Low-flow analysis in Mediterranean basins

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Konstantina Risva[1], Dionysios Nikolopoulos[2], Andreas Efstratiadis[2] and Ioannis Nalbantis[1]

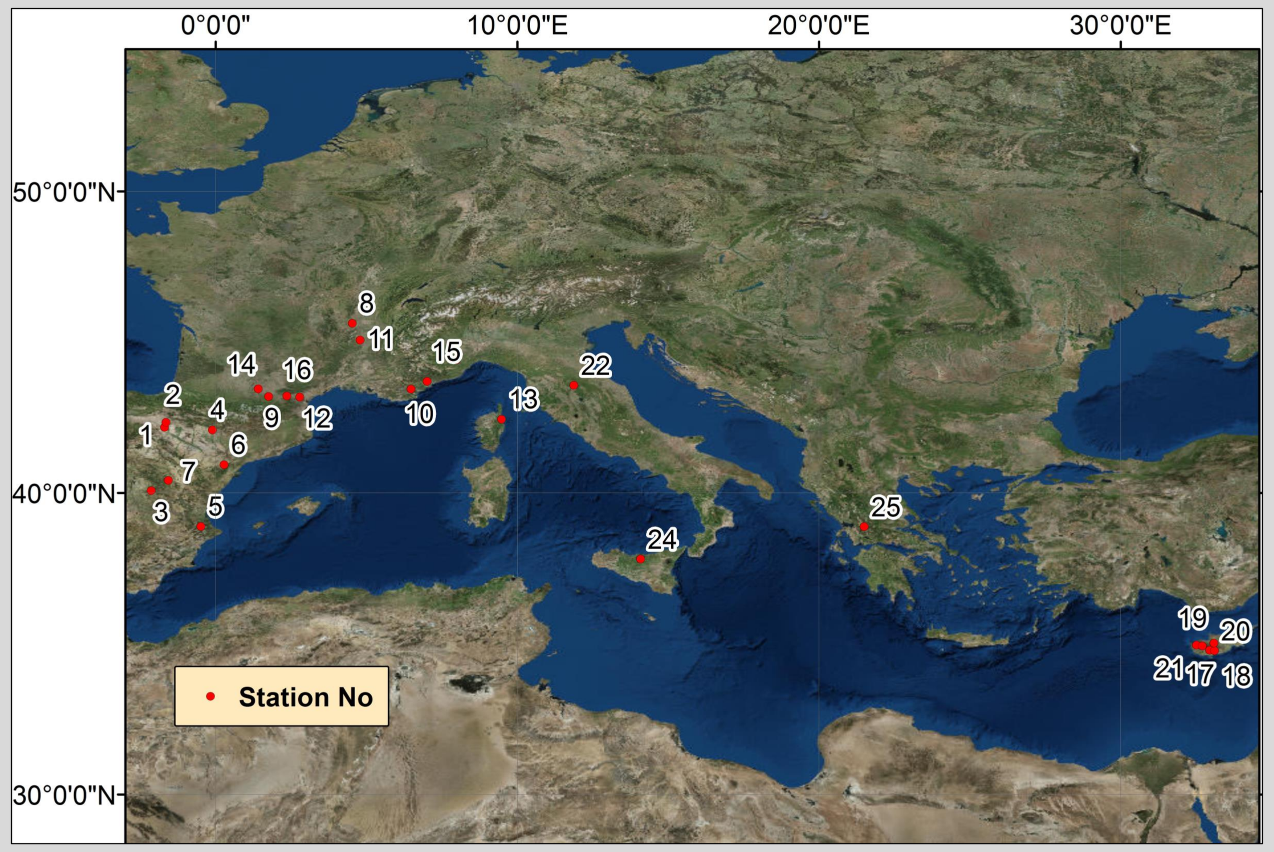
(1) Department of Infrastructure & Rural Development, National Technical University of Athens, Greece; (2) Department of Water Resources & Environmental Engineering, National Technical University of Athens, Greece

