Quantification and transferability of decentralised Nature-based Solutions' effects for pluvial flood mitigation

Jonas Neumann[1,], Christian Scheid[1] & Ulrich Dittmer[1]*

[1] Institute Water Infrastructure Ressources, Department of Urban Water Management, University of Kaiserslautern-Landau (RPTU), Paul-Ehrlich-Str. 14, 67663 Kaiserslautern, Germany

**Corresponding author email: jonas.neumann@rptu.de*

Abstract

Decentralised Nature-based Solutions (NBS), such as swales and green roofs, contribute to flood mitigation during heavy rainfall events. The quantitative impact of these systems on flood mitigation can be determined using 1D/2D coupled models. However, developing such models requires comprehensive geospatial data and technical expertise. This article presents a methodology to transfer the detailed flood reduction effects of NBS from a 1D/2D simulation to other catchment areas using effect curves. For this the following information is required: the total catchment area, the total roof area and the potential for implementing NBS. This includes the green area available for infiltration systems (roof area is connected to the systems) and the roof area that can be converted to green roofs. Given these characteristics, the validation shows that the effect curves can be used for an initial estimation of NBS performance in reducing floods in the new catchment area. However, simulations are required for a detailed assessment of NBS performance due to the heterogeneity of catchment areas.

Highlights

- Effect curves for transferring NBS flood reduction impacts to other catchment areas.
- 1D/2D coupled modelling of the effect of NBS for flood mitigation

Introduction

An increase in heavy rainfall events is expected due to climate change (IPCC, 2023). The risk of flooding is increasing, particularly in inner-city areas, due to high levels of surface sealing, resulting in precipitation runoff exceeding the design capacity of existing sewer networks. Nature-based Solutions (NBS) promote runoff prevention, infiltration and evaporation, among other benefits, and can thereby help mitigate flooding. The effects of NBS on flood reduction can be quantified using 1D/2D coupled models that simulate surface flooding processes. Developing such models is challenging and requires reliable geospatial data, including high-resolution digital terrain models, as well as significant expertise from the modeller. Furthermore, an appropriate representation of NBS in the model is required. However, their integration is not yet a standard feature in most modelling software. In addition to the complexity of quantifying the effects of NBS in flood mitigation, the fundamental question arises regarding the transferability of these quantification approaches.

This article presents a methodology for deriving effect curves for flood reduction based on detailed NBS quantification results in a study area. These effect curves are transferred to other catchment areas to estimate the flood mitigation effects of such measures. The results are validated using data from two areas.

Data basis and methodology

Data basis

The analyses in this article are based on the results of Neumann et al. (2024), which investigate the impact of various NBS on flood reduction in a flat catchment area (3.4 km²) using a 1D/2D model. Infiltration systems (swales, infiltration trenches, swale-trench elements) and green roofs (extensive green roofs, intensive green roofs and retention roofs) are analysed. The structure, dimensioning, selection of model parameters and integration of the NBS into the model are described in detail in Neumann et al. (2024). To assess the flood mitigation impact of the NBS, the simulation results of the base model without NBS are compared to the results of the models with the respective NBS. The focus is on roof areas, which are either connected to infiltration systems or converted to green roofs, with theoretical implementation levels of 25 %, 50 %, 75 %, and 100 % taken into account. By considering the full range of implementation levels (0 % to 100 %), a deliberate decision was made to deviate from realistic implementation potentials for NBS in order to quantify the full theoretical range of flood reduction impacts.

Methodology

The methodological approach for transferring the NBS effects consists of representing the reduced flooding volume depending on the proportion of the roof area (connected to infiltration systems or converted to green roofs) to the total catchment size as an effect curve. Figure 1 shows the effect curves created for this purpose using the example of swales (dimensioned to T = 5 a and 100 a) and retention roofs under a precipitation load of 100 mm (Euler type II distribution, D = 60 min) for the study area. The Y-axis represents the reduction of the flood volume in the entire study area, while the X-axis represents the roof area (connected to infiltration systems or converted to green roofs) in relation to the total catchment size. Table 1 (left column) provides the area distribution of the study area for reference: The roof area is 97.8 ha, which accounts for 28.8 % of the total area. This corresponds to an NBS implementation degree of 100 %.

