Modelling the effects of permeability, groundwater flow and water table depth on landscape evolution

Elco Luijendijk, University of Göttingen, elco.luijendijk@geo.uni-goettingen.de
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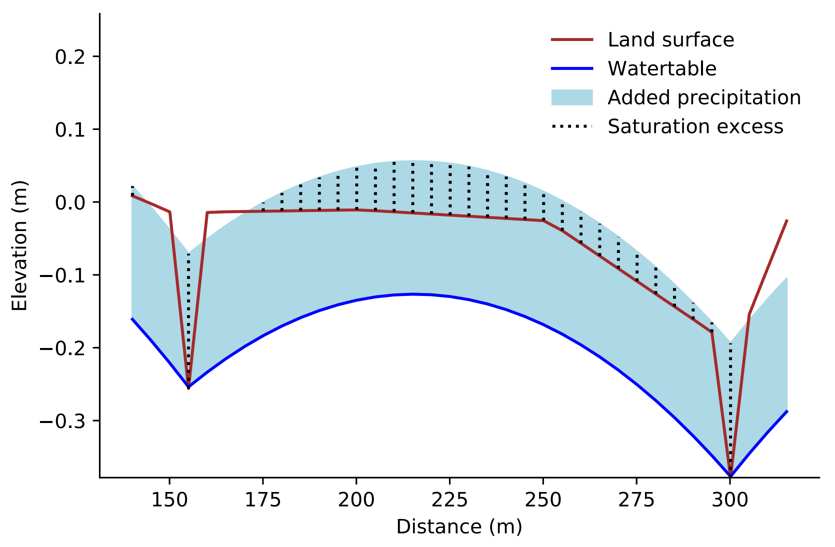
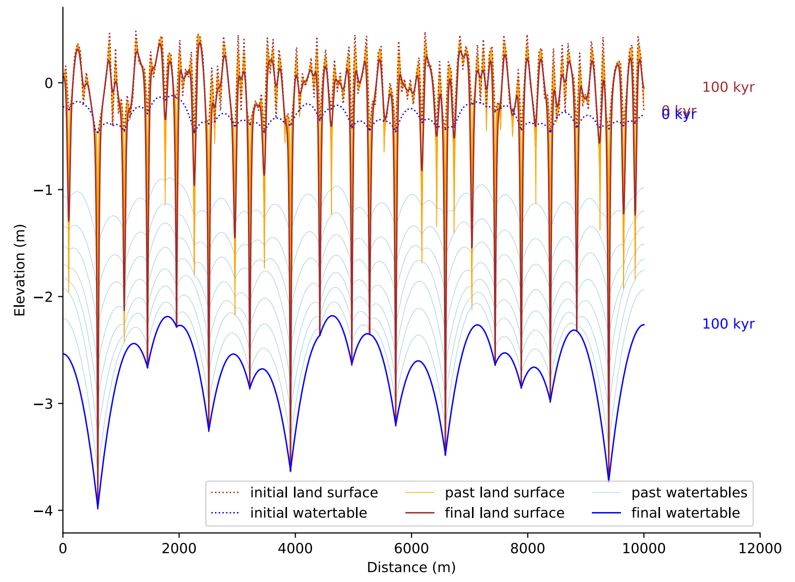
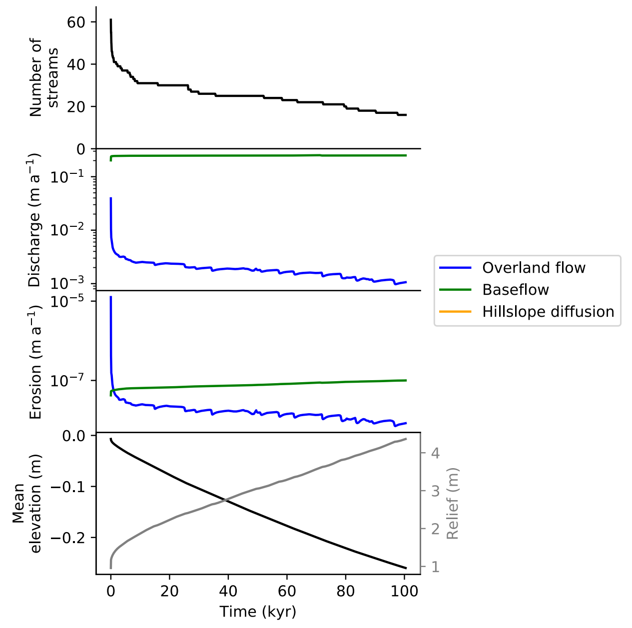
- Motivation: Explore the relation between groundwater flow, drainage density and erosion
- How: Model experiments with a new model code that combines groundwater flow, saturation excess overland flow, hillslope and stream erosion
- Conclusion: Groundwater flow & transmissivity exert a strong control on drainage density and erosion. Lower watertable gradients result in a higher chance that fast eroding streams draw the watertable below adjacent streams, which results in streams falling dry.
- Click on the following links for more details: model description, model experiment 1, 2, 3, comparison modeled land surface, and evolution over 100,000 years







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Description groundwater flow & erosion model code

- Philosophy: Construct the simplest possible groundwater flow & erosion model
- Cross-sectional 1.5 D model of groundwater, overland flow and erosion for 100,000 years, starting with a random initial topography
- Analytical solution to steady-state groundwater flow
- Saturation excess overland flow: Flow generated where precipitation exceeds available storage above the steady-state watertable & instantaneous drainage
- Erosion follows standard eqs. of most landscape evolution models. Precipitation statistics based on data from the Netherlands (~average humid climate)
- Different timescales overland flow & baseflow: new analytical solution to integrated erosion by overland flow per precipitation event

