# Mountain Block X - a novel hydrological model for a distinct seasonal water resources assessment in semi-arid mountain regions

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## 1 Motivation & Objectives

Mountain catchments are the major contributer to the total renewable water yield in (semi-)arid regions. Consequently, a distinct, well adapted assessment is essential for this hydrogeologic setting. Due to generally deep lying groundwater tables, the hydrologic response of a mountain catchment is divided into subsurface flow components and surface runoff in a (losing) channel. Thus, an assessment strategy which targets groundwater recharge is particularly appropriate.

Hydrologic modelling in this setting is subject to limitations, either due to an inadequate process representation (implying the need for a usually lacking empiricial reference) or due to a lack of an adequate data base for largely process based approaches.

Against this background, the proposed hydrological model aims at rainfall based, spatially distributed and seasonal water budget estimates in semi-arid mountain regions with pluvial hydrologic regime. Following the idea of simplicity [2], it aims at considering the main processes and mechanisms and at the same time using a minimal number of model parameters.

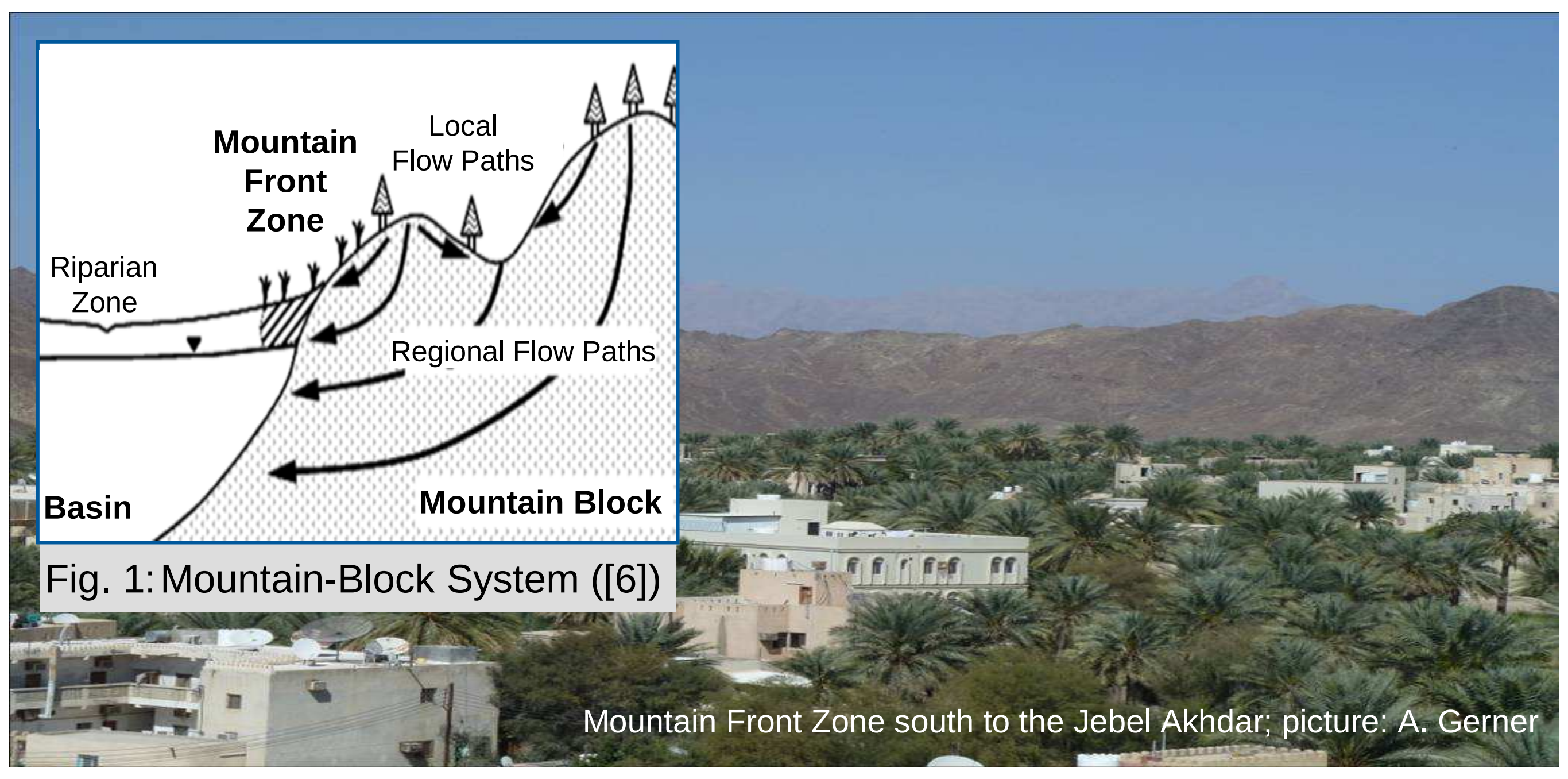


Fig. 1: Mountain-Block System ([6])

Mountain Front Zone south to the Jebel Akhdar; picture: A. Gerner

## 2 Methodology

The approach proposed by [3] follows the subdivision of precipitation based recharge according to Figure 2. Accordingly, Eq. 1 shows the water balance for a rain depth P which has precipitated on a discrete area in a discrete time step ∆t. Total recharge or total sub-surface runoff $Q_R$ is the sum of direct and indirect recharge (see Eq. 2).

