The role of seasonal recharge and storage concepts for low flow modelling

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1. Motivation

Despite the variety of existing hydrological models, low flow prediction is still challenging. Traditionally low flow is predicted by a function of subsurface storage depletion. Thus, model structures are assumed to incorporate different storages, namely aquifer types and their characteristics. Most often operational low flow prediction is based on a single storage-outflow model, whose parameters are calibrated regardless of what might be known about the catchments' geology and aquifer composition. We argue that linking model structures to the characteristic compositions of aquifer types in a catchment will improve low flow prediction.

2. Objectives

- To systematically evaluate structural differences of storage-outflow models which simulate baseflow as a proxy for low flow.
- To relate these model structural differences to geology and catchments' aquifer compositions.

3. Methods

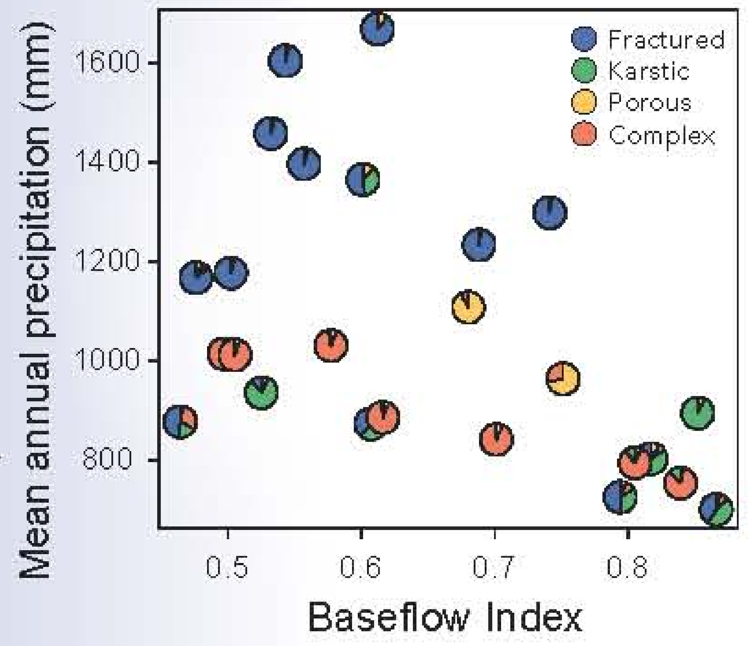
Nine different storage concepts were implemented into a model framework. All model structures were applied to 25 catchments.
Input: daily groundwater recharge rates that served as input to these structures were obtained by a physically-based and regionally established spatially distributed SWAT model (TRAIN-GWN).
Application: models were calibrated to baseflow as a proxy for low flow. Baseflow was separated from daily discharge series by a hydrograph separation procedure (see References).

4. Study catchments and aquifer types

25 meso-scale catchments (between 26 km^2 and 954 km^2) in the state of Baden-Württemberg in Germany represent a wide range of hydrogeological characteristics and are classifiable by four different aquifer types (fractured, karstic, porous and complex) and a fifth "mixed"-type, which is a combination of the latter four. The hydrological regimes are mostly dominated by rain with some influence of snow resulting in a peak in spring and typically low flows in summer. Streamflow in all catchments covers the period from 1971 to 2009, and is near-natural with no known influence by dams, withdrawals or return flow.

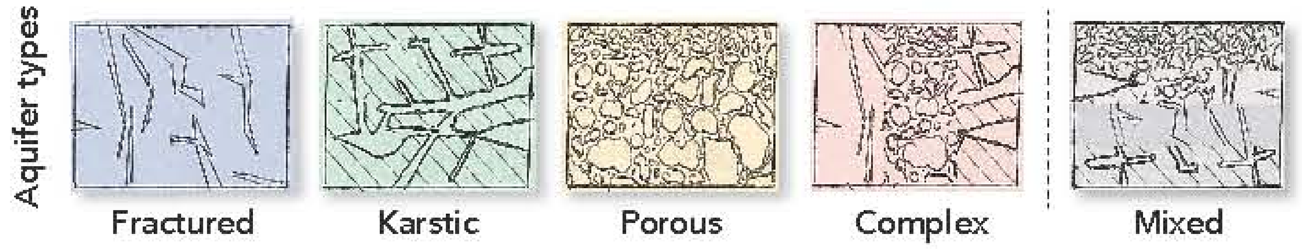
5. Baseflow response to climate

- Catchments with comparable precipitation amount and/or aquifer composition have different baseflow indices
- Low flow is not solely driven by climate