1. Abstract

In common hydrological practice, low flows refer to the **periodic phenomenon**, which is an inherent component of a river regime. Low flows are associated with the **storage dynamics** of the catchment, and, particularly, the aquifer outflows. In the everyday practice, the evaluation of low flows is essential for a range of water management goals such as water quality management, water supply, irrigation, hydropower planning, environmental flow assessment, and habitat protection. The importance of low flows, from a water management perspective, becomes even more significant in areas characterized by **dry climate and excessive water demand**, such as many Mediterranean catchments where the water availability reaches its minimum when the water demands are maximal, and vice versa. In particular, across the eastern and southwestern Mediterranean, the dry period, with minimal precipitation, usually lasts from April to October, while the water demands for domestic and agricultural use are major. Using Mediterranean basins, we examine the low flow characteristics during the dry season. A central assumption is a six-month period, from mid-April to mid-October, which is generally characterized by limited precipitation and increased water demands. Classic indices are calculated along a simple **exponential recession model**.

2. Study areas

- 25 Mediterranean catchments from Spain (7), France (9), Cyprus (5), Italy (3) and Greece (1) that cover a wide range of hydrological characteristics
- The data set also includes small catchments with intermittent flow.
- Daily flow data, mainly obtained from online databases.
- Largest basin: Ebro, Spain, @ Castejon station (25 000 km²)
- Smallest basin: Salso, tributary of Imera Meridionale, Sicily (28 km²)
- Highest runoff : Achelous, Greece (950 mm/year)
- Lowest runoff : Albaida, Spain, and Stavros tis Psokas, Cyprus (75 mm/year)

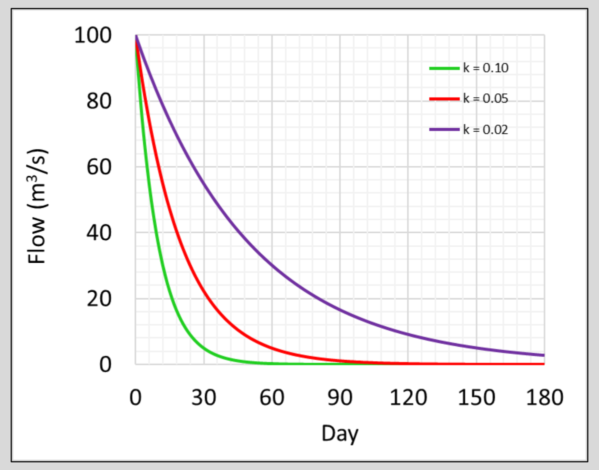


Study areas (see table in panel 4 for station details)

