5th International Workshop on Hydro Scheduling in Competitive Electricity Markets

Influence of the maximum flow ramping rates on the water value

I. Guisández, J.I. Pérez-Díaz and J.R. Wilhelmi

Ignacio Guisández González

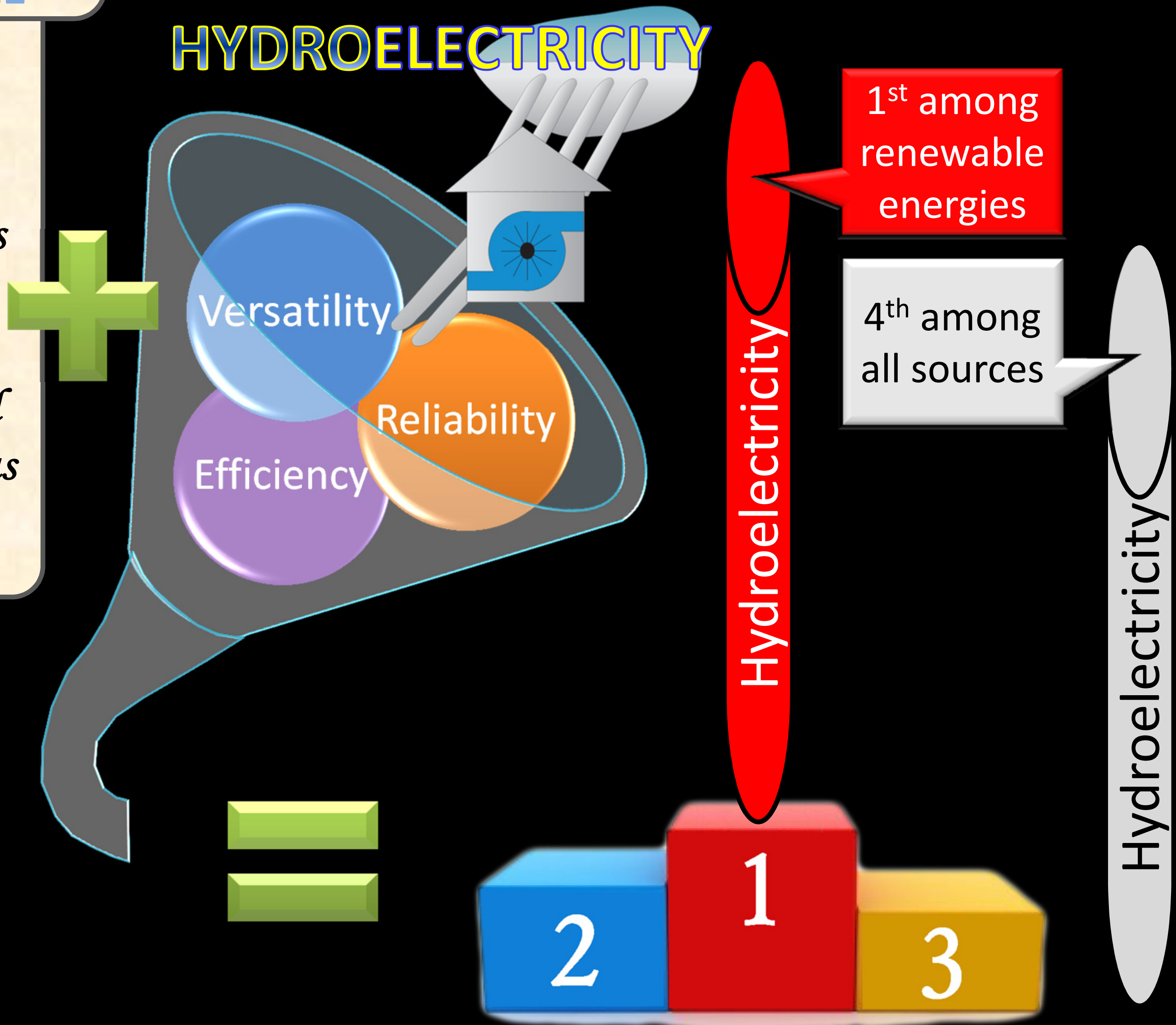
i.guisandez@upm.es

Trondheim, Norway, 17SEP15

Introduction

AGENDA 21

"All energy sources will need to be used in ways that respect the atmosphere, human health and the environment as a whole."



Introduction

Hydropower

\+

Maximum ramping rates (ρ)

=

↑ number of operating hours of the hydropower plant

↓ number of start-ups and shut-downs of the hydro units

↓ producer's revenue

AGENDA 21

"Water should be regarded as a finite resource having an economic value […] reflecting the importance of meeting basic needs."

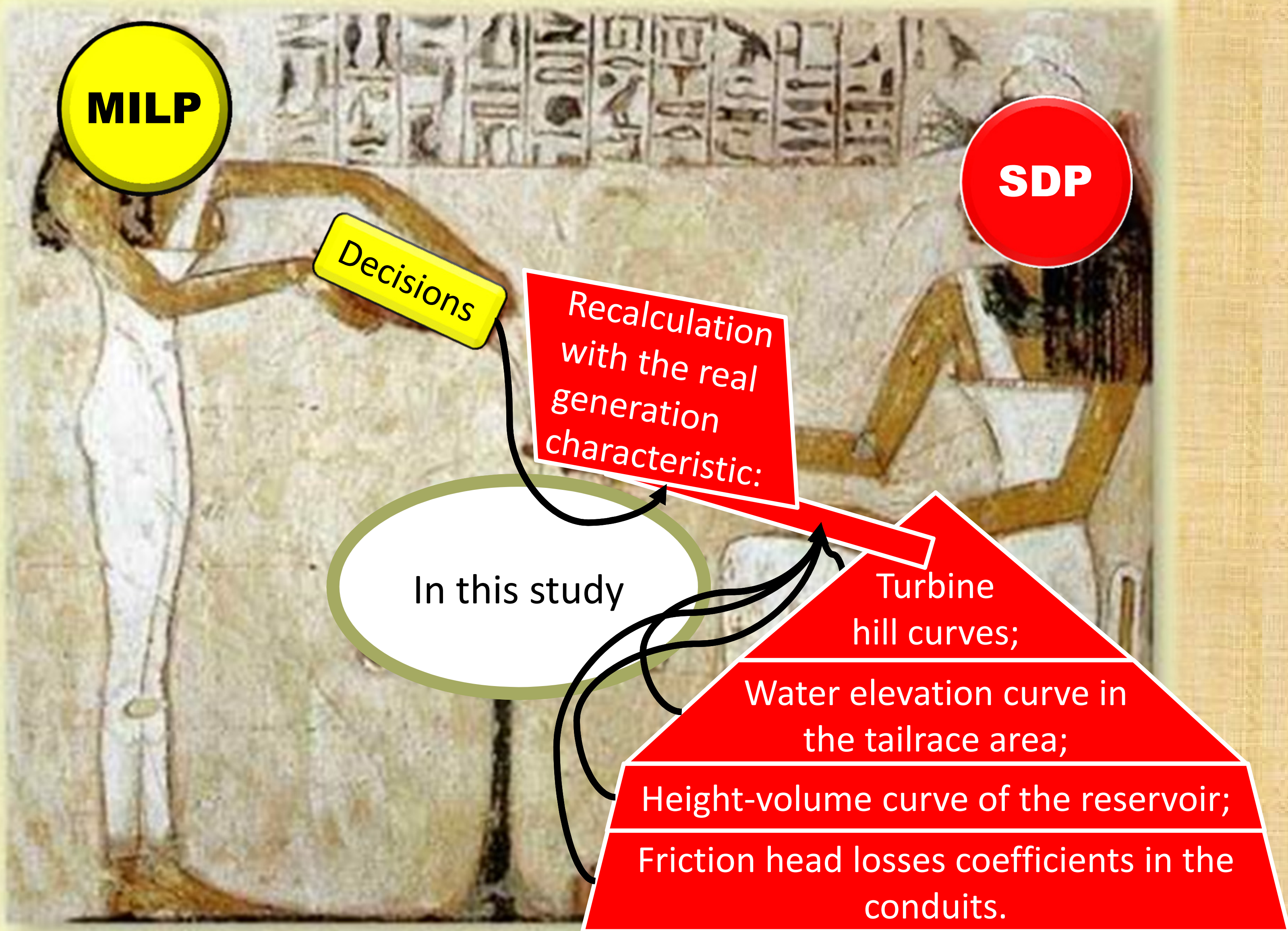
"HYDROPEAKER"