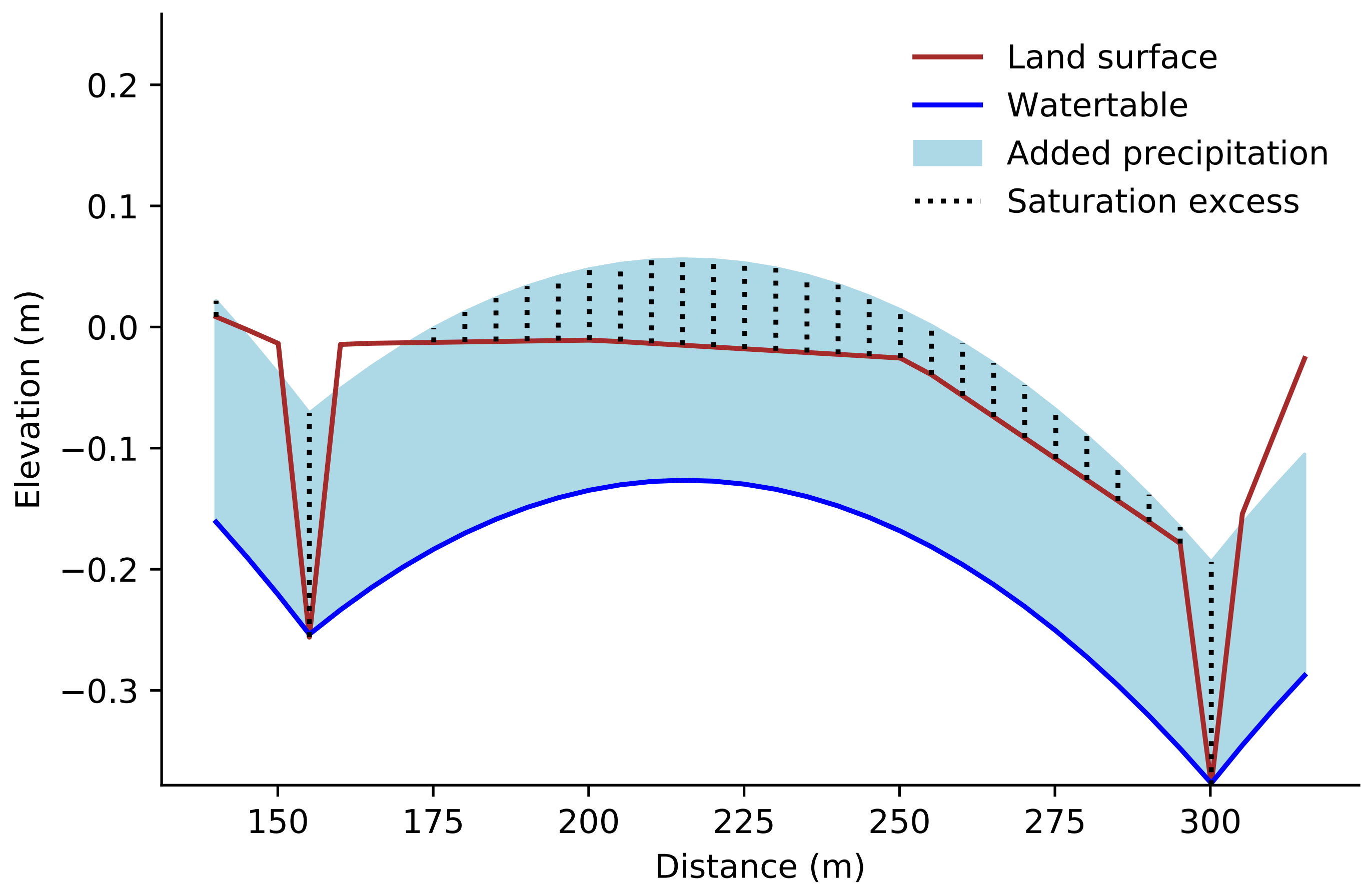
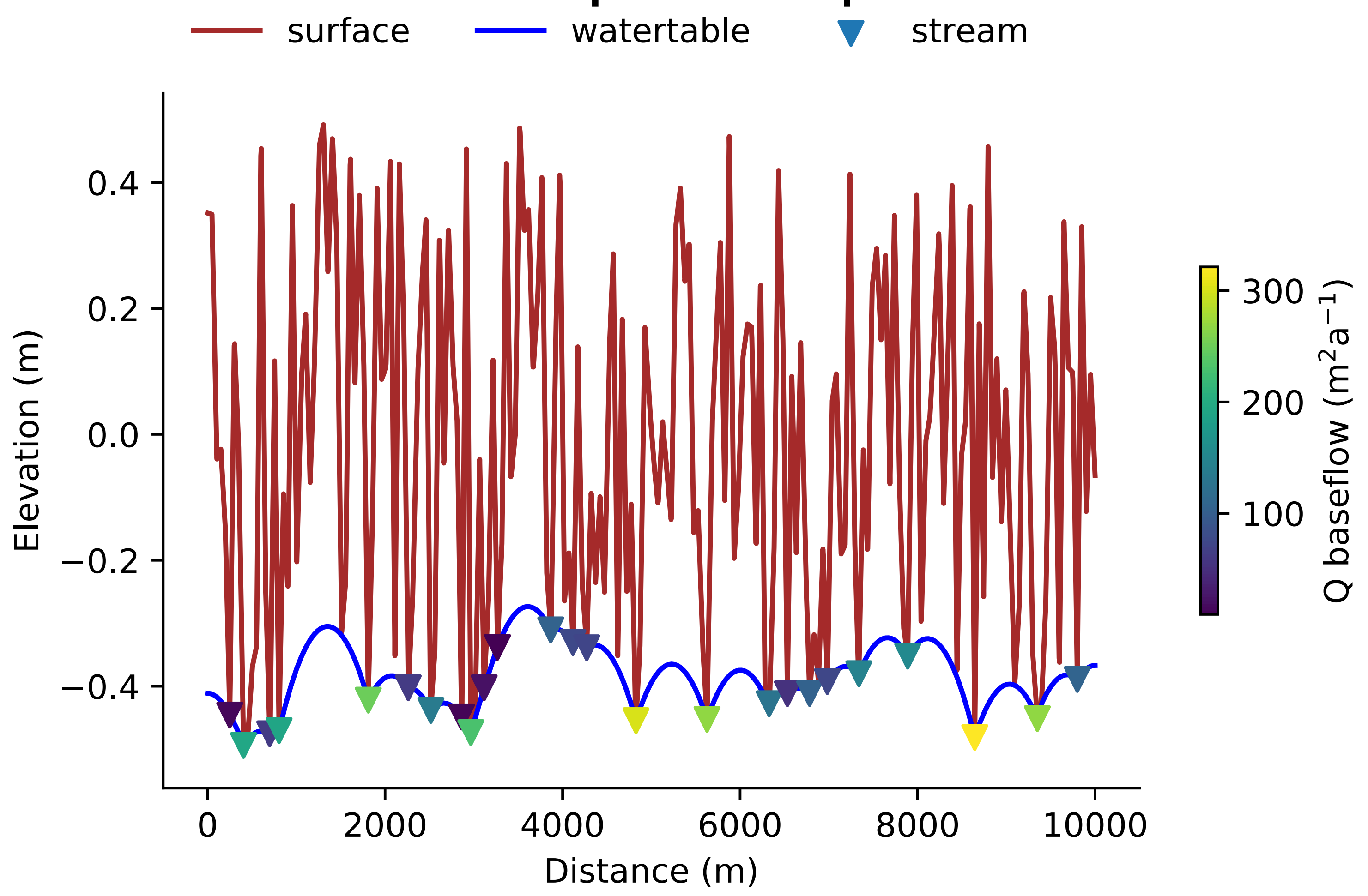


