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Factsheet on forest and floods

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Introduction

In 1841, Alexandre Surell [1] noted: "Forestation causes the extinction of torrents; deforestation revives the extinct torrents. At the beginning of the 19th century, the so-called overexploitation of forests was at the forefront of the perception that floods were aggravated by wood felling in the catchment area. The opinion was that a healthy forest retains precipitation more strongly than unwooded terrain and accordingly has a dampening effect on floods. The limits of the forest's storage capacity were also pointed out, but these were set too high.

Therefore, from about 1870 onwards, forests were regarded as flood preventers *par excellence*, and this also played a major role in the introduction of the Forest acts in Austria (1852), France (1859) and Switzerland (1876). Another important factor was the increase in frequency of extreme floods during that time [2].

In Switzerland, serious forest hydrological studies began in 1903 in the Sperbel- and Rappengraben in the Emmental, where precipitation and runoff were continuously measured. The Sperbelgraben was almost completely forested, the Rappengraben only to one third and was otherwise used for agriculture. On the basis of the results, [3] showed that forests reduce flood peaks mainly in the case of short intensive heavy precipitation, but this effect decreases with rainfall duration until eventually the storage capacity of the soil is exhausted. Since that time, a huge body of scientific work on forest and flood interactions has been published and the importance of other factors such as soil, catchment and precipitation characteristics has been recognised. In this fact sheet, we aim to summarize the currently known facts and findings and propose a conceptual model that can support practitioners in making decisions that concern forests and floods.

— by Massimiliano Schwarz and Luuk Dorren

Findings on forests and floods

River floods are affected by numerous processes and any changes in such processes may affect peak discharges. Following [4, 5] the drivers of such changes can be defined into three groups:

1. Atmosphere. Any change in rainfall, snowmelt and evaporation will induce changes in flood magnitudes directly or indirectly, for example via antecedent soil moisture.
2. Catchment. Land use due to de- and afforestation, agricultural use and urbanization has changed considerably in many areas around the world.
3. River system. Rivers have been changed significantly by humans.

Many authors (e.g., [4, 6]) discuss how the drivers belonging to these groups affect flood discharge at different spatial scales and for different event magnitudes [5]. Regarding spatial scales, it is quite common (e.g., [7, 6]) to distinguish micro scale catchments (up to 10 km^2), meso scale catchments (> 10 up to 1000 km^2) and macro scale (> 1000 km^2). When compared to other land uses, the "forest effect" can mainly be divided into two general parts:

1. increased retention through additional storage capacity (due to higher interception and soil storage) and
2. increasing time to runoff and decreasing flow velocity (due to improved infiltration, delayed lateral subsurface flow and additional roughness on the slope or in the floodplain).

There is clear evidence that appropriately chosen land-use and land-cover interventions can reduce local peak runoff following moderate rainfall events. The available evidence for the downstream effects of upstream land-use and land-cover changes in large catchments is more limited, but at present it does not suggest that land-use changes, such as conversion from cropland to woodland, will make a big difference to downstream flood risk [8].

In the extreme case, forest soils can store 70 mm more water compared to agricultural soils. Interception in forests is on average around 5 mm, in extreme cases 20 mm (or 0 mm in open deciduous forest in the winter). Evapotranspiration can be in the order of 2.5 (± 2) mm per hour (e.g., [9]). At plot and slope scale these forest effects can be relatively easily measured on permanent plots or using rainfall experiments. The latter, as carried out by [6] on 100 m^2 sloping plots, show for example that an undisturbed forest has a peak runoff coefficient (RC) of approx. 10% compared to pastures and ski pistes, which have RCs between 30% and 50%, and urbanised areas (RC > 70%). At micro scale, the potential forest effect is already more difficult to measure since it cannot be completely be disentangled from terrain effects such as variable geomorphological characteristics (e.g. channel density) and the spatial distribution of different soil types [10].

A partial solution to this problem was proposed by [11], who introduced frequency pairing (FP) instead of chronological pairing (CP). CP focuses only on quantifying a change in magnitude between mainly pre-harvest and post-harvest floods paired by equal meteorology or storm input. Changes in flood response, regardless of whether the cause is land cover or climate change, must be investigated within the context of a frequency distribution that reveals changes in magnitude of floods with equal frequency or the inverse. This is done in FP.