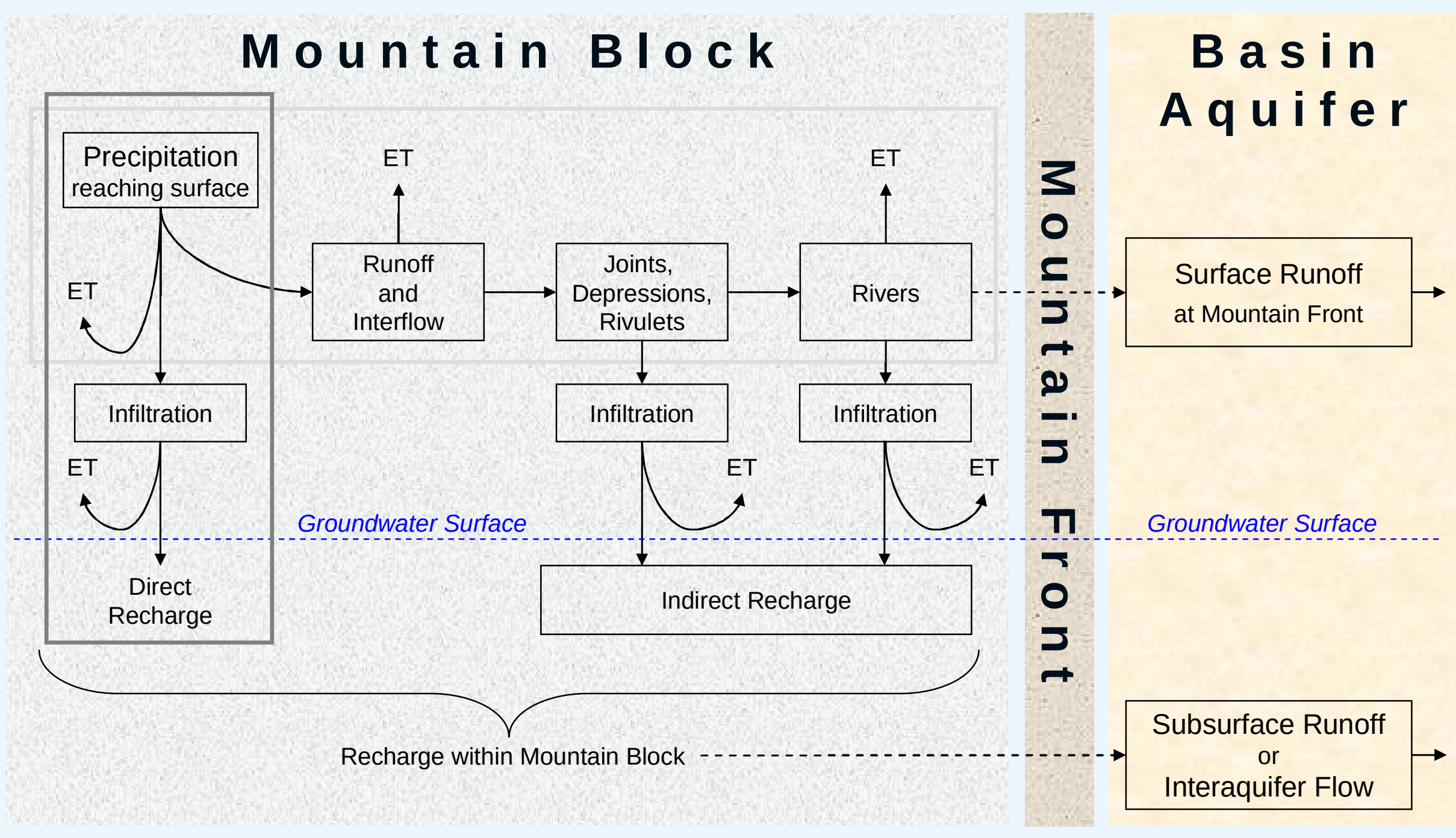


Fig. 2: Subdivision of precipitation based recharge (modified after [4])

$$P = ET_{surface} + SMR + Q_{R,\ direct} + SMR_{alluvium} + Q_{R,\ indirect} + Q_{surface} \qquad \text{(Eq. 1)}$$

where
$P$ = rainfall
$ET_{surface}$ = surface wetting loss
$SMR$ = soil moisture replenishment
$Q_{R,\ direct}$ = direct recharge
$SMR_{alluvium}$ = soil moisture replenishment in alluvial valleys
$Q_{R,\ indirect}$ = indirect recharge
$Q_{surface}$ = surface runoff at Mountain Front

$$Q_R = Q_{R,\ direct} + Q_{R,\ indirect} \qquad \text{(Eq. 2)}$$

### Main Simplification

A mean seasonal soil moisture status is assumed instead of a demanding and yet uncertain continuous soil moisture accounting.

### Seasonality and Spatial Distribution

- Parameterisation according to
  - **seasons**, i.e. selected calendar months with similar characteristics regarding rainfall and soil moisture status
  - **response units** (RUs) according to geomorphology
- Gridded rainfall and preferably monthly time step