Illustration of the calculation of saturation excess overland land flow. Groundwater recharge is calculated as the added precipitation minus a fixed evapotranspiration rate



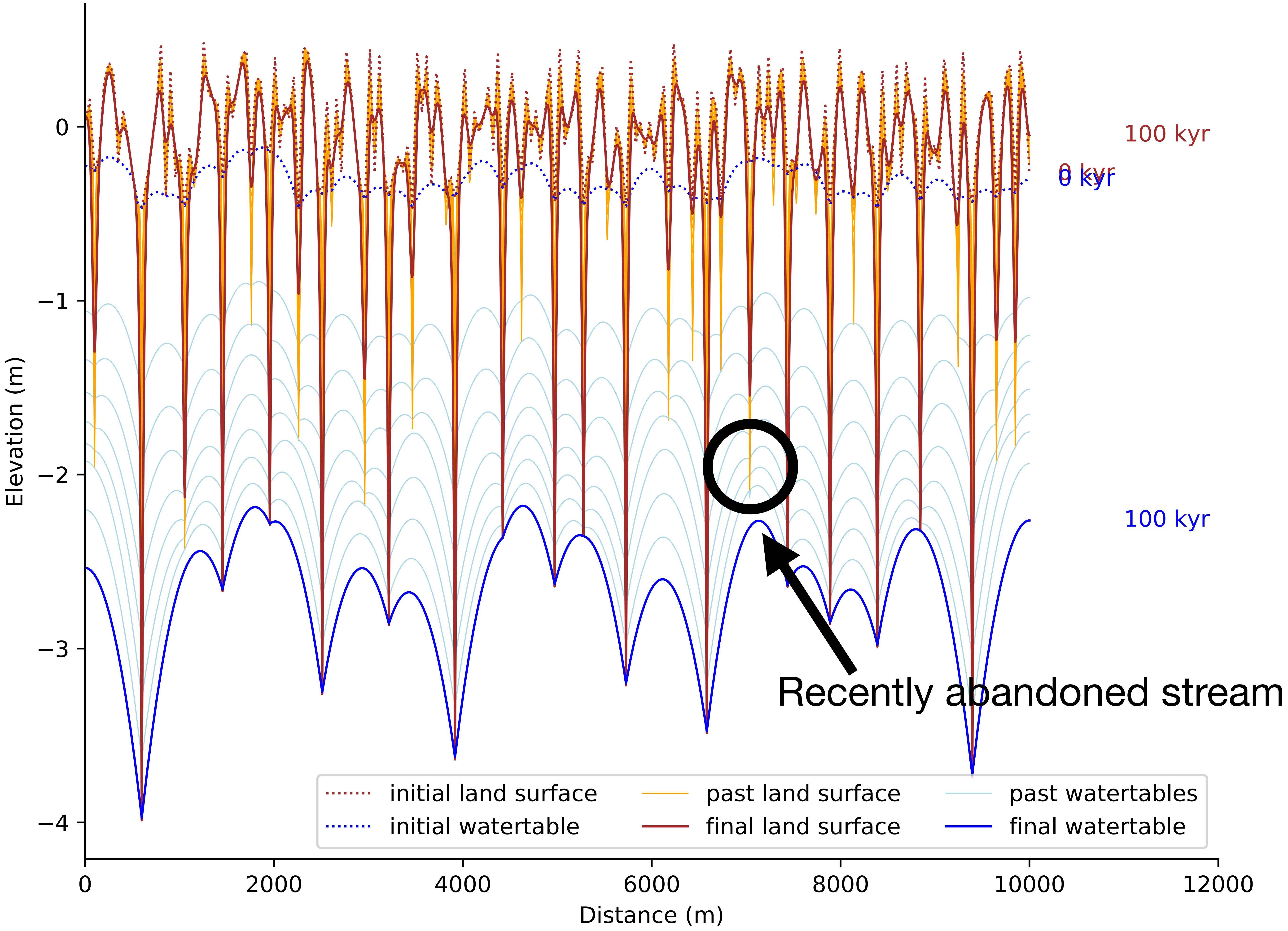
Initial calculated watertable and baseflow at the start of a model run with a randomly generated topography

Model experiment 1: Moderate transmissivity

- Moderate transmissivity (hydraulic conductivity x aquifer thickness) = 10^{-3} m^2/sec =~medium grained sand

