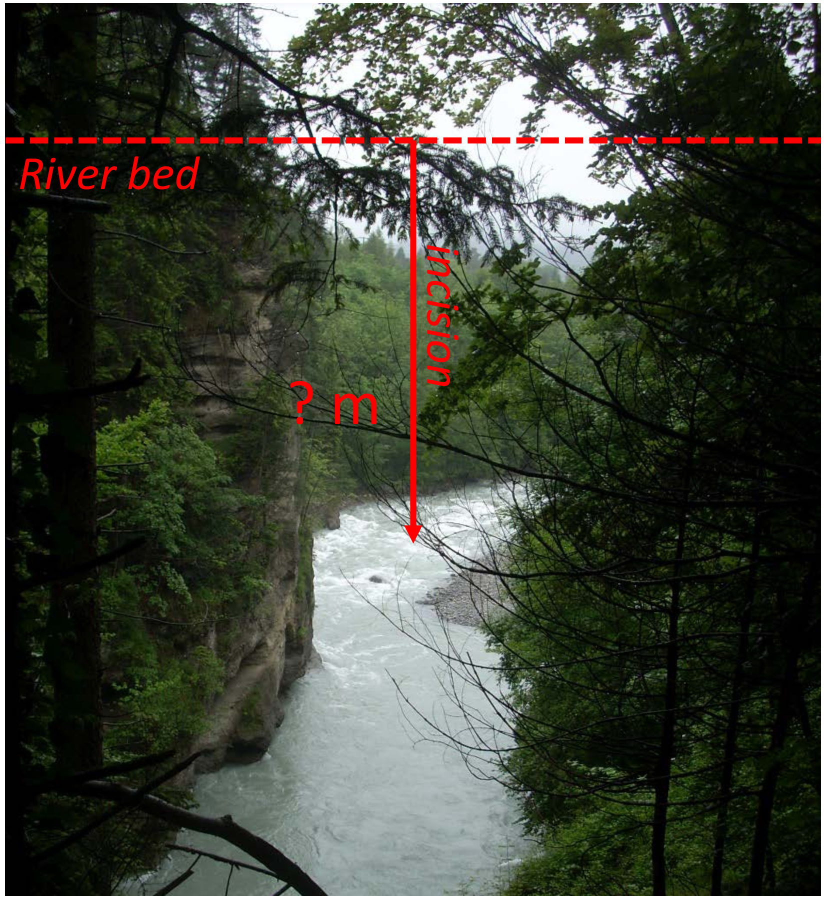
Flood duration (hr) \ Peak discharge ($m^3 s^{-1}$)	50	100	200	300	400	500
6						
12						
24						
48						
72						X
144						

