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Appropriate river flood modelling with respect to climate change

M.J. Booij

Introduction

Flood frequency estimation with climate change involves a number of *uncertainties*, which should be reduced. Also, computational costs have to be minimised, consequently *appropriate models* should be used for which further refinement is no longer useful from the point of view of propagation of uncertainties. Uncertainties and appropriate modelling with respect to the impact of climate change on river flooding is the main focus of the PhD-project by the author. Here, appropriate modelling with respect to the river system is considered.

The main objective is to estimate downstream flood frequency curves given upstream ones with different flood routing methods varying in complexity. If results from a simple and a more complex method show no significant differences, then the more simple method could be appropriate to describe the propagation of flood waves for that particular case. This problem will be handled with simple flood routing methods applied to a very schematic one-dimensional model of the river Meuse (Western Europe).

Flood routing

Flood generation

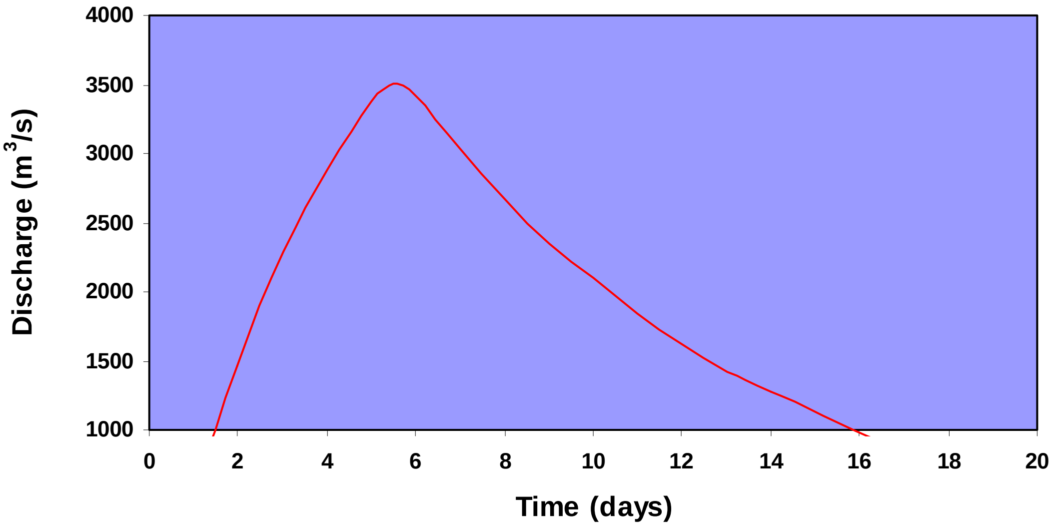
According to the Gumbel extreme value distribution, annual peak discharge Q_p as a function of return period T is defined as:

$$Q_p = -ln\left(-ln\left(1-\frac{1}{T}\right)\right)\alpha + \xi \qquad (1)$$

where α and ξ are two parameters related to the moments of the populations of Q_p values. With known parameter values and random frequencies, annual peak discharges can be generated.

Flood wave shape

A flood wave is generated by using a known flood wave shape for a specific peak discharge Q_s. This flood wave can be scaled geometrically to other peak discharges Q_p by multiplying with a factor Q_p/Q_s. The flood wave shape for the river Meuse belonging to Q_s (=3500 m^3/s) is shown below.



Flood routing methods

One method for lumped flood routing (Kalinin-Milyukov) and three methods for distributed flood routing (kinematic wave, diffusion wave and dynamic routing) are used.

1. Kalinin-Milyukov method

This method is derived from the diffusion wave method and considers a river section Δ as a series of linear reservoirs. The length of these reservoirs *λ* and corresponding characteristic time *k* should fulfil the following:

$$\lambda = \frac{2D}{c} \qquad [L]$$

$$k = \frac{2D}{c^2} \qquad [T]$$

Here, *c* is the velocity of wave propagation and *D* the diffusion coefficient. The transfer function of a cascade of *n* (= Δ/λ) identical linear reservoirs is:

$$u(t) = \frac{1}{(n-1)!}\frac{1}{k^n} t^{n-1} e^{-t/k} \qquad (2)$$

This transfer function can be combined with the derived flood wave to a convolution integral for the transformation of upstream discharge $Q_u(t)$ to downstream discharge $Q_d(t)$:

$$Q_d(t) = \int_0^\infty Q_u(t-\tau)\; u(\tau)\, d\tau \tag{3}$$

2. Kinematic wave method

Here, the momentum equation reduces to a simple equilibrium between bottom friction and gravity. Assuming that the width-to-depth ratio is large and introducing this into the equation of continuity gives the following linear approximation for the depth of flow h:

$$\frac{\partial h}{\partial t} + c\frac{\partial h}{\partial x} = 0 \tag{4}$$

with the velocity of propagation c:

$$c = \frac{3}{2}\frac{B_s}{B}\sqrt{\frac{gh_0\left(i_b - \frac{\partial h}{\partial x}\right)}{c_f}} \qquad [LT^{-1}]$$

where B_s = stream width [L]
B = width [L]
g = acceleration due to gravity $[LT^{-2}]$
h_0 = equilibrium depth of flow [L]
i_b = mean bottom slope [1]
c_f = bottom friction coefficient [1]

Eq. (4) represents a wave going through a river section Δ with travel time Δ/c and no attenuation. The bottom friction coefficient c_f equals g/C^2, where C is the Chézy coefficient $[L^{½}T^{-1}]$.

3. Diffusion wave method

Here, the momentum equation reduces to a local equilibrium between bottom friction and gravity. Applying the same procedure as before leads to the linear approximation for the depth of flow h:

$$\frac{\partial h}{\partial t} + c\frac{\partial h}{\partial x} - D\frac{\partial^2 h}{\partial x^2} = 0 \tag{5}$$

with diffusion coefficient:

$$D = \frac{h_0}{2}\frac{B_s}{B}\sqrt{\frac{gh_0}{c_f\left(i_b - \frac{\partial h}{\partial x}\right)}} \qquad [L^2T^{-1}]$$

Then the transfer function for the convolution integral can be derived:

$$u(t) = \frac{\Delta}{\sqrt{4\pi D t^3}} e^{\frac{-(\Delta - ct)^2}{4Dt}} \qquad (6)$$

4. Dynamical routing method

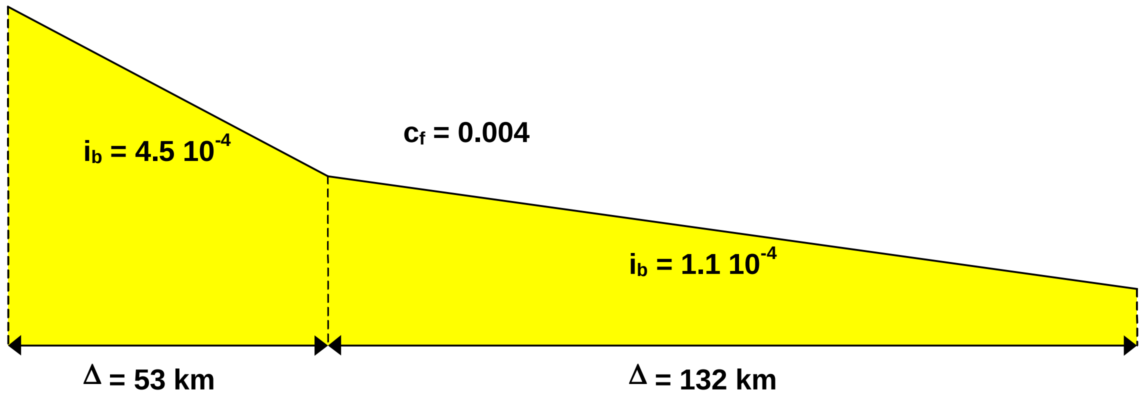
In this method the complete Saint-Venant equations are used. This has been done with the one-dimensional modelling system SOBEK. In SOBEK the momentum equation and continuity equation are solved numerically using a finite difference method based on the Preissmann box scheme.

Research area and design

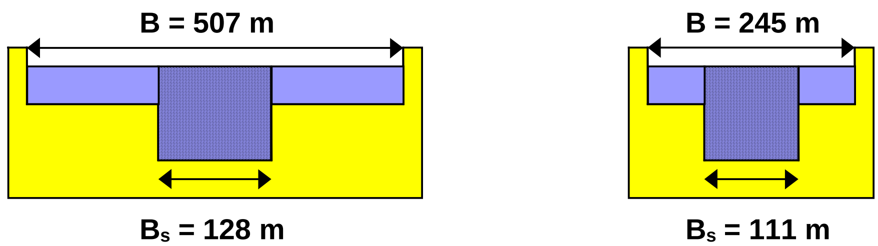
The research area is a Dutch section of the river Meuse from Borgharen up to Lith. This section is schematised into two different uniform parts as illustrated in the figure. The velocity of propagation c is determined from the 1993 and 1995 Meuse floods, after which B (an effective width), D, n and k could be obtained.