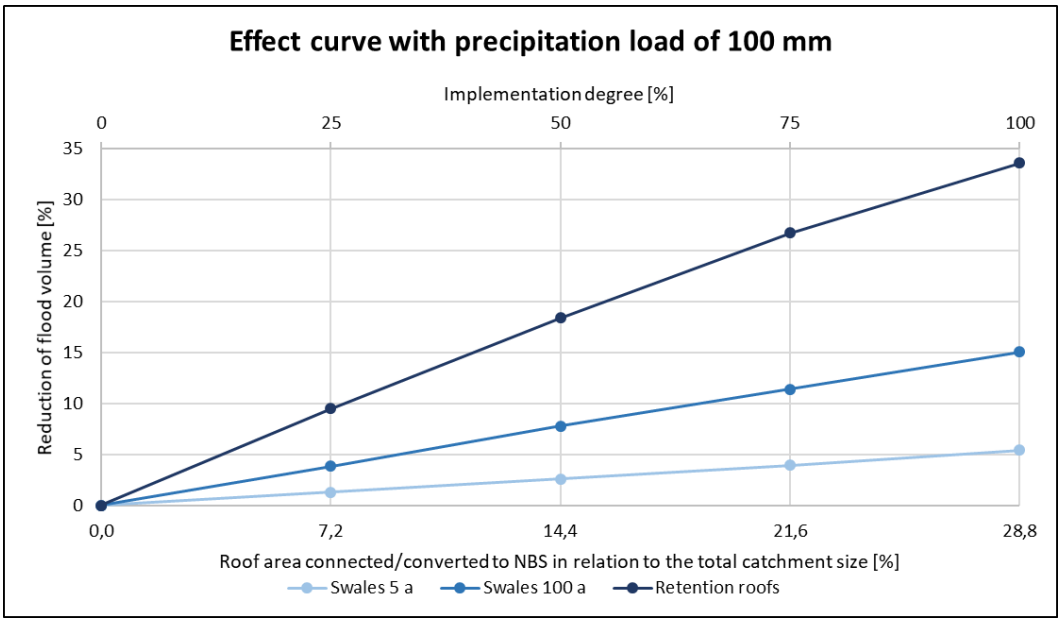


Figure 1. Effect curves for swales dimensioned to T = 5 a and 100 a and retention roofs under a precipitation load of 100 mm.

Table 1. Area distribution of the study area and the new, hypothetical catchment.

Areas	Area distribution study area		Area distribution new, hypothetical catchment	
	[ha]	[%]	[ha]	[%]
Catchment area	339,7	100	220	100
Roof area	97,8	28,8	50	22,7

Application and validation of transferred effect curves

Application

The effect curves from the study area are used for an estimation of flood volume reduction due to NBS in a new, hypothetical catchment area with a different area distribution as provided in Table 1 (right column). Additionally, for the new catchment area information is required on the amount of green space available for swales and the extent of roof area that can be converted into retention roofs. Table 2 summarizes these data and results for the new catchment area: With 5 ha of green space available, all roof areas (50 ha) can be connected to swales designed for a 5-year return period. Due to the larger area requirements, only 36.18 ha of roof area can be connected to swales designed for a 100-year return period. For swales designed for a 5-year return period, the 50 ha of connected roof area corresponds to 22.7 % of the total catchment area (220 ha). For swales designed for a 100-year return period, this share is 16.4 %, and for retention roofs, it is 9.1 %.

Using these new relations as input values for the respective effect curve, the reduction in flood volume for the new catchment can be determined (see Figure 2). In this example, the reduction in flood volume is 4.3 % for swales designed for a 5-year return period, 8.8 % for swales designed for a 100-year return period, and 11.7 % for the retention roofs.

Table 2. Area information and results for the new catchment area.

Area information		Roof area that can be connected/converted to NBS		Roof area connected/converted to NBS in relation to the total catchment size	
Available green area	5 ha	Swales 5 a	50 ha	Swales 5 a	22,7 %
		Swales 100 a	36,18 ha	Swales 100 a	16,4 %
Convertible roof area	20 ha	Retention roofs	20 ha	Retention roofs	9,1 %