COMPETITIVE MARK€T

Water value = Variation of the company's profit with respect to its available hydraulic resources.

Methodology

Methodology



Description of the master module

- 1-year planning period with weekly time steps;
- State variables: stored volume of water in the reservoir at the beginning of each week (V), weekly water inflow (W), and average weekly energy price (P).

SDP

Goulter and Tai (1985)

V

9 volumes

Little (1955)

W

Lag 1 & 5 classes

Akaike (1973)

Nandalal and Bogardi (2007)

Markov chain

Gjelsvik et al. (1999)

P

Lag 1 & 3 classes

Markov chain

Guisández, I, Pérez-Díaz, JI, Wilhelmi, JR. "Influence of the maximum flow ramping rates in the water value"

Description of the slave module

MILP

- 1-week planning period with hourly time steps;
- Decision variable: Hourly variation of released flow.

Guisández, I, Pérez-Díaz, JI, Wilhelmi, JR. "Influence of the maximum flow ramping rates on the water value"

Aspects considered by the slave module

- Maximum legal and technical storage capacities;
- Minimum reservoir level for plant operation and dead reservoir volume;
- Maximum flows released through the hydro units, the bottom outlets and the spillways according to the reservoir level;
- Start-up and shut-down costs of the hydro units;
- Wear and tear costs of the hydro units caused by power variations;
- Hourly evaporations losses, water inflows and energy prices;
- Plant generation characteristic model consisting of one non-concave power-discharge piecewise linear curve;
- Up and down maximum ramping rates.

Conejo et al. (2002)

Case study

Max. legal storage capacity (15th Oct.-15th Apr.)= 607.6Mm^3

Max. legal storage capacity (16th Apr.-14th Oct.)= 644.6Mm^3

Max. technical storage capacity = 654.1Mm^3

Min. technical volume = 71.0Mm^3

Dead reservoir volume = 48.1Mm^3

Max. net head = 132m

Min. net head = 72m

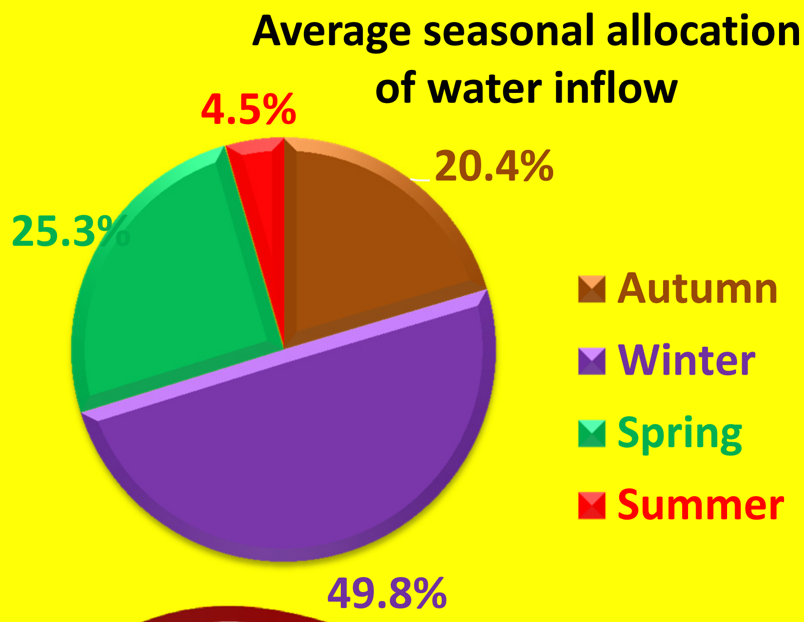
Hydro units = 3 Francis

Max. plant flow = 279m^3/s

Min. hydro unit flow = 40m^3/s

Max. power output = 312.5MW

Min. power output = 22.2MW



Considered problems

Maximum ramping rates = maximum rates of change of flows.