3. Modelling framework

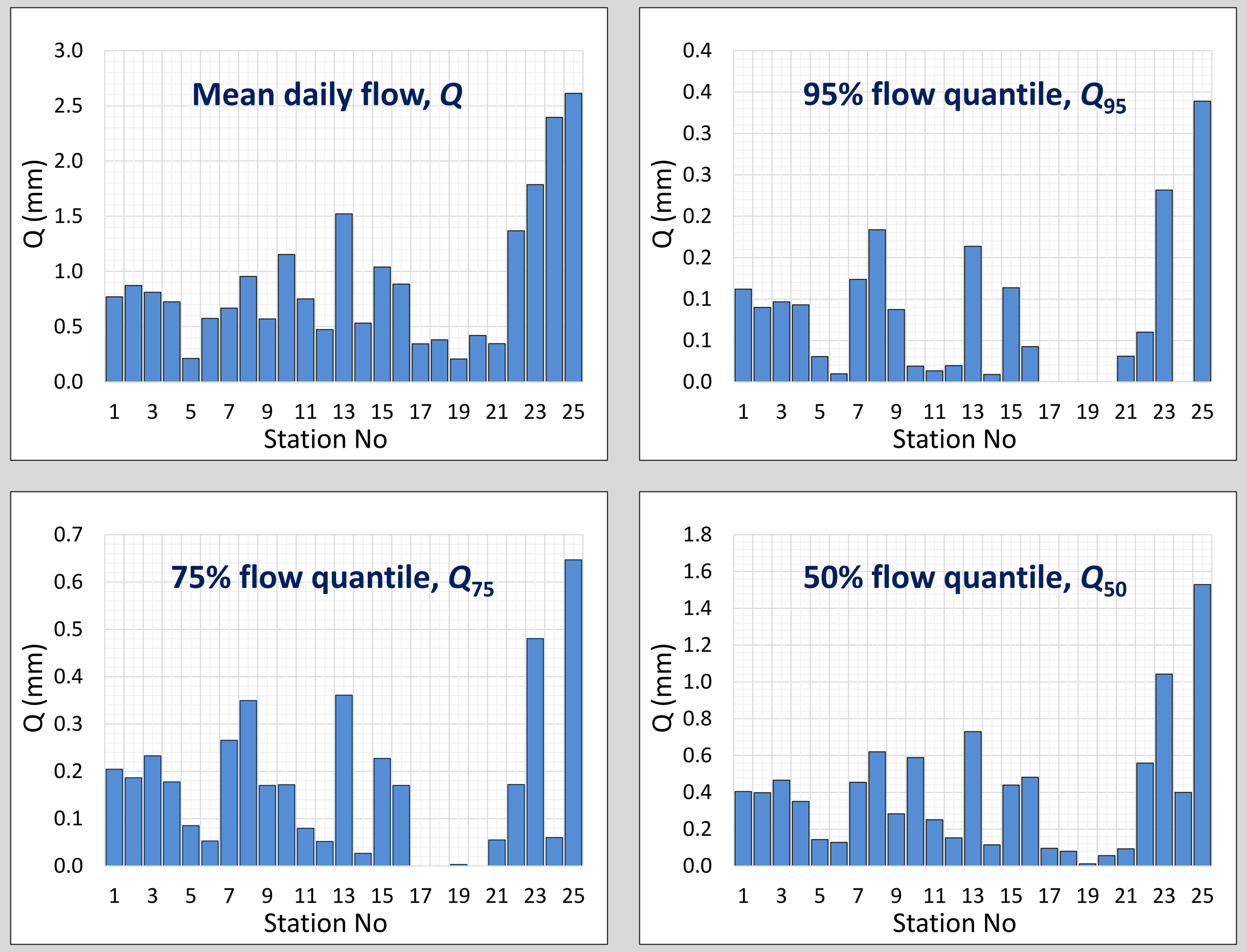
- **Rationale**: Baseflow is the key driver of low flows during dry periods, modelled as outflow through a linear reservoir.
- **Modeling scheme**: The low flow during the dry-period of a given year j is represented by an exponential decay function, i.e.

$$q_{jt} = q_{0j}\exp(-k_j t)$$



- **Reference time horizon**: April 15th to October 15th (conventional)
- **Adjusted low flows**: Estimated on the basis of dry-period hydrograph, after filtering and removal of flow maxima.
- **Initial discharge**, q_{0j}: Minimum daily discharge during the first two weeks of April, a priori determined according to the observed flow data.
- **Recession parameter**, k_j: Inferred through calibration, by fitting eq. (1) to the adjusted low flow data of year j.