When moving to bigger scales however, the drivers of change belonging to the groups Atmosphere and River system become more and more dominant. Therefore, the only possibility to objectively study the effect of forests at meso and macro scale catchments is to use hydrological models or statistical models (if the available data sets include long-term measurements with sufficient data quality). The results of the many existing modelling studies vary from 0% to 12% reduction in peak discharge (in extreme cases 15 to 20%) when comparing entirely forested landscapes to the actual landscapes, which are mostly a mix of agricultural, urban and forest land use. Many of the published modelling studies at meso and macro scales applied conceptual models using parameter values averaged per month and present the results on a yearly instead of a scenario basis.

A completely different chapter regarding the effect of forests on floods is large wood (LW) recruitment and transport. LW can exacerbate flood damage near infrastructure due to logjams and backwater rise. In an attempt to reduce such problems, channel slopes and banks are often clear cut in practice. However, a careful and objective analysis should identify situations where the positive effects of vegetation to maintain streambank and hillslope stability succumb to the negative effects of LW. In the case where trees with stem diameters larger the 10 cm do have the potential to reduce the magnitude and frequency of LW recruitment processes, forest interventions need to be purposeful and locally optimized [12]. The upcoming ecorisQ tools BankforMAP and SlideforMAP aim to provide an objective basis for such LW-reduction targeted forest management on and above channel and river banks.

Conceptual model

Based on the sparse quantitative and scenario-based evidence in the overwhelming amount of available literature on the effect of forests on floods, we propose a conceptual model based on [13], which is presented in Fig. 1. Since the effect of the forest differs based on the event magnitude and the rainfall duration, we differentiated event magnitudes and defined $\leq$ 10 and $\geq$ 100 year return period (RP) rainfall events and summarised the forest effect on the reduction of the peak discharge in function of the rainfall duration. Since the forest effect is strongly determined by the underlying soil and its infiltration and storage capacity (which can, depending on the soil type, again be improved by forest vegetation over time), but also on the forest structure, we only indicated the maximum effect for each event RP.

The critical rainfall duration, which is linked to the size of a catchment, maximises the peak discharge for the specified rainfall amount with the corresponding recurrence time. The dashed lines indicate the maximum effect for both RP, with the minimum effect being a worst-case 0% reduction in peak discharge, although, mainly for a RP $\leq$ 10 years in small catchments this will usually not be the case. In addition, existing studies show that the effect of forests on the reduction of peak discharge only becomes noticeable at all if there is an increase or decrease of about 20% in forest area relative to the total catchment area. As described by a.o. [5], [8] and [9], a very strong decrease of the effect of forests on the peak discharge is visible in catchments with an area between 5 and 50 km^2, because in this range an increasing saturation excess (from small to larger catchments) and a decreasing infiltration excess is to be expected. The analysis of [5] implies that the tipping point lies aound a catchment area of 14 km^2.

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Table 1: Data underlying Fig. 1 using Nr. as a reference to the symbols shown; Reference shows the corresponding scientific publication in the bibliography; Area is the projected catchment area; Return period of the flood studied; δPeakD is the reported reduction on peak runoff; Forest cover (δ) is the maximum forest cover with the absolute change in forest cover in brackets, where a negative value indicates logging and a positive value indicates forest growth or (re-)afforestation. The last column indicates whether the values were obtained from measurements or modelling

Nr.	Reference	Area (km^2)	Return period (yr.)	δPeakD (%)	Forest cover(δ) (%)	Method
1	[14]	≤4.7	2	+58	100(-95)	measurement
	id.	≤4.7	2	+23	100(-40)	id.
2	[15]	4.5	9	+45	100(-23)	measurement
	id.	27	9	0	100(-2)	id.
3	[16]	26	10	+14	53(-53)	modelling
	id.	26	100	+13	53(-53)	id.
	id.	26	10	+5	53(-19)	id.
	id.	26	100	+4	53(-19)	id.
4	[11]	1	10	+40	75(-75)	measurement
5	[17]	6’000	11	-12	92(+50)	modelling
	id.	160’000	11	-5	82(+40)	id.
6	[18]	160’000	10	-9	96(+57)	modelling
	id.	160’000	200	-3	96(+57)	id.
7	[19]	315	100	-21	99(+55)	modelling
	id.	315	100	-16	67(+25)	id.
8	[20]	1’545	10	-11	69(+21)	measurement
	id.	434	10	-11	82(+50)	id.
	id.	734	10	0	29(+15)	id.
	id.	650	10	0	49(+13)	id.
9	[21]	0.05	10	-62	100(+100)	measurement
10	[22]	1’616	10	-16	93(+73)	modelling