$$\rho = \frac{d\,\text{FLOW}}{dt} = [h]^{*}$$

* hours necessary for maximum variations of the plant flow

SENSITIVITY ANALYSIS

Future plan of the river basin authority

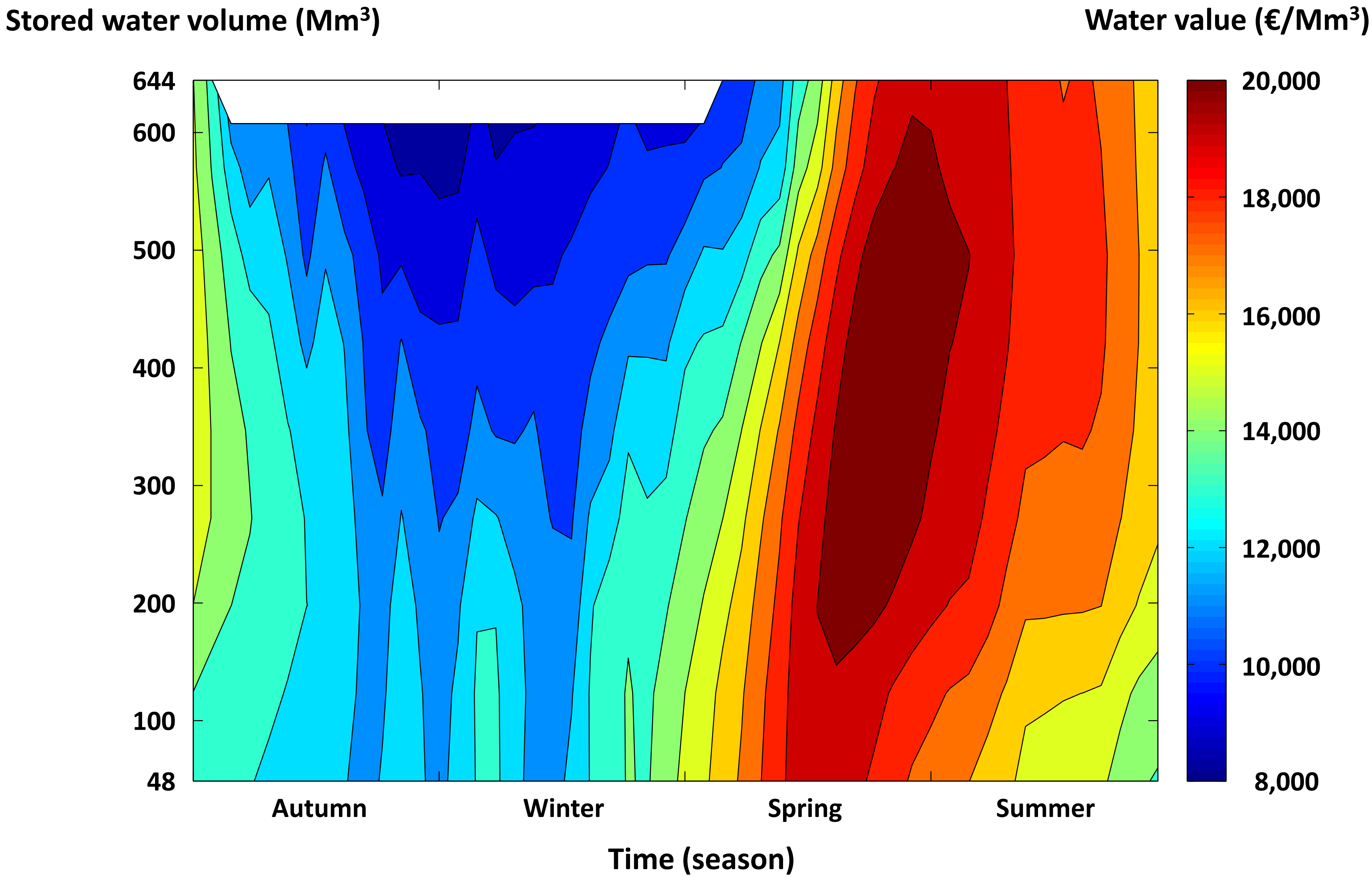
ρ = 0h; 6h; 12h; 24h; 36h; 48h; 60h; 72h

Up maximum ramping rate= 0.75·ρ

Down maximum ramping rate = 1.50·ρ

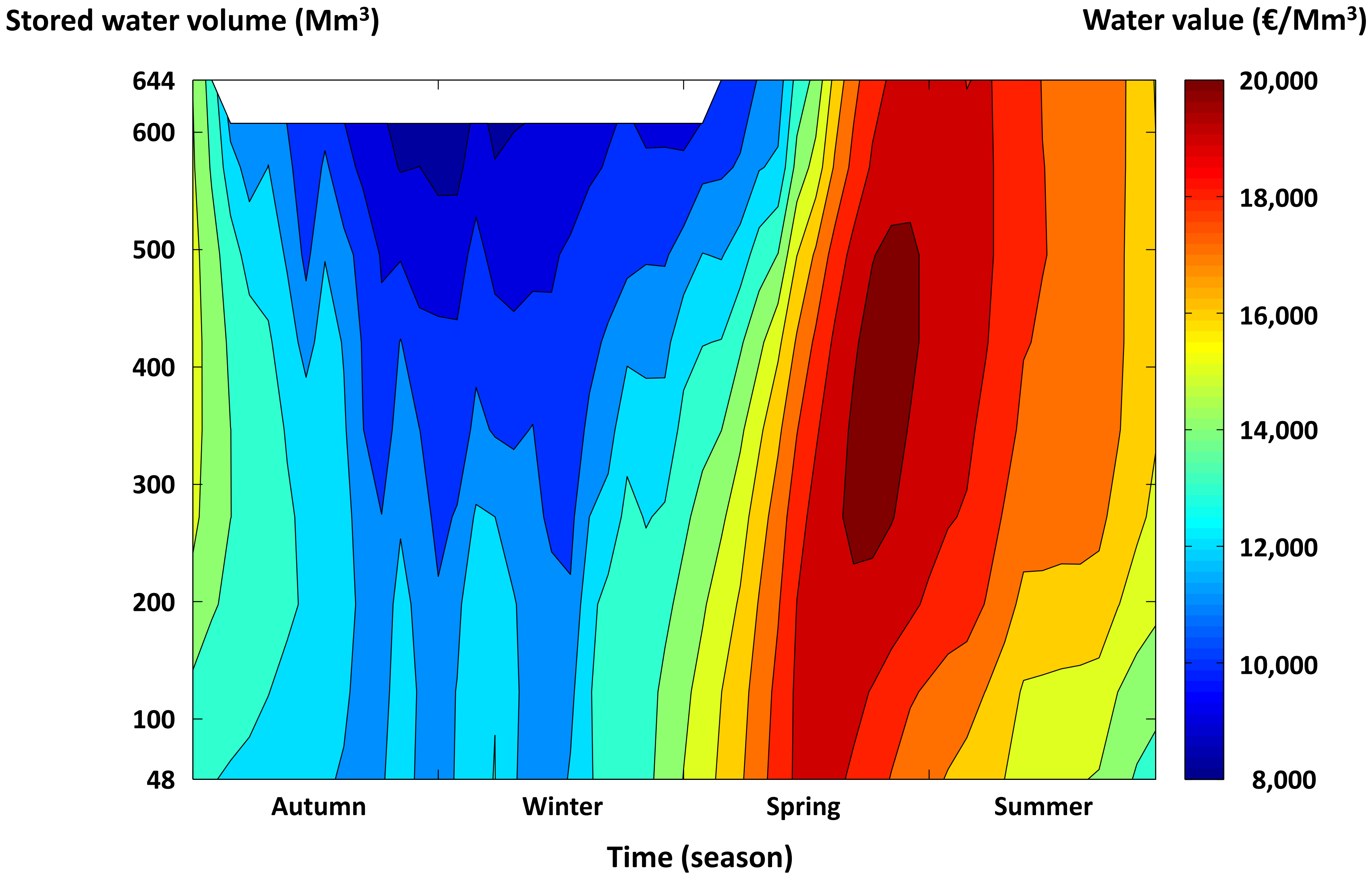
Guisández, I, Pérez-Díaz, JI, Wilhelmi, JR. "Influence of the maximum flow ramping rates on the water value"