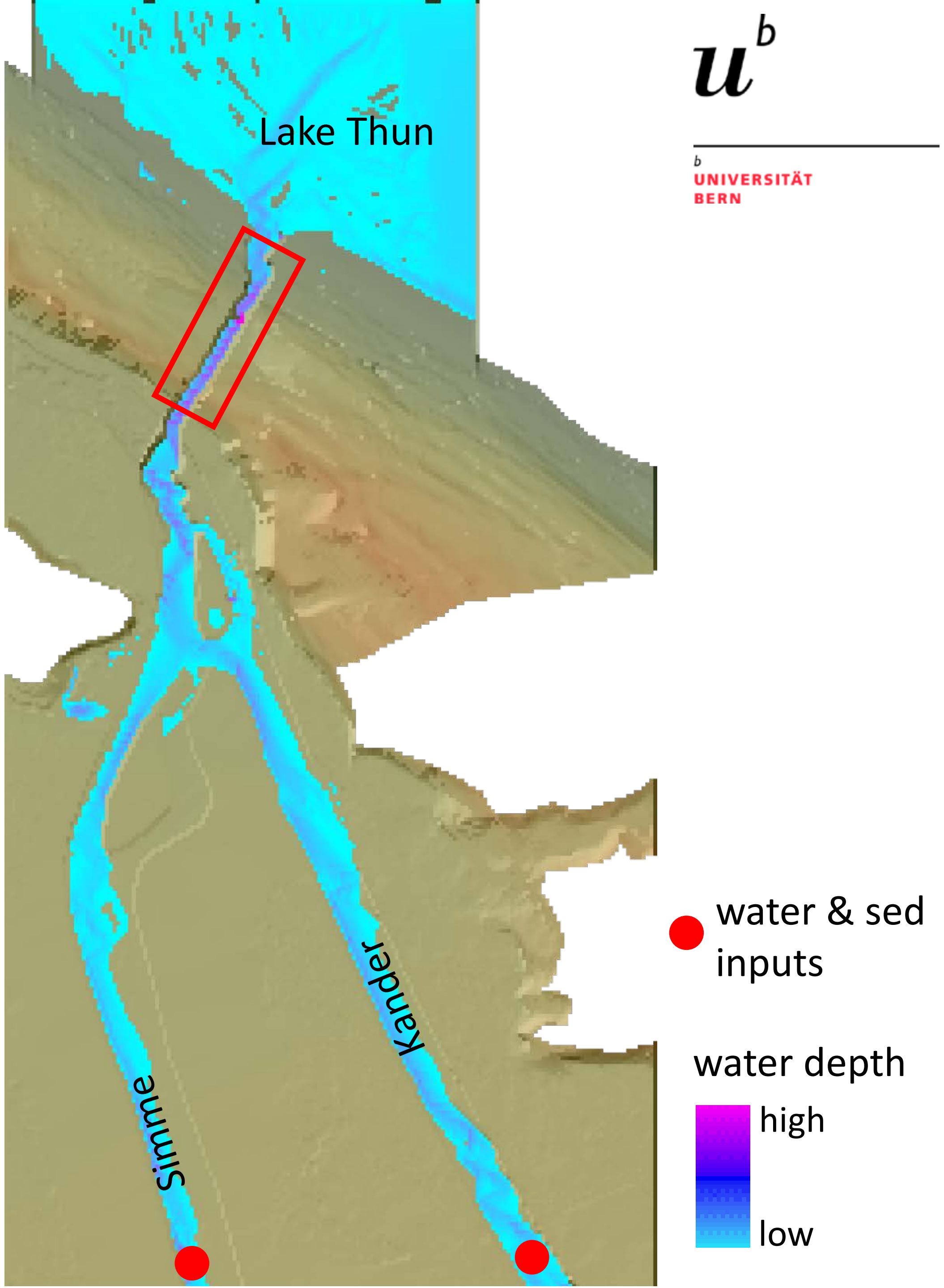


Response to extreme floods

- Determine how much incision occurs with flood events of different magnitude and duration

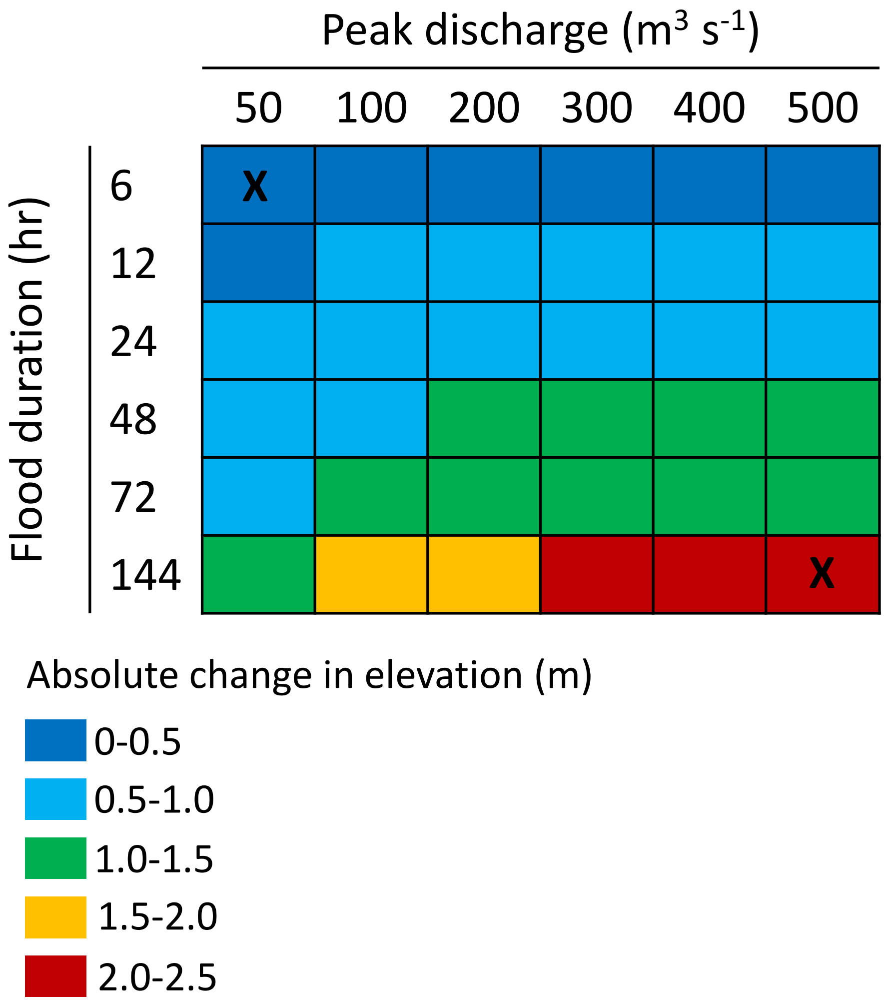
1714
(year 0)