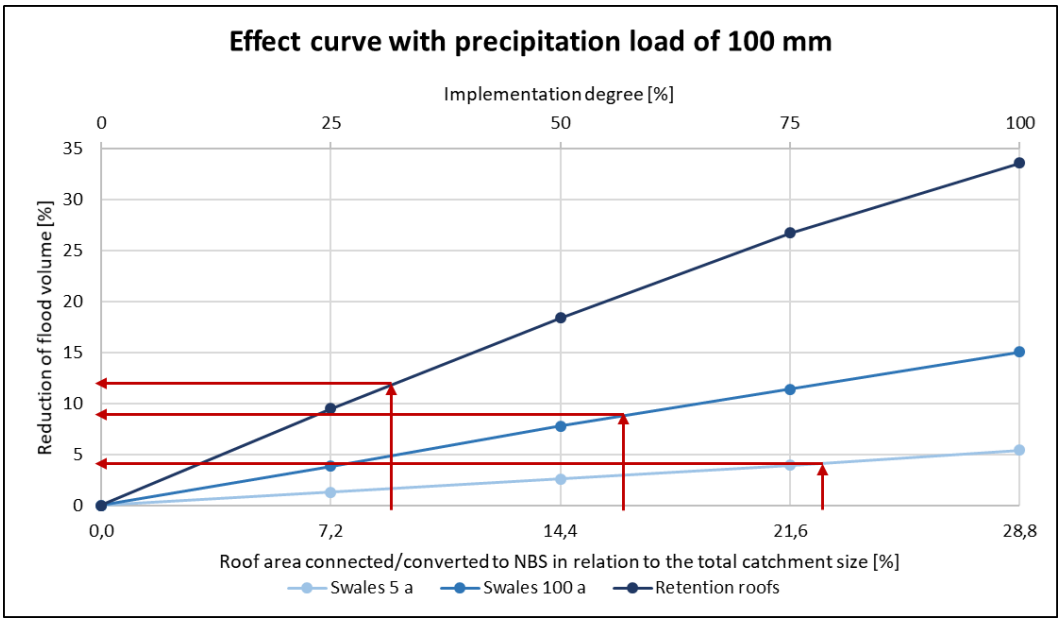


Figure 2. Estimation of the flood reduction for a new catchment area by applying the effect curves of three different NBS.

Validation

To assess the transferability of the results, the effect curves of the study area are compared with those of two validation areas. The validation areas are adjacent to the study area and share a flat topography, but their settlement structures differ. Table 3 presents the area distribution for the study and validation areas. Among the three areas, validation area 2 has the highest proportion of roof area.

Table 3. Area distribution in the study area and the two validation areas.

Areas	Study area		Validation area 1		Validation area 2	
	[ha]	[%]	[ha]	[%]	[ha]	[%]
Total catchment area	339,7	**100**	909,0	**100**	455,9	**100**
Roof area	97,8	**28,8**	209,3	**23,0**	148,7	**32,6**

Figure 3 shows the effect curves for retention roofs under a precipitation load of 100 mm in the study area and the two validation areas. A perfect match of the effect curves would indicate similar flood reduction effects of retention roofs in all considered catchment areas. The effect curves for validation area 2 and the study area are in good agreement whereas validation area 1 shows significantly lower flood reduction effects as in the study area. In this case, the results cannot be reliably transferred. This discrepancy can be explained by a significantly higher susceptibility to flooding in validation area 1 than the other two areas, which reduces the effectiveness of retention roofs.