Water values with ρ = 0h



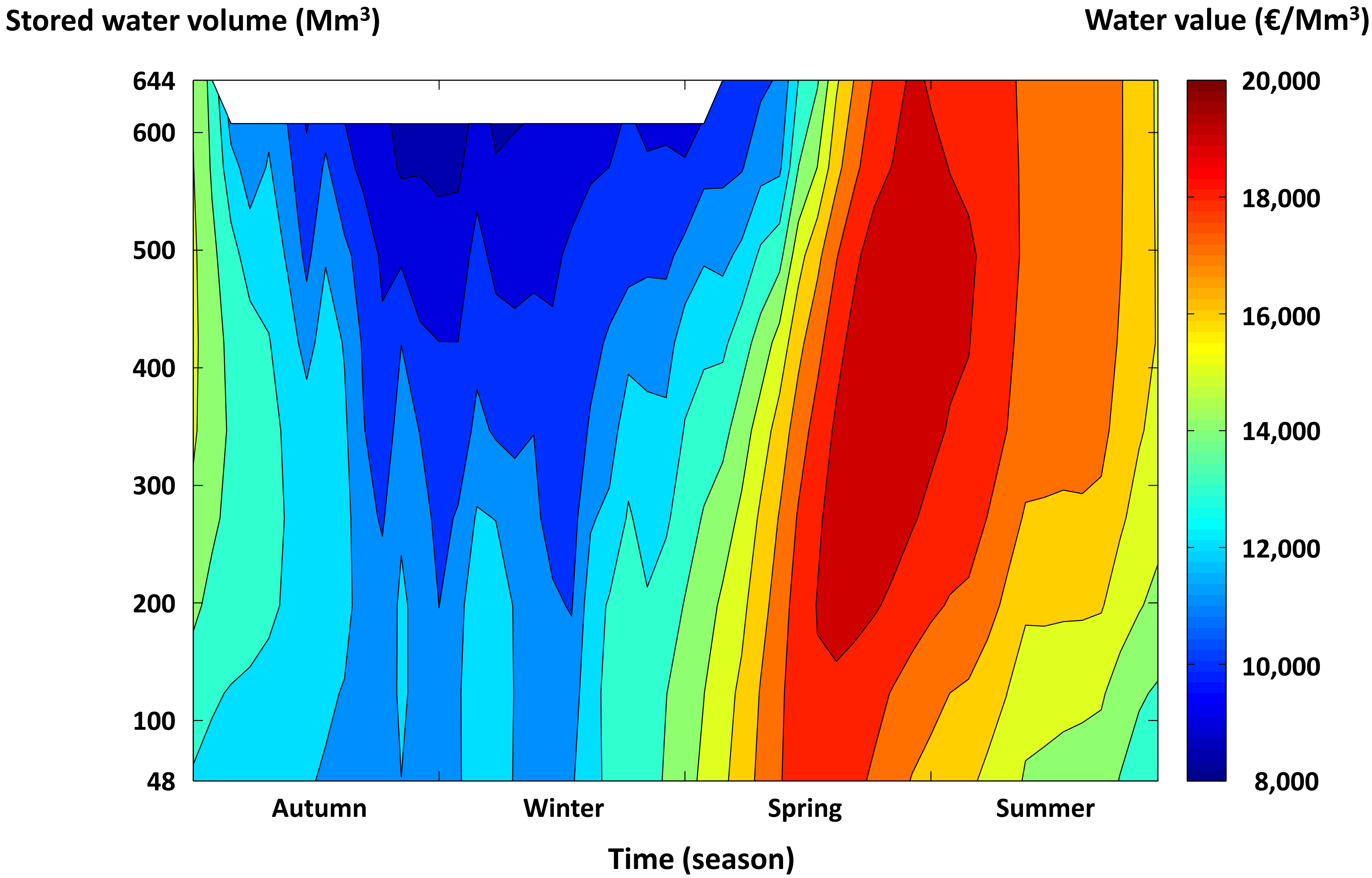
Guisández, I, Pérez-Díaz, JI, Wilhelmi, JR. "Influence of the maximum flow ramping rates on the water value"

Water values with ρ = 6h



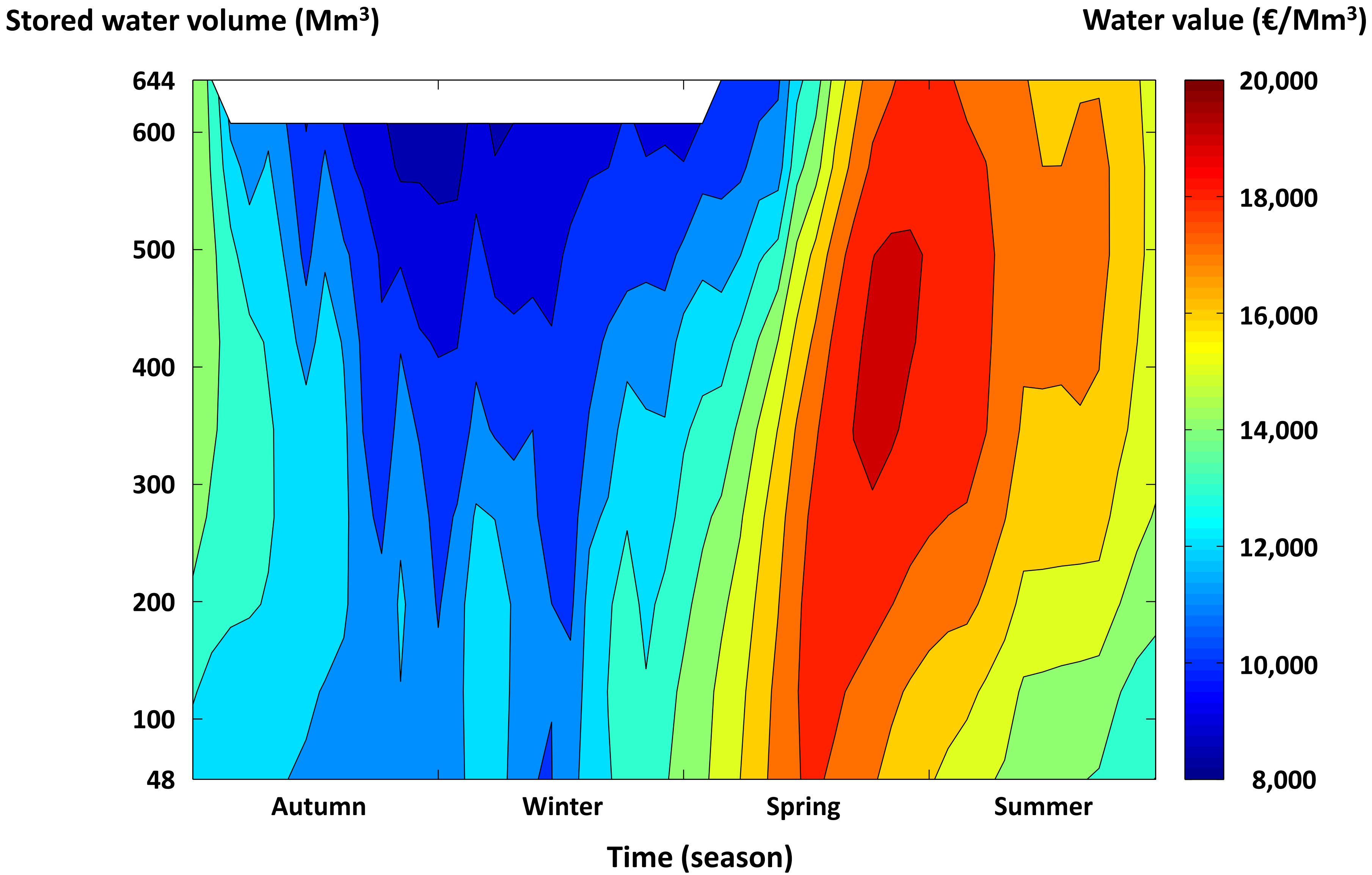
Guisández, I, Pérez-Díaz, JI, Wilhelmi, JR. "Influence of the maximum flow ramping rates on the water value"