### Implementation

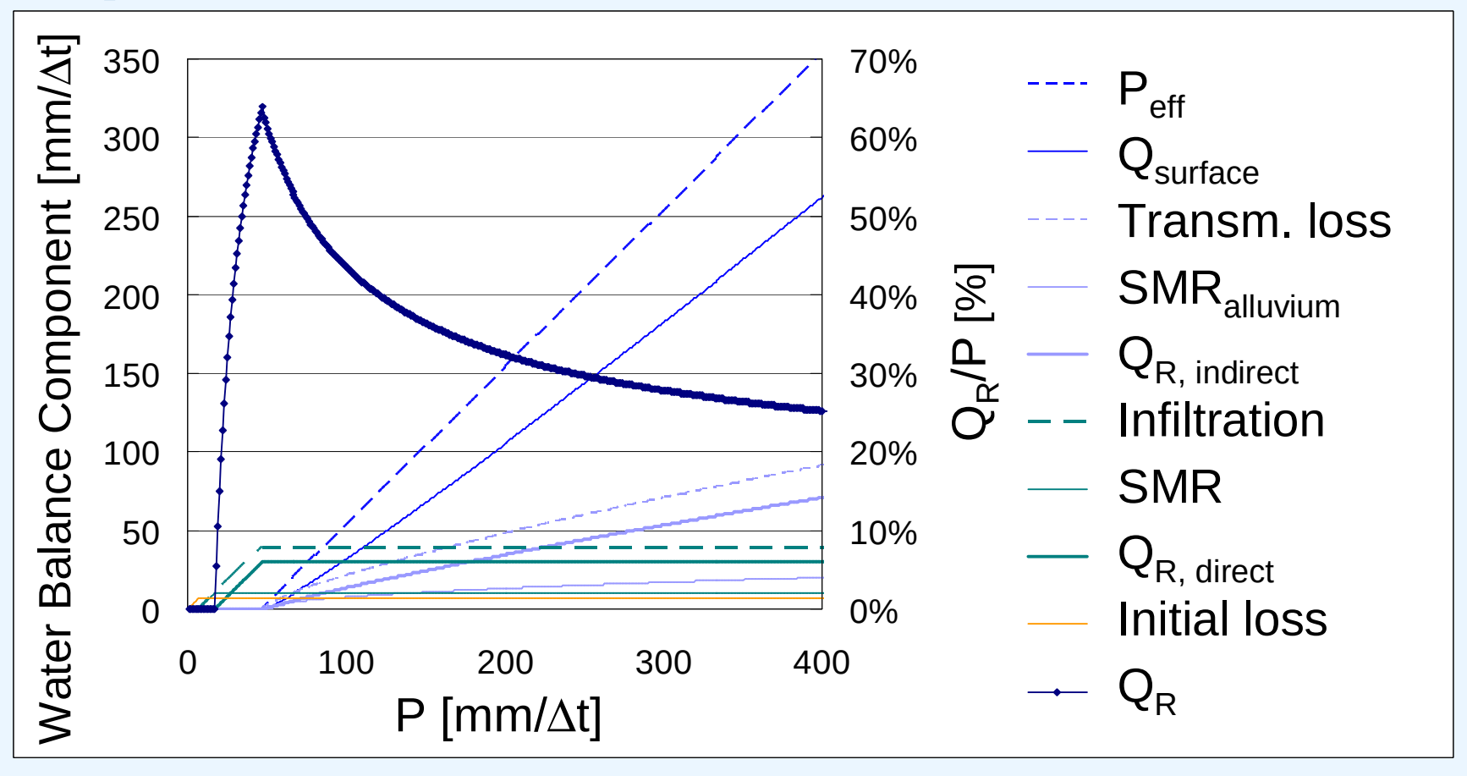