- Moderate stream density after 100,000 yrs: 1 stream per 700 m

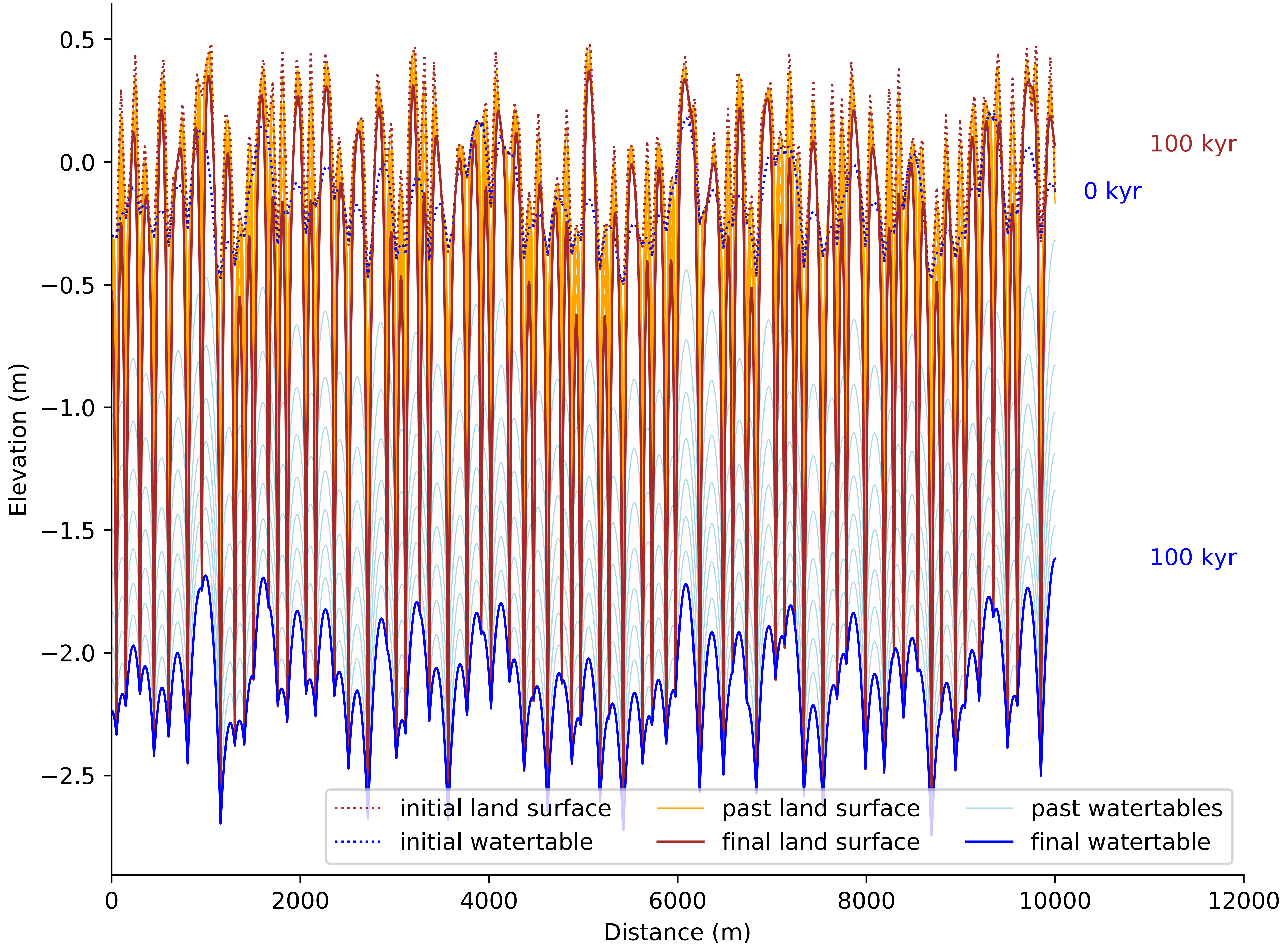
- Note the presence of abandoned stream channels where faster eroding streams have drawn the watertable below slower streams, causing them to fall dry



Modelled position of the land surface and watertable over 100 kyr.
Note that the topography looks somewhat odd due to the very high aspect ratio of the figure

Model experiment 2: Low transmissivity

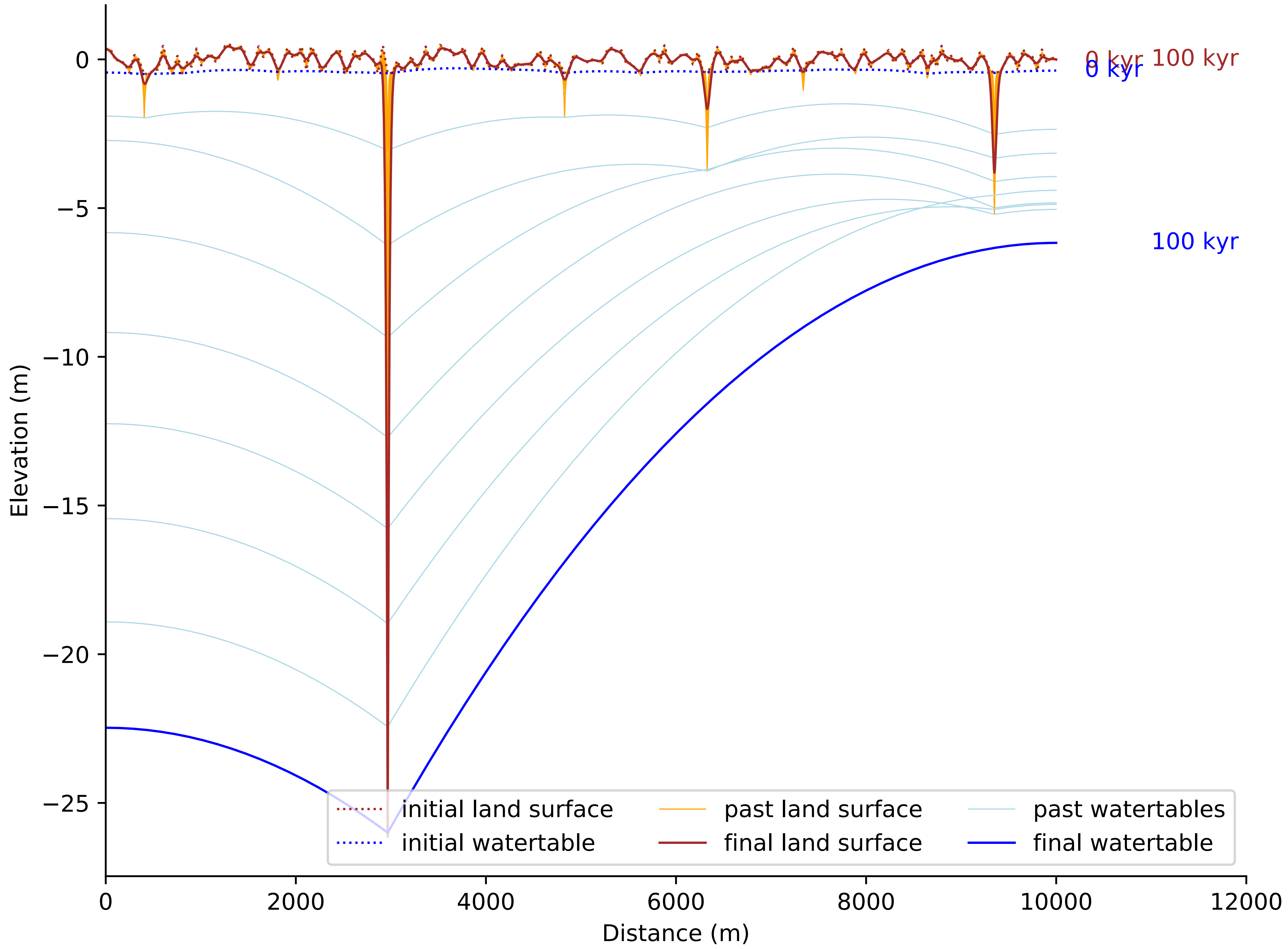
- Low T = 10^{-4} m^2/sec =~silt
- Very high stream density, 1 stream per 150 m
- Very little abandonment of streams. High curvature of watertable means that watertable difficult to detach from neighbouring streams



