klimaat voor ruimte
climate changes spatial planning

CS9 Increased recent and late Holocene discharge and flood frequency of the River Meuse: effects of climate change versus land use change

P.J. Ward[1], H. Renssen[1], J.C.J.H. Aerts[2], R.T. van Balen[1] and J. Vandenberghe[1]

[1] Department of Palaeoclimatology and Geomorphology, Faculty of Earth and Life Sciences, Vrije Universiteit Amsterdam

[2] Institute for Environmental Studies, Faculty of Earth and Life Sciences, Vrije Universiteit Amsterdam

E-mail: philip.ward@falw.vu.nl

vrije Universiteit amsterdam

Introduction

In recent years the frequency and magnitude of high-flow events in the Meuse Basin (see map on accompanying poster) has been relatively great, and flooding has become a major research theme. To date, research has focused on observed discharge records of the last century and simulations of the coming century. However, it is difficult to delineate changes caused by human activities (land use change and greenhouse gas emissions) and natural fluctuations on these timescales. Studies of palaeodischarge provide a means to address the lack of long-term observed discharge data.

Methods and Research Approach

We have coupled a climate model (ECBilt-CLIO-VECODE)[1,2,3] with a hydrological model (STREAM)[4] to simulate daily Meuse discharge in two time-slices: (a) 4000-3000 BP (natural situation); and (b) 1000-2000 AD (includes anthropogenic land use and climate change). By comparing the discharge characteristics of these two periods we were able to examine the effects of anthropogenic influences on discharge and flood frequency (see Fig. 1).

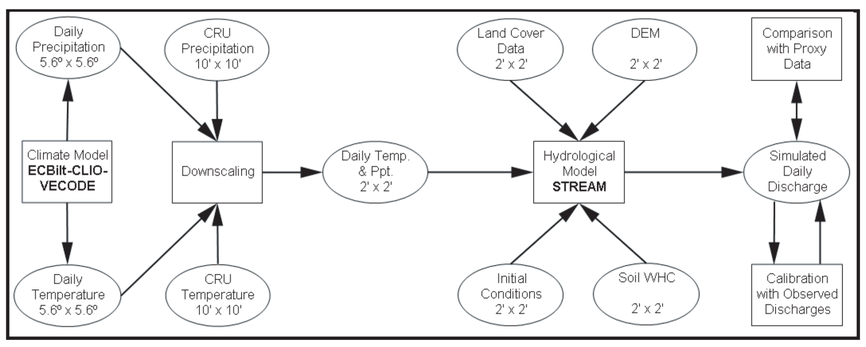


Fig. 1 (left): Overview of the general research approach.

Land use change

We created land use maps for each century (Fig. 2) based on CORINE data, census data, historical records, and pollen analyses.

The most striking change in land use is the huge reduction in forested area between the natural situation (98%), and the situation at 1000 AD (53%) (at the expense of agriculture). This reduction continued until the 19th Century AD (29%); in the 20th Century AD forest and urban area expanded at the expense of agriculture.