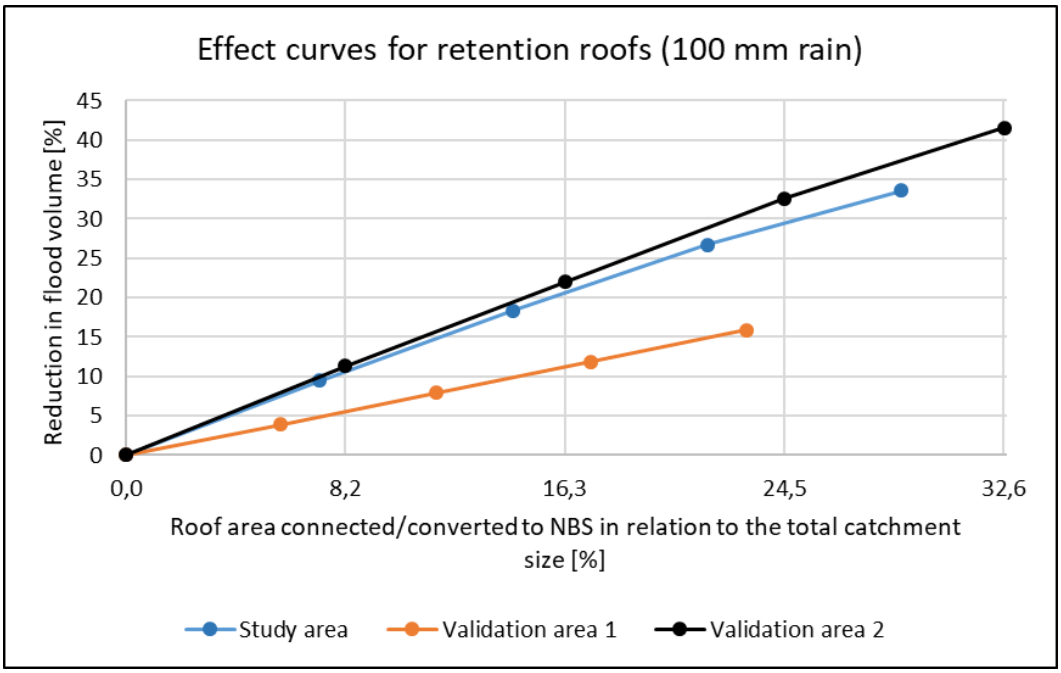


Figure 3. Effect curves for retention roofs under a precipitation load of 100 mm in the study area (blue), validation area 1 (orange) and validation area 2 (black).

Conclusion and future work

The effect curves allow an initial estimation of the effect of NBS for flood mitigation in new catchment areas. Furthermore, the relative comparison of the effectiveness of different NBS is valid regardless of the catchment area. However, the use of the effect curves is limited to a preliminary estimation: Due to the varying characteristics of catchments, a direct transfer of NBS effects on flood mitigation is challenging and subject of further investigations, e.g. 1D/2D simulations for a detailed quantification of the NBS performance are required. Further analyses are planned to account for the diverse characteristics of catchment areas, aiming to enhance the transferability of NBS effects on flood mitigation.

Acknowledgement

This work was carried out as part of the AMAREX research project (https://amarex-projekt.de/en), which is funded by the German Federal Ministry of Education and Research under the funding code 02WEE1624 as part of the WaX (Water Extreme Events) funding programme. The authors would like to express their sincere thanks for this project funding.

References

IPCC, 2023: Sections. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assess-ment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 35-115, https://doi.org/10.59327/IPCC/AR6-9789291691647.

Neumann, J.; Scheid, C.; Dittmer, 2024: U. Potential of Decentral Nature-Based Solutions for Mitigation of Pluvial Floods in Urban Areas—A Simulation Study Based on 1D/2D Coupled Modeling. Water, 16, 811. https://doi.org/10.3390/w16060811.

13th Urban Drainage Modelling Conference, Innsbruck (Austria), September 2025

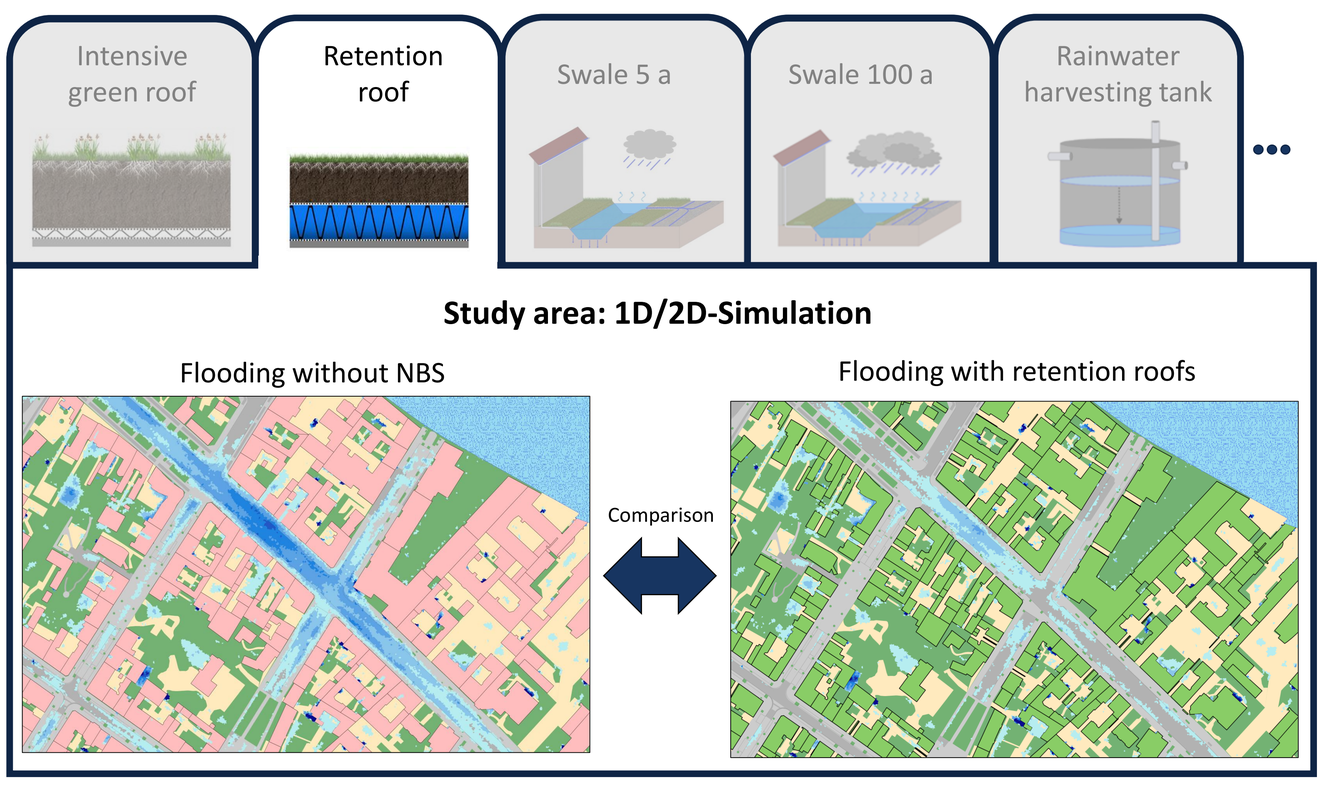
Quantification and transferability of decentralised Nature-based Solutions' effects for pluvial flood mitigation