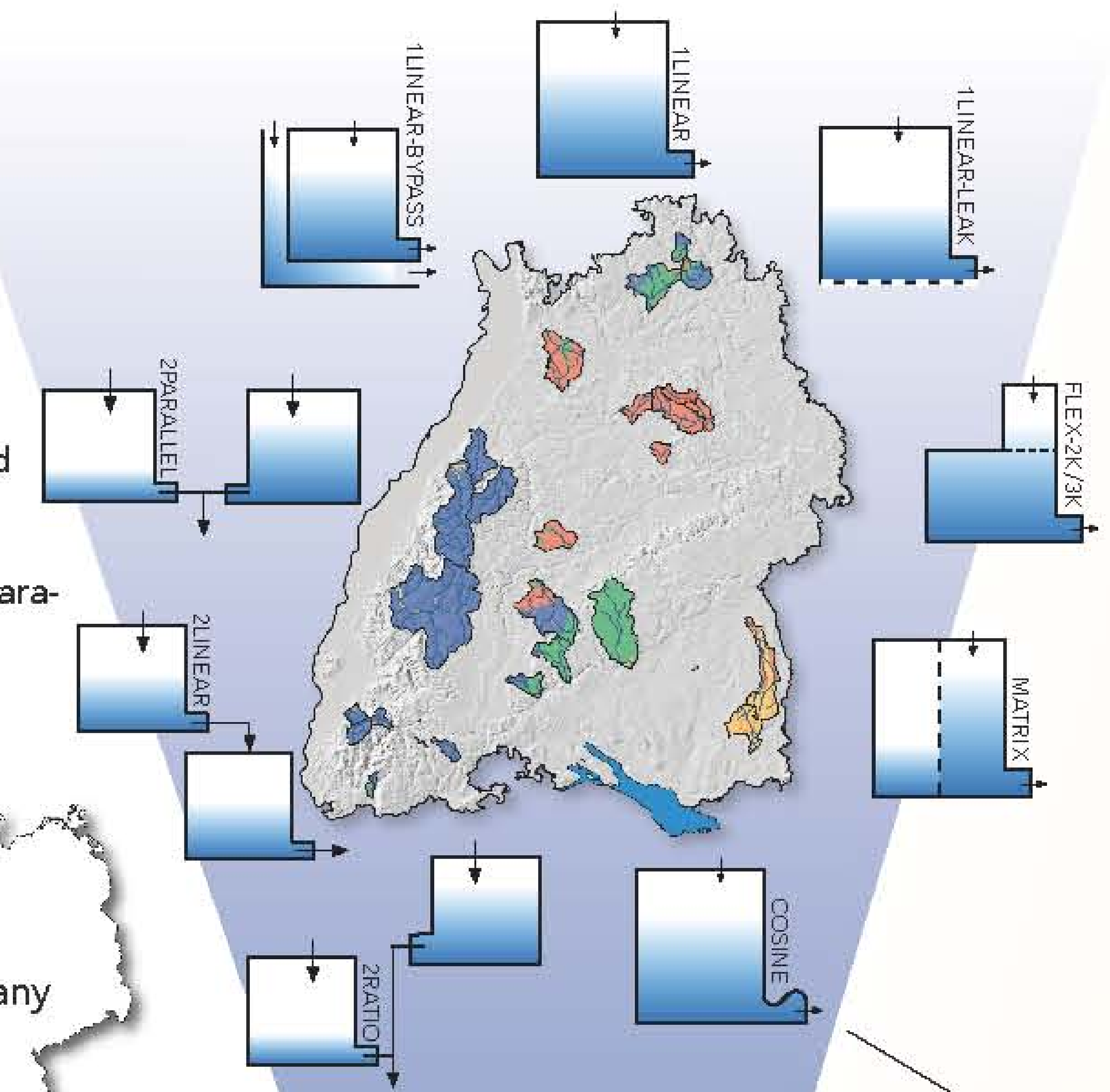
From recharge to baseflow

Model input: Groundwater recharge



9 conceptual storage-outflow models each with *only* 2 parameters

Parameter 1: storage coefficient K_1
Parameter 2: storage coefficient K_2 or shape/function