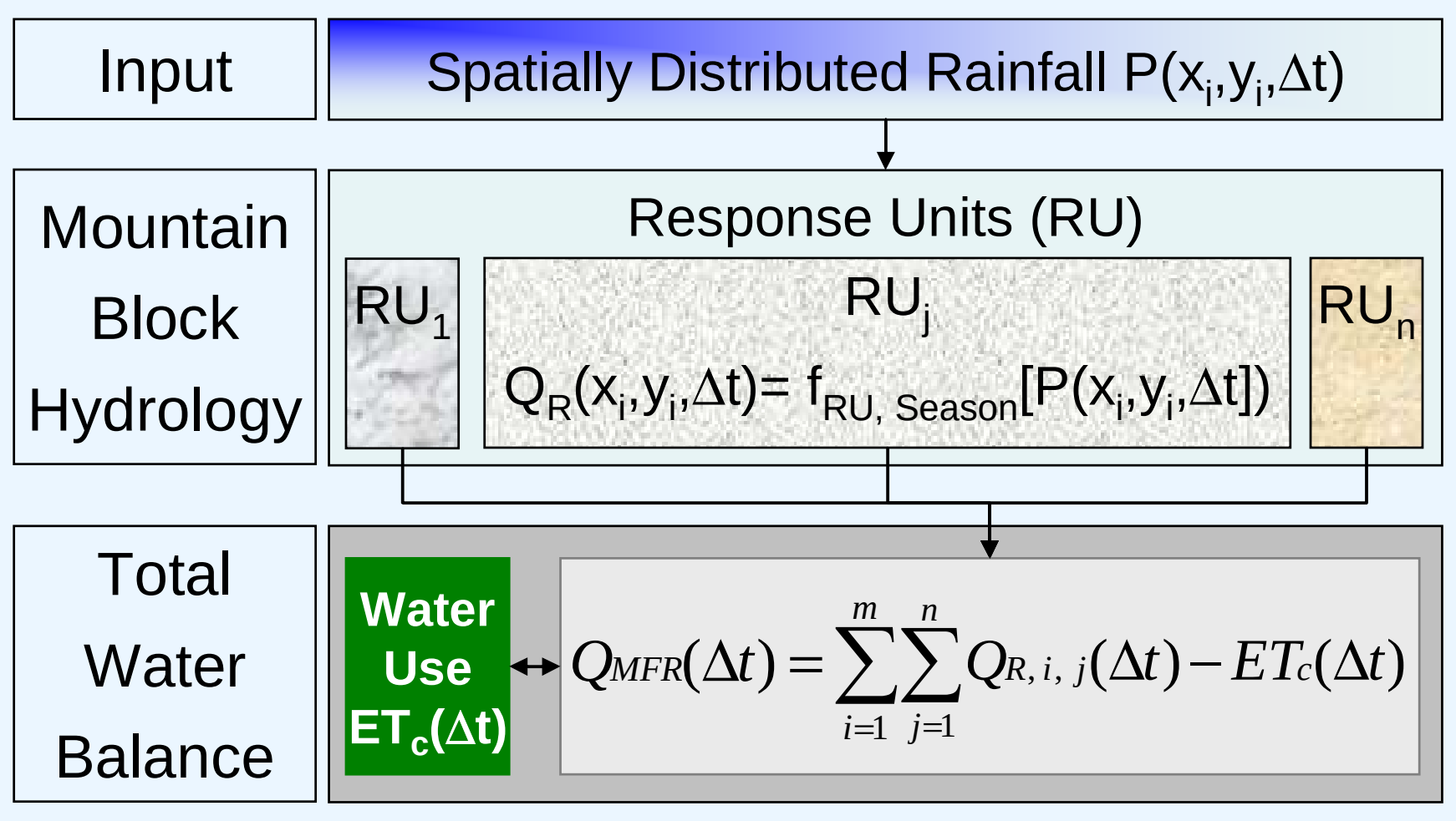


