New estimation models for determining the Q_{347}

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Introduction

In Switzerland, low flows are described by the five percent quantile denoted by Q_{347}. This threshold value not only has consequences for the planning, but also necessitates authorities to adjust the operation of pertinent infrastructure to mitigate ecological impacts on watercourses. In accordance with Swiss federal law (1991), determination of the Q_{347} must be done using the duration curve of a discharge time series spanning at least a ten-year period. Typically, said time series are not available for smaller catchments necessitating the estimation of the threshold value Q_{347}. In Switzerland, the use of multiple linear regression has been established to estimate the area-specific discharge q_{347} (Aschwanden, Kan 1999). However, this regionalization method is associated with significant uncertainties for estimated values (Naef et al. 2015).

Study area and data processing

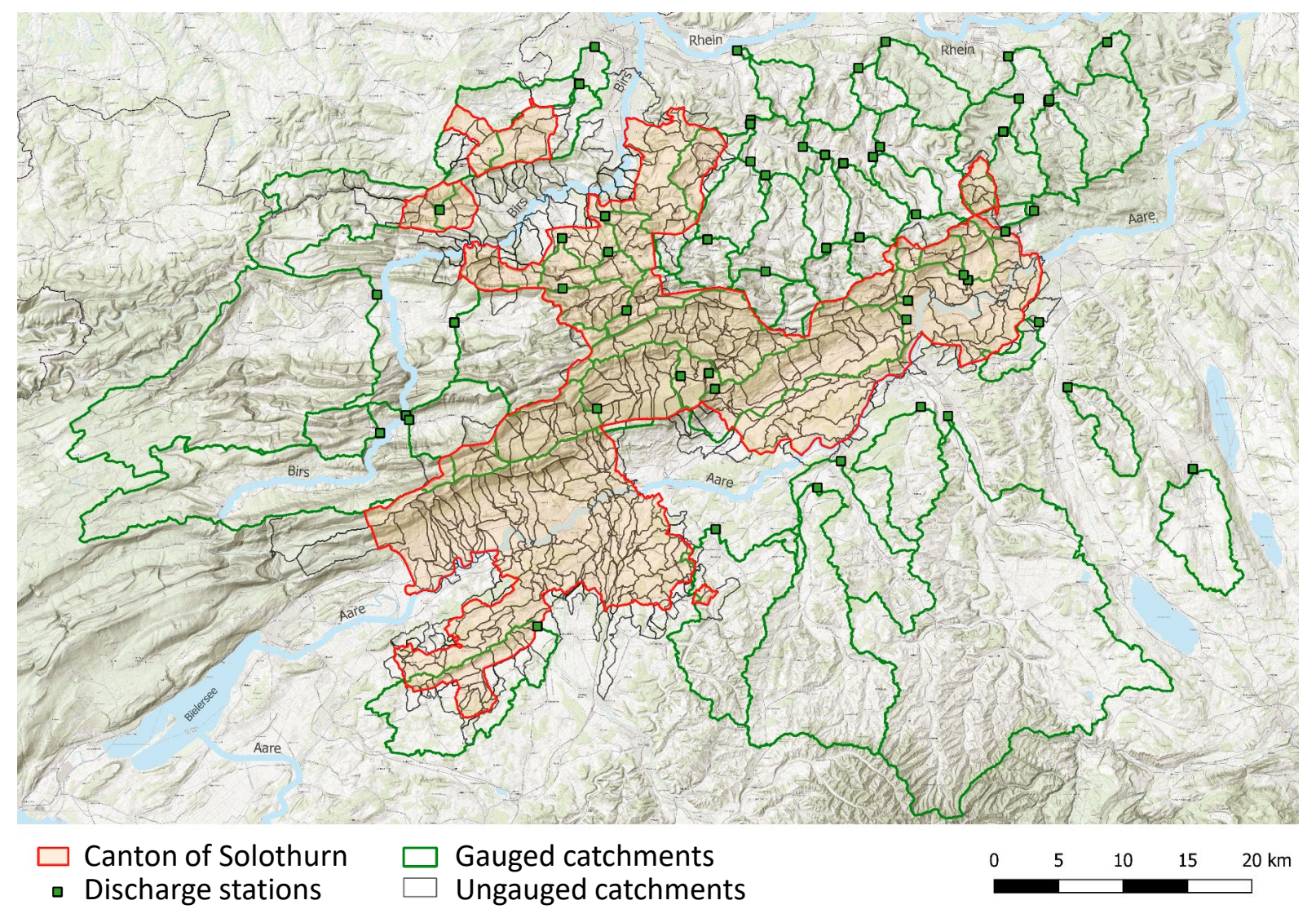

Fig. 1 Study area and discharge stations with gauged and ungauged catchments

The primary objective of these investigations is to estimate the Q_{347} value for 383 ungauged catchments in the Canton of Solothurn, each covering an area less than 100 km². Daily discharge, precipitation and temperature timeseries ranging from 1990 to 2020 were collected from 56 gauged catchments smaller than 500 km² surrounding the target area. 30 «static» parameters describing geometry, topography, geology, land use, and drainage along with nine «climatic» parameters describing temperatures, precipitation distributions, and potential evapotranspiration were defined and computed to characterize gauged and ungauged catchments.