Water values with ρ = 12h



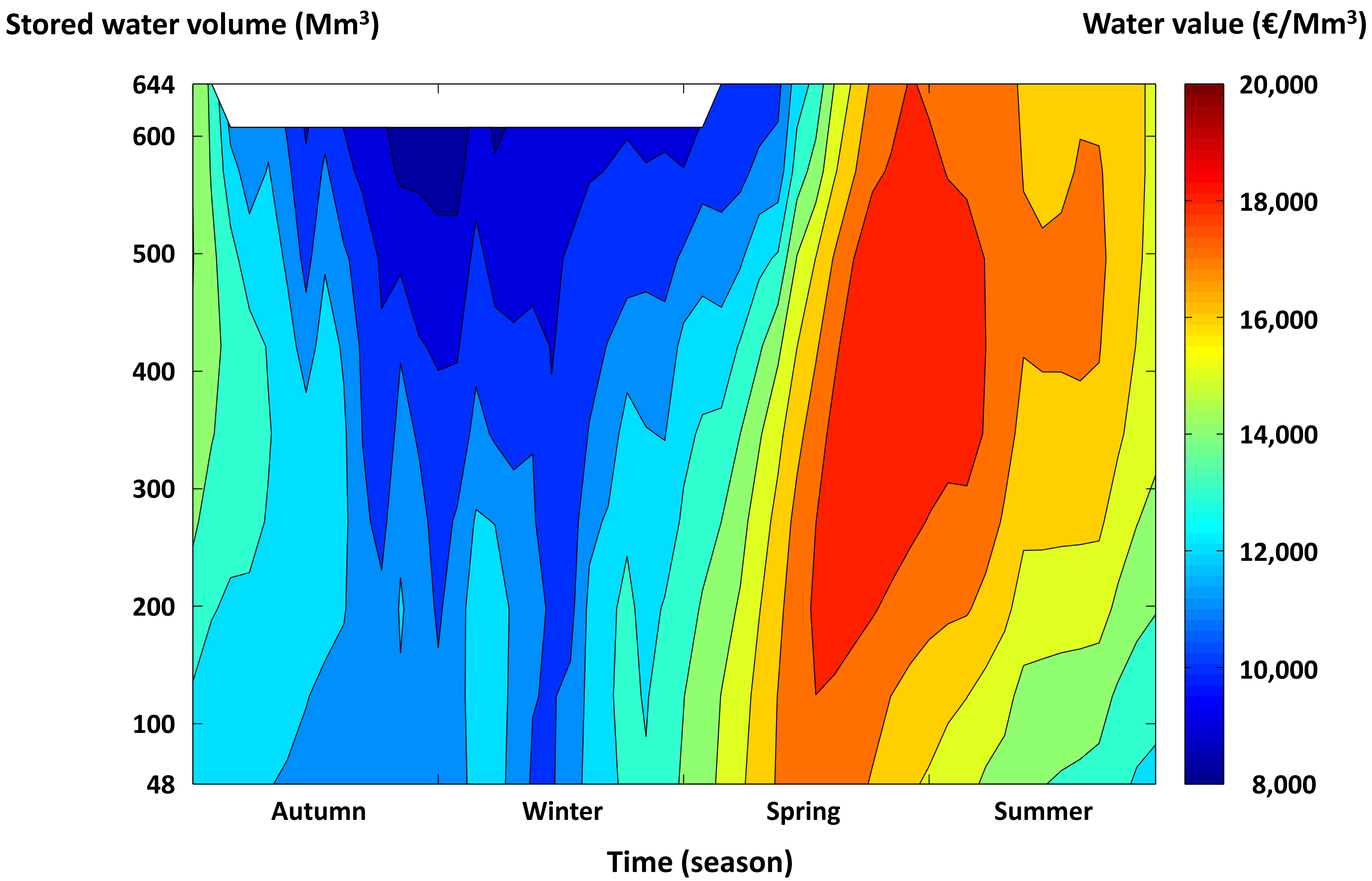
Guisández, I, Pérez-Díaz, JI, Wilhelmi, JR. "Influence of the maximum flow ramping rates on the water value"

Water values with ρ = 24h



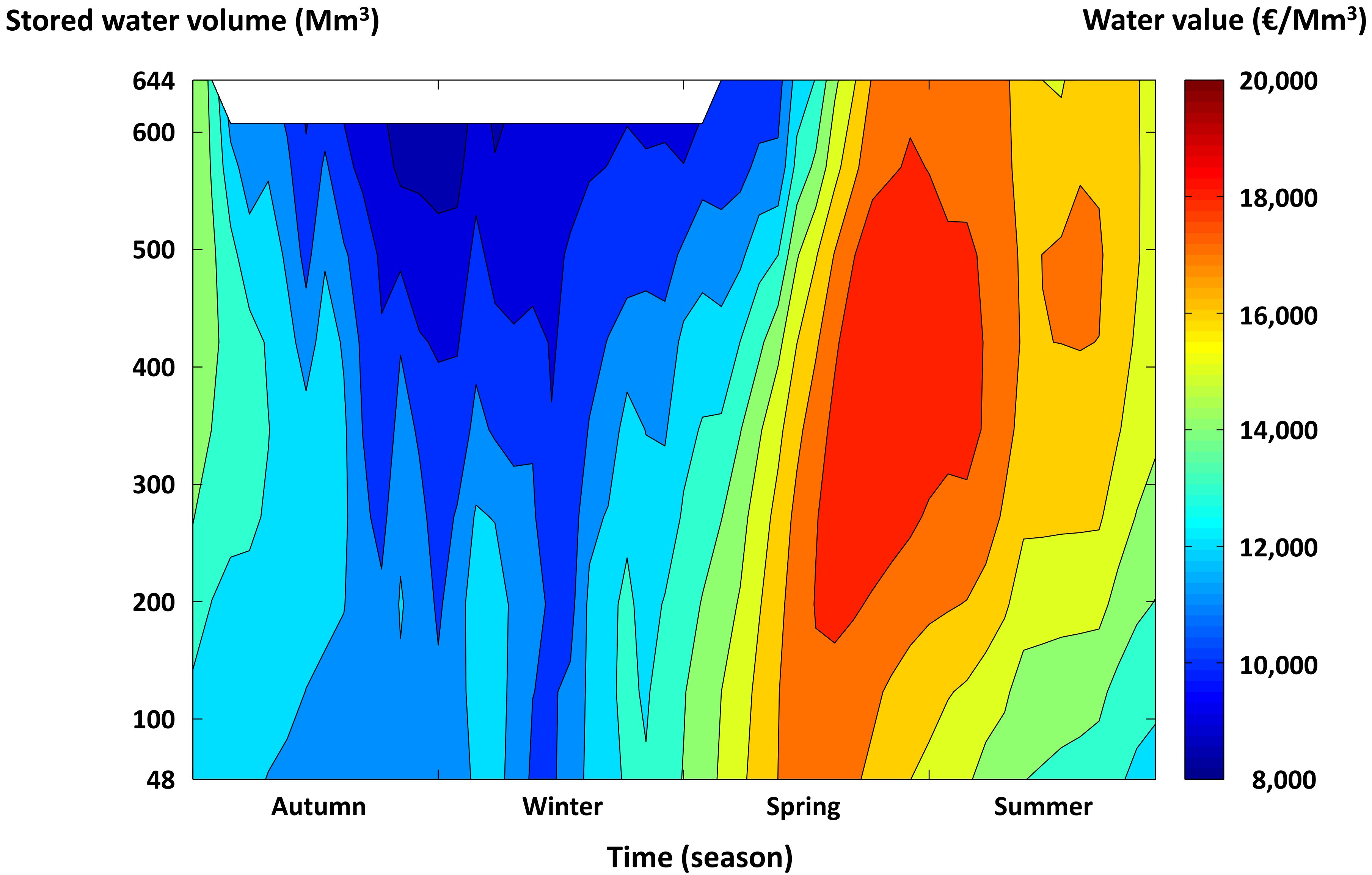
Guisández, I, Pérez-Díaz, JI, Wilhelmi, JR. "Influence of the maximum flow ramping rates on the water value"