4. Catchment characteristics & low flows indices



No	River	Country	Station name	Mean elev. (m)	Basin area (km²)	Data period
1	Ebro	Spain	Castejon	265	25194	1949-2012
2	Aragon	Spain	Caparosso	302	5469	1950-2013
3	Jucar	Spain	Cuenca	916	984	1950-2013
4	Alcanadre	Spain	Lascellas	390	501	1945-2013
5	Albaida	Spain	Montaberner	162	320	1992-2013
6	Algas	Spain	Horta de San Juan	418	115	1965-2013
7	Turia	Spain	Tramacastilla	1278	95	1945-2013
8	Aude	France	Carcassone	96	1754	1969-2016
9	Argens	France	Arcs	36	1730	1966-2016
10	Doux (Rhône)	France	Tournon	127	640	2005-2016
11	Orbieu	France	Luc	34	586	1969-1998
12	Lèze	France	Labarthe	159	351	1969-2016
13	Loup	France	Tourrettes	124	206	1972-2016
14	Vixiège	France	Belpech	243	196	1969-2016
15	Fium-Alto	France	Taglio-Isolaccio	35	114	1961-2016
16	La Coise	France	Larajasse	571	61	1970-2016
17	Limnatis	Cyprus	Kouris Dam	277	115	1984-2009
18	Germasogeia	Cyprus	Foinikaria	100	110	1969-2009
19	Stavros Psokas	Cyprus	Skarfos	185	78	1985-2009
20	Peristerona	Cyprus	Panagia Bridge	546	77	1966-2012
21	Xeros	Cyprus	Lazarides	553	69	1971-2011
22	Arno	Italy	Subbiano	750	751	1992-2013
23	Tanaro	Italy	Piantorre	1067	500	2002-2012
24	Salso	Italy	Petralia	760	28	1954-2003
25	Achelous	Greece	Kremasta dam	146	3570	1967-2008