Fig. 3: Response functions according to Eq. 1 for a single parameter set



Input: Spatially Distributed Rainfall $P(x_i,y_i,\Delta t)$

Mountain Block Hydrology: Response Units (RU)
$RU_1$
$RU_j$: $Q_R(x_i,y_i,\Delta t) = f_{RU,\ Season}[P(x_i,y_i,\Delta t)]$
$RU_n$

Total Water Balance: Water Use $ET_c(\Delta t)$ ↔

$$Q_{MFR}(\Delta t) = \sum_{i=1}^{m}\sum_{j=1}^{n} Q_{R,\ i,\ j}(\Delta t) - ET_c(\Delta t)$$

Fig. 4: Accounting Scheme

## 3 Exemplary Application to parts of the Jebel Akhdar Mountains (Sultanate of Oman)

### Study area

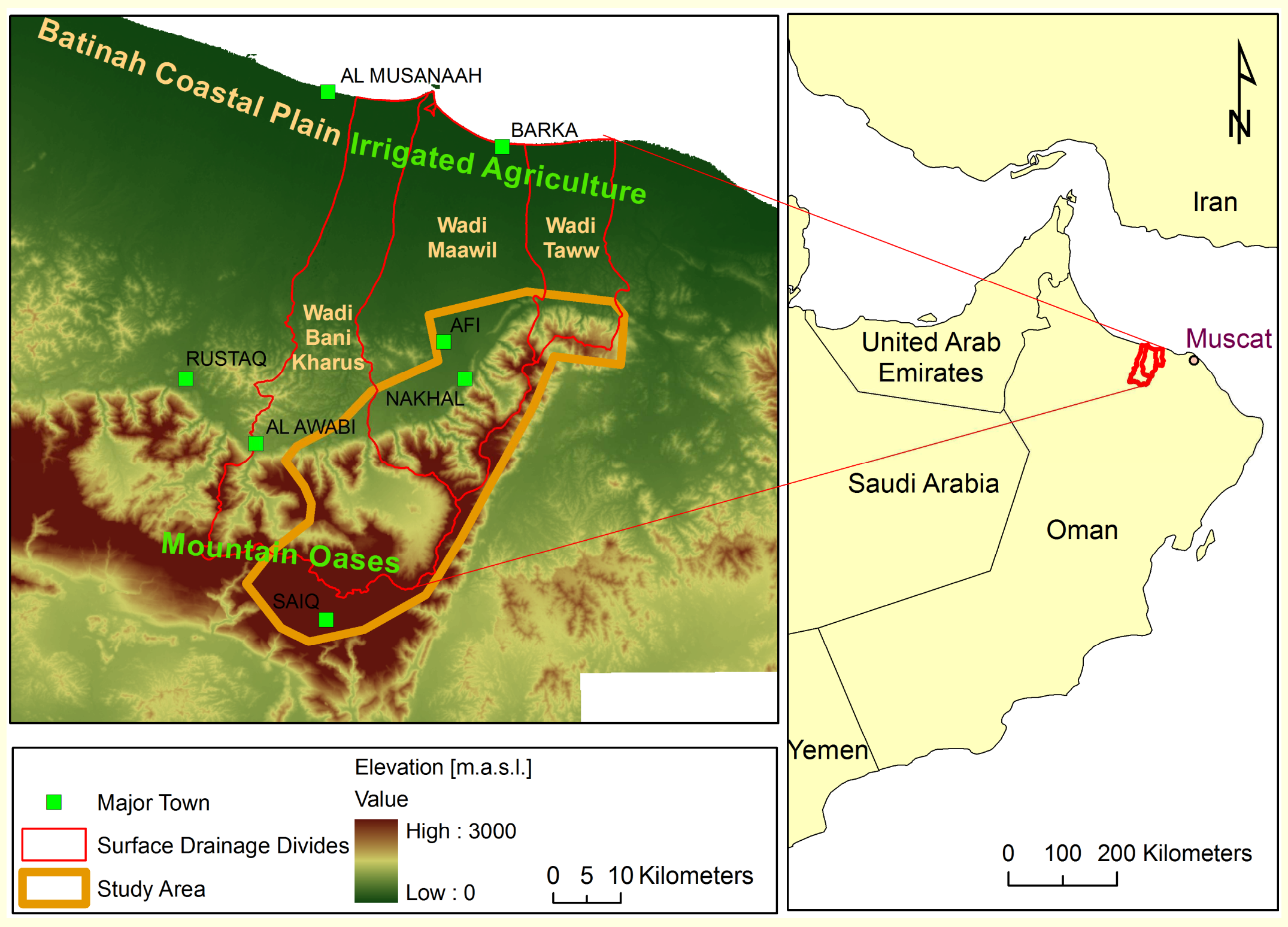


Fig. 5: The Study Area

- The water yield of the Jebel Akhdar Mountains is crucial to the irrigated agriculture on the Batinah coastal plain
- Considered catchment area: about 1300 km²
- Elevation ranges from 200 to > 2000 m a.s.l
- Average rainfall around 160 mm/a (whole area) and above 300 mm/a (high altitudes); particular years with > 600 mm/a
- Lithology: predominantly karstified carbonates
- Water use in mountain oases
- Available long-term average reference values based on inverse groundwater modelling ([5]) and regionalisation approach APLIS ([1])