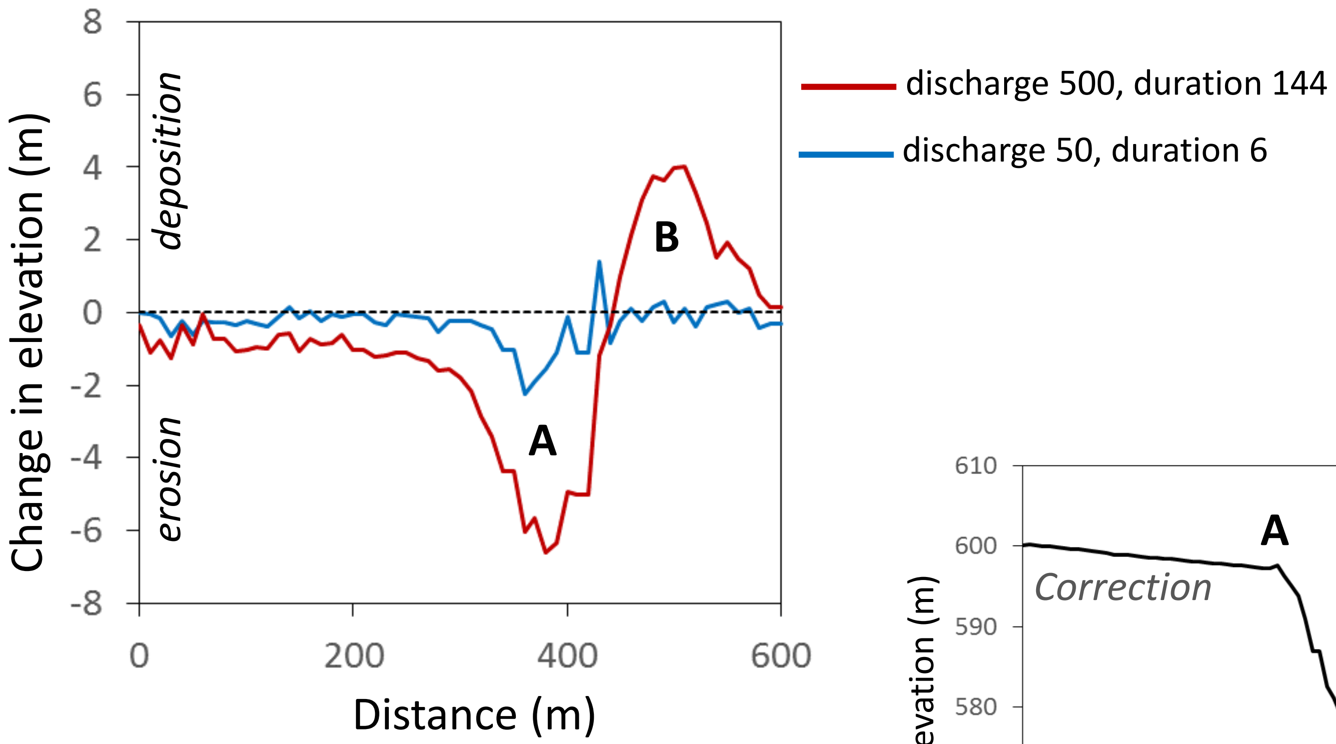


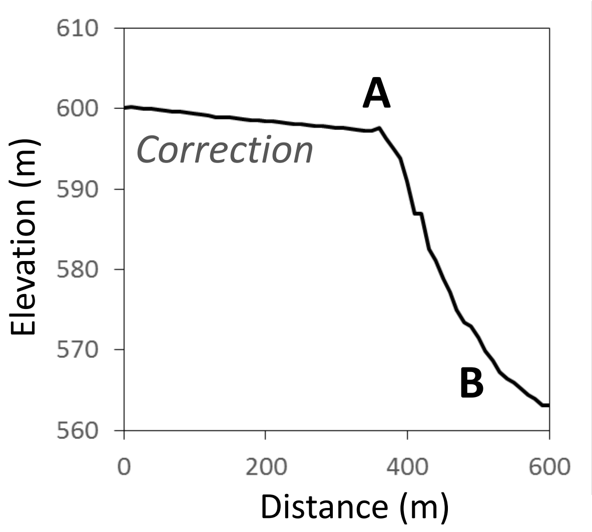


Geomorphic change

Model produces plausible erosion and deposition under extreme flood conditions
Flood duration has greater effect on change in elevation than peak discharge
Single extreme flood events can produce up to 6 m of erosion, 4m of deposition