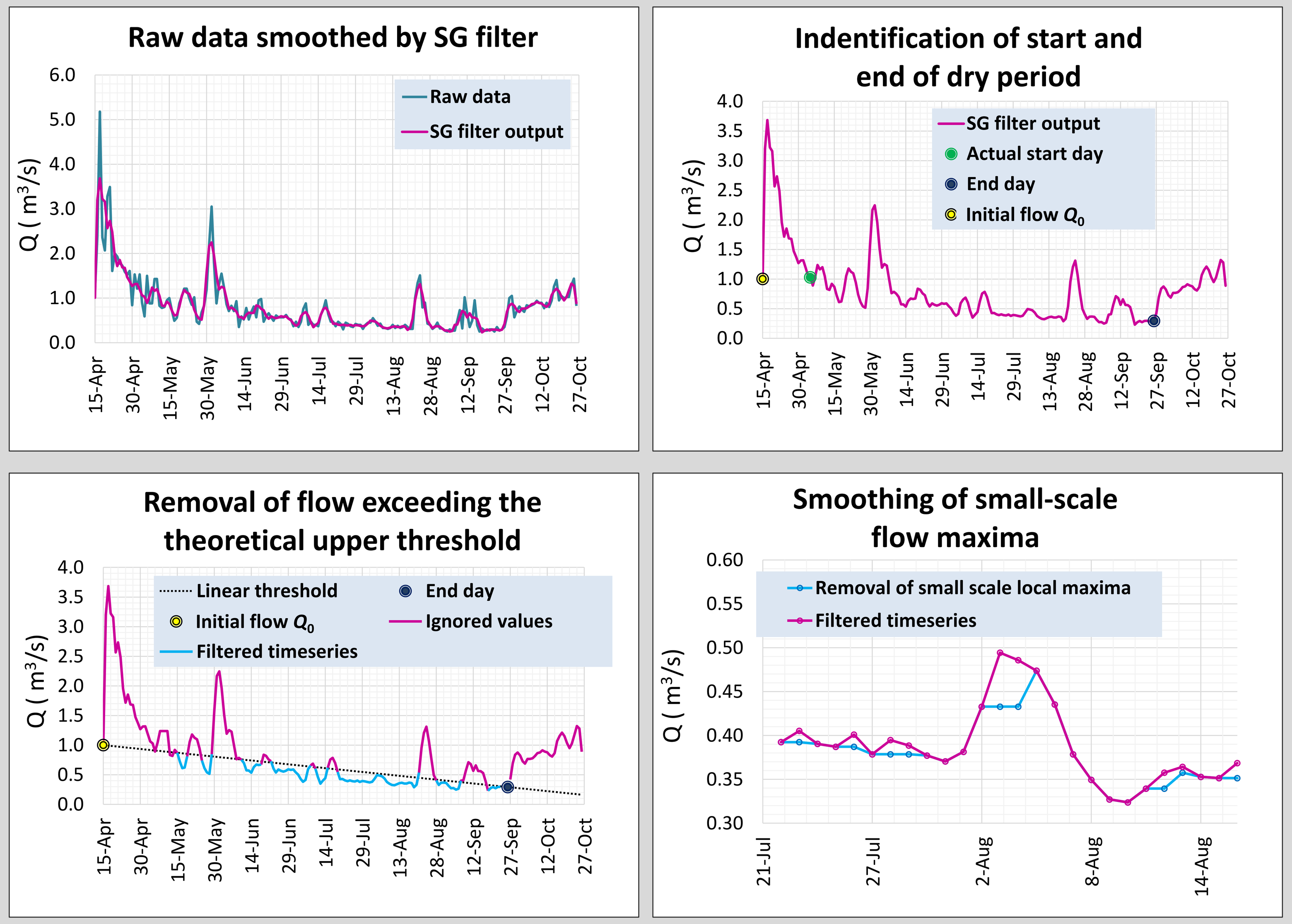
5. Recession analysis

- Real-world dry period hydrograph ⟶ rising and recession limbs, individual peaks ⟶ underestimation of recession parameter
- Extraction of actual low flows from the total hydrograph ⟶ adjusted low flows, derived through the following procedure:
  - Smoothing of hydrograph by employing the Savitzky and Golay (1964) numerical filter;
  - Identification of beginning and end of dry period
  - Removal of flows above a theoretical upper threshold.
  - Smoothing of small-scale flow maxima.
- Adjusted sample: non-continuous, much less values than the full dry-period sample.
- Estimation of recession rate k by fitting the linear reservoir model to the adjusted flow data, using as objective function a modified efficiency, defined as:

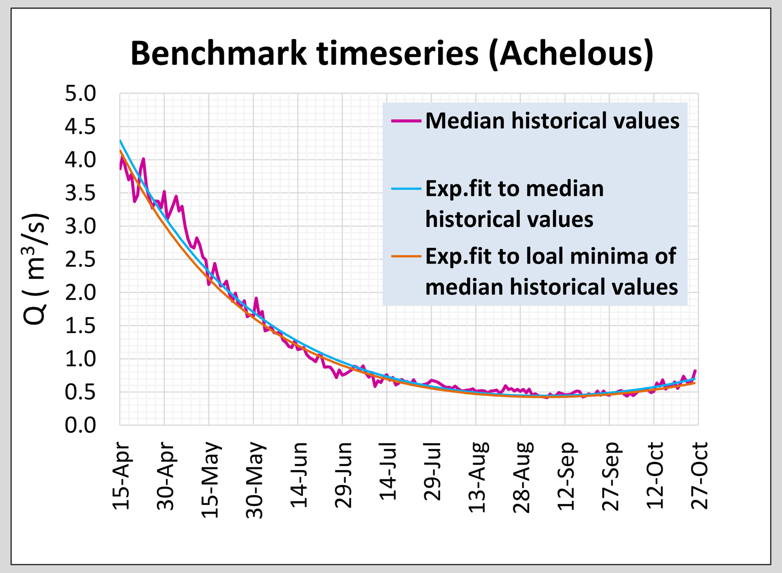
$$MNSE = 1 - \frac{\sum_{j=1}^{N}\sum_{i=b_j}^{e_j}\left(q_{0j}\exp(-k_j t_i) - q'_{ij}\right)^2}{\sum_{j=1}^{N}\sum_{i=b_j}^{e_j}\left(m_i - q'_{ij}\right)^2}$$

where m_i is the benchmark flow of day i, obtained from the master recession curve (MRC) of the basin.

