ecorisQ Factsheet

Quantitative facts 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 19^{th} 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. Although the limits of the forest's water storage capacity were acknowledged, they were overestimated.

Therefore, from about 1850 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 combination with the dramatic state of the forests in the Alps [3].

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, [4] 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, ecorisQ aims to summarize the currently known facts and findings and proposes a conceptual model that can aid practitioners in making decisions that concern **re-afforestion as nature-based solution for flood management**.

— by Luuk Dorren

Findings on forests and floods

River floods are influenced by various processes, and changes in these can alter peak discharge levels. Following [5, 6] the drivers of such changes can be defined into three groups:

1. Atmosphere. Long term, as well as high intensity rainfall, exacerbated by snowmelt can lead to floods, depending on antecedent soil moisture, which is highly influenced by evapotranspiration.
2. Catchment. Catchment size and topography, as well as geo-hydrology and soil types are key determining factors for floods. Land use changes — such as deforestation, afforestation, agriculture, and urbanization — can significantly impact flooding in many areas around the world.
3. River system. Rivers have been changed significantly by humans - think of river straightening and widening, construction of levees and dams.

Many authors (e.g., [5, 7]) discuss how the drivers belonging to these groups affect flood discharge at different spatial scales and for different event magnitudes [6]. Regarding spatial scales, it is quite common (e.g., [8, 7]) 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 soil storage and interception)
2. increasing time to run-off and decreasing flow velocity (due to improved infiltration, delayed lateral subsurface flow and additional roughness on the slopes or in the floodplain).

There is clear evidence that appropriately chosen land-use and land-cover interventions can reduce local peak run-off following moderate rainfall events [9]. Evidence for downstream impacts of upstream land-use and land-cover changes in **large catchments** (macro-scale) remains limited, but at present it does not suggest that land-use changes, such as conversion from cropland to woodland, will make a huge difference to downstream flood risk [10] in such catchments.

In the extreme case, forest soils can store around 70 mm more water compared to agricultural soils (e.g, [11]). Storage in the litter layer roughly adds 1 to 3 mm [12]. Interception by and storage in the canopy can be up to approx. 5 mm [12, 13, 14], mostly determined by leaf type. Evapotranspiration can be up to the order of 2.5 mm per hour (e.g., [15]), depending on the windspeed and the relative humidity [16]. At plot and slope scale these forest effects can be relatively easily measured on permanent plots or using rainfall simulator experiments. The latter, as carried out by [7] on 100 m^2 sloping plots, show for example that an undisturbed forest has a peak run-off 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 [17].

A partial solution to this problem was proposed by [18], 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.

An entirely separate aspect of forest influence on flooding involves the recruitment and transport of large wood (LW). 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 [19]. The 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.

Model for the effect of forest on floods

Based on the sparse quantitative and scenario-based evidence in the overwhelming amount of available literature on the effect of forests on floods, a conceptual model based on [20] is proposed (see Fig. 1). Since the effect of the forest differs based on the event magnitude and the rainfall duration, event magnitudes are differentiated and defined as $\leq$ 10 and $\geq$ 100 year return period (RP) rainfall events. The forest effect on the reduction of the peak discharge in function of the rainfall duration is summarised accordingly. 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, only the **maximum effect** for the two mentioned event RP is indicated.

The critical rainfall duration — linked to catchment size — maximizes peak discharge for a given rainfall amount and return period. 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. [6], [10] and [15], 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 [6] implies that the tipping point lies around a catchment area of 14 km^2. In all these studies it is important to realise that a reduction of forest compared to something else can lead to very different effects. If 25% of the catchment area is converted from forest to grassland is not the same as forest converted to barren land or residential area. Nevertheless, the conceptual model provides a first quantitative basis for evaluating the effect of forest cover change in a catchment as a function of catchment size and return period of the precipitation event.