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Geomorphic change

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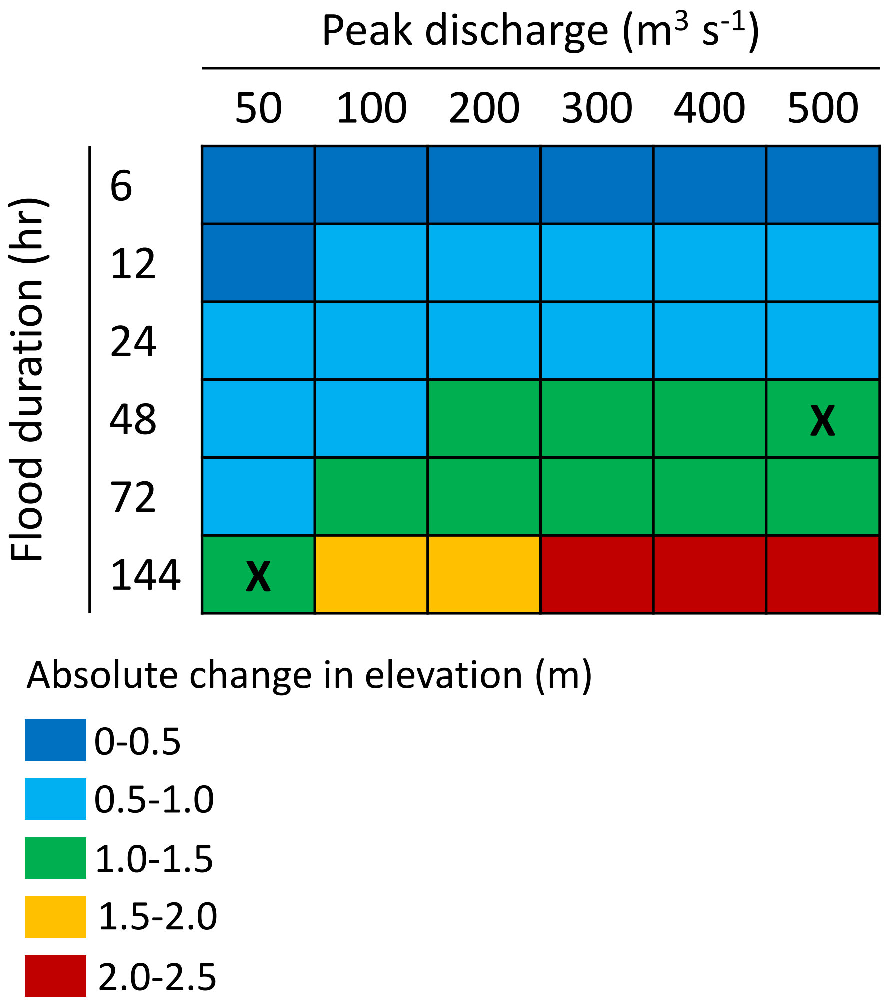
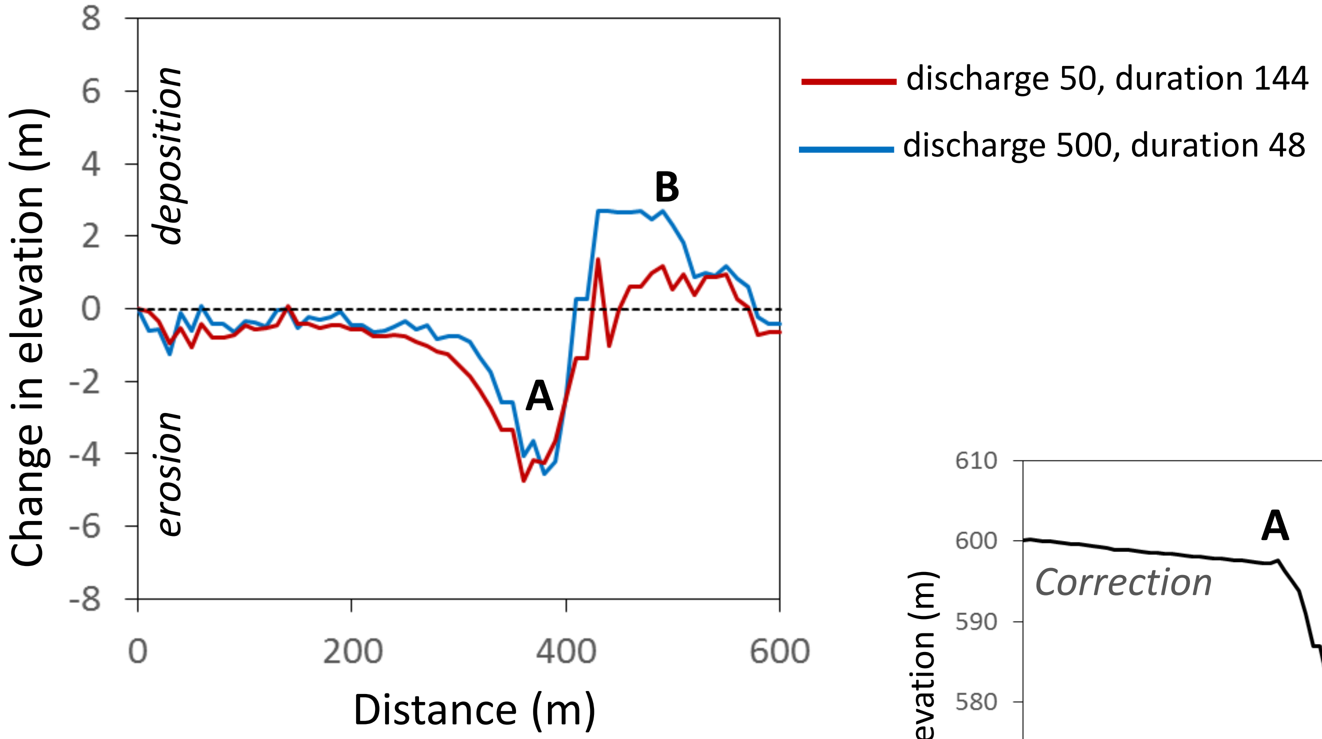
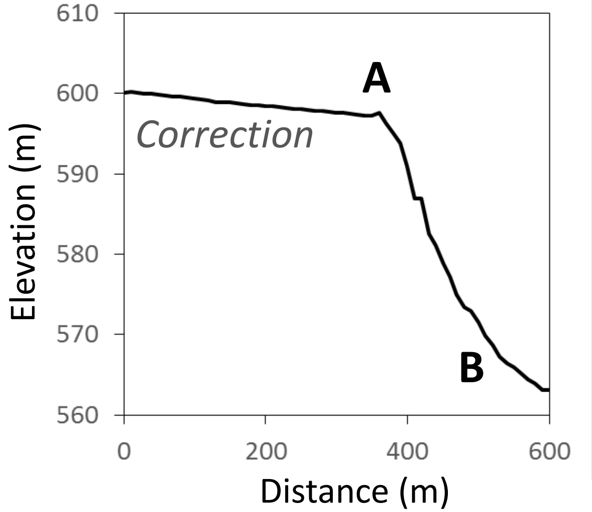
Flood that is 3 times longer, and 10 times lower in peak discharge produces similar change in elevation
Long duration floods (6 day) with relatively low discharge are geomorphically important







Conclusions

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CAESAR lisflood can replicate geomorphic effects of human intervention in fluvial systems, this includes:

- River bed incision
- Upstream incision
- Delta formation

Model produces plausible erosion and deposition under extreme flood conditions

Long duration floods with relatively low discharge are geomorphically important