Previous investigations

a) Variability of Q_{347} over the study period and by decades

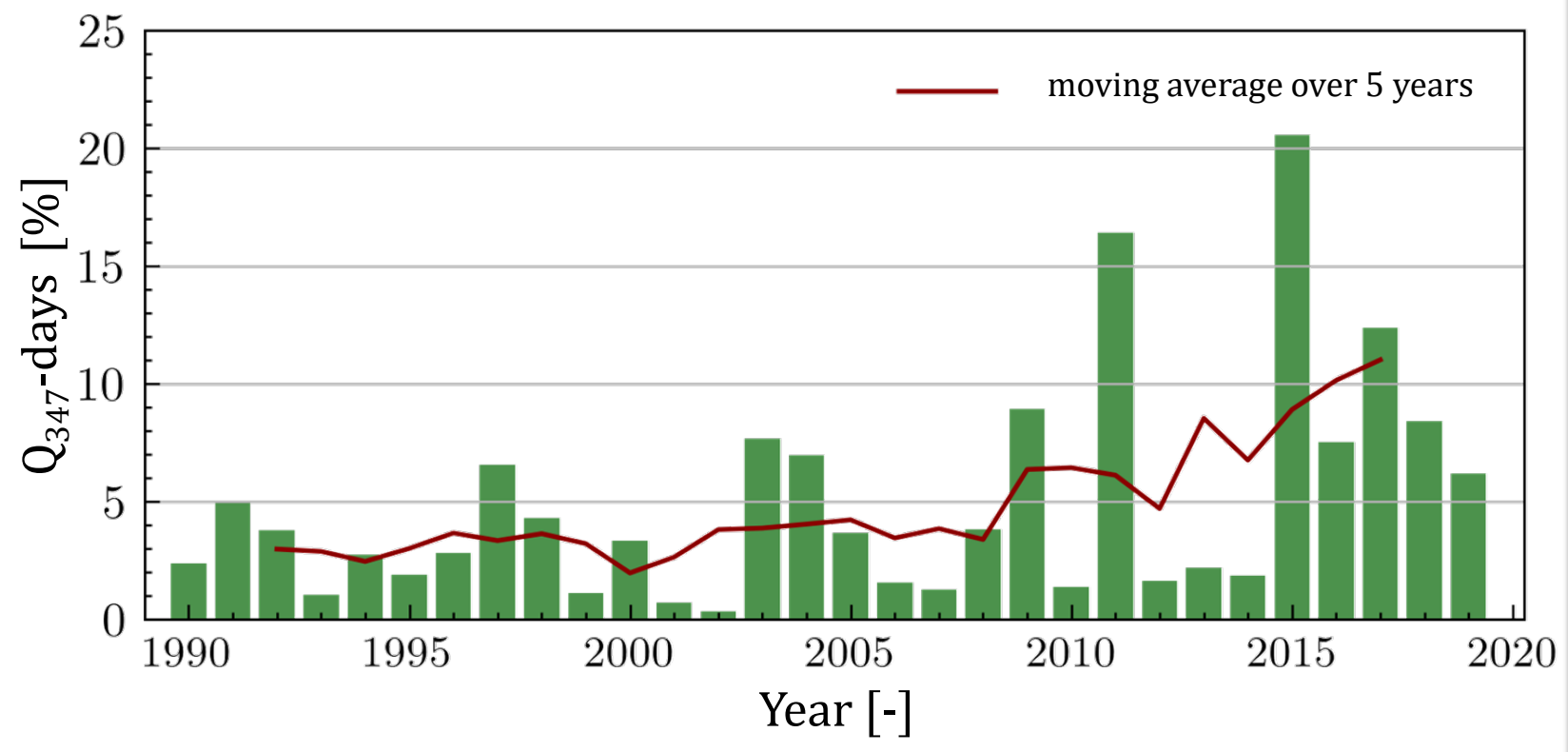

Fig. 2 Percentage distribution of Q_{347} days and 5 year moving average from 1990 to 2019.