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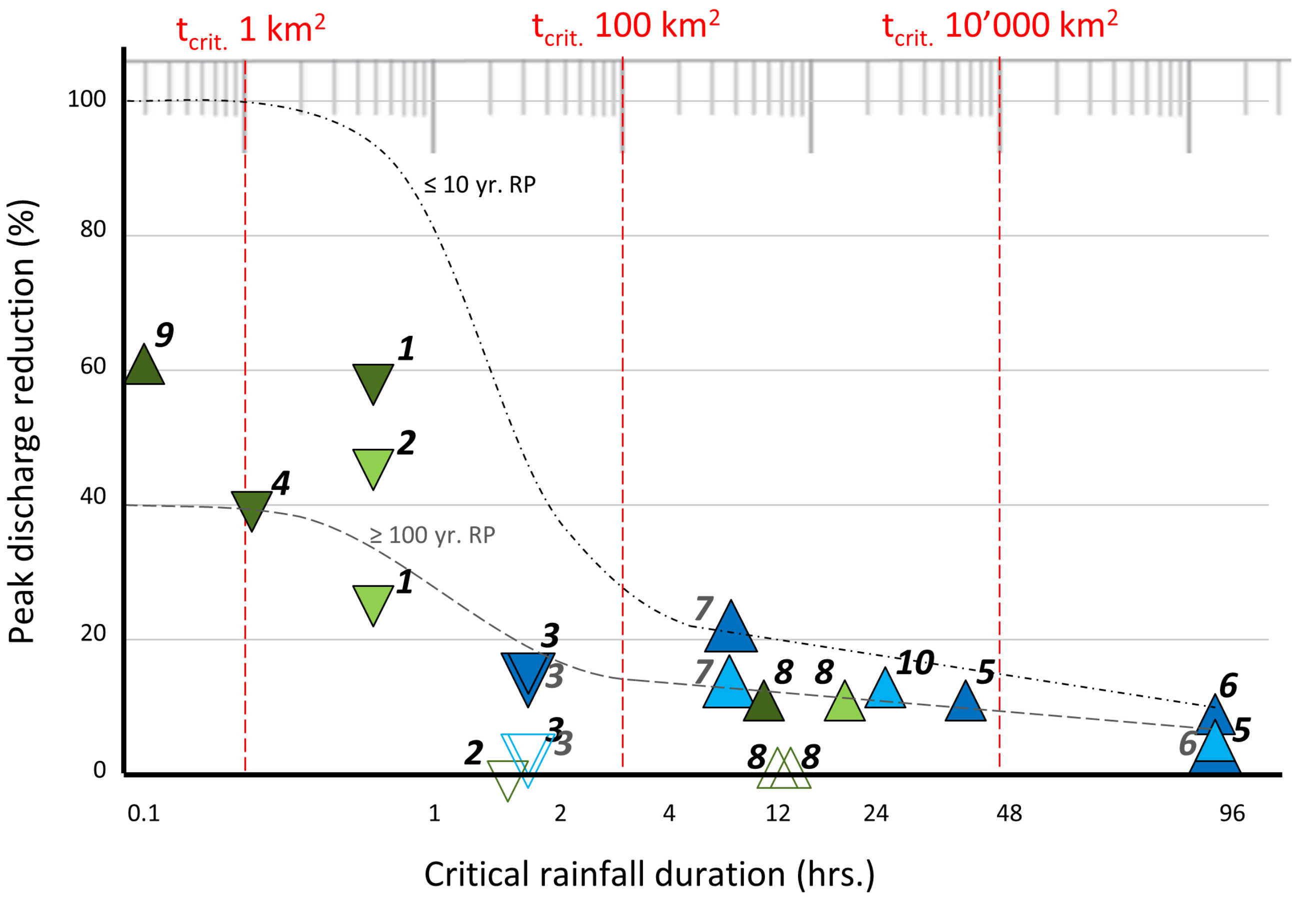

Figure 1: Conceptual model for the effect of afforestation on the reduction of peak discharge (y-axis) after precipitation with a return period (RP) of $\leq$ 10 and $\geq$ 100 years as a function of critical rainfall duration (x-axis). The dashed lines indicate the maximum effect for both RP. The underlying data (for the references belonging to the numbers (see Tab. 1) is represented as triangles. Such with the point downwards represent deforestation and with the point upwards forest growth or (re-)afforestation. Green triangles represent measurements and blue for modelled results (transparent = 0 - 20% change in forest cover; light colour: >20 - 50%; dark colour: >50%). The smallest triangles (with the ref. numbers shown in black) represent an RP up to 11 years and the larger triangles (with the ref. numbers shown in dark grey) represent an RP of 100 - 200 years.