Water values with ρ = 36h



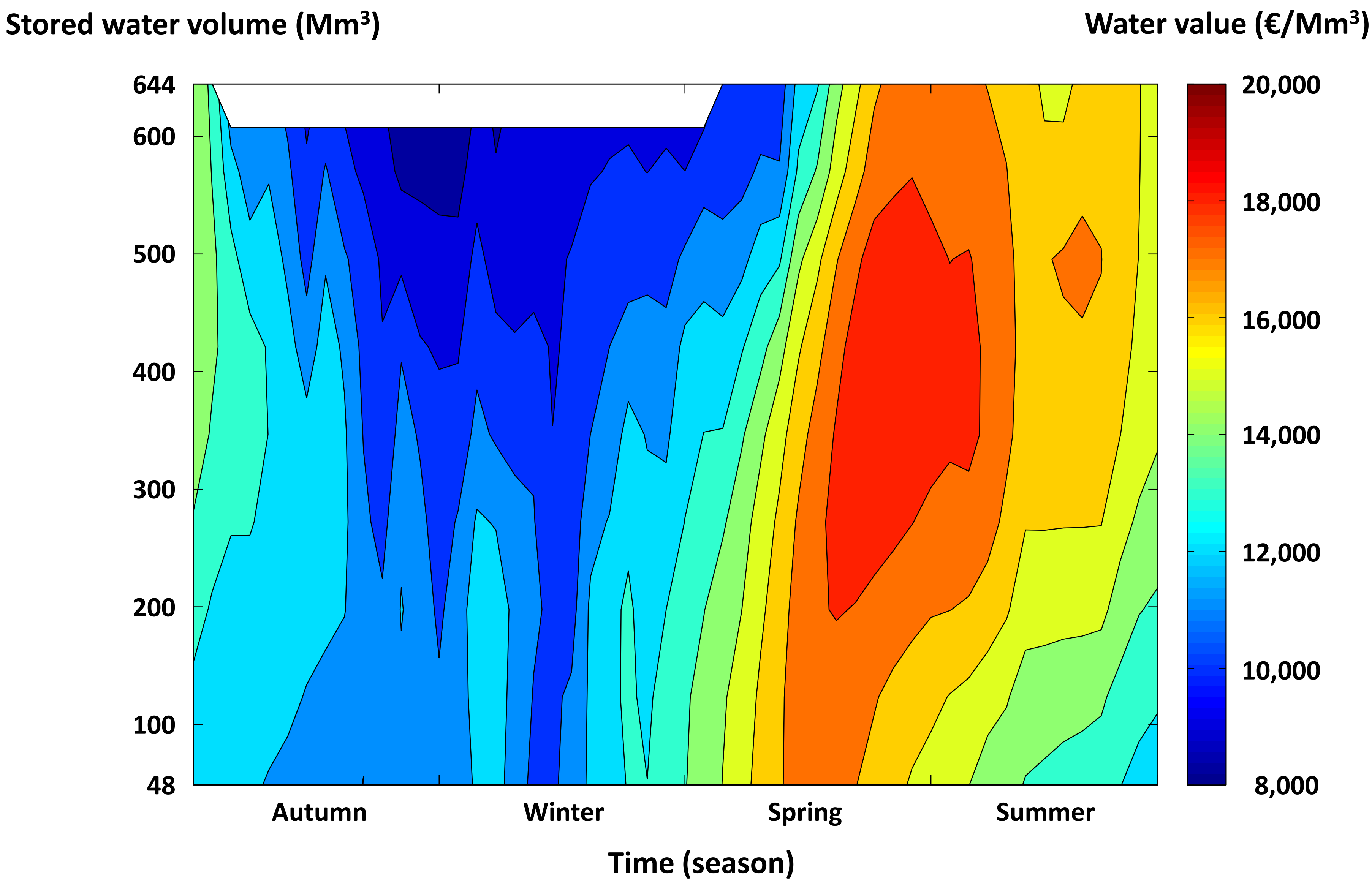
Guisández, I, Pérez-Díaz, JI, Wilhelmi, JR. "Influence of the maximum flow ramping rates on the water value"