Modelled position of the land surface and watertable over 100 kyr.
- no stream left behind -

Model experiment 3: High transmissivity

- High T= 10^{-2} m^2/sec =~coarse sand
- Much lower drainage density, only one stream survives = 1 stream per 10000 m
- Much higher rate of incision: More groundwater flow drained per stream, and therefore higher erosion rates



Modelled position of the land surface and watertable over 100 kyr.
- the winner takes it all -

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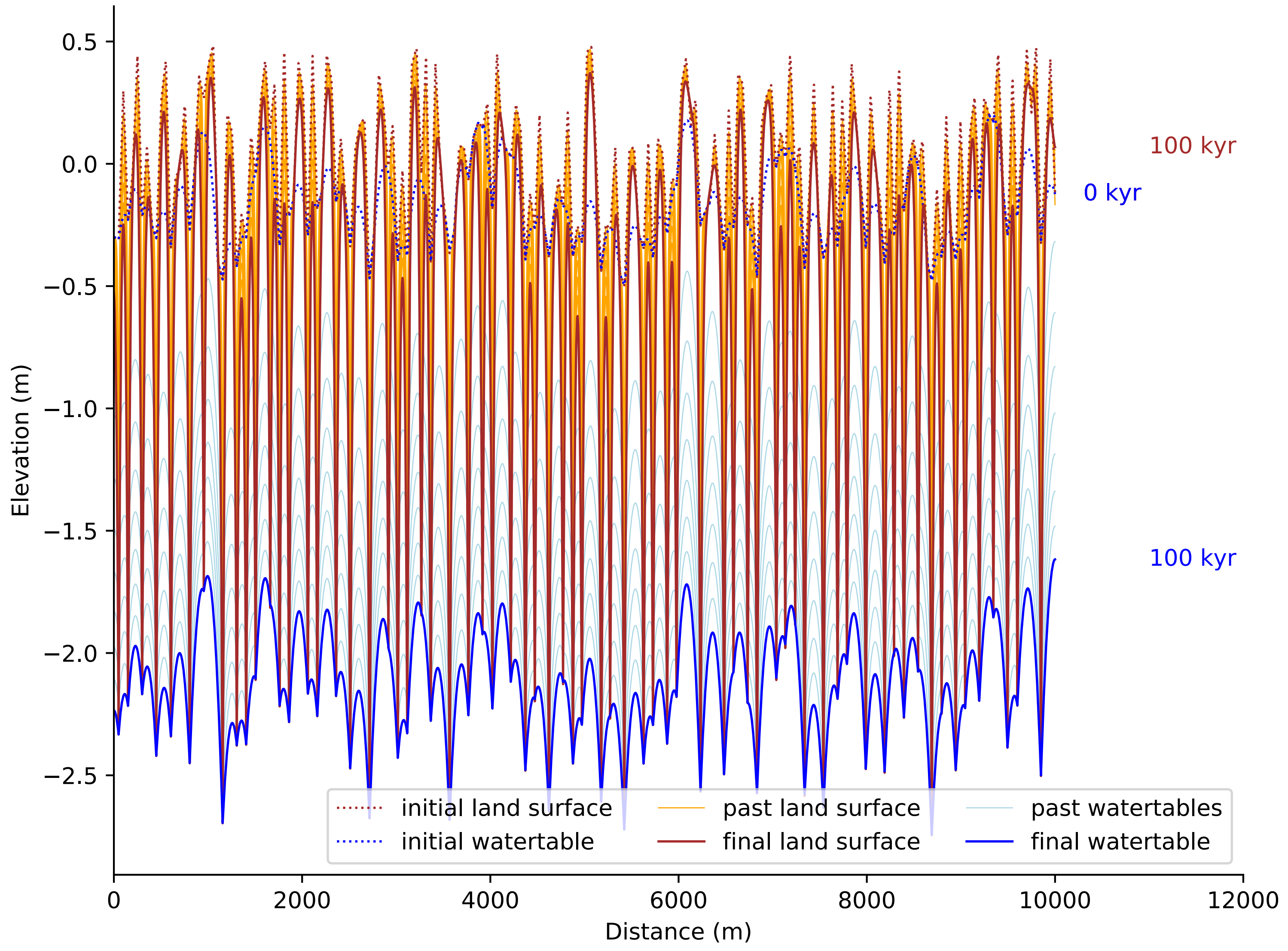
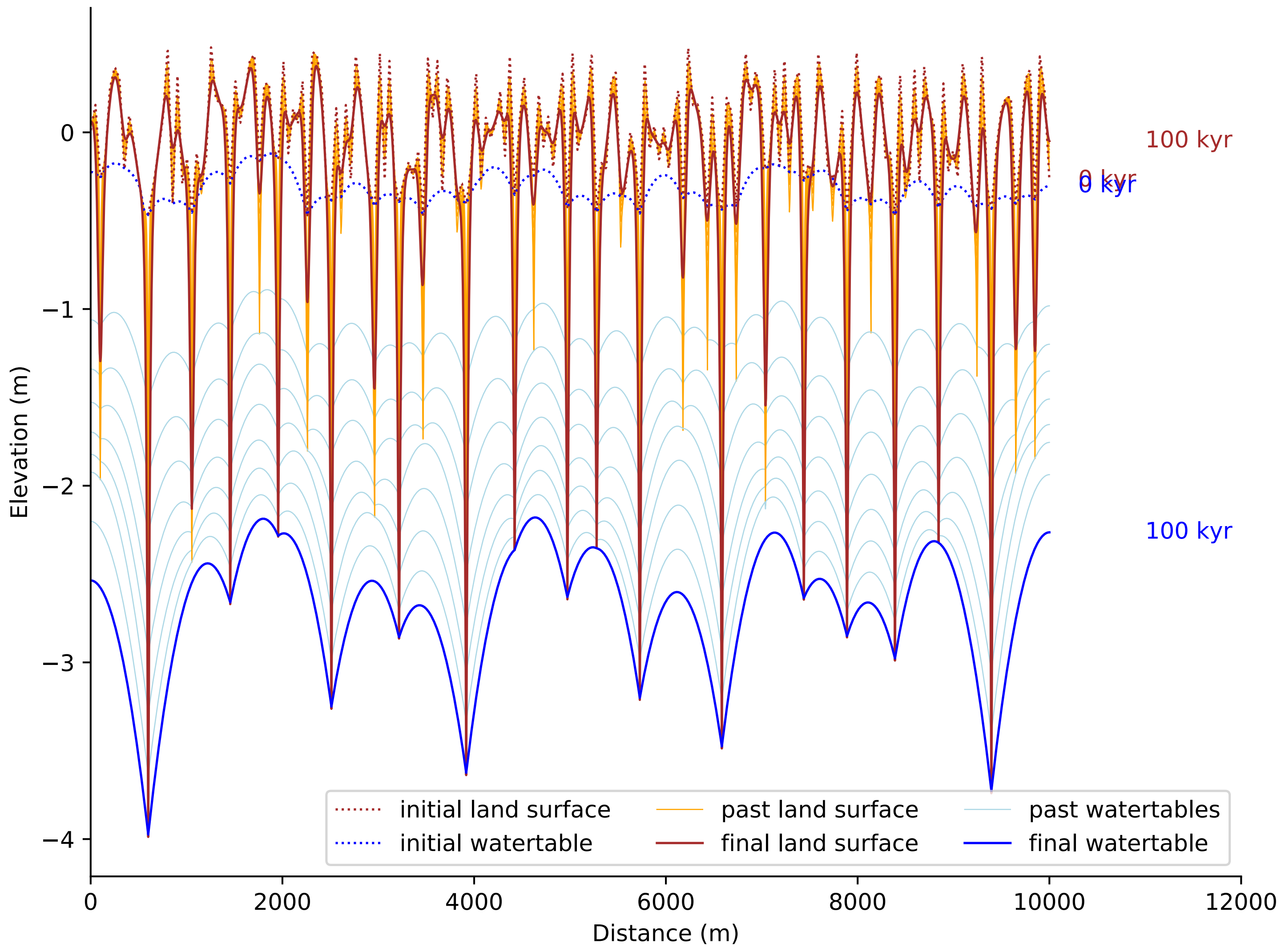
Comparison three model experiments