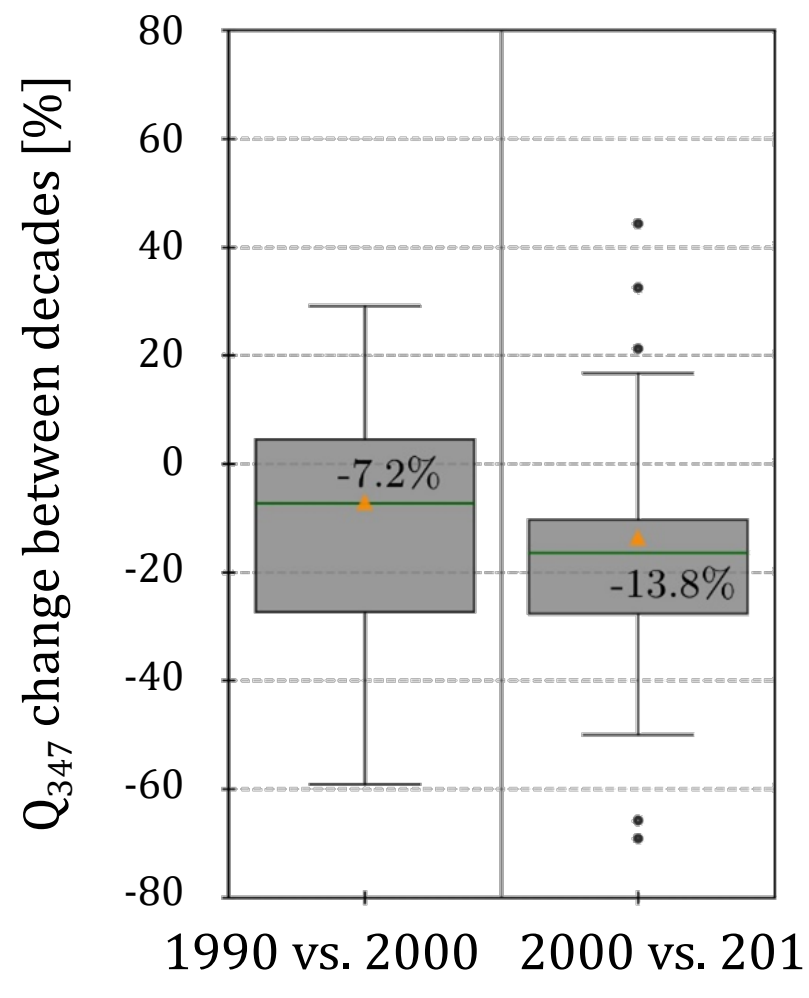

Fig. 3 Q_{347} change between decades

By definition, an average of 5 percent of all days must have Q ≤ Q_{347}. Figure 2 shows the percentage of Q_{347}-days per year with a moving average of 5 years and illustrates a non-uniform distribution with an ascending trend in the frequency of low-flow events. Figure 3 illustrates the relative change in Q_{347} if the value is computed for each decade within the study period: 1990–1999, 2000–2009, and 2010–2019. Comparing the first two decades, Q_{347} is decreased on average by 7.2 %. This negative trend is further intensified for the second two decades between 2000 and 2019: for 89 % of the gauged catchment Q_{347} decreased with an average decrease of -13.8 %.