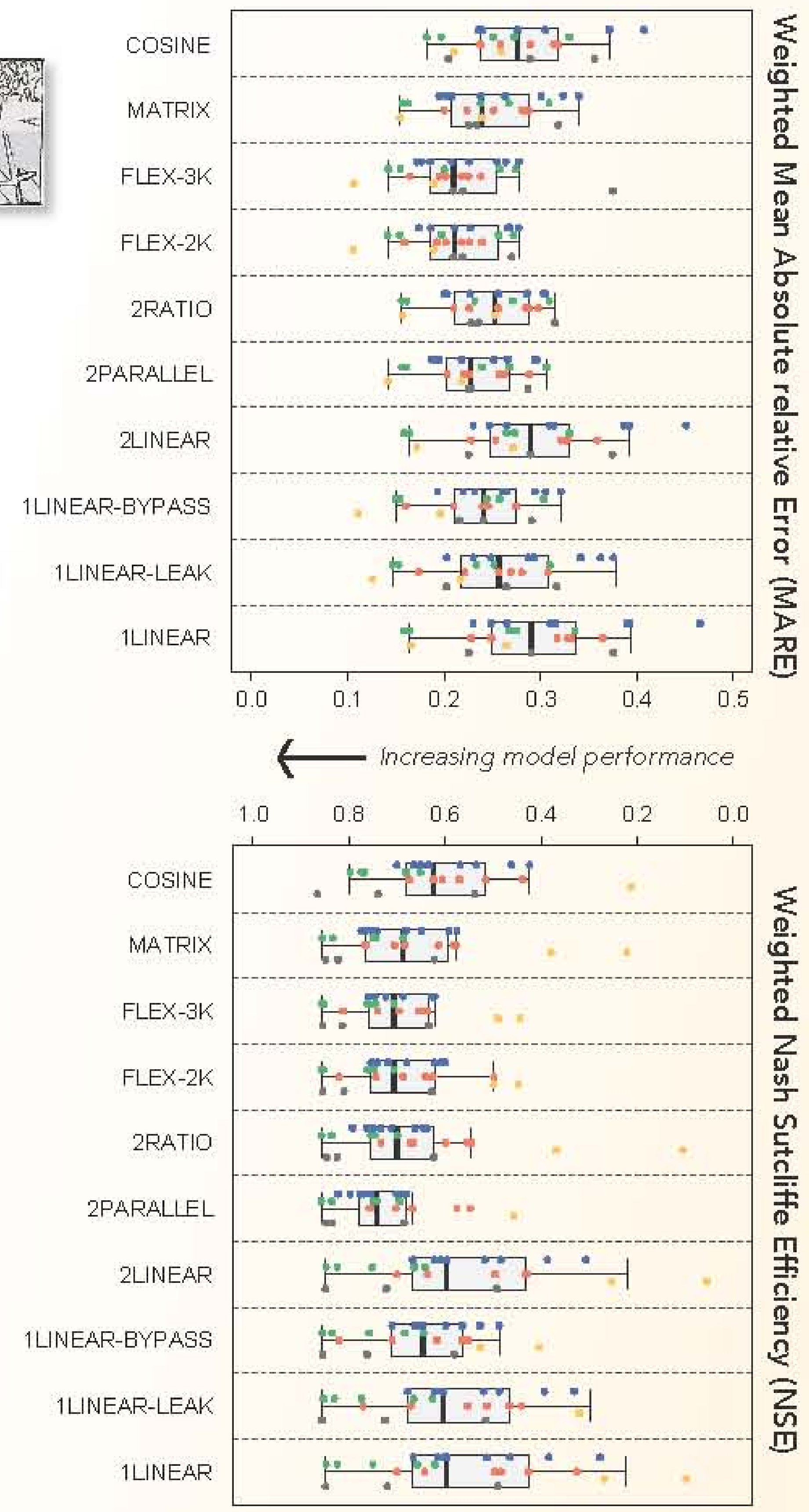


Model output:
Storage-outflow is fitted to baseflow by the means of two weighted objective functions