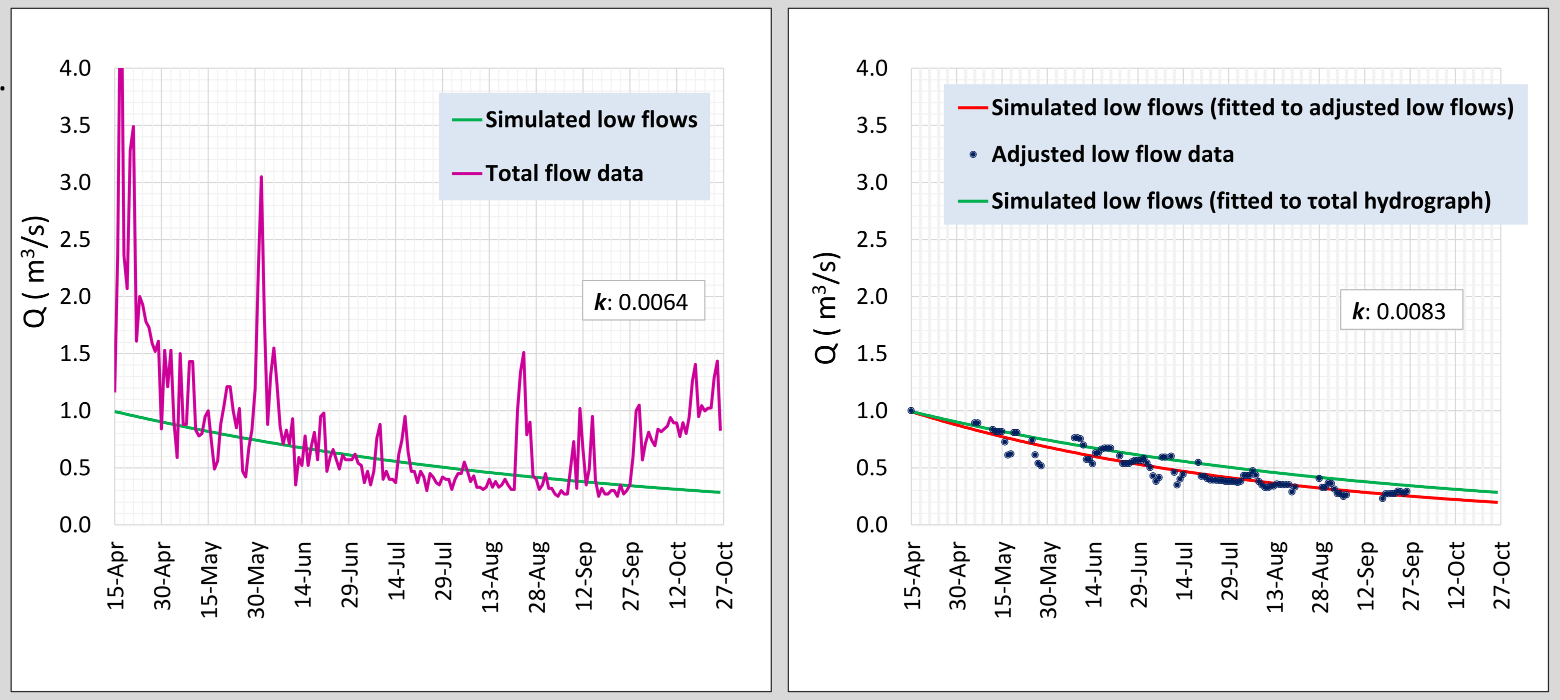
- The MRC is estimated as the lower envelope of the observed median flows, and it is considered the most representative low flow pattern during the dry period.