b) Short discharge time series as source of uncertainty

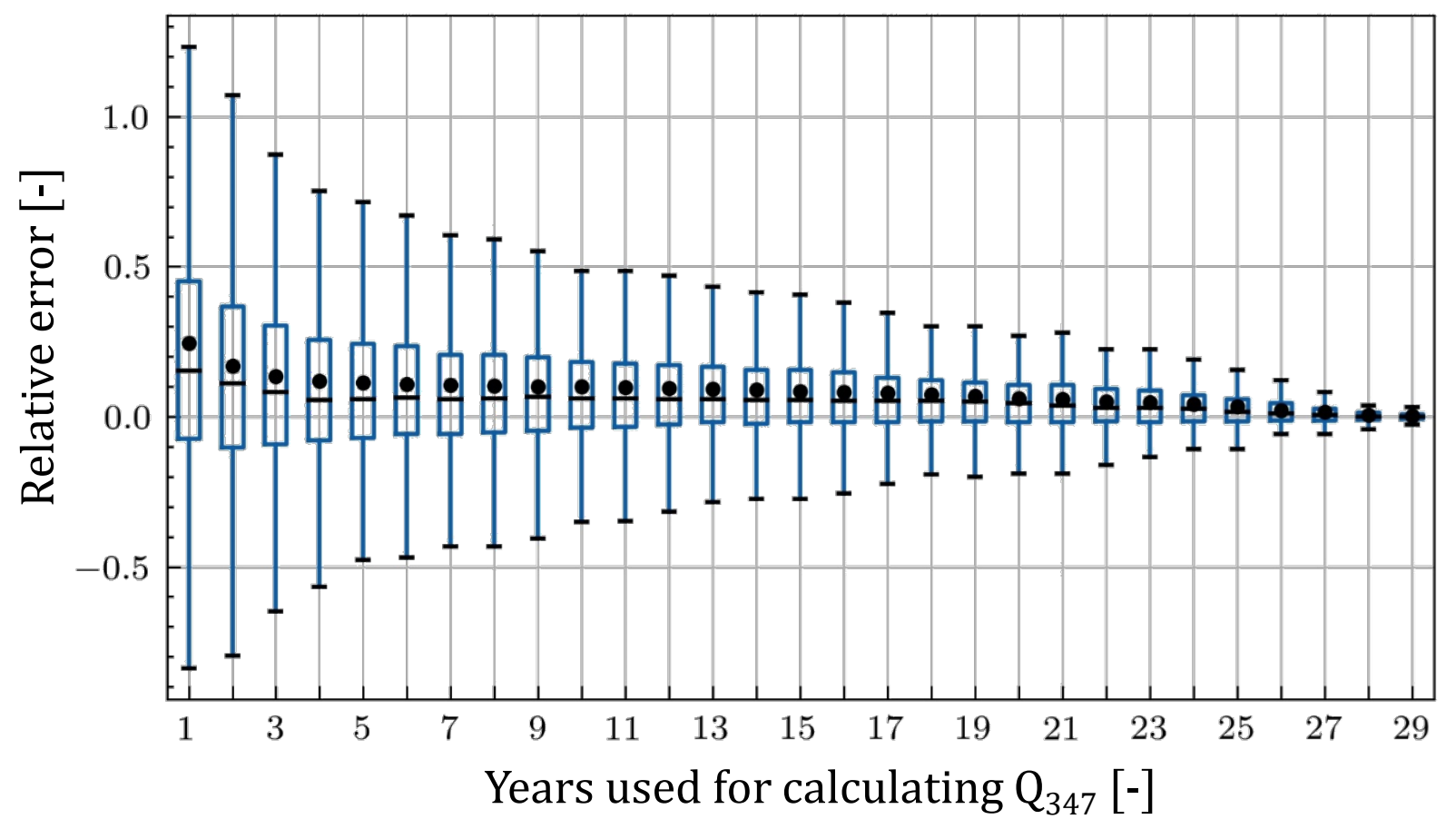

Fig. 4 Relative error in Q_{347} as a function of used data

Figure 4 demonstrates the relative errors resulting from recalculated Q_{347} values after excluding data from randomly selected years within long-term time series. Short time series can be idetified as significant source of uncertainty in estimating Q_{347}

Regression models for estimating Q_{347}

a) Regression models

Three regression models (M1 – M3), in combination with two methods (API, HEZG) for adjusting shortened time series (plus no adjustment), are proposed and compared with two reference models (BAFU and 123).

M1 «Strong linear regression»: More robust linear regression estimates can be achieved by simulating the linear regression, considering the variability of the observations (Pavia, 2022). The following steps are taken:

1. Fit linear model with 7 «best» parameters from «backward elimination»
2. Calculate residuals and take n of them $r_i = y_i - \hat{y}_i$
3. Form Ensemble $\{\hat{y}_1, \hat{y}_2, ...\hat{y}_n\}$, $\hat{y}_i = \beta_0 + \beta_1 \cdot x + r_i$
4. Aggregate ensemble by mean $\hat{y} = \frac{1}{n}\sum_{i=0}^{n} \hat{y}_i$

M2 «Adopt model from gauged downstream catchment»: A linear regression model is fitted for each discharge station to estimate upstream ungauged catchments. Therefore, the station is omitted to find the seven «best» parameters per station applying «backward elimination» with minimization of the leave-one-out cross-validation error. M2 consists of 56 models, each associated with one discharge station plus one model that covers the entire study area to estimate ungauged catchments not having a gauged downstream station.

M3 «Clustering of catchments»: Similar catchments are identified based on their characteristics using the Random Forest method (Tyralis, 2019). Catchments are then divided into three clusters with a regression model considering the «best» parameters being fitted for each of them. Ungauged catchments are assigned to one of the three clusters and estimated with the corresponding model.