- Comparison of three model experiments show that the hydraulic conductivity / transmissivity of the subsurface exerts a strong control on drainage density and incision rates:

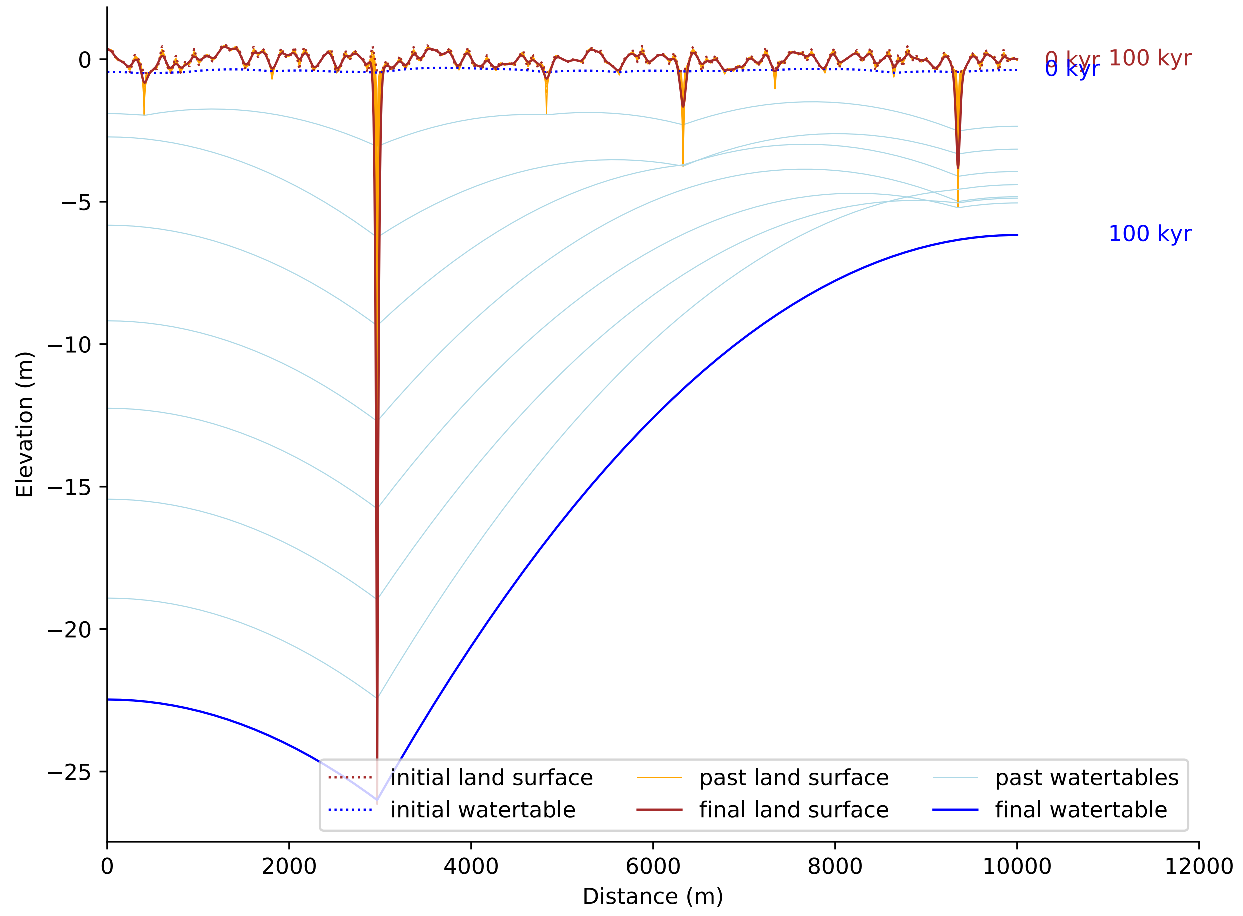
T=10^{-4} m^2/sec



T=10^{-3} m^2/sec



T=10^{-2} m^2/sec