Preprocessing steps to obtain the adjusted low flow data



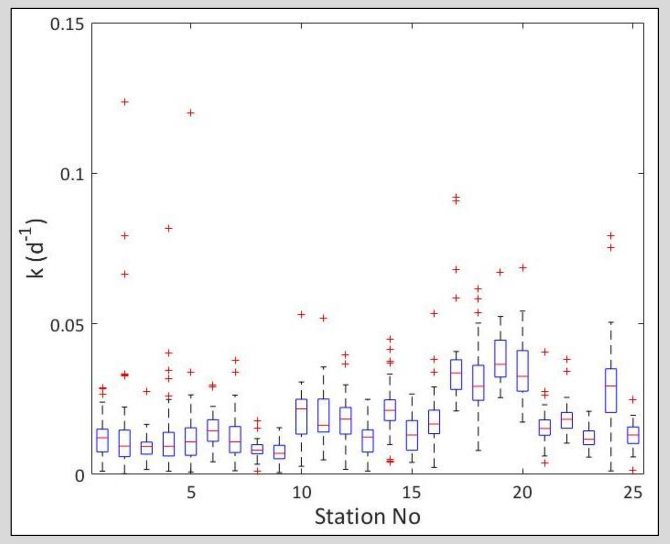
Example of alternative master recession curves used as benchmark functions, extracted from the observed dry-period flow data at Achelous River, Greece.



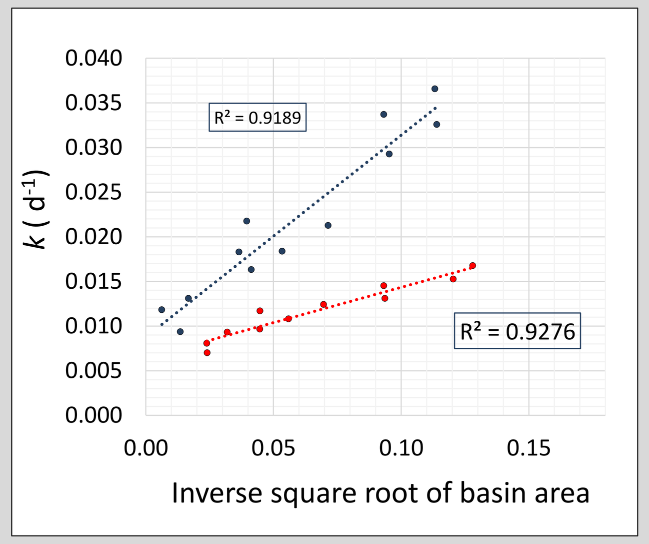
Examples of fitting the exponential decay function to the full daily hydrograph over the entire reference period (green line), contrasted to the final expression fitted to the adjusted flow data (red line). The recession rate is higher when the function is fitted to the adjusted low flows.