b) Temporal adjustment of short discharge time series

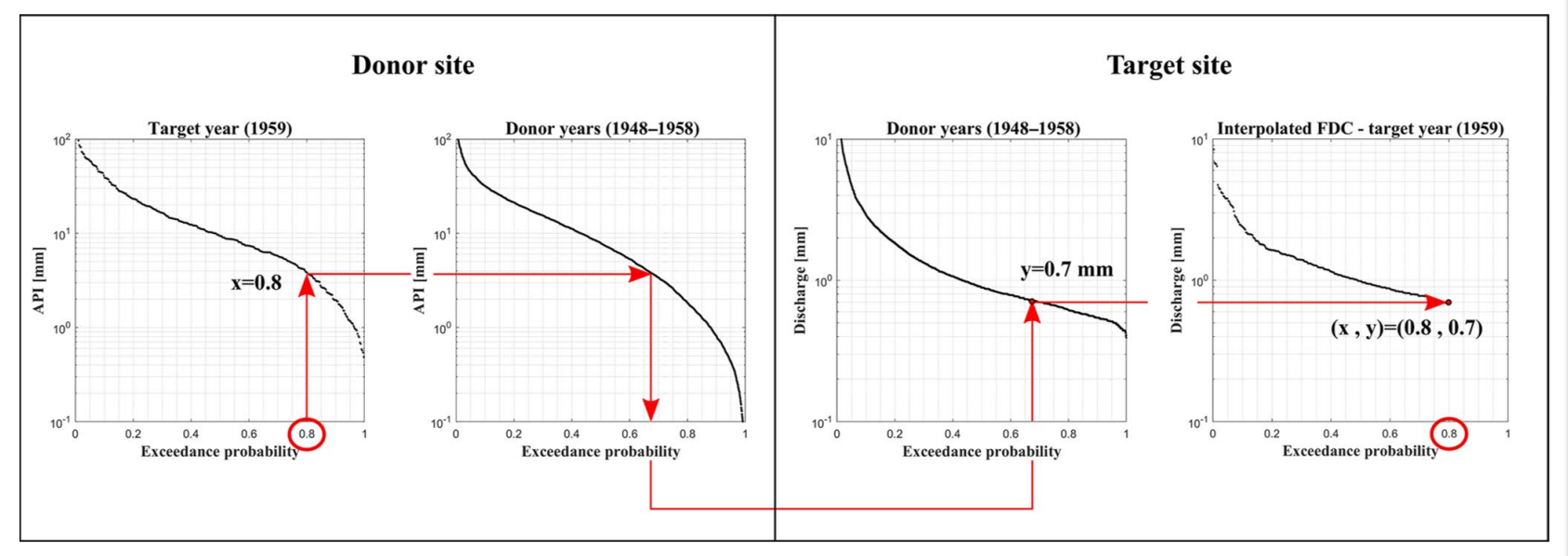

Fig. 5 Systematics of adjustment using API by the example of the 80th percentile (Ridolfi et al., 2020)

API: The method (Ridolfi et al., 2020) extends the flow duration curve for missing years by using the corresponding exceedance probability of the Antecedent Precipitation Index (API).

HEZG: The closest downstream discharge station (HEZG) is used to correct the Q_{347} (Laaha & Blöschl, 2007) of the catchment with a short time series using (1) .

$$QT_{pred} = QT_O \left(\frac{QD}{QD_O}\right) \quad (1)$$

where:

QT_{pred} Q_{347} for target catchment in target periode

QT_O : Q_{347} for target catchment in overlapping periode

QD_O : Q_{347} for donor catchment in overlapping periode

QD : Q_{347} for donor catchment in target periode

c) Validation and regionalization

The proposed models were validated against the 56 gauged catchments and evaluated using three metrics: the linear correlation coefficient (Cor.), the mean error (ME), and the mean absolute percentage error (MAPE).

		New models									Reference models	
Model		M1			M2			M3			BAFU	1-2-3
Adjustment		No	API	HEZG	No	API	HEZG	No	API	HEZG		
Metrics:												
Cor.	[-]	**0.77**	**0.73**	-0.24	0.61	**0.65**	-0.29	0.46	0.37	-0.13	0.16	-0.27
ME	[L/s·km²]	**0.03**	0.08	12.5	-0.06	**-0.02**	12.52	**-0.03**	0.3	5.83	-0.23	-0.75
MAPE	[%]	**45**	**47**	858	59	58	1045	**55**	62	416	109	58

Table 1 Results of the validation on the gauged catchments (best three per metric are in bold)

For 383 ungauged catchments in the study area, the Q_{347} values were estimated using all three models in combination with the adjustment methods. The spatial distribution of the estimated Q_{347} values is shown in figure 6.