Water values with ρ = 48h



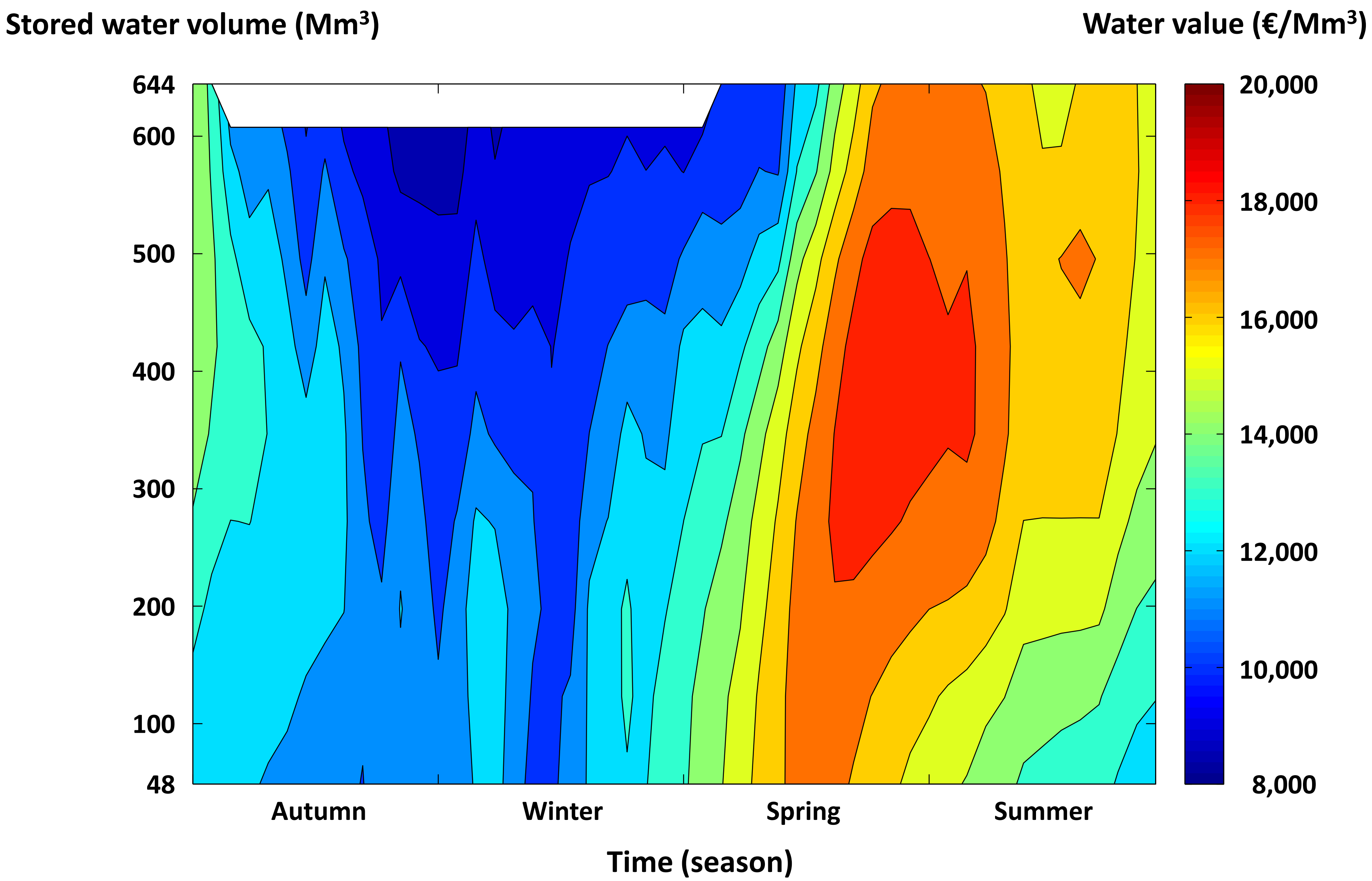
Guisández, I, Pérez-Díaz, JI, Wilhelmi, JR. "Influence of the maximum flow ramping rates on the water value"

Water values with ρ = 60h



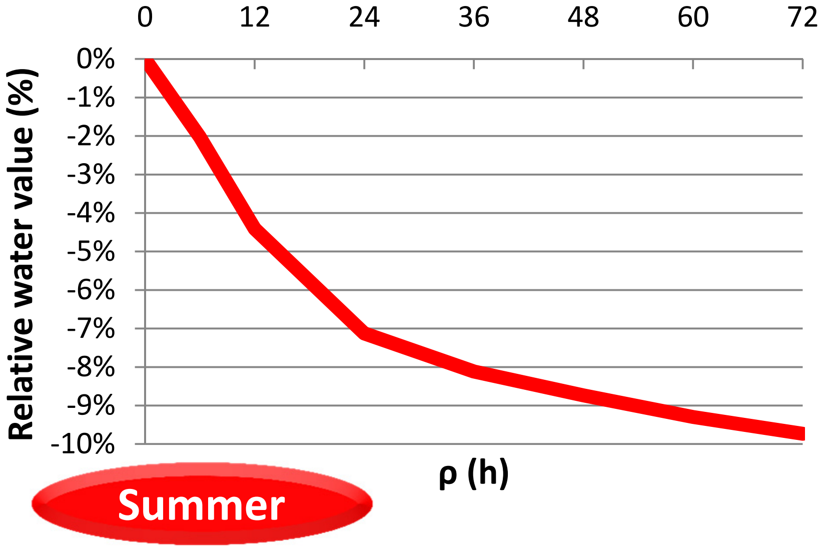
Guisández, I, Pérez-Díaz, JI, Wilhelmi, JR. “Influence of the maximum flow ramping rates on the water value”