With eq. (1) hundred random annual peak flows Q_p have been generated and used to create flood waves. These waves $Q_u(t)$ have been routed through the river section with *three* routing methods to obtain flood waves at Lith $Q_d(t)$ (kinematic wave method only shifts a wave). Finally, flood peaks as a function of frequency for the different routing methods can be derived.

LONGITUDINAL PROFILE



CROSS SECTION



PARAMETER VALUES

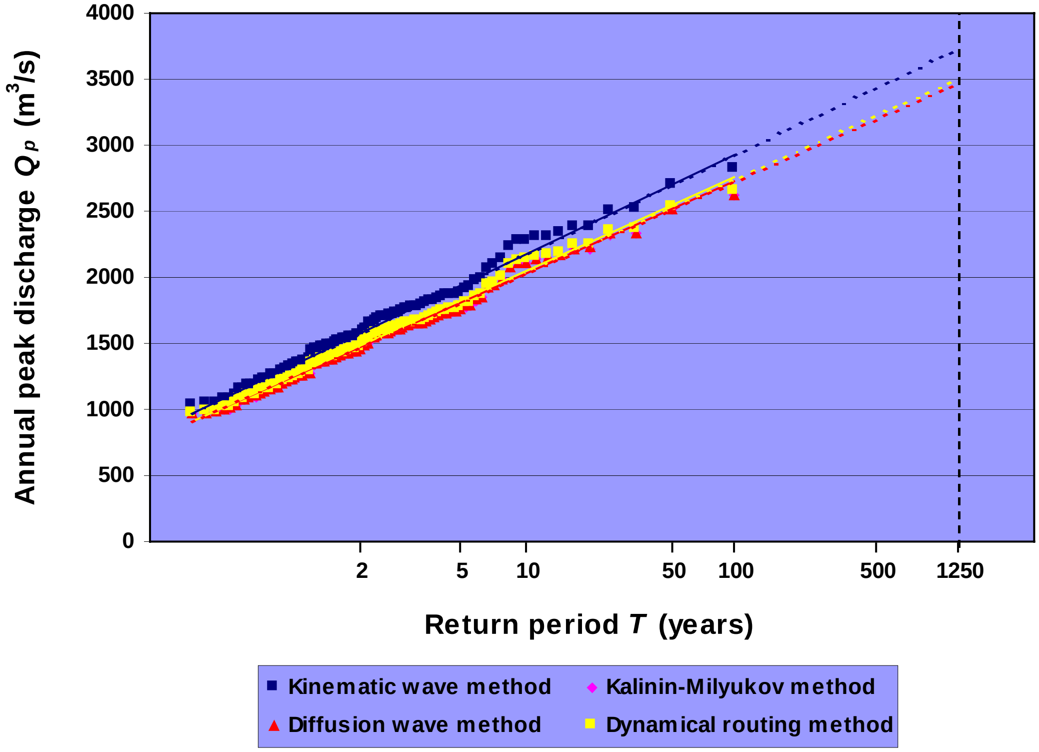
$h_o = 6.15$ m	$h_o = 4.18$ m
$c = 0.99$ m/s	$c = 0.72$ m/s
$D = 4.6\ 10^3\ m^2/s$	$D = 9.4\ 10^3\ m^2/s$
$n = 6$	$n = 5$
$k = 8.9\ 10^3$ s	$k = 37\ 10^3$ s

Results and discussion

Below downstream Q_p as a function of T for four routing methods is given. Extrapolation till T = 1250 years is applied to obtain downstream design discharges.

As expected, there is no difference between Q_p at Borgharen (not shown here) and Q_p at Lith derived with the kinematic wave method. Difference between Q_p at Lith derived with this method and other three methods is substantial; 7.0, 6.8 and 6.1 % for respectively Kalinin-Milyukov, diffusion wave and dynamical routing. As expected, differences between Kalinin-Milyukov and diffusion wave are relatively small; less than 1 %, this applies also for the dynamic routing method. It seems

Kalinin-Milyukov can be used for simple flood routing instead of more complex methods like diffusion wave or dynamical routing.



Conclusions

1. Substantial differences between downstream flood frequency curves derived with kinematic wave method and other methods incorporating wave attenuation.
2. Relatively small differences between Kalinin-Milyukov, diffusion wave and dynamical routing; less than 1 %.
3. It seems Kalinin-Milyukov can be used for simple flood routing instead of more complex methods like diffusion wave or dynamical routing.