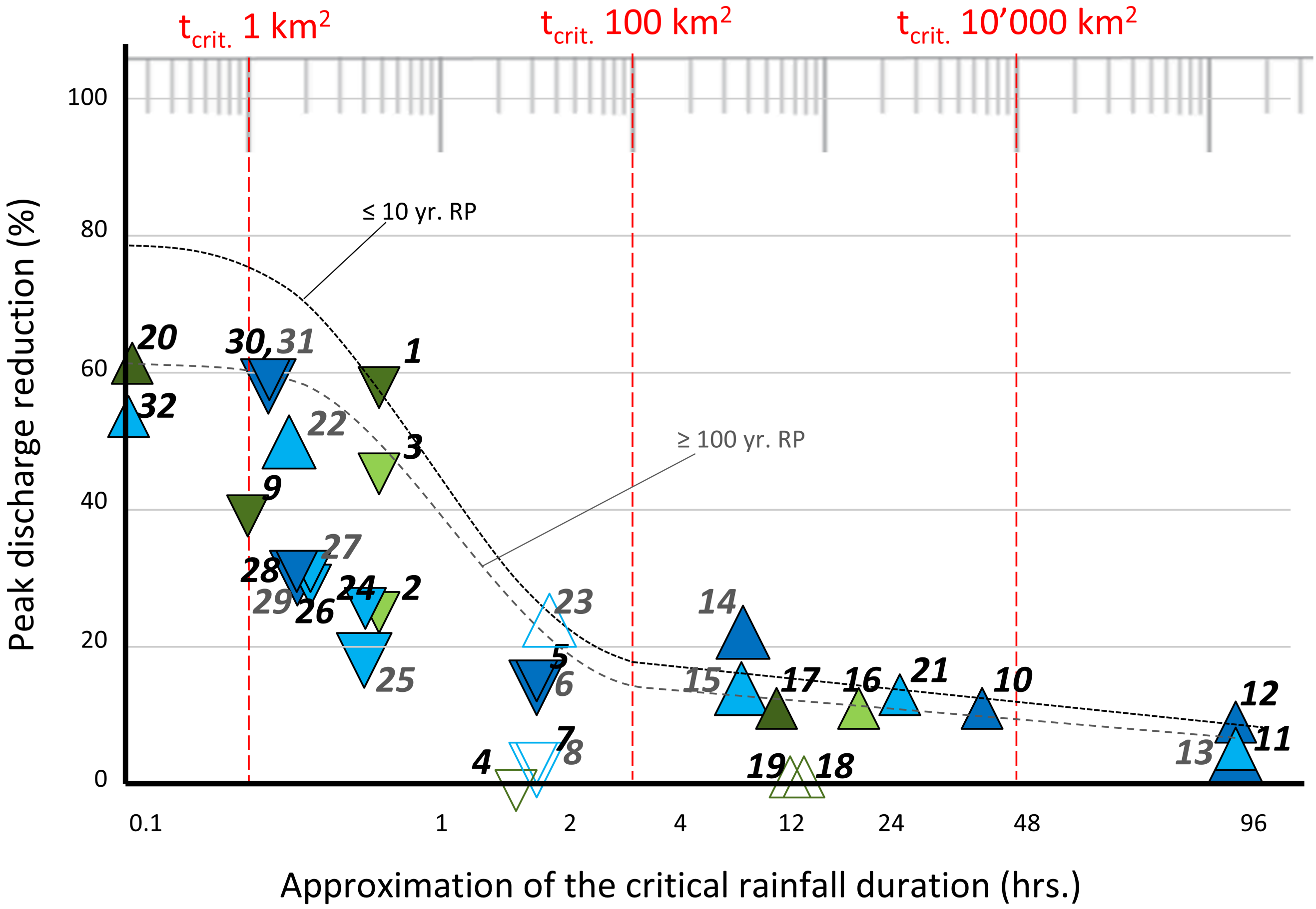

Figure 1: Conceptual model for the effect of afforestation on the reduction of peak discharge (y-axis) after precipitation with a return period (RP) of $\leq$ 10 and $\geq$ 100 years as a function of an approximation of the critical rainfall duration (x-axis). The dashed lines indicate the **maximum effect** for both RP. The underlying data (for the references belonging to the numbers (see Tab. 1) is represented as triangles. Those with the point downwards represent deforestation and with the point upwards forest growth or (re-)afforestation. Green triangles represent measurements and blue ones represent 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 of 2 to 11 years and the larger triangles (with the ref. numbers shown in dark grey) represent an RP of 100 or 200 years.

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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; δQ_{Peak} is the reported reduction in peak discharge (in %, where the reference situation is the higher discharge) or the difference in the reported run-off coefficients; F.C. (δ) is the maximum forest cover with the absolute change in forest cover in brackets, where negative values indicate logging and positive values indicate forest growth, (re-)afforestation or comparison between sites with forest and non-forest land cover. id. = same as above; * = modelling based on infiltration and run-off measurements from rainfall simulator experiments in the study area

Nr.	Reference	Area (km^2)	Return period (yr)	δQ_{Peak} (%)	F.C.(δ) (%)	Measurement or Modelling
1	[21]	$\leq$4.7	2	+58	100(-95)	measurement
2	id.	$\leq$4.7	2	+23	100(-40)	id.
3	[22]	4.5	9	+45	100(-23)	measurement
4	id.	27	9	0	100(-2)	id.
5	[23]	26	10	+14	53(-53)	modelling
6	id.	26	100	+13	53(-53)	id.
7	id.	26	10	+5	53(-19)	id.
8	id.	26	100	+4	53(-19)	id.
9	[18]	1	10	+40	75(-75)	measurement
10	[24]	6'000	11	-12	92(50)	modelling
11	id.	160'000	11	-5	82(40)	id.
12	[25]	160'000	10	-9	96(57)	modelling
13	id.	160'000	200	-3	96(57)	id.
14	[26]	315	100	-21	99(55)	modelling
15	id.	315	100	-16	67(+25)	id.
16	[27]	1'545	10	-11	69(21)	measurement
17	id.	434	10	-11	82(50)	id.
18	id.	734	10	0	29(15)	id.
19	id.	650	10	0	49(13)	id.
20	[28]	0.05	10	-62	100(100)	measurement
21	[29]	1'616	10	-16	93(73)	modelling
22	[30]	1.7	100	-50	40(30)	modelling*
23	[31]	46.6	100	-24	30(15)	modelling*
24	[32]	4	10	+25	35(-35)	modelling*
25	id.	4	100	+19	35(-35)	id.
26	id.	2.3	10	+29	42(-42)	id.
27	id.	2.3	100	+33	42(-42)	id.
28	id.	1.8	10	+33	53(-53)	id.
29	id.	1.8	100	+33	53(-53)	id.
30	id.	1.4	10	+60	90(-90)	id.
31	id.	1.4	100	+60	90(-90)	id.
32	[33]	0.001	10	-54	100(100)	measurement