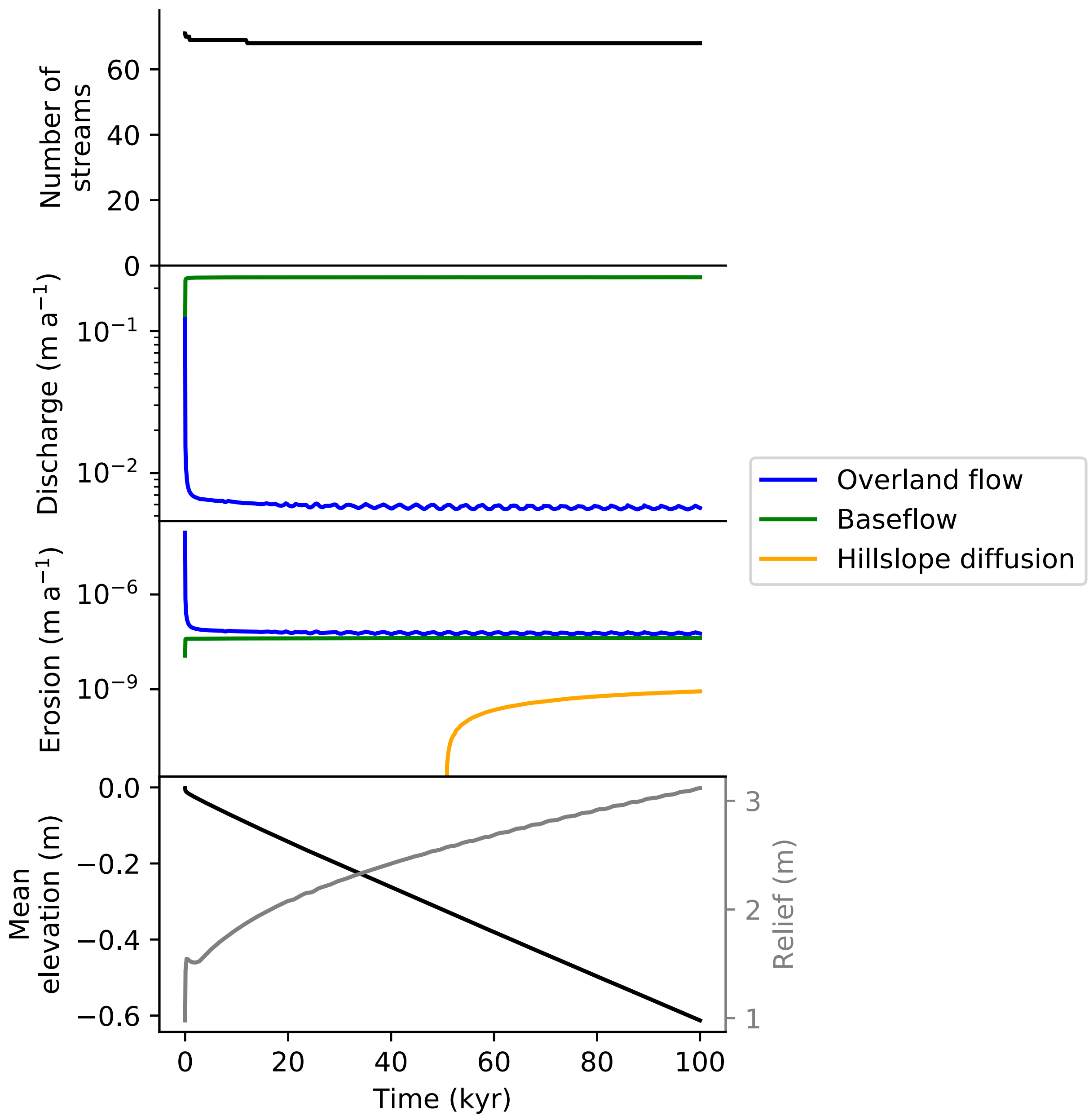


Comparison modelled position of the land surface
and watertable over 100 kyr
from low transmissivity (left) to high transmissivity (right)

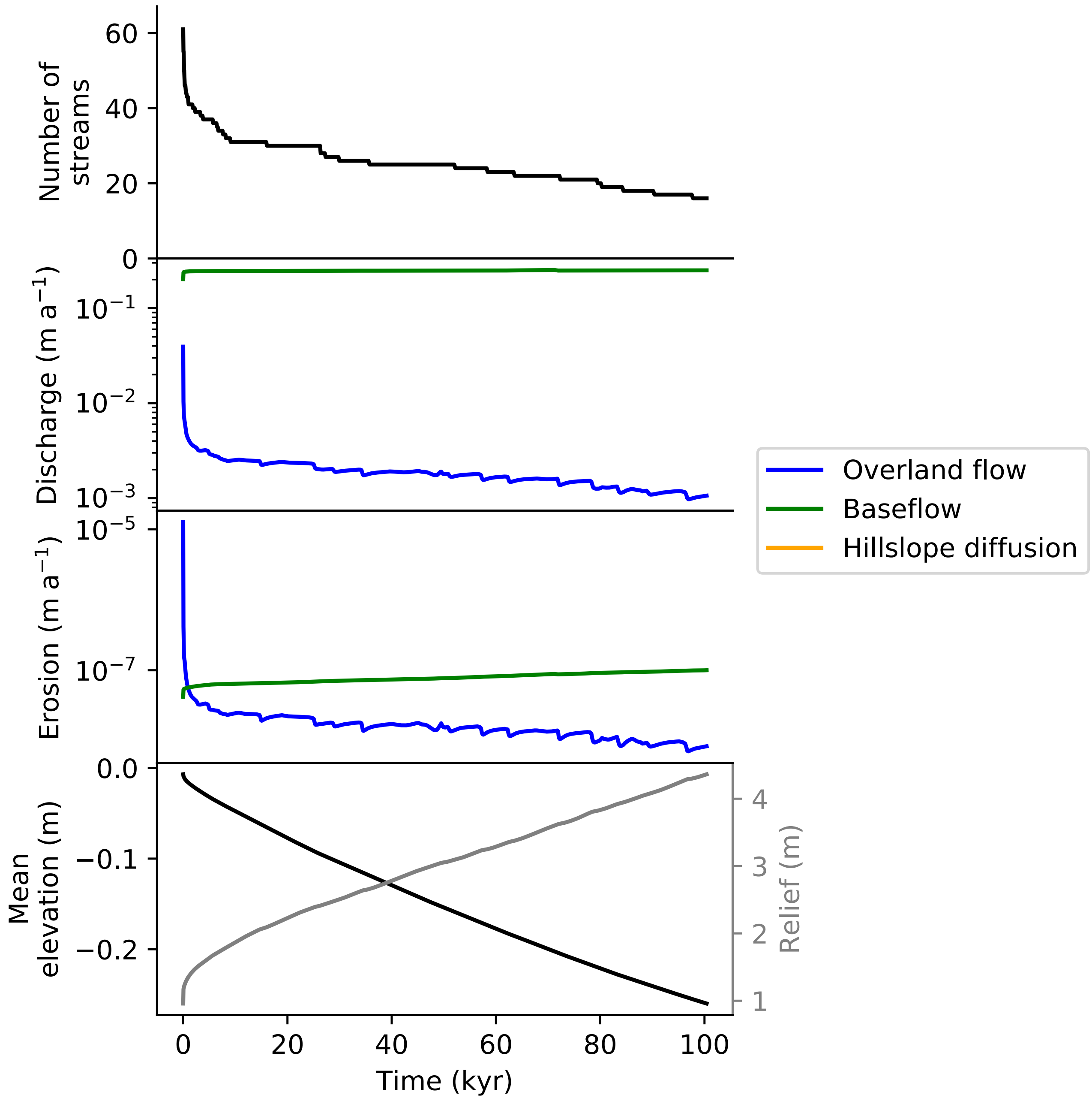
Comparison modelled evolution over 100 kyr