6. Statistical analysis of optimized recession parameters

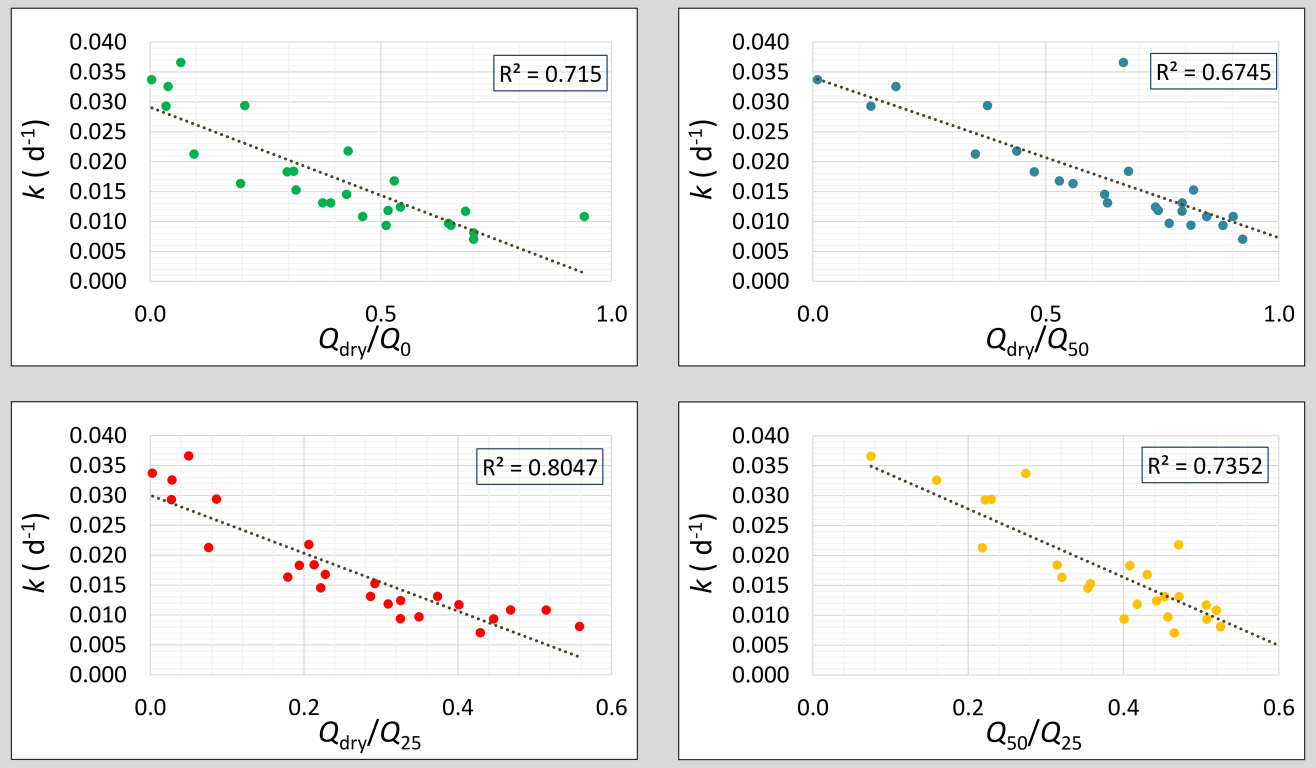
- Two levels of analyses, i.e. temporal (variability of k values across dry periods, for each catchment) and spatial (variability of median k across catchments).
- Scatter plots of median k against four hydrological indices, i.e. Q_{dry}/Q_{50}, Q_{dry}/Q_0, Q_{dry}/Q_{25} and Q_{50}/Q_{25}, and the quantity $A^{-1/2}$, where Q_{dry} is the median flow value across all dry periods and A is the catchment area in km².



The recession parameter k exhibits different annual variability patterns across catchments; their coefficient of variation ranges from 1.89 (No 2, Aragon, Spain) to only 0.24 (No 19, Stavros Psokas, Cyprus).



Scatter plots of median recession rates against the inverse square root area of the examined catchments. Two distinct clusters are formulated.



Scatter plots of median k with four hydrological indices, all exhibiting quite good correlation; the highest correlation is obtained with the ratio of Q_{dry} to Q_{25}, which indicates that the seasonal variability of runoff plays a crucial role in the low flow dynamics (the recession coefficient is associated with the "distance" of Q_{dry} referring to the dry period and Q_{25} to the wet)

7. Conclusions

- The variability of the recession rate across Mediterranean rivers is significant, due to the remarkable hydroclimatic and physiographic diversity.
- Most rivers also exhibit large variability of the recession parameter across different dry periods, and in some cases this is explained by the flow conditions at the beginning of each specific period.
- The spatial variability of median recession coefficients is well-explained by typical hydrological indices, particularly the ratios Q_{dry}/Q_{25} and Q_{50}/Q_{25}.
- In an attempt to relate the median k with the corresponding basin area, two distinct clusters of catchments were formulated, yet in the absence of other information (e.g. permeability) is was not possible to explain this behavior.
- For both clusters, the median k is inversely proportional to the $A^{-1/2}$, which is consistent with the theoretical basis of the linear reservoir model, i.e. the Boussinesq equation (Eng and Milly, 2007).

References

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Contact info: conrisva@gmail.com ; presentation available at: http://www.itia.ntua.gr/1781/