Jonas Neumann, Christian Scheid und Ulrich Dittmer

Institute Water Infrastructure Ressources, Department of Urban Water Management, University of Kaiserslautern-Landau (RPTU), Paul-Ehrlich-Str. 14, 67663 Kaiserslautern, Germany

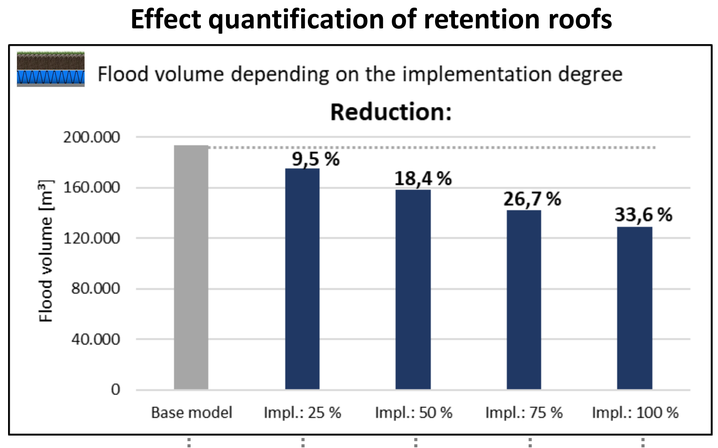
Problem Statement and Objective

- Climate change is causing more frequent heavy rainfall events, with inner-city areas particularly affected by an increasing risk of flooding
- **Nature Based Solutions (NBS)** like swales and green roofs can contribute to flood protection
- However, quantifying the flood reducing effect of NBS with a model is complex and requires a solid (geo)data basis
- **Objective:** To present a methodology for deriving effect curves based on detailed NBS quantification in a study area, transferring them to other catchments to estimate their impacts and validating the results



Data basis and modelling

- Detailed simulation results regarding flood mitigation effects of **14 types of NBS** in a study area
- Evaulated NBS: Infiltration systems, green roofs and rainwater harversting tanks; the **roof areas** (97,8 ha) are managed by the NBS
- 1D/2D-Simulation, modelling of the NBS with the SWMM LID approach



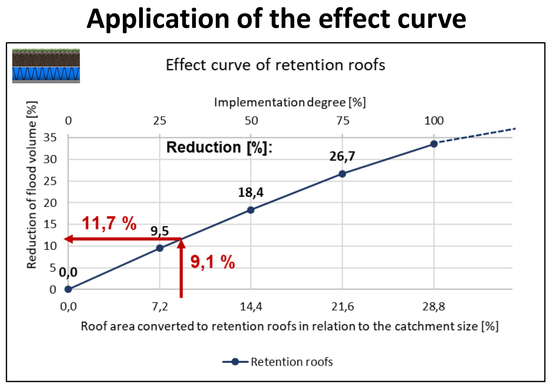
Effect curves

Derivation of the effect curve :