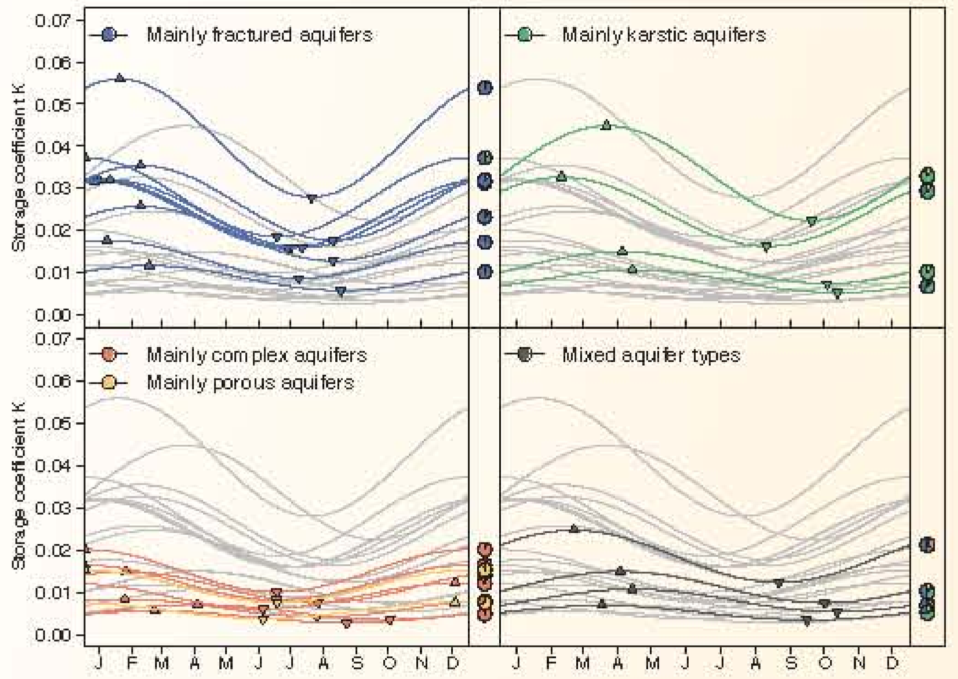
1. Logarithmic Nash-Sutcliffe-Efficiency (NSE)
2. Mean Avarage Relative Error (MARE)

Weight w is calculated as the quotient of baseflow and discharge. First two years are used for model spin-up and time steps with missing discharge values (NA) are also non weighted (w=0).

Models' performance

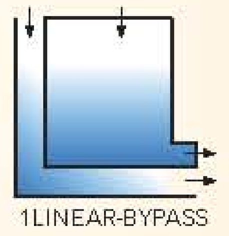


Seasonality of storage coefficients

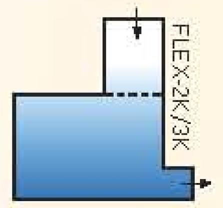


Storage concepts & aquifer compostion

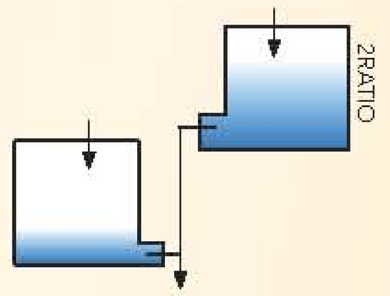
4 exemplary best model runs (MARE):

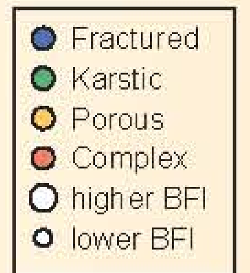


- Fractured aquifers (as prime example for storage bypass) can be classified as more quickly responding or „flashy" catchments
- Porous and karstic aquifers with higher BFI's have a smaller „bypass"- proportion

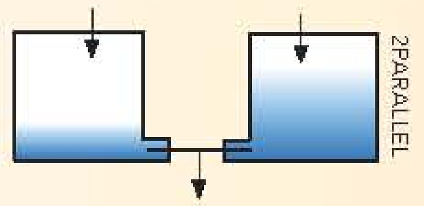


- The „flexible" storage concept indicated that for many catchments a „faster" storage depeltion can be assumend above 100-150 mm dynamic storage volume
- Larger thresholds are correlated with smalller storage coefficients