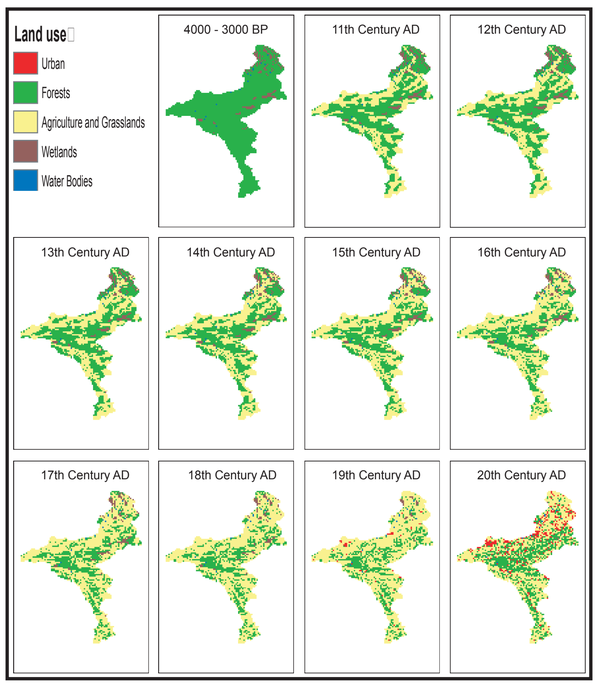
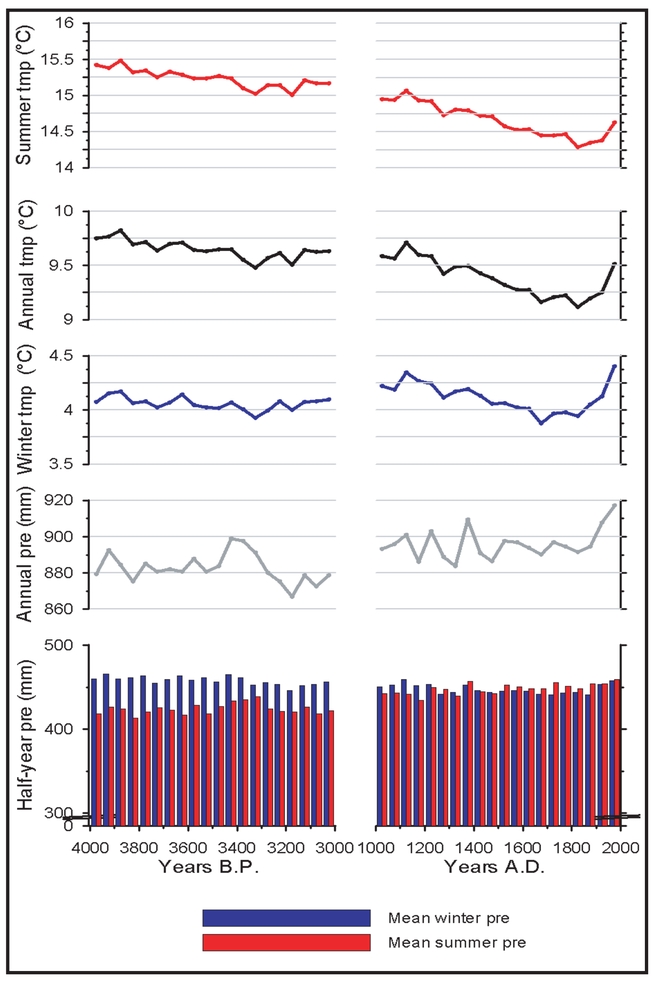


Fig. 2 (right): Land use maps for 4000-3000 BP and 1000-2000 AD, showing the large decrease in forested area between 4000-3000 BP and 1000-2000 AD. In the 20th Century AD some reforestation has occurred.



Climate development

In 1000-2000 AD annual precipitation was higher than in 4000-3000 BP (Fig. 3). However, intense precipitation events were more common in the latter period. Over the entire course of the last 1000 years precipitation shows no trend, but 20th Century precipitation was higher than in any preceding century. Mean temperature decreased over the late Holocene, but increased significantly in the last 100 years (especially in winter).

Fig. 3 (left): Average basin precipitation (pre) and temperature (tmp) over the periods 4000-3000 BP and 1000-2000 AD (50-yr means).

(1) Opsteegh et al. 1998, Tellus 50A, 348-367
(2) Goosse & Fichefet 1999, JGR 104, 23,337-23,355
(3) Brovkin et al. 2002, GBC 16, 1139
(4) Aerts et al. 1999, Phys. Chem. Earth, B24, 591-595

Changes in discharge and evapotranspiration

Mean discharge in 1000-2000 AD (blue line, Fig. 4) was significantly higher than in 4000-3000 BP, and shows an increasing trend over the last 1000 years. Actual evapotranspiration (AE) (red line, Fig. 5) was higher in 4000-3000 BP than in the last millennium, and decreased over the last millennium, following the reduction in forested area. In the last 100 years both discharge and AE increased significantly compared to the preceding century.

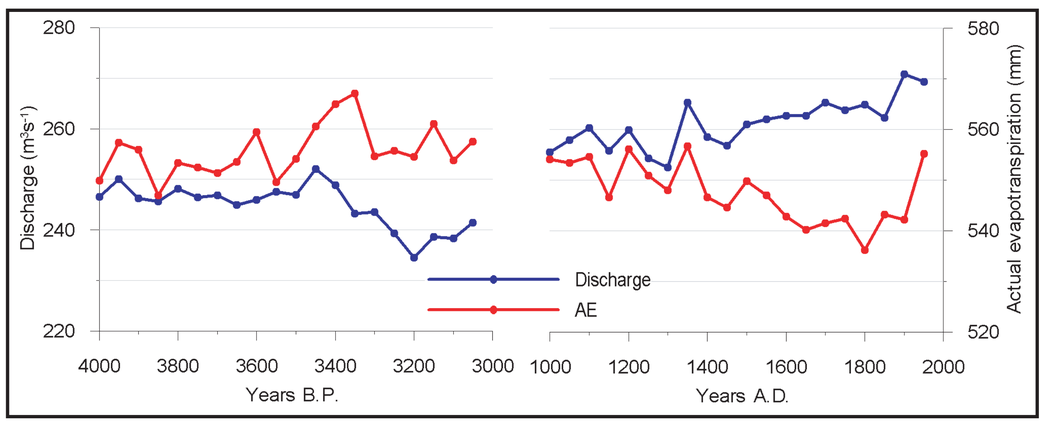


Fig. 4 (above): Discharge (blue) and actual evapotraspiration (red) over the periods 4000-3000 BP and 1000-2000 AD (50-yr means). Discharge increased significantly between the natural situation and 1000-2000 AD, whilst AE fell in response to reduced forest cover.