- Reaction time of high transmissivity model run is much faster than the moderate transmissivity model run where streams are still being abandoned after 100,000 years
- After initial phase these systems are dominated by groundwater discharge (baseflow). Results may be different for systems controlled by overland flow, i.e. higher precipitation or lower storage potential (drainable porosity) in unsaturated zone

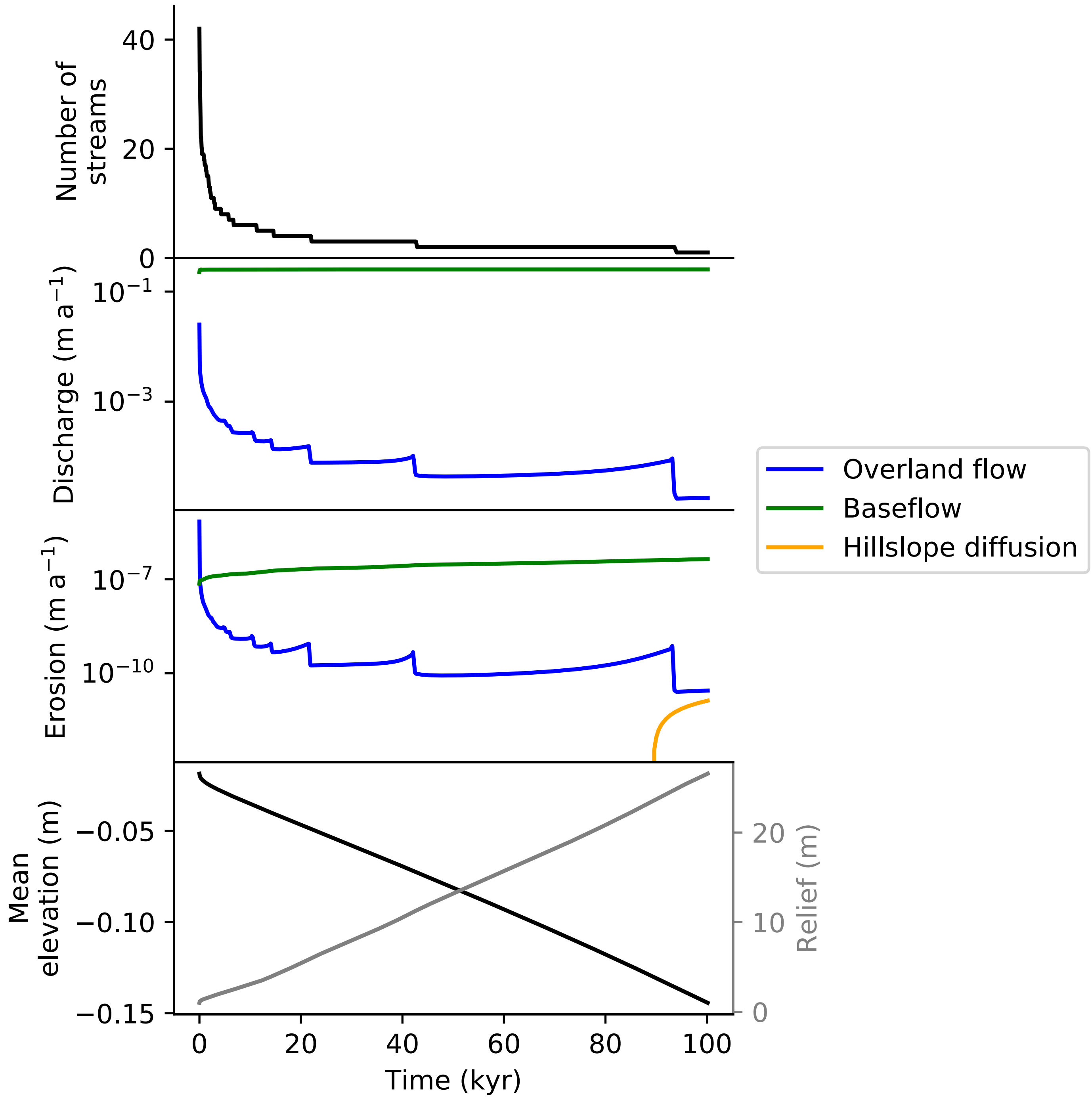
T=10^{-4} m^2/sec



T=10^{-3} m^2/sec



T=10^{-2} m^2/sec



Comparison modelled stream density, water fluxes and erosion over 100 kyr
from low transmissivity (left) to high transmissivity (right)

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