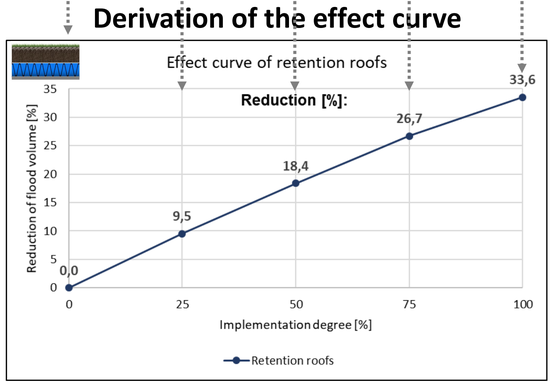
- Flood reduction due to retention roofs depending on the implementation degree

Application of the effect curve:

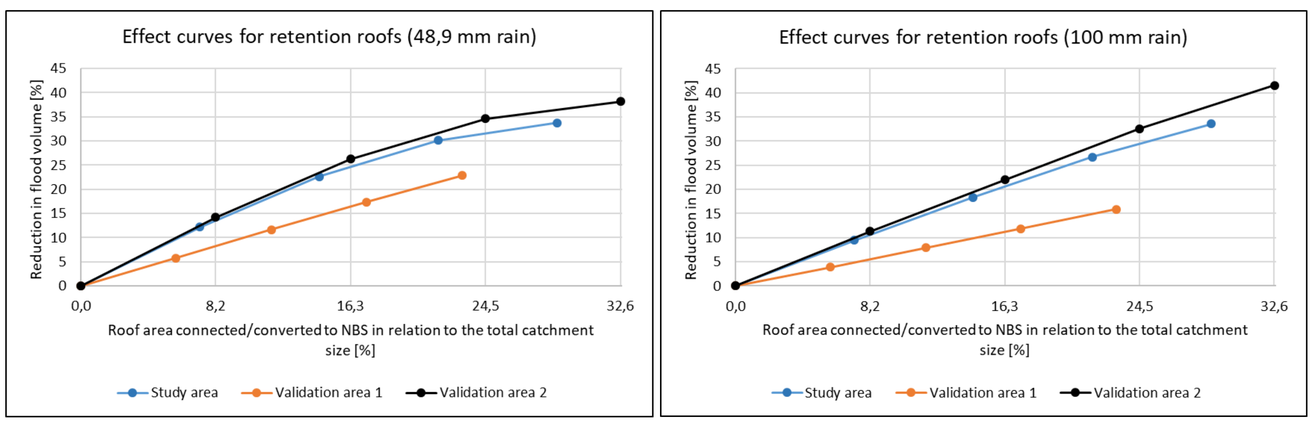
- X-axis: roof area converted to retention roofs relative to the total catchment area → 97,8 ha of retention roofs corresponds to 28,8 % of the total study area (340 ha)
- Transfer to new catchment (220 ha):
  Retention roofs: 20 ha, corresponds to 9,1 % of the catchment size
- Mapping onto the effect curve: Flood reduction of 11,7 %



Transfer to new catchment



Comparison with effect curves of 2 Validation areas



Effect curves for retention roofs under a precipitation load of 48,9 mm (left, T = 100 a) and 100 mm (right) in the study area (blue), validation area 1 (orange) and validation area 2 (black)

Validation of the effect curves

- Effect curves are also generated for two validation areas, following the same approach as in the study area
- **Comparison of the curves:** Agreement between the curves indicates that flood reduction in the validation areas can be reliably assessed using the effect curve from the study area
- **Results:** Mixed picture, transferability is inconsistence, detailed quantification of the flood reduction of NBS for other catchments is not possible with effect curves

➢ **However:** The relative effectiveness of NBS is valid independently of the catchment and can thus support measure prioritization

Contact:

Christian Scheid
christian.scheid@rptu.de
+49 631 205-3826
Paul-Ehrlich-Str. 14, 67663 Kaiserslautern

Department of Urban Water Management
https://bauing.rptu.de/ags/wir/fg-siwawi

This work was produced as part of the AMAREX project:

https://amarex-projekt.de/en

Funding reference number: 02WEE1624

AMAREX

Adapting Stormwater Management to Extreme Weather Events

With funding from the:

Federal Ministry of Research, Technology and Space

WaX Wasser-Extremereignisse

FONA Forschung für Nachhaltigkeit