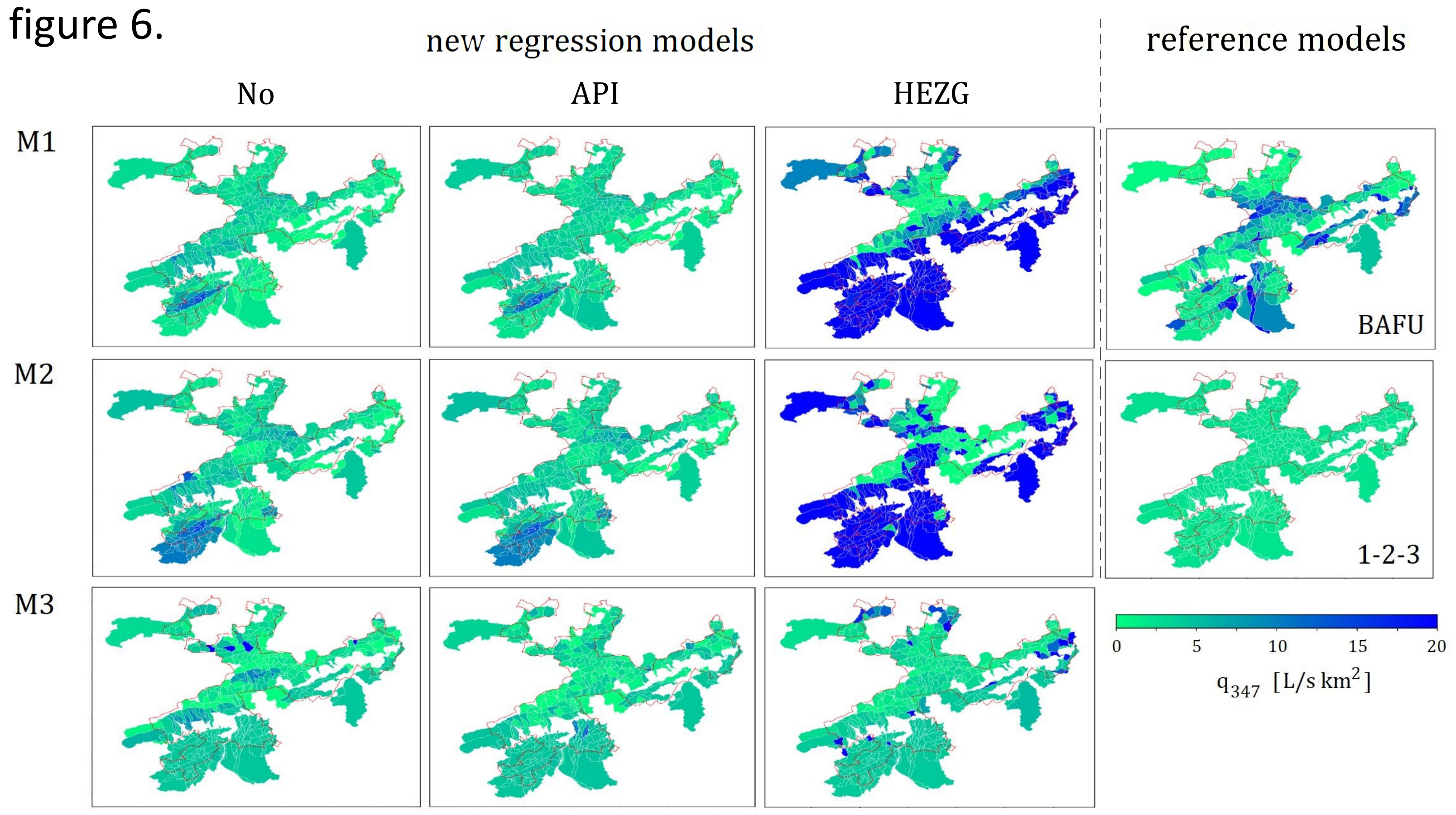

Fig. 6 Spatial representation of estimated Q_{347} values for 389 ungauged catchments applying nine proposed models and two reference models.

Conclusions

- The frequency of low flow events below Q_{347} increased while the 10-year Q_{347} value of said catchments decreased over the last 30 years
- M1, M2, and M3 in combination with none or API adjustment for short time series improve the estimation of Q_{347}
- Temporal adjustment using HEZG leads to large overestimations

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