Changes in flood frequency

Fig. 5 shows that large floods are now more common than under natural conditions. The recurrence time of large high-flow events (discharge > 3000m^{3}s^{-1}) has almost halved from 77 years (natural situation) to 40 years (20th Century AD).

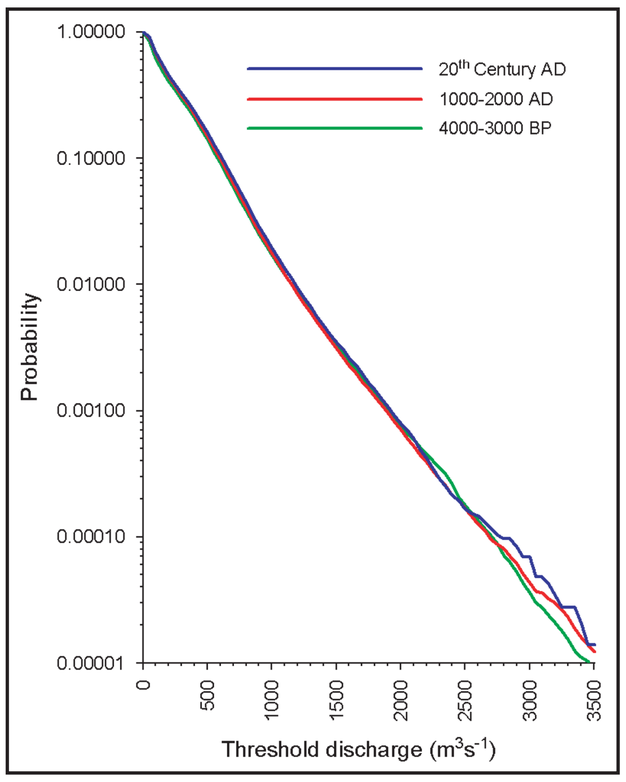


Fig. 5 (right): Probability of daily discharge above a given threshold. The frequency of high-flow events has increased in relation to the natural situation (4000-3000 BP).

Causal mechanisms of increased discharge

The increase in discharge and flood frequency between the natural situation and the 20th Century AD can be almost fully attributed to changes in land use (reduced AE due to deforestation) (Table 1). However, the increase between the 19th and 20th Centuries AD is driven by increased annual and winter precipitation.

	Q_{ann}	Q_{75}	Q_{90}	Q_{95}	Q_{99}
% change between 4000-3000 BP and 20th Century AD					
Climate and land use	+12.5	+11.3	+7.1	+5.6	+4.1
Climate only	-	-0.4	+0.6	+0.1	-0.6
Land use only	+12.4	+11.7	+6.6	+5.5	+4.8
% change between 19th Century AD and 20th Century AD					
Climate and land use	+3.5	+4.3	+2.9	+3.2	+4.0
Climate only	+4.5	+5.5	+3.7	+3.7	+4.5
Land use only	-1.0	-1.2	-0.8	-0.5	-0.5

Table 1: Percentage change in mean discharge (Q_{ann}) and various high-flow percentiles between 4000-3000 BP and the 20th Century AD (above), and between the 19th and 20th Centuries AD (below).

Conclusions

Mean discharge and flood frequency were significantly higher in the last millennium than in the natural situation (4000-3000 BP).

On the millennial timescale these increases can be almost fully attributed to the large-scale deforestation of the basin; the effects of changes in climate are insignificant.

Over the last 100 years a large increase in annual and winter precipitation has caused a further increase in mean discharge and flood frequency. The occurrence of large high-flow events (discharge > 3000 m^{3}s^{-1}) was almost twice as frequent in the 20th Century as under natural conditions. Climatic change has overwhelmed land use change as the dominant mechanism on this timescale.

This poster is based on the following discussion paper which is currently under peer-review:
Ward, P.J., Renssen, H., Aerts, J.C.J.H., Van Balen, R.T., Vandenberghe, J., 2007. Strong increases in flood frequency and discharge of the River Meuse over the late Holocene: impacts of long-term anthropogenic land use change and climate variability, Hydrology and Earth System Sciences Discussions, 4, 2521-2560.