### Rainfall Characteristics

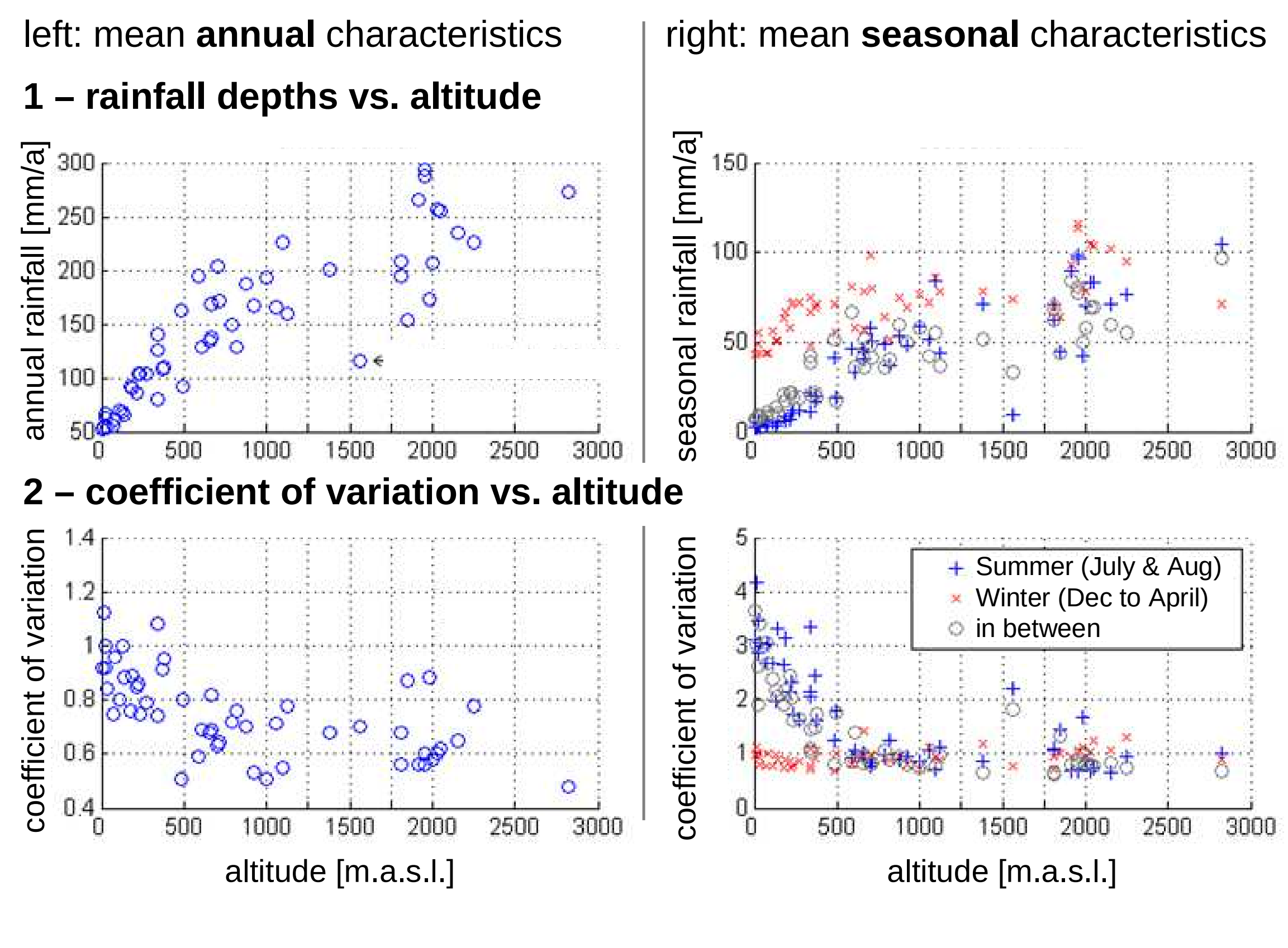


Fig. 6: Rainfall analysis based on 53 rainfall stations [3]

### Definition of Seasons

Tab. 1: Definition of Seasons

| Season | Months | Rainfall Characteristics |
|---|---|---|
| **Summer** | July & August | variable in time & space |
| **Winter** | December to April | less variable, lasting |
| **‚in between‘** | remaining months | indistinct, low mean amounts |

### Response Units according to Geomorphology

Tab. 2: Definition of Response Units

| Response Unit | Slope | Altitude | Lithology |
|---|---|---|---|
| **Quarternary** | low to mean | < 1800 m.a.s.l | Alluvium,<br>Slope Colluvium |
| **Slopes** | steep to very steep | arbitrary | Limestone,<br>Dolostone |
| **High Altitudes** | low to steep | ≥ 1800 m.a.s.l | |

### Provision of Parameter sets

An **ensemble of parameter sets** is used to tackle **uncertainties due to data scarcity**.

### Results

Fig. 7 shows mean annual values of Subsurface Runoff at Mountain Front.

Distinct results acc. to seasons and response units for a selected model run are shown in Tab. 3.