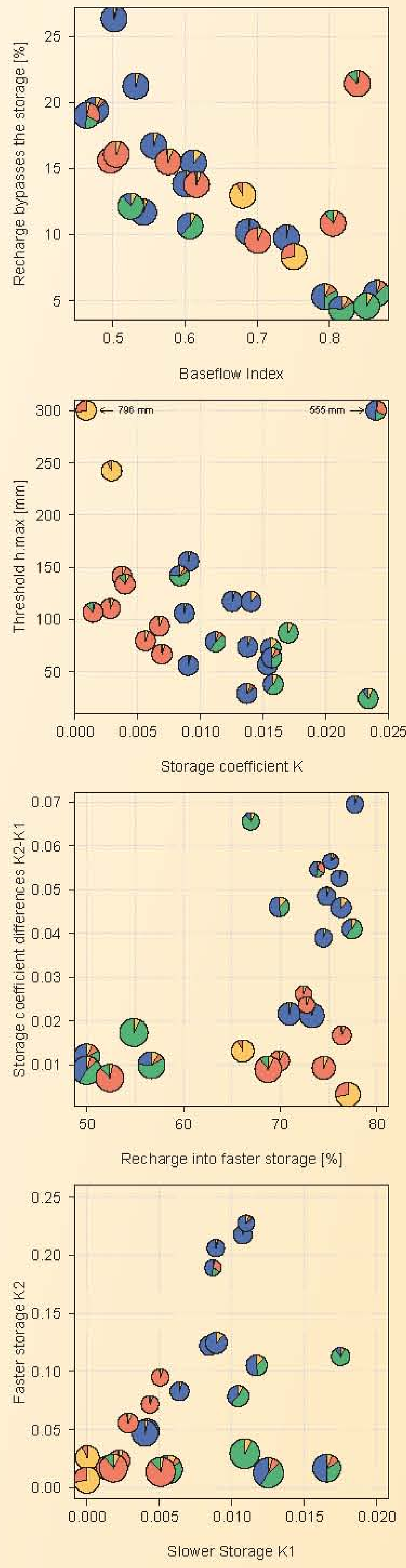




- Storage coefficents K_1 and K_2 depend directly on the particular received recharge rate (<50% and >50%)
- Fractured and complex aquifers show both high recharge rates into the „faster" storage
- Fractured aquifers lead to larger differences between both storage coefficients



- This concept helps to separate slower and faster storages for different aquifer types
- Mainly fractured catchments are assumed to have one „faster" storage
- Lower BFI values (smaller symbols) are more correlated with distinguishable storage types (fast/slow)



Evaluation of storage concepts

The storage concepts are evaluated by relating NSE and MARE values for each catchment to performance ranks (1=best model, 9=poorest model). With this rank-matrix mean ranks for different aquifer types are calculated (with MARE).
For example, for 8 mainly fractured catchments (blue) the mean rank for the FLEX-3K model is 1.2.

	All catchments NSE	All catchments MARE	Fractured MARE	Karstic MARE	Complex MARE	Porous MARE	Mixed MARE
COSINE	6.4	7.1	7	6.8	8	8	5
MATRIX	3.6	4.5	4.2	5	4.3	5	4.3
FLEX-3K	2.4	1.8	1.2	2	1.1	1	4.7
2RATIO	3.7	4.8	3.4	5	5.7	6	5.3
2PARALLEL	2.8	3.2	1.8	4.6	3.6	4	3.7
2LINEAR	7.4	7.8	7.9	7.2	8.1	8.5	7
1L-BYPASS	4.1	3.2	4.4	3	2.3	2	3.3
1L-LEAK	5.9	4.4	6.2	3.2	4	3	3.7
1LINEAR (1L)	8	8.2	8.9	8.2	7.9	7.5	8

Conclusions

- Structural differences of storage concepts lead to clearly distinguishable storage-outflow characteristics for different aquifer compositions
- Consequently, to improve low flow prediction a storage-outflow model has to incoporate aquifer composition
- Seasonality of storage coefficients depends on aquifer types

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References

Gustard, A. and Demuth, S. (Eds.): Manual on Low-flow Estimation and Prediction, World Meteorological Organization (WMO), Geneva, 2009.
Koffler, D.: lfstat: Calculates Low Flow Statistics for daily stream flow data, R package, CRAN repository, 1–36, 2013.