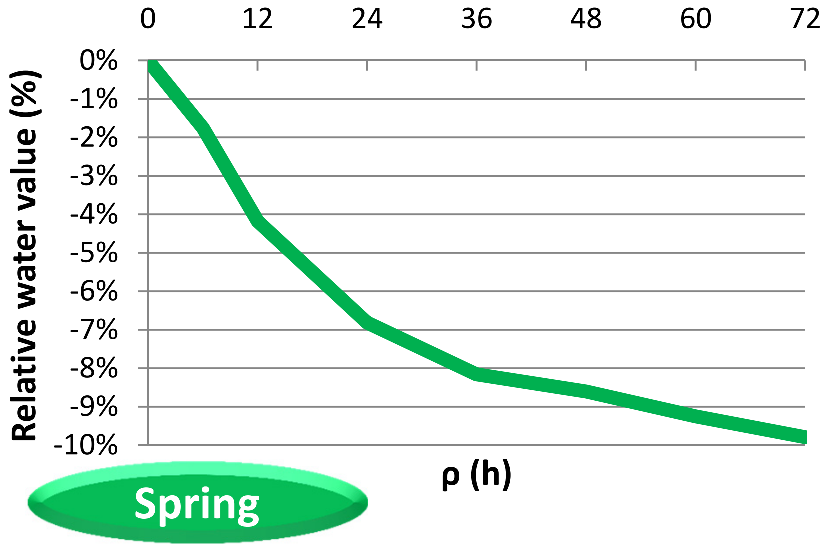
Water values with ρ = 72h

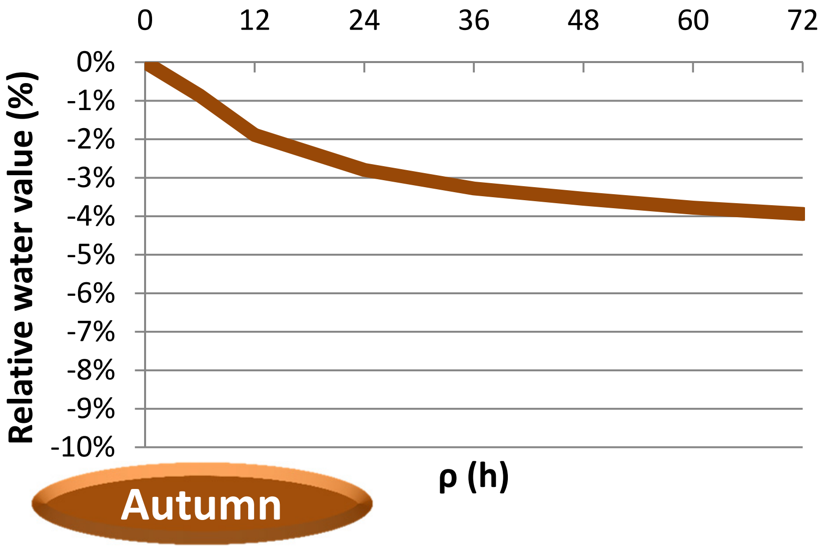


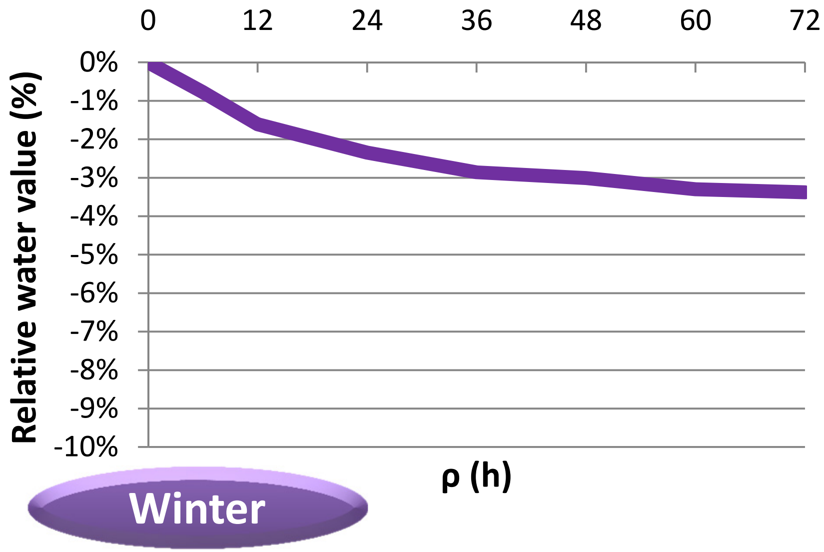
Guisández, I, Pérez-Díaz, JI, Wilhelmi, JR. "Influence of the maximum flow ramping rates on the water value"

Relative water values according to ρ and seasons



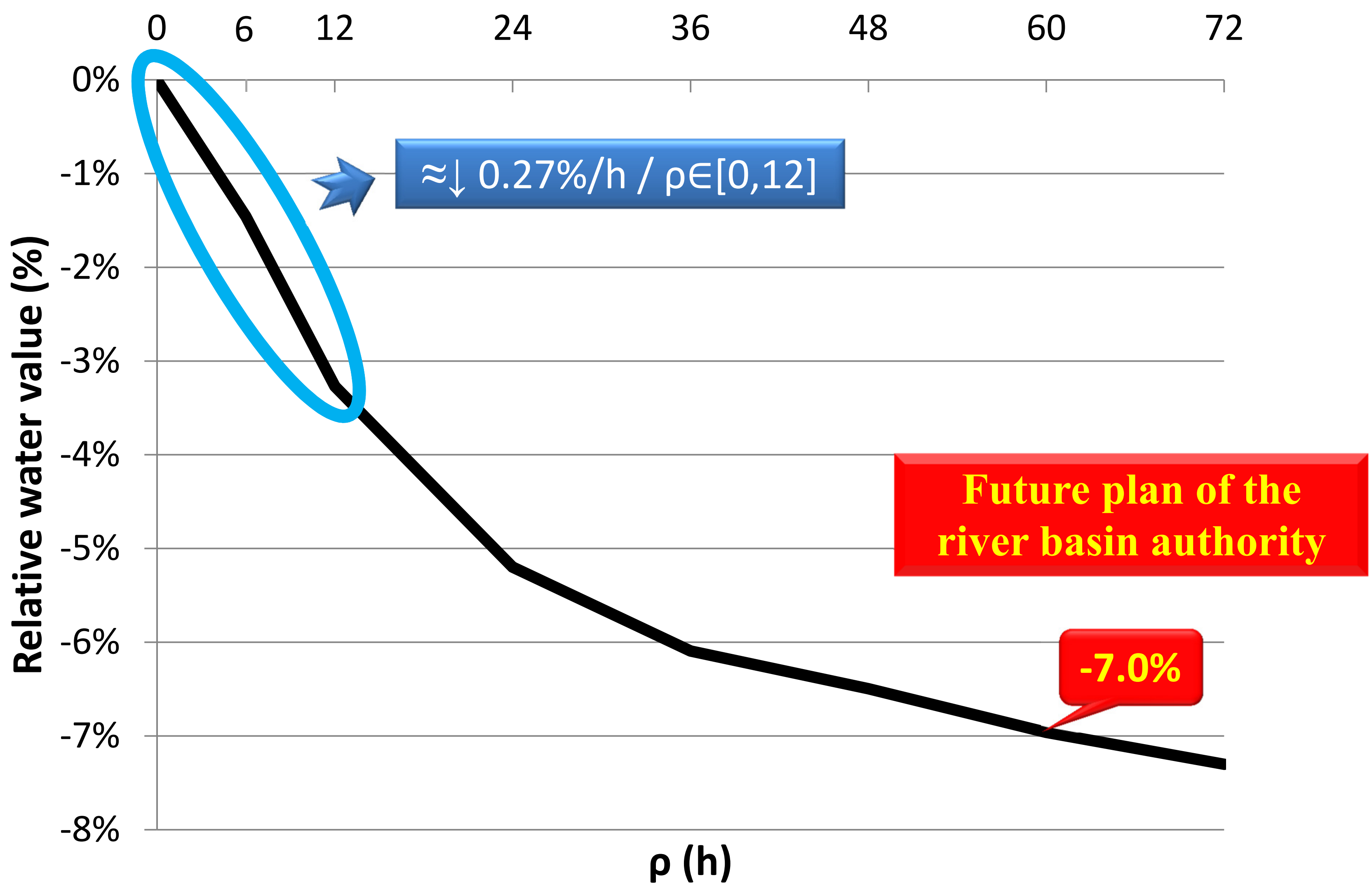






Guisández, I, Pérez-Díaz, JI, Wilhelmi, JR. “Influence of the maximum flow ramping rates on the water value”

Average relative water values according to ρ



Guisández, I, Pérez-Díaz, JI, Wilhelmi, JR. "Influence of the maximum flow ramping rates on the water value"

Conclusions

I Water values are very sensitive to the presence of maximum ramping rates, as well as their magnitudes.

II The reduction of the water values caused by this constraint follows an approximate quadratic behaviour.

III This reduction is considerably higher during the months of low water inflows than during the ones of high water inflows.

Main references

Abgottspon, H, Andersson, G. "Approach of integrating ancillary services into a medium-term hydro optimization". *Proceedings of 12th SEPOPE*, Rio de Janeiro, Brazil; 2012.

Akaike, H. "Information theory and an extension of the maximum likelihood principle". *Proceedings of 2nd ISIT*, Budapest, Hungary; 1973.

Conejo, AJ, Arroyo, JM, Contreras, J, Villamor, FA. "Self-scheduling of a hydro producer in a pool-based electricity market". *IEEE Transactions on Power Systems*; 2002. vol. 17 (4). p. 1265-1272.

Gjelsvik, A, Belsnes, MM, Haugstad, A. "An algorithm for stochastic medium-term hydrothermal scheduling under spot price uncertainty". *Proceedings of 13th PSCC*, Trondheim, Norway; 1999.

Goulter, IC, Tai, FK. "Practical implications in the use of stochastic dynamic programming for reservoir operation". *Journal of the American Water Resources Association*; 1985. vol. 21 (1). p. 65-74.

Little, JDC. "The use of storage water in a hydroelectric system". *Operations Research*; 1955. vol. 3 (2). p. 187-197.

Nandalal, KDW, Bogardi, JJ. *Dynamic programming based operation of reservoirs*. Applicability and limits. Cambridge University Press, Cambridge, England; 2007.