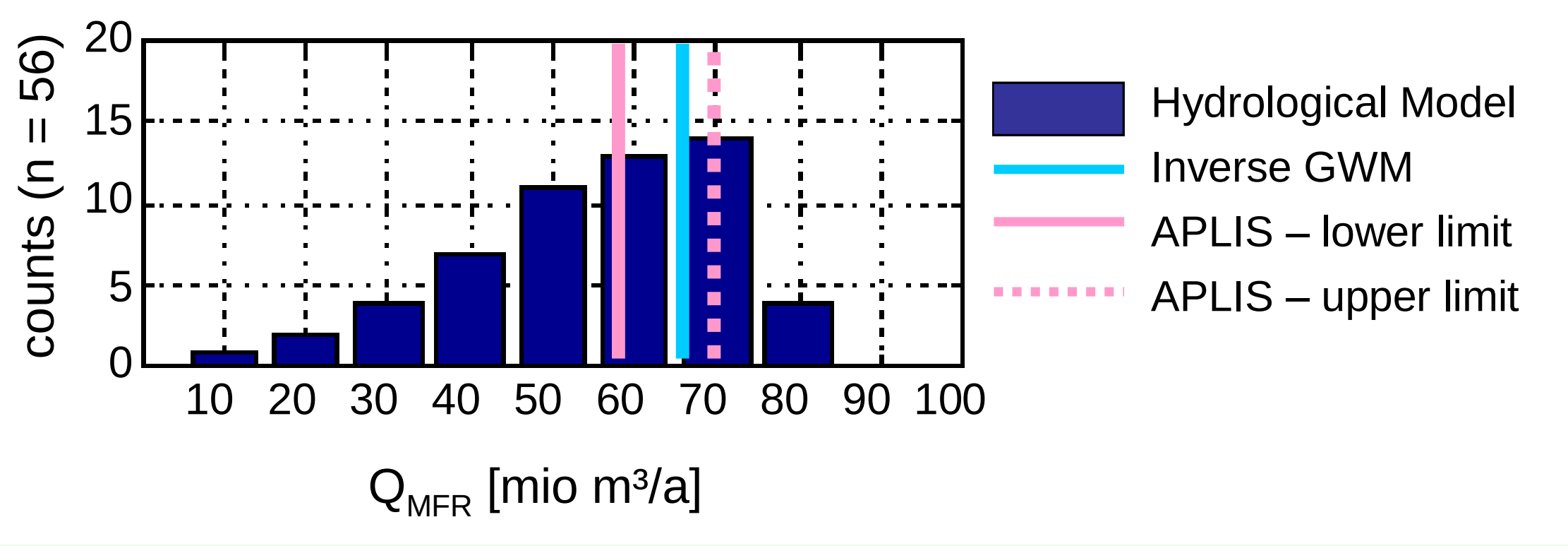


Fig. 7: Long-term mean subsurface runoff with reference to the mountain front $Q_{MFR}$ for an ensemble of data sets in comparison to available reference values

Tab. 3: Results acc. to RUs and Seasons

| Response Unit | Season | $P_{Season}/P_{year}$ | $Q_R/P_{Season}$ |
|---|---|---|---|
| Quaternary | Summer | 22 % | 11 % |
| | in between | 24 % | 20 % |
| | Winter | 54 % | 27 % |
| Slopes | Summer | 26 % | 33 % |
| | in between | 27 % | 37 % |
| | Winter | 47 % | 57 % |
| High Altitudes | Summer | 33 % | 46 % |
| | in between | 28 % | 42 % |
| | Winter | 39 % | 63 % |

## 4 Conclusions & Recommendations

The model results are conclusive with regard to distinct response units and seasons and also plausibly compared to the available complementary approaches. It is concluded, that the proposed model is a reasonable approach to provide spatially distributed seasonal water balance estimates in data scarce arid mountain regions. Expert knowledge on seasonal rainfall characteristics and geomorphology can substantiate model parameterisation.

Due the simplified soil moisture accounting, it is particularly appropriate in regions with shallow soils and pluvial hydrologic regime. Regarding the general lack of time-dependent reference values, hydrogeologic survey and groundwater monitoring in the alluvial basin aquifer near to the mountain front is the most promising option to substantiate water resources assessment in this setting.

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